International Conference on Research on Food Security, Natural Resource Management and Rural Development

Tropentag 2026

Towards multi-functional agro-ecosystems promoting climate-resilient futures

Book of Abstracts

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Tropentag 2026

International Research on Food Security, Natural Resource Management and Rural Development

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Preface

Dear participants of Tropentag 2026,

It is our great pleasure to welcome you to Tropentag 2026, held this year at Göttingen under the theme **"Towards multi-functional agro-ecosystems promoting climate-resilient futures"** and jointly hosted by the universities of Göttingen and Kassel.

The annual Tropentag conference has become a unique forum for dialogue and exchange, uniting senior and early-career scientists, practitioners, policymakers, and students who share a commitment to advancing knowledge and solutions for sustainable agriculture, food security, natural resource management, and rural development in the tropics. It has also become a major platform for collaboration between the international research for development (R4D) community in Germany and International Agricultural Research Centres of the CGIAR, and others.

CHALLENGES WE FACE
Agriculture as developed and expanded after the second world war (WWII) is at the center of global land use changes and considered a major contributor to the global environmental crisis. The latter is triggered by anthropogenic climate change, biodiversity loss, excessive consumption, pollution, and land and soil degradation. Agriculture and forestry, shaping food systems and rural livelihoods, are also directly and indirectly – often negatively - affected by accelerated climate change and related extreme weather as well as by increasing resource limitations – threatening global environmental sustainability and rural livelihoods at large.

The global environmental crisis is aggravated by continued rapid population growth and urbanisation – in particular in the Global South. Due to substantial global economic growth since the 1960s, global welfare has increased and the share of the population affected by hunger and poverty has been declining even if their absolute size has unfortunately remained remarkably constant, reflecting insufficient policies. At the same time, increasing economic disparities between the rich and poor have been observed, both in the Global North and South. These have recently resulted in distinctly larger social unrests and migration from the poorer to richer regions and rural to urban areas. Moreover, increasingly fierce competition of tech-giants (and associated governments) for scarce natural resources in order to provide ever-new technologies, key products, and services (including AI) to meet the consumption needs – mainly of the rich - increasingly trigger political conflicts and wars, shifts in the geopolitical landscape and threats to democracy and human dignity at the individual and community level.

To meet these challenges of the advanced anthropocene (as characterised by the above-described crises) with intensified pressure on land and natural resources, there is urgent need for reconciliation of planetary health with a sustainable, yet productive agriculture, as well as with measures to strengthen societal cohesion, the dignity of individual farmers and all other members of rural communities.

MEANS AND PATHWAYS

Such reconciliation requires means and pathways that can simultaneously enhance food security, adapt to and mitigate climate change, enhance soil fertility, available water resources, and other ecosystems functions and services - not the least such that will strengthen rural communities and economic development. We consider multifunctional agro-ecosystems and related climate adaptations and mitigations as necessary means to change towards the promotion of more climate-resilient futures in the near- and long-term.

Tropentag 2026 will, therefore, examine how agriculture, forestry, and other land use systems in the Global South can contribute to sustainable development and future agro-ecosystems that are more resilient than the current ones under multiple stresses triggered by the projected climate /environmental and socio-economic changes. The conference will highlight interdisciplinary research on multifunctional systems that integrate all important ecological, economic, and social dimensions.

Discussions will address the meaning of sustainable agricultural systems and multifunctional agro-ecosystems in the local context of the challenges faced jointly by the Global South and North. We will discuss strategies to strengthen resilience at household and community-level as well as in farming and forest landscapes. These include a wide range of adaptation practices to on going global change processes such as climate change, demographic change and further globalization of markets. Such adaptations can be low cost, nature based, and knowledge intensive. But climate smart production systems may also use digital tools, ICT technology, machine learning, and artificial intelligence, combining increasingly available and accessible global data with site-specific ground truthing. Adaptations may use alternative regenerative energy resources and high-tech approaches for mechanization, or they may comprise organizational innovations that advance sustainable value chains benefitting both people and ecosystems.

As 2026 is the *International Year of Rangelands and Pastoralists*, particular attention will be given to pasture-based livestock systems, their contribution to global food security, to local, regional and international value chains and agricultural income, and to other increasingly important ecosystem functions and services.

SOLUTIONS

Jointly with the conference convenors, participants will synthesize and distil knowledge from the presentations and identify which of the proposed means and pathways appear promising in promoting climate-resilient futures in the short- and long-term. In such synthesis we will explore and appraise how innovation, knowledge exchange, and inclusive governance can foster multifunctional agro-ecosystems that enhance

food security, build climate resilience, and support most other global sustainability goals. Emphasis will be placed on equitable partnerships for finding solutions, and the essential role of local communities in shaping pathways toward sustainable, multifunctional and climate-resilient rural landscapes.

Presentations and discussions on these, will be organised under six key thematic areas spread over 20 scientific sessions during the conference; in addition, some of these themes and related topics will be dealt with in pre-conference workshops.

We are especially pleased to welcome the many early-career researchers from more than 74 countries with a high diversity of disciplinary backgrounds, who will contribute their perceptions, creativity and fresh ideas to this year's conference. Their perspectives, alongside those of experienced scientists and practitioners, exemplify the diversity and the intergenerational dialogue that are so vital for shaping fair, sustainable and resilient futures.

We deeply thank our partners and sponsors for their invaluable support! Finally, we wish you all an inspiring, stimulating and fruitful conference that will either ignite or further strengthen collaborations in the short- and long-term.

With cordial greetings,
sincerely yours,

Reimund Rötter
Eva Schlecht
Andreas Buerkert
Christian Hülsebusch
Simone Pfeiffer
Eric Tielkes

Tropentag 2026 Organising Committee
Göttingen and Witzenhausen, September 2026

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Managing soil fertility in Africa – why, where, how, and by whom?

Eric Smaling

Wageningen University & Research / International Fertilizer Development Center (IFDC), The Netherlands

Why?
There is growing evidence that soil fertility in Africa is declining, as nutrients taken up by harvested crops are not sufficiently replenished by inputs. Reasons for concern are manifold and include crop yield stagnation, looming scarcity of finite nutrients such as phosphorus, declining topsoil carbon stocks, and perhaps the key question: how reversable and costly is this decline? At the same time, population growth in Africa implies a growing food market and opportunities for agriculture to thrive.
Where?
Major differences in soil fertility levels exist in Africa requiring customized management approaches. Fragile sandy soils in the Sahel produce less than the deep red clay soils on the volcanic Rift Valley slopes. Next levels of relevance are toposequence and heterogeneity management, often related to cherishing plots with high value crops. Manure management is an important element. Meanwhile, the more fertile farms in Africa become smaller all the time, gradually falling below household food security levels.
How?
It has become increasingly clear that a combination of organic and mineral fertiliser gives the highest return on investment. The current regenerative agriculture debate turns this too much into an 'either-or' issue. It is necessary to better know soil nutrient levels and crop needs to maximise nutrient use efficiency. Plant analysis should play a more prominent role here. Also a broader Genotype * Environment * Management approach is needed for effective soil fertility strategies. Larger system changes may come into the
picture (e.g., cluster farming), but will meet with loss of employment.
By whom?
Producers, policy makers and private sector interaction is the (not so suprising) answer. The 2024 Africa Fertiliser and Soil Health Summit delivered promises on implementation at national level. The private sector should now see that agriculture in Africa is a growth market. Farmers should be encouraged with knowledge, local business development, and digital tools to keep young people interested. Meanwhile, a lot goes on including large programmes on soil fertility improvement funded by Germany (ProSoil, Soil Matters) and The Netherlands (Soil Values, TRANSFORM, managed by IFDC).

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Assessing the multifunctionality of pastoralism: A holistic framework for resilient rangelands

Serena Ferrari

Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD), UMR Selmet, Ethiopia

Pastoral systems are frequently evaluated solely on economic yield or caloric output, a narrow scope that systematically underestimates their systemic value in arid and semi-arid regions. Addressing this gap, this presentation outlines the multidimensional framework developed under the Global Agenda for Sustainable Livestock (GASL) to capture the true multifunctionality of pastoralism.

The framework evaluates pastoral systems across four core, interdependent pillars:

- Production: Beyond standard economic output, it measures the tangible provision of meat, milk, and hides, alongside the conservation of livestock genetic diversity via specialised local breeds.
- Environmental Stewardship: It assesses critical ecosystem services, including landscape management, biodiversity maintenance, soil fertility enhancement, nutrient fluxes, carbon sequestration, and greenhouse gas mitigation.
- Social Cohesion: It quantifies broader socio-cultural outcomes, including local employment generation, social inclusion, community networks, and the preservation of cultural heritage.
- Local Economic Development: It tracks territorial economic impacts through local income generation, market integration, value-chain creation, and micro-business viability.

Aligned with the UN International Year of Rangelands and Pastoralists (IYRP 2026) and UNCCD COP17, this assessment highlights that pastoralism extends far beyond livestock production – it is a vital mechanism for climate adaptation, ecosystem restoration, and rural livelihood stability. Recognizing and safeguarding these multifunctional foundations is essential for maintaining rangeland resilience against accelerating environmental and socio-economic pressures.

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Multifunctional landscapes for climate-resilient futures: Connecting food, nature, livelihoods and governance at scale

Lulseged Tamene Desta
The Alliance of Bioversity International & CIAT, Multifunctional Landscapes, Kenya

Agrifood systems must now deliver food, nutrition, livelihoods, climate resilience, biodiversity conservation and ecosystem restoration at the same time. Yet these goals are often pursued through separate projects, policies and institutions. This fragmentation makes it difficult to manage trade-offs or build synergies across land, water, food, markets and governance. The challenge is urgent: 85 percent of wetlands are degraded, around 10 million hectares of forests are lost each year, one million species are at risk, global emissions remain at 50 to 60 gigatonnes of CO_2 equivalent annually, and about three billion people cannot afford a healthy diet.

The CGIAR Multifunctional Landscapes Science Program responds by placing the landscape at the centre of agrifood systems transformation. Its ambition is to sustainably transform landscapes so they can deliver food, climate, nature and livelihood benefits simultaneously and at scale. The programme focuses on the critical space between farms and national or global systems, where decisions on production, restoration, water, biodiversity, tenure, markets and investment come together.

CGIAR MFL uses a participatory, transdisciplinary and integrated socio-ecological systems approach. It brings together five connected areas of work: Agroecology+ Solutions and Innovations; Landscape Optimisation and Inclusive Planning; Markets, Business Models and Sustainable Finance; Governance, Policy, Institutions and Inclusion; and Performance Assessment and Evidence Generation. Together, these areas support context-specific solution bundles rather than isolated interventions.

The programme works through Multifunctional Living Landscapes, which serve as long-term platforms for co-design, implementation, negotiation, monitoring and learning. In these landscapes, researchers, governments, farmers, pastoralists, Indigenous Peoples, civil society, private actors and development partners identify priorities, align land and water management, strengthen governance, mobilise finance and generate evidence for scaling. MFL operates across diverse systems in Africa, Asia and Latin America, including highland-lowland mosaics, forest-savannah transitions, drylands, Sudano-Sahelian systems, Andean-Amazon systems and the Lower Mekong.

For Tropentag's theme on multifunctional agro-ecosystems and climate-resilient futures, CGIAR MFL offers a practical model for connecting science with action. Its projected benefits include improved livelihoods and diets for about eight million people, restoration of more than 15 million hectares, around 800 million tonnes of CO_2 equivalent mitigation, and maintenance or restoration of biodiversity and semi-natural habitats.

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Transforming Asia's rice systems: Integrated pathways to climate-resilient, low-emission, and inclusive futures

Alice Laborte

International Rice Research Institute (IRRI), Philippines

Rice is fundamental to Asia's food security, rural economies, and cultural identity, yet the systems that sustain it are under growing pressure. Climate extremes, water scarcity, environmental degradation, labour shifts, and changing markets are reshaping rice production, rural livelihoods, and the wider food systems in the region.

Meeting these challenges requires more than a series of stand-alone innovations. It calls for coordinated change across crop improvement, water and soil management, climate and digital services, risk reduction, markets, and institutions. IRRI's experience and partnerships across the region demonstrate how research can shape policy, guide investment, strengthen national capabilities, and support the wider adoption of solutions suited to local conditions. Progress will depend on sustained collaboration among governments, researchers, the private sector, and farming communities. The task is to build rice systems that remain productive under a changing climate, reduce emissions, widen opportunities, and protect the natural resources on which Asia's long-term food security depends.

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Living *with* forests: Insights from the past into land 'use' for climate resilient ecosystems and futures

Patrick Roberts

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Land use is one of the most tangible expressions of our intensifying impact on the Earth system in the Anthropocene. This is particularly the case in the latitudinal tropics, where alterations to land cover have impacts on biodiversity, the climate, and carbon cycle which can be felt on regional and global scales. While these human-forest-Earth system relationships are key parts of a number of so-called 'Anthropocene crises' in the 21st century, their origins lie much deeper in the past. In this talk, I argue that the past is key to understanding baselines of change, feedbacks between human activities, land cover, and the Earth system, and historical path dependencies and inequalities which characterise human-forest relationships in the latitudinal tropics today. I highlight how multidisciplinary approaches to historical land use change are providing a tangible, quantitative, and contextualized bases for charting more just and resilient future courses, enabling us to test and validate scenarios of land use change and ecosystem and Earth system response. Moreover, I emphasise how archaeology, history, ethnography and, critically, amplifying the voices of Indigenous communities, can lead us to consider more diverse perspectives to our relationship with land and forests than simply 'use'. In this way the past, instead of being an anecdote, becomes a key landmark for understanding the diversity of ways people not only *have* but also *can* live with tropical ecosystems.

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Innovation and resilience in smallholder cropping systems

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Fruit and vegetable species richness and seasonal availability on smallholder farms in Kilifi county, Kenya

Friederike Krüger[1], Fabio Pugin[1], Quinter Aoko[2], Katja Kehlenbeck[3], Rose Kigathi[4], Robert Ngala[5], Marcel Robischon[1]

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Fruits and vegetables are important for healthy diets, providing vitamins, minerals and phytochemicals, and could thus contribute to addressing micronutrient deficiencies. However, these crops are highly seasonal, often depending on rainfall patterns. Diversified cultivation of several fruit and vegetable species in an agroforestry system can potentially mitigate the impacts of seasonal food scarcity, a severe problem of many smallholder farming households in sub-Saharan Africa, including Kenya. This study aimed at determining richness and seasonal fruit and vegetable species availability in Kilifi County, Kenya. Four farms that participated in an agroforestry project (AfriNutriForest) were selected and wild and cultivated fruit and vegetable species inventoried. After assessing seasonal availability of the documented fruit and vegetable species in Focus Group Discussions (FGD) with local farmers, harvest calendars were developed.

In total, 37 vegetable species were documented, including 19 wild native ones. Only 10 vegetable species were present on all four farms, including cultivated ones, like spiderplant (*Cleome gynandra*) and *moringa* (*Moringa oleifera*) and wild species, including bitter lettuce (*Launaea cornuta*) and *Oxygonum stuhlmannii*. Regarding fruits, 41 species were recorded, including eight wild species. Nine fruit species were found on all four farms, most commonly coconuts (*Cocos nucifera*), bananas (*Musa* spp.) and mangoes (*Mangifera indica*).

The harvest calendars indicated that availability of mature fruit and vegetable species ran asynchronously throughout the year. Vegetable availability peaked just after the 'long rains' (March-May) in May and June, followed by a lean season in Aug-Sep and a second peak during/after the short rains in Oct-Dec, followed again by lower availability from Jan-March. Contrarily, fruit availability reached a clear peak in Nov-Jan and a less pronounced peak in July-Aug, while from Feb-May fruit availability was low. These asynchronous harvest patterns may help farming households cope with food insecurity, as vegetables were generally available when fruits were not and vice versa, however, only if a diverse set of both fruit and vegetable species are produced on the farm throughout the year. Diversified horticultural production in agroforestry systems could thus be promoted, but more robust data should be collected.

Keywords: Agrobiodiversity, agroforestry, climate resilience, food security

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Technical efficiency and profitability of rice ratooning in Africa: Evidence from seven countries

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Rice consumption in Africa is growing rapidly, yet conventional rice cultivation contributes to greenhouse gas emissions, soil degradation, and wetland loss. Ratooning-harvesting a second crop from stubble of the main crop-offers a potential pathway for sustainable intensification, but evidence under real farm conditions across Africa remains scarce. This study assesses whether rice ratooning improves technical efficiency and profitability among smallholders, using cross-sectional farm household data from 3,276 rice farmers across seven African countries (Senegal, Côte d'Ivoire, Nigeria, Uganda, Kenya, Tanzania, and Madagascar). We estimate a stochastic frontier production function to derive technical efficiency and inefficiency determinants, and calculate gross margins, average and marginal value-cost ratios. To address self-selection bias, we apply propensity score matching to estimate the causal effect of ratooning on gross margins per hectare. Descriptive results show that ratoon yields range from 34 % to 68 % of main crop yields, while ratoon costs per hectare range from 12 % to 52 % of main crop costs, indicating substantial cross-country heterogeneity. Stochastic frontier estimates reveal that ratooning significantly reduces technical inefficiency in Senegal (-1.985, $p < 0.05$) but increases inefficiency in Kenya (1.250, $p < 0.05$) and Tanzania (1.825, $p < 0.01$). Propensity score matching results show a positive and significant average treatment effect on the treated for Senegal ($+286\,\text{USD}\,\text{ha}^{-1}$, $p < 0.05$), but negative effects for Kenya ($-631\,\text{USD}\,\text{ha}^{-1}$, $p < 0.01$) and Madagascar ($-457\,\text{USD}\,\text{ha}^{-1}$, $p < 0.05$). We conclude that rice ratooning is not universally profitable or efficient in Africa; its performance is highly context-specific. Promising use cases exist (e.g., Senegal), but blanket promotion without agronomic support, particularly in East Africa, is unwarranted.

Keywords: Africa, profitability, propensity score matching, rice ratooning, stochastic frontier analysis, technical efficiency

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Is crop diversification associated with farm-level agricultural sustainability? Evidence from smallholders in irrigated areas of Kyrgyzstan

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This study investigates the relationship between crop diversification and farm-level sustainability outcomes among smallholder farmers in Kyrgyzstan. Using survey data collected from 410 heads of smallholders in 2024, the study looks whether crop diversification is nonlinearly associated with agricultural sustainability and adoption of sustainable agricultural practices. We measure crop diversification using the inverse Simpson diversity index, and sustainability as a composite indicator of environmentally oriented farm management practices. To address potential endogeneity in farmers' crop diversification decisions, the study employs seemingly unrelated regression built on the control function approach to jointly estimate two interrelated sustainability outcomes, while accounting for unobserved farm and farmer-level heterogeneity. The results reveal a nonlinear inverted U-shaped relationship between crop diversification and both sustainability outcomes. Low and high levels of crop diversification are associated with lower environmental sustainability and narrower adoption of sustainable agricultural practices and technologies. The findings suggest that excessive diversification may increase management complexity and reduce sustainability gains. Overall, the study provides new empirical evidence from Central Asia on the relationship between crop diversification, and sustainable agricultural management.

Keywords: Control function approach, crop diversification, Kyrgyzstan, seemingly unrelated regression, smallholder farmers, sustainable agricultural practices

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Pineapple-legume rotation drives first-cycle pineapple growth, yield, and quality improvements while reducing mineral fertiliser needs

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Pineapple production in southern Benin is constrained by declining yields and heterogeneous fruit quality, largely driven by continuous monoculture and inefficient fertilisation practices. Leguminous cover crops are widely recognised for restoring soil fertility in tropical systems, yet their benefits are generally assumed to manifest only after multiple cropping cycles. This study evaluated whether pineapple–legume rotations can generate immediate agronomic benefits within a single production cycle and reduce dependence on mineral fertilisers. An unbalanced factorial design in randomised blocks including 13 treatment combinations and four replications was implemented across four farmer fields on Ferralsols of the Allada plateau. Treatments combined three cropping systems - pineapple monoculture (control), pineapple–*Mucuna pruriens*–pineapple, and pineapple–*Crotalaria juncea*–pineapple – with varying levels of recommended mineral fertiliser (0 %, 50 %, 100 %) and compost (0 %, 50 %, 100 %) amendments. Cover crops were grown for four months, incorporated into the soil, and followed by pineapple cultivation (cv. Sugarloaf). Growth, biomass, yield, and fruit quality were analysed using linear mixed-effects models. Both *Mucuna* and *Crotalaria* produced comparable biomass (~10 t ha^{-1}), indicating similar organic matter inputs. Rotation treatments significantly improved pineapple growth, biomass accumulation, fruit weight, juice weight, and total soluble solids from the first production cycle. Notably, rotations combined with 50 % of the recommended mineral fertiliser consistently matched or outperformed conventional monoculture under equivalent fertiliser levels. In contrast, compost-only treatments improved performance relative to monoculture but remained inferior to mineral fertiliser amendments, highlighting the critical role of mineral nutrients, particularly potassium. These findings demonstrate that pineapple–legume rotations can deliver immediate productivity and quality gains while enhancing fertiliser use efficiency. The absence of major differences between *Mucuna* and *Crotalaria* suggests that the rotation effect itself is more important than species choice. This study provides strong evidence for integrating leguminous cover crops into pineapple systems as a cost-effective, sustainable intensification strategy with direct relevance for smallholder adoption in West Africa.

Keywords: Cover crops, *Crotalaria*, fertiliser use efficiency, *Mucuna*, pineapple, rotation

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Reduced tillage, not residue retention, drives soil fauna recovery: A global meta-analysis

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Conservation agriculture (CA), defined by minimum soil disturbance, permanent soil cover, and diversified rotations, is adopted on about 200 million hectares of tropical, subtropical, and temperate croplands and is promoted as a cornerstone of sustainable intensification. Despite nearly four decades of adoption, its effects on non-harvested agrobiodiversity remain debated, largely because the contributions of reduced tillage and residue retention are difficult to isolate. This gap matters for smallholders, where residues compete with fodder and fuel uses, and where no-till's substitution of herbicides for mechanical weed control raises non-target biodiversity concerns. We synthesize global evidence on soil faunal diversity under CA versus paired conventional tillage controls, to decouple the contributions of reduced tillage from residue retention. We compiled 682 effect sizes from 51 field studies spanning six continents (1986–2025), distinguishing reduced tillage alone (Decoupled Framework; 254 effect sizes, 16 studies) from the composite tillage-residue package (Composite Framework; 579 effect sizes, 40 studies). Rotation, the third CA pillar, was held constant within paired comparisons and tested only as a moderator across studies. CA increased overall faunal biodiversity by 44.4 % (95 % CI: 12.6 to 85.2) under the Decoupled Framework and 36.2 % (CI: 17.46 to 57.9) under the Composite Framework, with residue retention adding no detectable additional benefit. Our results indicate that reduced mechanical disturbance, not residue retention, is the primary driver of biodiversity recovery. Abundance and biomass recovered significantly, but species richness did not, indicating numerical rather than compositional restoration. Responses were strongest on highly weathered tropical soils (Ferralsols, Acrisols, Lixisols: 145.8 %, Composite), cereal rotations (115.3 %, Composite), and soil-dwelling taxa (52.6 %, Decoupled). Concurrent herbicide and insecticide use did not systematically offset these gains. The findings suggest that recognising tillage reduction as a valuable component independent of residue retention within CA programmes could provide flexibility for farmers. This would be especially beneficial in tropical mixed crop-livestock systems where residue retention is constrained by fodder demands, and tillage reduction has the highest positive ecological effect per hectare. For tropical smallholders facing residue-allocation trade-offs, reducing tillage alone within prevailing agrochemical regimes is sufficient to initiate measurable soil faunal recovery.

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Adoption of climate-smart agricultural practices among smallholder farmers in northern Thailand: The role of socioeconomic and institutional factors

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Climate change is increasingly threatening agricultural production, particularly for smallholder farmers who face limited adaptive capacity. While the impacts of climate variability on crop production are well documented, there remains limited evidence on the determinants of farmers' adaptation strategies in Northern Thailand. This study aims to identify the key climate change adaptation practices adopted by smallholder farmers and to examine the socioeconomic and institutional factors influencing their adoption decisions.
A mixed-methods approach was employed, combining household survey data from 198 farmers with Key Informant Interviews and Focus Group Discussions. A descriptive analysis using the Weighted Average Index (WAI) ranked adaptation practices, while the Problem Confrontation Index (PCI) identified major constraints. A binary logistic regression model was used to analyse factors influencing the adoption of adaptation practices. The results show that multi-cropping (WAI=5.38), irrigation systems (WAI=4.88), changing cropping dates (WAI=3.69), and Alternate Wetting and Drying (WAI=2.98) are the most widely adopted strategies. The logistic regression results indicate that gender, age, education, land ownership, access to credit, and non-farm income significantly influence adoption decisions. The PCI results further reveal that high input costs, water scarcity, a lack of storage facilities, and labour shortages are the most critical barriers farmers face. The findings highlight the importance of strengthening institutional support systems to enhance farmers' adaptive capacity. Policy interventions should focus on improving access to credit, expanding extension and climate information services, subsidising agricultural inputs, and investing in water management infrastructure. These measures are essential for promoting climate-resilient and multifunctional agroecosystems. This study provides insights for policymakers, development practitioners, and stakeholders working toward sustainable agricultural adaptation in Southeast Asia.

Keywords: Adaptive capacity, binary logistic regression, climate change, climate-smart agriculture, Northern Thailand, smallholder farmers

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Beyond awareness: Structural barriers to regenerative agriculture adoption among smallholder bean farmers in Embu county, Kenya

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Common bean (*Phaseolus vulgaris* L.) is a critical food and income crop for smallholder farmers in East Africa, yet productivity remains constrained by biophysical, socioeconomic, and management factors. Understanding the diversity of current farmer practices is essential for designing context-appropriate pathways toward multi-functional, climate-resilient agro-ecosystems, particularly as regenerative agriculture gains traction as a framework for sustainable intensification.

This study documents the farming practices, knowledge, attitudes, and perceptions of bean producers in Embu County, Kenya. A mixed-methods approach combined a quantitative survey of 200 smallholder farmers with in-depth key informant interviews (n=6). The farming practices questionnaire used the Periodic Table of Food Initiative (PTFI) metadata framework, covering 48 practices across 13 management categories. Six lead farmers hosted Mother demonstration plots with four treatments: T1 control (no inputs), T2 conventional (DAP, tillage, inorganic pesticides), T3 regenerative monocrop (organic manure, reduced tillage, mulch), and T4 regenerative intercrop (maize-bean, same regenerative management). Baby demo farmers replicated one or two of treatments T2–T4 on their own fields. Key informant interviews (KIIs) were conducted after harvest.

Surveyed farmers were predominantly women (69 %), experienced (78 % with over ten years of farming), and low-income (70 % earning under USD 80/ month). High adoption of diversification practices – intercropping (80 %), crop rotation (71 %), and agroforestry (86 %) – indicates an existing foundation for multi-functional agro-ecosystems, yet this coexisted with dominance of conventional tillage (72 %), chemical pest control (78 %), and mineral fertilisation without crop-specific guidance (80 %). Key informant interviews revealed sophisticated farmer decision-making. Farmers valued regenerative practices for long-term soil health but found DAP-fertilised plots more resilient under severe drought due to faster early establishment. A clear

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"double standard" emerged: mineral fertilisers for market-oriented production, organics for household consumption – reflecting rational optimisation rather than lack of awareness. Labour and transport of organic inputs were the primary structural barriers, compounded by knowledge gaps in organic pest management and absent organic value chains.
These findings offer a replicable, mixed-methods approach for characterising smallholder farming systems, demonstrating that scaling regenerative agriculture requires structural interventions – labour-saving technologies, organic pest control, and market linkages – rather than awareness campaigns alone.

Keywords: Climate resilience, common bean, crop diversification, Embu County, regenerative agriculture, smallholder farmers, soil health, structural barriers

Beyond formal interventions: indigenous agricultural practices and water use efficiency (WUE) among smallholders in South Punjab, Pakistan

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Water scarcity has become a critical constraint for agricultural sustainability in South Punjab, Pakistan where smallholder farmers rely heavily on irrigation for crop production. Formal interventions like government irrigation regulations, extension services, and input subsidies are intended to enhance water management, their effectiveness is frequently constrained at the farm level however this study goes beyond formal interventions. Therefore, by investigating indigenous (non-formal) agricultural strategies that farmers create and implement locally to deal with water constraint, some indigenous practices can reduce water efficiently under changing climatic conditions. These methods include growing traditional cereals, adjusting planting times, and substituting water-intensive crops like rice and sugarcane with Kharif crops like (sesame, guar, and pulses etc.). While these indigenous techniques exist, their scalability and effectiveness remain limited due to weak market linkages and lack of proper institutional support. With an emphasis the role of indigenous knowledge and co-designing solutions with other stakeholders and institutional support (such as other farmers, universities, extension services etc.), the study examines how such practices affect WUE. A structured questionnaire and multistage sampling were used in cross-sectional data of 200 smallholder farmers. The study uses a multinomial logit model to examine the effects of cropping decisions and Stochastic Frontier Analysis (SFA) to estimate WUE. Variety of indigenous innovation approaches, such as bed-furrow irrigation, residual moisture farming, using drought-tolerant native seeds, and rainfall-adjusted sowing, are compared in terms of water use and productivity.

Results show that crop choice and participation in farmer organisations significantly improve WUE. Groundwater depletion and increased production costs are caused by market-driven growth of water-intensive crops. And water efficiency and resilience may be improved by combining indigenous knowledge with institutional support and stakeholder participation. In order to encourage the scaling of indigenous methods for sustainable agricultural output and better smallholder livelihoods, study suggests encouraging climate-smart, low-water crops, supporting farmer organisations, and coordinating policies.

Keywords: Formal interventions, indigenous innovations, smallholder livelihoods, sustainable agriculture, water scarcity, water use efficiency

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Restoring ecological integrity through agroforestry: Survey insight from Ghana's forest fringe communities

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The ecological integrity of Ghana's forest-fringe landscapes is under increasing pressure from land degradation, deforestation, and biodiversity loss. These changes are not distant environmental statistics; they are lived realities for farming households whose livelihoods depend on the land's resilience. In recognition of this urgency, the EMBRACE project, led by CSIR–Crops Research Institute, conducted ecological surveys across Ashanti, Ahafo, and Western North regions to establish baseline data for agroecological restoration. Our participatory approach combined structured questionnaires, focus group discussions, and ecological sampling, ensuring that both scientific rigour and community voices shaped the findings. Results revealed a striking ecological divide. Forest reserves supported higher species richness, with abundant insects, birds, and butterflies, while adjacent degraded lands showed diminished diversity and weakened ecological functions. Farmers themselves vividly articulated these differences, describing how soils on degraded plots "no longer breathe" and how the absence of shade trees intensifies heat stress on crops. Socio-economic data added further context: farming was the dominant occupation, migration rates were high, and formal education levels were limited, particularly in Ahafo and Western North. Yet, amid these challenges, agroforestry awareness was widespread (75–93 %), and more than 90 % of farmers actively integrated trees into cropping systems, deliberately preserving native species during land preparation. Farmers consistently cited practical benefits of shade, soil fertility, erosion control, and climate regulation, demonstrating that ecological stewardship is rooted in livelihood needs rather than in cultural taboos alone. These insights highlight clear pathways for scaling interventions: embedding agroforestry into farmer field schools, promoting native tree species, and tailoring restoration models to local ecological zones. By fostering community ownership, EMBRACE strengthens the feasibility of long-term ecological stewardship. Agroforestry thus emerges not only as a conservation strategy but as a lifeline restoring biodiversity while securing the resilience of rural livelihoods in Ghana's forest-fringe communities.

Keywords: Agroforestry, biodiversity, ecological restoration, forest fringe communities, Ghana, participatory research

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Circular bioponics for African indigenous vegetables using waste-derived and mineral fertilisers

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To develop climate-resilient food production systems, it is imperative to adopt innovative strategies that incorporate nutrient recycling and minimise the reliance on synthetic fertilisers. African indigenous vegetables (AIVs) are crucial for nutrition and livelihoods in sub-Saharan Africa; however, their cultivation is hindered by high input costs and unsustainable fertiliser practices. This study assessed a circular bioponic system that integrates waste-derived fertilisers, black soldier fly (BSF) frass, chicken manure, and fish sludge with mineral NPK fertiliser for the cultivation of African nightshade (*Solanum villosum*), amaranth (*Amaranthus dubius*), and cowpea (*Vigna unguiculata*) crops.

Plant performance was evaluated based on parameters such as plant height, leaf characteristics, chlorophyll content, branching, and biomass. The type of fertiliser applied significantly affected all measured parameters ($p < 0.05$), indicating pronounced crop-specific nutrient response. NPK fertilisation facilitated rapid early growth, with amaranth achieving the highest biomass at 240.52 g plant^{-1}. Fish sludge enhanced structural growth in African nightshade, resulting in a plant height of 53.8 cm, whereas chicken manure increased branch number in African nightshade to 18 branches per plant and improved chlorophyll content in cowpea by up to 59 % compared to NPK alone. Waste-derived fertilisers, particularly fish sludge and BSF frass, achieved biomass levels comparable to NPK during the mid-growth stage, demonstrating effective nutrient release within the bioponic system. Although cowpeas generally exhibited lower biomass accumulation, organic treatments maintained sustained growth performance, indicating their potential as partial or complete substitutes for mineral fertilisers. This study illustrates that the integration of organic waste streams into circular bioponic systems can enhance nutrient recycling, diminish reliance on synthetic inputs, and maintain the productivity of vegetables. This methodology supports climate-resilient intensification of African Indigenous Vegetable production and contributes to the sustainable development of agroecosystems in sub-Saharan Africa.

Keywords: African indigenous vegetables, bioponics, circular agriculture, climate-resilient agriculture, nutrient cycling, sub-Saharan Africa, waste valorisation

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Integrating solar-based irrigation and vermicompost using living-lab approach: Effects on yield, soil, and livelihoods, Ethiopia

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This study in Ethiopia's Rift Valley used field experiments and key informant interviews to evaluate (i) the combined effects of solar-based irrigation and soil fertility management on yield and soil moisture dynamics, and (ii) farmers' perceptions of solar-based irrigation's contributions to livelihoods and environmental sustainability. The participatory on-farm trial used cabbage and pepper as test crops and employed a randomised complete block design with three treatments: (i) Control/Treatment 1 - solar-based irrigation with farmers' current practices; (ii) Treatment 2-solar-based irrigation plus farmers' practices and 4 t ha^{-1} of vermicompost; and (iii) Treatment 3-solar-based irrigation plus farmers' practices and 8 t ha^{-1} of vermicompost. The study shows that integrating solar-based irrigation with vermicompost significantly increased crop yield and volumetric soil moisture content across sites. Financial analysis also indicates that the yield gains from this bundling technology were economically viable, with a benefit-cost ratio ranging from 0.38 to 2.46. Farmers reported that solar-based irrigation enabled livelihood diversification by expanding irrigated land, increasing harvest frequency, and supporting a shift from staple cereals to vegetables, fruits, and fodder crops. These changes strengthened household income, food security, and nutrition, while also improving dry-season feed availability. The adoption of solar-based irrigation generated environmental co-benefits, including tree planting, biodiversity-supportive practices, and improved ecosystem services. However, biodiversity efforts largely focused on economically valuable species, indicating the need for broader conservation strategies. Findings underscore that solar-based irrigation delivers the greatest benefits when integrated with soil fertility management practices, highlighting that scaling efforts should prioritise bundled interventions to maximise agronomic, economic, and livelihood impacts in Ethiopia and similar agro-ecological contexts.

Keywords: Crop yield, livelihood diversification, soil moisture dynamics, soil-organic fertiliser, solar-based irrigation

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Root yield and response to tillage of three improved cassava varieties introduced to Liberia

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Cassava is next to rice, the most important food crop in Liberia. Despite its importance smallholders are dominantly growing highly cassava mosaic virus (CMV) susceptible local varieties that have no tolerance against a wide array of insect pests. Agronomic practices are designed for subsistence systems than to produce high yields to process for marketing. Fields are established by horizontally burying 2–3 planting stakes in the same place, producing a large number of small storage roots, which are harvested sequentially from plants without uprooting them (milking). This approach causes delayed sprouting and strong internal competition, aggravating CMV, with consequent low root yields around 5 to 7 Mg ha^{-1} fresh roots. In 2024, the UNIDO GROW2 project introduced three improved cassava varieties to Liberia and conducted on-farm trials, evaluating yield responses to tillage in Bong and Nimba counties.

Single cassava stakes were planted at 1 m by 1 m distance in June 2024 and harvested 12 months after planting. Participating farmers managed the trials sites and participated in the harvest. The varieties TMS95/0289, TMS01/1371 and TMS0040 were compared with the local variety in 5 sites. Tillage was flat, ridged or mounded. The local variety was planted only on flat soil. Variety TMS95/0289 attained the highest average root yield (19.08 Mg ha^{-1}), followed by TMS01/1371 (12.29 Mg ha^{-1}) and TMS0040 (7.14 Mg ha^{-1}). The local variety produced 3.80 Mg ha^{-1} fresh roots. Tillage by ridging attained the highest average root yield across the improved varieties (19.68 Mg ha^{-1}), followed by 13.87 Mg ha^{-1} on flat soil and 12.12 Mg ha^{-1} when mounded. The poor root yield of the local variety was partially related to the low establishment and survival to the harvest rate of 39 %, compared to 65 % in TMS01/1371, 70 % in TMS0040 and 72 % in TMS95/0289. Root yield in the local variety had the following regression with plant density : yield = 28.23 plants m^2 – 7.2 (r^2=0.898). No such relationship was observed in the improved varieties, this however, likely due to the much smaller range of plant densities. Tillage had an effect on survival to the harvest with 64 % in flat soil, 68 % on mounds and 77 % when ridged.

Keywords: Cassava, Liberia, root yield, tillage, varieties

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Survival first, biomass later: Trade-offs shaping dryland restoration outcomes in the Sahel

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Land degradation severely constrains livelihoods and ecosystem services across the Sahel. Large-scale restoration commonly combines soil and water conservation (SWC) structures with plantings of native woody species, yet post-planting survival and accumulation of biomass remain highly variable, limiting long-term restoration outcomes. We quantified survival and aboveground biomass of native woody plantings across restored degraded sites and tested how SWC structures, geomorphological units, post-planting management, and planted-species diversity shape restoration performance and trade-offs between survival and biomass.

We inventoried 2,097 planted trees belonging to six native species (*Acacia nilotica*, *A. raddiana*, *Senegalia senegal*, *Vachellia seyal*, *Bauhinia rufescens*, *Ziziphus mauritiana*) across 14 restored sites in three villages of the Tahoua region (Niger). Aboveground biomass was estimated using allometric models. Drivers of individual survival were analysed using Bayesian logistic regression, and plot-level biomass was analysed using Bayesian log-normal regression, with predictors including SWC structure type, geomorphological unit (plateau, pediment, slope), management regime, and planted-species diversity (Shannon α-diversity).

SWC structures exerted strong but contrasting effects on restoration performance. Trenches, half-moons, stone bunds, and stone bund combined with trenches generally increased survival and biomass, with the strongest and most consistent positive effects associated with trenches. Benches and stone wall–trench combinations were associated with lower survival and biomass. Post-planting management was decisive: sites combining guarding, maintenance, and replanting achieved the highest survival and biomass, whereas weakly managed or unmanaged sites performed substantially worse. Planted-species diversity increased biomass production but had no detectable effect on survival.

Restoration outcomes in Sahelian drylands are shaped by clear trade-offs between survival and biomass. Survival emerges as a prerequisite for productivity and is primarily controlled by post-planting management, whereas biomass accumulation depends on both management and the capacity of SWC structures to enhance resource availability. Geomorphology plays a secondary, context-modifying role.

Keywords: Aboveground biomass, Bayesian modelling, land restoration, Sahel, soil and water conservation, survival, water harvesting, woody species diversity

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Growth and yield evaluation of marigold (*Tagetes erecta*) landraces at Bhaktapur, Nepal

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Marigold (*Tagetes erecta* L.) is an economically important floricultural crop widely cultivated for decoration, religious offerings, and its carotenoid and essential oil content. Despite growing domestic demand for flowers, which is currently met by local production at only about 20 %, no indigenous Nepalese marigold landraces have been formally characterised or recommended for commercial cultivation. This study was conducted to evaluate seven elite marigold landraces (Co16861, Co16864, Co16868, Co16874, Co16875, Co16881, and Co16883) that were collected, morphologically characterised, and genetically assessed by the project "Agro-Morphological and Genetic Characterisation of Marigold (Tagetes spp.) Landraces of Eastern Nepal". The experiment was laid out in a Randomised Complete Block Design (RCBD) with three replications. Growth parameters, including plant height, plant spread, number of branches, number of nodes, and inter-nodal length, were recorded at 30, 60, and 90 days after transplanting (DAT). Floral traits, including days to bud formation, days to first harvest, number of harvests, number of flowers per plant, flower weight, flower diameter, and petaloid number, were also recorded. Data were analysed using R 4.2.1. Significant differences were observed among landraces for plant height at 30 and 60 DAT, number of nodes at 60 DAT, and inter-nodal length at all three observation periods. All floral quality traits, flower weight, flower diameter, and petaloid number differed highly significantly among genotypes. Landrace Co16883 emerged as the top performer, recording the highest number of flowers per plant (127.66) and maximum harvests (12), while Co16868 produced the heaviest flowers (9.58 g) and the largest flower diameter (6.84 cm). Similarly, landraces Co16881 and Co16861 also showed strong commercial potential, with Co16861 having the shortest duration to bud initiation and first harvest (60.66 and 71.66 days), while Co16881 had the highest petaloid number. These findings suggest that several Nepalese marigold landraces possess strong commercial potential and could be integrated into formal breeding programmes to develop high-yielding, locally adapted varieties for Nepal's growing floriculture sector.

Keywords: Agro-morphological characterisation, floral quality, floriculture, growth parameters, randomised complete block design

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Factors explaining the adoption of water-saving strategies by irrigators in Burkina Faso

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In a context marked by increasingly scarce water resources and the growing vulnerability of agriculture to the effects of climate change, it is essential to promote the adoption of Water Saving Strategies (WSS) in order to improve water use efficiency and strengthen the resilience of agricultural systems. This study examines the determinants of WSS adoption and intensity of adoption among irrigators in Burkina Faso. The analysis is based on primary survey data collected from 1,126 irrigators in several areas covering 13 of the country's 17 regions. The methodological approach is based on the estimation of a Ridge (L2) regularized multinomial logistic regression model to identify the micro, meso-individual, and meso-structural factors influencing adoption behaviour. The intensity of adoption was measured using a categorical variable reflecting the number of water-saving strategies implemented by each irrigator. The results indicate that institutional support, particularly from local water committees, significantly increases the probability and intensity of WSS adoption. Environmental awareness alone is not sufficient to promote consistent adoption. However, its interaction with institutional support produces a strong and statistically significant positive effect, highlighting the complementary role of cognitive and institutional factors. Farm size also positively influences the intensity of adoption, suggesting that large-scale irrigators are more inclined to invest in water-saving practices. On the other hand, high opportunity costs are a major constraint, limiting irrigators' ability to adopt such strategies. These results highlight the importance of strengthening institutional support mechanisms, improving access to extension services, and raising environmental awareness in order to promote sustainable water management. The study contributes to the literature by providing empirical evidence from the Sahelian context and by incorporating the interaction effects between environmental awareness and institutional support.

Keywords: Adoption of innovations, Burkina Faso, irrigation, sustainable water management, water-saving strategies

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Crop health under climate variability: pests, pathogens, and agroecological solutions

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Nematode management in the face of climate change: From chemical control to climate-smart soil systems

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Potato (*Solanum tuberosum*) production in sub-Saharan Africa is increasingly constrained by nematodes, particularly *Meloidogyne* spp. (root knot nematodes) and Globodera rostochiensis (potato cyst nematode). Under changing climatic conditions, the impacts of these nematode pests are expected to intensify. Rising temperatures will translate into shorter nematode life cycles leading to more rapid population build-up, while erratic rainfall patterns will increase crop vulnerability. Tightening environmental regulations will also further limit conventional chemical nematicide use. This creates additional pressure for developing and identifying suitable nematode management strategies that are both effective and compatible with climate-resilient agricultural systems. The banana fibre technology has been shown to be such a promising option, as a precision delivery system for low dose nematicides, which outperform recommended applications leading to reduced total chemical inputs. Our studies have also shown that the use of impregnated banana fibre limits the negative impact to soil microbial communities. Using banana fibre to deliver microbial biological products can also be effective, including on the microbiome. Our finding highlights the potential of fibre-based delivery systems to enhance input-use efficiency and reduce environmental loading. Beyond field performance, this work contributes to a broader shift toward planning for future climates by using climate smart technologies. Our ongoing studies using phytotrons are designed to simulate future climate conditions (elevated CO_2 and temperature) and assess their effects on crop nutritional quality and pest susceptibility. This will be critical for understanding how climate stress alters host resistance, nematode dynamics, and overall soil system resilience, allowing us to better prepare effective solutions.

Keywords: Biocircular economy, climate-smart agriculture, *Globodera* spp., precision delivery

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Mapping biotic stressors across mediterranean cropping systems: Current distributions and climate-driven future projections

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Biotic stressors, including pests, weeds, and diseases, are major constraints on agricultural productivity and the economic viability of farming systems. In Mediterranean regions, where high-value crops such as olive and tomatoes play a globally significant role, yield losses attributable to these stressors are substantial. Increasing evidence suggests that climate change is intensifying their impacts by accelerating proliferation, shifting geographical distribution, and altering phenology. As a result, crop losses are becoming severe, including in areas previously considered low risk. This study examines nine Mediterranean countries (France, Italy, Greece, Turkey, Lebanon, Jordan, Egypt, Tunisia, and Morocco) and three major cropping systems (olive-based, tomato-based, and cereal-legume based cropping systems). The objectives are to identify key biotic stressors, characterise their current distributions, and predict their future distribution across the broader Mediterranean basin. We conducted a systematic literature review to identify frequently reported biotic stressors, and applied species distribution modelling approach using maximum entropy to estimate their current and future distributions. A synthesis of 1,550 peer-reviewed articles shows that research is heavily skewed towards cereal-legume systems, with weeds emerging as the most frequently reported stressor type (59.7 %). *Sinapis arvensis* L. and *Anagallis arvensis* L. are the most commonly documented weed species. The dominant weed families were Asteraceae and Poaceae, while the predominant pest families include Thripidae, Tetranychidae, and Aleyrodidae. Geographically, the literature is disproportionately concentrated in Italy, highlighting regional research imbalances. Model projections under a business-as-usual climate scenario indicate yield losses across three cropping systems. These findings underscore the urgency of implementing agroecological interventions, including integrated pest management strategies and the use of service crops for weed suppression. Overall, this study provides evidence that is directly relevant to farmers, extension officers, and policymakers to support the scaling of agroecological transitions, thereby enhancing the resilience and sustainability of Mediterranean farming systems.

Keywords: Agroecology, cereal-legume, olive, pests, predict, tomatoes, weeds

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Optimising field screening for cassava brown streak disease resistance: Enhancing efficiency and reducing costs

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Cassava brown streak disease (CBSD) remains the most severe threat to cassava production in the Great Lakes region and Southern Africa. Screening for virus resistance by subjecting cassava to high virus pressure in the epidemic zone (hotspots) is a common but lengthy process because of unpredictable and erratic virus infections requiring multiple seasons for disease evaluation. This study investigated the feasibility of graft-infections to provide a highly controlled infection process that is robust and reproducible to select and eliminate susceptible cassava at the early stages and to predict the resistance of adapted and economically valuable varieties. To achieve this, a collection of cassava germplasm from the Democratic Republic of Congo and a different set of breeding trials comprising two seed nurseries and one preliminary yield trial were established. The cassava varieties OBAMA and NAROCASS 1 infected with CBSD were planted one month after establishment of the main trials in a 50 m^2 plot to serve as the source of the infection and to provide scions to graft approximately 1 ha. Grafted plants were inspected for virus symptoms and additionally tested by RT-qPCR for sensitive detection of the viruses. The incidence and severity of CBSD and cassava mosaic disease (CMD) symptoms were scored at different stages of plant growth and fresh root yield determined at harvesting. The results from the field experiments proved that graft-infection with infected plants showed rapid symptom development in susceptible cassava plants allowing instant exclusion of those lines from the next breeding cycle. High heritability, with values ranging from 0.63 to 0.97, was further recorded for leaf and root symptoms, respectively. Indeed, only a few cassava progenies were selected while clones DSC260 and two species of *Manihot glaziovii* (Glaziovii20210005 and Glaziovii20210006) showed resistance to CBSD. Taken together, grafting scions from infected cassava is a highly efficient and cost-effective method to infect cassava with CBSD even under rugged field conditions. It replaces an erratic infection process with a controlled method to ensure precise screening and selection for virus resistance. The clones identified as resistant could serve as elite donors for introgression, facilitating the transfer of resistance to CBSD.

Keywords: Breeding, field screening, grafting, heritability, hotspot, RT-qPCR

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Exploring the diverse world of cassava virus diseases: Advances and innovations

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Cassava is a staple crop for millions of people, yet its production is severely threatened by a wide range of viral diseases. Our work focuses on understanding cassava viruses, identifying sources of resistance, and developing practical strategies to protect this important crop. In our work, we use an extensive virus collection from South America, Africa, Brazil, and Asia to study both established and emerging pathogens affecting cassava.

Our research covers several interconnected areas. We identify and characterise causal agents of major cassava diseases, including cassava root rot, cassava witches' broom, cassava frog skin disease, cassava mosaic disease, and cassava brown streak disease. We also investigate host–virus interactions, with particular focus on cassava brown streak viruses and cassava mosaic viruses, using molecular tools, confocal microscopy, infectious clones, and modified viral genomes. These approaches allow us to follow infection processes in cassava and Nicotiana benthamiana and to better understand viral replication, movement, symptom development, and resistance responses. A major achievement of our work has been the identification and characterisation of cassava lines resistant to Cassava Brown Streak Disease, one of the most serious threats to food security in sub-Saharan Africa. By exploring cassava diversity from its center of origin in South America, we identified valuable resistant germplasm, defined resistance patterns, and supported the deployment of these resources to disease-affected regions in Eastern and Central Africa. We continue to expand this work by integrating additional resistance traits and evaluating the durability of resistance under field conditions. To uncover the mechanisms behind resistance, we combine high-throughput screening, omics technologies, high-resolution imaging, Genome-Wide Association Studies, mapping by sequencing, and small RNA analysis. These studies have highlighted viral and host factors involved in resistance, including the role of the Ham-1 gene in virus replication, movement, symptom expression, and resistance. Additional signals on chromosomes 11 and 3 suggest possible host genomic regions associated with CBSV and UCBSV resistance, while small RNA sequencing has revealed novel miRNAs and lipid-transfer-related genes that may contribute to plant immunity.

Overall, our research links fundamental virus biology with translational plant health solutions, aiming to support virus exclusion, resistance deployment, and sustainable cassava production for farming communities worldwide.

Keywords: Cassava, cassava brown streak disease, cassava mosaic disease, cassava viruses, food security, germplasm screening, host–virus interactions, plant health, plant immunity, virus resistance

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RNA interference-based suppression of *Fusarium* wilt in banana for climate-resilient agroecosystems

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Banana is among the world's most exported fresh fruits and a staple food for millions of people in tropical regions. However, global banana production is increasingly threatened by *Fusarium oxysporum* f. sp. *cubense* Tropical Race 4 (FocTR4), a destructive soil-borne pathogen that causes severe yield losses and threatens sustainable banana production in tropical agroecosystems. Conventional disease management strategies that rely on toxic soil fumigants and chemical pesticides remain largely ineffective because of the pathogen's long-term persistence in soil and the limited availability of resistant cultivars. RNA interference (RNAi) has emerged as a promising, environmentally friendly approach to sustainable plant disease management through sequence-specific gene silencing. While previous RNAi studies targeting FocTR4 have focused solely on the single gene DCL2, the functional roles of DCL1 and potential redundancy between DCL1 and DCL2 in pathogenicity remain unexplored. In this study, we investigate the RNAi machinery of FocTR4, with emphasis on both Dicer-like genes DCL1 and DCL2, which regulate small RNA biogenesis and may contribute to fungal pathogenicity. Preliminary expression analysis indicates that both genes are differentially regulated during interaction with banana roots, confirming their involvement in host–pathogen communication. To identify effective RNAi targets, double-stranded RNA (dsRNA) molecules are designed against two conserved domains of each DCL1 and DCL2. This enables a comparative analysis of silencing efficiency across different target types and both genes. The silencing efficiency of these target regions is currently being assessed. In parallel, fluorescently labelled dsRNA is used to monitor uptake by FocTR4 and movement within banana tissues to better understand cross-kingdom RNAi dynamics. The most effective dsRNA construct will be selected for nanoformulation to improve molecular stability, delivery efficiency, and persistence under real-world tropical field conditions. This work contributes to climate-resilient agroecosystems by reducing chemical inputs and supporting sustainable banana production.

Keywords: Banana, climate-resilient agriculture, dicer-like genes, *Fusarium* wilt, RNA interference

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Drone-enabled precision spraying as a pathway to resource-efficient and climate-resilient cotton farming: Evidence from Pakistan

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Agrochemical overuse in smallholder farming systems is a critical driver of soil degradation, greenhouse gas emissions, and ecosystem disruption, undermining the long-term resilience of agro-ecosystems in the Global South. Precision drone spraying offers a technology-driven pathway to reduce agrochemical inputs, improve yields, and strengthen the economic viability of smallholder farms. Yet rigorous field-level evidence on the resource-efficiency gains and economic returns of drone adoption remains scarce in South Asia. This study addresses that gap by quantifying the input-use efficiency and economic outcomes of agricultural drone adoption among cotton farmers in Multan district, Punjab, Pakistan. Primary data were collected from 292 cotton farmers using commercial drone-spraying services. A three-stage benefit-cost analysis (BCA) captured per-acre changes in fertiliser, pesticide, and labour inputs, along with yield and revenue outcomes before and after drone adoption. Paired-sample t-tests assessed the statistical significance of all pre-post differences. Results reveal significant and measurable resource-efficiency gains. Precision GPS-guided spraying reduced per-acre fertiliser expenditure by 3,780 PKR (USD 14) and pesticide expenditure by 4,290 PKR (USD 16), directly reflecting reduced agrochemical loads on the agro-ecosystem. Labor costs fell by 3,025 PKR (USD 12) per acre. Collectively, total per-acre input costs declined by 4,985 PKR (USD 24; $t = 25.89$, $p < 0.001$). Simultaneously, cotton yield increased by 156 maunds (6.18 metric tons) per acre ($t = 23.75$, $p < 0.001$), and per-acre revenue rose by 45,210 PKR ($t = 23.75$, $p < 0.001$). The benefit-cost ratio improved from 5.27 before adoption to 7.12 after adoption, a statistically significant net gain of 1.85 ($t = 17.93$, $p < 0.001$). Improved crop quality ($N = 61$), cost-effectiveness ($N = 48$), and reduced environmental impact ($N = 15$) were the most frequently reported benefits. These findings demonstrate that precision drone spraying functions as a multi-functional agro-ecosystem intervention: it reduces agrochemical pressure, strengthens farm-level economic resilience, and enhances production efficiency, precisely the convergence demanded by climate-adaptive agriculture. The study offers actionable evidence for policymakers, agribusiness actors, and development organisations seeking scalable, resource-efficient farming solutions for smallholder systems in climate-vulnerable regions.

Keywords: Agricultural drones, agrochemical reduction, benefit-cost analysis, climate-resilient farming, input-use efficiency, precision agriculture, smallholder farmers

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Intrinsic competition between extant and novel parasitoids (Braconidae) in the cotton leafworm *Spodoptera littoralis* under laboratory conditions

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Parasitoids may compete at the adult stage when foraging hosts (extrinsic competition), or at the larval stage, when supernumerary parasitoids develop in the same host (intrinsic competition). A study including lepidopteran pest *Spodoptera littoralis* and novel (*Cotesia marginiventris*) and extant (*Microplitis rufiventris*) hymenopteran endoparasitoids, was carried out to investigate the effect of single and double parasitism at 2hr and 48hr ovipotion times on endo-development of the wasps and competitive interactions between the parasitoid larvae. No significant differences in the endo- development time of the wasps were found between single or superparasitised hosts. Conversely, multiple parasitism increased the endo developmental time of both wasps. Singly parasitised hosts by *M. rufiventris* produced more wasps than those of *C. marginiventris*. Also, the percentage of emergence success by superparasitised M. rufiventris, was, greater than those recorded by superparasitised C. marginiventris. Muliparasitised hosts produced more *C. marginiventris* than *M. rufiventris* wasps. However, the outcome of competition, by both wasp larvae principally depended on the wasp species that was first to attack and on the time interval between two oviposition's by wasp females. The intrinsic and competitive interactions between the parasitoid larvae in multiple parasitism experiments was more intensive than in superparasitism experiments. The novel parasitoid, *C. marginiventris* was intrinsically superior competitor comparing with the extant *M. rufiventris*, so the use of the two species simultaneously may lead to competitive exclusion and influence the stability of the extant parasitoid population. The competition was asymmetrical, meaning one species (the exotic) had a competitive advantage as competitor being the victor whatever the sequence of attack, over the other species. Introducing *C. marginiventris* to Egypt, may be not a good option for biological control of both, the new invasive pest, *S. frugiperda* and local one, *S. littoralis*.

Keywords: *Cotesia marginiventris*, endo-development, intrinsic competition, *Microplitis rufiventris*, single and double parasitism, *Spodoptera littoralis*

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Monitoring (functional) insect biodiversity in tropical agroecosystems: The potential for a DNA-based monitoring approach

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Biodiversity and particularly functional insect diversity are key contributors to agroecosystem resilience and productivity, especially in tropical smallholder agroecosystems. Monitoring insect biodiversity is essential for understanding (tropical) agroecosystem functioning and guiding more sustainable agricultural management. DNA-based environmental monitoring is increasingly seen as an alternative to traditional monitoring methods that remain constrained by scalability, required expertise and cost. Here, we explore an integrated DNA-based monitoring approach to assess arthropod diversity across ten coffee farms in Anserma (Caldas, Colombia), comparing five large monoculture and five small diversified production systems.

We combined standardised trapping of flying and ground-dwelling arthropods (SLAM/ Malaise and pitfall traps), complemented by sticky trap sampling in 4 farms, across wet and dry seasons. Using a non-destructive DNA extraction protocol to allow counting the arthropods post-extraction and COI metabarcoding, we identified 1,870 taxa spanning 36 arthropod orders, revealing substantial arthropod diversity in coffee systems. We also show that DNA can be successfully extracted from sticky traps with simple scalable modifications to the sample handling process.

Our results indicate that sampling method strongly determines observed community composition, with minimal overlap between the sample types. This demonstrates that single-method approaches risk severely underestimating biodiversity. While local (alpha) diversity did not differ significantly between monoculture and diversified farms, total (gamma) diversity was significantly higher in diversified systems, indicating that management effects emerge primarily at larger spatial scales.

Species accumulation analyses revealed substantial undersampling, indicating that complete inventories of tropical arthropod diversity are unrealistic. Nevertheless, consistent patterns in community composition and management effects were detected, showing that meaningful insights can be obtained from DNA metabarcoding. This suggests monitoring should prioritise repeatable sampling and focus on ecologically relevant target groups rather

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than exhaustive species detection. Functional trait analyses showed limited differences between systems, likely because broad categories fail to capture ecological variation, especially across life stages.
We conclude that scalable DNA-based monitoring can deliver robust biodiversity indicators for tropical agriculture, provided it integrates complementary sampling and appropriate analytical frameworks. However, limited reference databases remain a key constraint and future work should incorporate the generation of this type of baseline data.

Keywords: Biodiversity monitoring, DNA, insects, tropical agroecosystems

SIFS farms as multi-trophic biodiversity refugia across three agroclimatic zones of India

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Conventional high-input farming has been associated with substantial biodiversity declines and cascading ecosystem service consequences across agricultural landscapes. Sustainable Integrated Farming Systems (SIFS), combining crops, horticulture, agroforestry, livestock, and aquaculture with minimal external inputs, represent a climate-smart alternative promoted by Welthungerhilfe across India, Nepal, and Bangladesh. Despite growing adoption, multi-trophic evidence for SIFS as biodiversity refugia remains limited.

We assessed whether SIFS enhances multi-trophic biodiversity spanning pollinators, arthropod natural enemies, herbivores, soil macrobiota, non-crop plants, and birds relative to conventional farming across three agroclimatic zones of India, while examining plant–arthropod interaction networks for important species.

We surveyed 45 farms across West Bengal (Sundarbans), Rajasthan (Banswara), and Jharkhand (Deoghar) under Old SIFS, New SIFS, and Conventional management from December 2024 to April 2026. Bees were sampled by transects and pan traps; floral visitation by quadrats; arthropods by vacuum sampling; soil macrobiota by monoliths; and birds by point-count transects. Interaction networks were built from focal observations. Responses were modelled by GLMMs.

Old SIFS farms supported 2.3-fold higher bee abundance ($p < 0.01$) and 49 % higher bee species richness ($p < 0.05$) than Conventional farms. Flower visitation was elevated in New SIFS (×2.1; $p < 0.05$) and Old SIFS (×2.5; $p < 0.01$). Spider abundance was 1.9-fold greater in Old SIFS ($p < 0.05$), and predatory soil macrobiota were 3.1-fold more abundant in Old SIFS ($p < 0.05$), extending natural enemy gains below-ground. Bird species richness and guild-specific abundances (granivores, carnivores, nectarivores) were significantly higher in Old SIFS. Additional biodiversity responses were variable and will be discussed in full. Interaction networks revealed pronounced regional structuring in connectance, nestedness, and specialisation. Bee-specific

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sub-networks identified non-crop plants with high degree and betweenness centrality, acting as generalist connectors and structural bridges within farm-level pollination networks.
SIFS farms function as multi-trophic biodiversity refugia within smallholder landscapes. Ecosystem service recovery was not always uniform along the SIFS transition. These findings provide among the first multi-trophic, cross-regional evidence that SIFS constitutes a nature-based solution for biodiversity conservation, climate resilience, and food security in South Asian smallholder landscapes.

Keywords: Agroecology, biodiversity refugia, ecosystem services, interaction networks, multi-trophic, nature-based solutions, SIFS, smallholder farming, South Asia

Unlocking regenerative farming for climate-resilient crop production in Kenya: Evidence from African indigenous vegetables

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Climate change poses significant threats to agricultural systems in Kenya, with rising temperatures, erratic rainfall, and increased frequency of droughts undermining smallholder productivity and food security. African Indigenous Vegetables (AIVs) – including crops such as amaranth, spider plant, African nightshade, and cowpea – are increasingly recognised as climate-resilient crops due to their drought tolerance, short growth cycles, and adaptability to marginal environments. While regenerative agriculture offers potential solutions, adoption among vegetable-growing smallholders remains low. The study assessed awareness, knowledge levels, adoption rates, and perceived effectiveness of 15 regenerative technologies, including integrated pest management, mulching, minimum tillage, agroforestry, crop rotation, cover cropping, composting, vermicomposting, bio-slurry, and micro-irrigation. The study employed a mixed-methods design, combining household surveys (n=240), focus group discussions, and key informant interviews across major AIV-producing regions in Kenya. Findings show that, while awareness of regenerative practices is high (organic manure: 94%; crop rotation: 94%; mulching: 84%; composting: 77 %), adoption of these technologies remains limited. Only 34 % of farmers use micro-irrigation, 28 % conduct soil testing, and just 25 % practice vermicomposting. The gap between awareness and adoption widens for practices requiring capital investment or technical training. Farmers practicing crop rotation (96 % adoption) and organic manure application (93 % adoption) report improved soil moisture retention and reduced crop failure during dry spells. Key constraints to adoption include: perceived high upfront costs (micro-irrigation, composting infrastructure); labour intensity (mulching, minimum tillage conflicts with competing farm activities); lack of premium prices for regeneratively grown produce; limited technical extension support (government extension focuses on maize, coffee, tea – not vegetables); and soil fertility decline that pushes farmers toward quick-fix synthetic inputs. Regenerative farming holds significant promise for climate adaptation among smallholder vegetable farmers in Kenya, but current adoption is constrained by knowledge gaps, productivity trade-offs, and lack of market incentives. Bridging the awareness-adoption divide requires moving beyond training to address capital constraints, labour demands, and the absence of premium pricing. Without these complementary interventions, farmers will rationally prioritise conventional systems that deliver higher short-term returns, leaving climate adaptation potential unrealised.

Keywords: African indigenous vegetables, climate resilience, Kenya, regenerative farming, smallholder farmers

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Histopathological effect on larval growth and mortality of *Spodoptera litura* (Fabricius)

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The rapid development of insecticide resistance in *Spodoptera litura* (Fabricius), a destructive polyphagous pest infesting over 70 crop species, necessitates sustainable alternatives to synthetic pesticides. The present study evaluated the bioinsecticidal efficacy and histopathological effects of *Pongamia pinnata* methanolic leaf extract against third-instar larvae under controlled laboratory conditions. Leaf disc bioassays were conducted using concentrations of 1 %, 0.50 %, 0.25 %, and 0.125 % on *Ricinus communis*, with 30 larvae per treatment. Mortality, growth inhibition, behavioural responses, and biochemical alterations were assessed. A clear concentration-dependent toxicity was observed, with maximum mortality ranging from 70 % to 93.33 %, reaching 100 % at 1 % concentration within 72 hours. Corrected mortality values were 92 %, 80 %, 60 %, and 40 % across descending concentrations. Probit analysis demonstrated a significant dose–response relationship ($Y = 6.396 + 1.848X$; slope $= 1.848 \pm 0.0389$ SE), yielding LC_{50} and LC_{90} values of 0.176 % and 0.865 %, respectively. Treated larvae exhibited marked physiological and behavioural abnormalities, including reduced feeding, gut purging, haemolymph leakage, retracted thoracic legs, growth retardation, weight reduction, and malformed pupae. SDS-PAGE analysis revealed significant protein modulation, with reduction of mid-range proteins (30–70 kDa) and appearance of low molecular weight fragments (10–20 kDa), indicating metabolic disruption ($p < 0.05$). Histopathology of midgut tissues showed severe degeneration of columnar epithelial cells, cytoplasmic vacuolisation, disruption of the peritrophic membrane, and loss of cellular integrity, impairing digestion and absorption. These findings confirm that bioactive phytochemicals in *P. pinnata*, such as karanjin and pongamol, induce toxicity through physiological, biochemical, and tissue-level damage. Overall, the study establishes *P. pinnata* as a potent eco-friendly botanical insecticide with significant potential for incorporation into integrated pest management strategies for sustainable control of *S. litura*.

Keywords: Botanical insecticide, larval mortality, midgut histopathology, *Pongamia pinnata*, probit analysis, sustainable pest management

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Storage root and stem yield of improved cassava varieties introduced to Liberia

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Next to rice, cassava is the most important food crop in Liberia. However, the local varieties are highly susceptible to cassava mosaic virus (CMV) and develop frequently severe symptoms of the disease. Further, planting methods are designed to furnish a high number of small storage roots, harvested sequentially from plants without uprooting them (milking). Two to three planting stakes are horizontally buried, causing delayed sprouting and strong internal competition, aggravating CMV, causing low root yields around 5 to 7 Mg ha^{-1} fresh roots. The UNIDO GROW2 project introduced TME419, an improved cassava variety to Liberia and conducted on-farm trials to evaluate yield response to fertiliser and lime application and the crop age at harvest in Margibi, Bong and Nimba counties. Planting material yield as stem length (m ha^{-1}) and fresh storage root yield (Mg ha^{-1}) were determined Cassava was planted in mid-November 2024. Single planting stakes were vertically inserted to 2/3 of their length. The local cassava varieties produced 3.896 Mg ha^{-1} fresh storage roots. Fertiliser application (60–28–48 kg ha^{-1} NPK) increased yield marginally to 3.921 Mg ha^{-1}. Variety TME419 produced 19.800 Mg ha^{-1} without inputs, 20.116 Mg ha^{-1}, with fertiliser and 24.016 Mg ha^{-1} with 1 or 2 Mg ha^{-1} lime as $Ca(OH)_2$. Local varieties produced 17,353 m ha^{-1} stem without fertiliser and 19,101 m ha^{-1} with fertiliser. TME419 produced 23,754 m ha^{-1} without inputs, 21,604 m ha^{-1} with fertiliser and 28,817 m ha^{-1} with lime. Yield gains were attained when the harvest was delayed by 2 months from 9 months after planting (MAP) to 11 MAP. TME419 produced 5.227 Mg ha^{-1} more without inputs, 5.873 Mg ha^{-1} more with fertiliser and 5.455 Mg ha^{-1} more with lime. Stem production increased by 4,825, 2,176 and 6,483 m ha^{-1} in TME419 control, fertilised and limed, respectively. The local varieties experienced root yield losses of 0.721 Mg ha^{-1} without inputs and gains of 0.200 Mg ha^{-1} when fertilised. Stem growth gains were larger than in TME419 with 8,694 m ha^{-1} without inputs and 9,908 m ha^{-1} with fertiliser. Average root yield gains of 5.518 Mg ha^{-1} and stem length gains close to 4,500 m ha^{-1} indicate that the additional 2 months of growth are beneficial. Later harvests did not result in similar root yield gains.

Keywords: Cassava, fertiliser, Liberia, lime, root yield, stem yield, varieties

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Preferences for adoption of integrated pest management in Nigeria: A discrete choice experiment approach

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Adoption of sustainable agricultural practices, including integrated pest management (IPM), has remained relatively low among smallholder farmers in Nigeria. Despite the potential benefits of these practices, research and dissemination efforts have not translated into widespread uptake among farmers. This persistent gap highlights the need to better understand the factors influencing farmers' adoption decisions and the trade-offs they face when considering alternative pest management strategies. To address this, the study employs a discrete choice experiment (DCE) to examine cucumber farmers' preferences for IPM attributes and to identify key barriers and enablers of adoption. The experiment captures key attributes related to the adoption of IPM, including sources of advisory support, reduction of pesticide residues from the environment, transition time and changes to farm income and yields. A mixed logit model that accounts for unobserved preference heterogeneity is used to analyse the preferences and trade-offs, and subsequently, willingness to accept (WTA) measures are estimated. Results reveal that financial constraints, risk aversion to production losses, limited effectiveness of advisory services, and aversion to long transition periods significantly limit IPM uptake among farmers. Farmers strongly prefer practices that substantially reduce pesticide residues from the environment but require substantial compensation to offset perceived economic and yield-related risks. Public advisory support is less favoured by IPM-aware farmers, indicating the need for more tailored and effective extension strategies. Policy measures to promote IPM adoption should include financial incentives, improved access to credit, and support for shorter transition periods. Gender-responsive and context-specific interventions, along with strengthened farmer networks, are essential for scaling up sustainable pest management practices across diverse agricultural systems.

Keywords: Discrete choice experiment, integrated pest management, sustainable

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Integrated bioagent-organic formulations for enhancing seed quality and suppressing soil-borne pathogens in legumes under biotic stress

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Sustainable management of soil-borne pathogens remains a critical challenge in legume production systems, necessitating eco-compatible alternatives to chemical fungicides. The present investigation synthesizes three field experiments evaluating bioagents (*Trichoderma asperellum*, *Pseudomonas fluorescens*) and organic formulations (Beejamrit, Jeevamrit and Herbal Kunapjal) against *Macrophomina phaseolina* in soybean and *Fusarium oxysporum* and *Rhizoctonia bataticola* in chickpea. A total of 12 treatments comprising seed treatment (ST) alone and in combination with soil drenching at 15, 30 and 45 DAS were assessed. Across all pathosystems, integrated application (ST + soil drenching) significantly outperformed individual seed treatments.

Field emergence increased substantially under all treatments. In soybean, emergence improved from 65 % in control to 85 % under *T. asperellum* ST + drenching and 93 % in chemical check. Similarly, chickpea recorded enhancement from 47–57 % (control) to 84–89 % under integrated bioagent treatments and 91–92 % under chemical control.

Disease incidence at 60 DAS was markedly reduced across treatments. In soybean (*M. phaseolina*), it declined from 58.10 % (control) to 17.85 % with *T. asperellum* ST + drenching (69.28 % reduction) and 12.95 % under chemical treatment. In chickpea, *F. oxysporum* and *R. bataticola* incidences were reduced to 17.55 % (71.25 %) and 15.95 % (73.96 %), respectively. Growth parameters improved substantially, with soybean recording increases from 13.8 to 28.1 cm (shoot length) and 2.3 to 3.95 g (biomass), while chickpea attained 24.85–26.25 cm shoot length and 3.45–3.95 g biomass.

Among organic formulations, Beejamrit and Herbal Kunapjal (ST + drenching) also demonstrated substantial efficacy, reducing disease by 65–71 % and improving biomass over control. However, treatments involving only seed application consistently showed lower performance, highlighting the necessity of integrated application strategies.

In conclusion, *T. asperellum* applied as seed treatment combined with periodic soil drenching emerged as the most effective non-chemical approach, delivering disease suppression comparable to chemical fungicides while significantly enhancing plant vigour. The study strongly advocates the integration of bioagents and organic inputs as a viable, sustainable alternative for managing soil-borne diseases in legume-based cropping systems.

Keywords: Beejamrit, chickpea, dry root rot, Herbal Kunapjal, soybean, *Trichoderma asperellum*

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Ecological intensification of maize-kale systems in Kenya by biofertilisation and push-pull management shifts nematode communities

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Plant-parasitic nematodes (PPNs) pose a persistent threat to vegetable production in Kenya, contributing to reduced yields and soil degradation. The management of PPNs in vegetables in Kenya has largely remained unaddressed. The integration of ecological intensification strategies such as the vegetable integrated push-pull (VIPP) system and the use of black soldier fly frass fertiliser (BSFF) is gaining traction in sustainable agriculture. The aim of this study was to determine the effects of integrating VIPP and BSFF on nematode abundance and diversity in maize-kale cropping systems. Field trials were conducted in two different agroecological zones in Kenya. Each trial had 12 treatments replicated four times and six treatments were assigned to each crop (maize and kale). The treatments were as follows: 1. Control (non-amended monocrops), 2. Inorganic fertiliser (DAP and NPK) treated plots, 3. VIPP plots, 4. BSFF-amended plots, 5. VIPP and BSFF plots with either maize or kale, and 6. VIPP and BSFF plots with both maize and kale. Soil samples were collected from experimental plots and nematode community composition determined using modified Baermann technique. Plots under VIPP augmented with BSFF exhibited significantly higher populations of free-living nematodes and lower densities of PPNs compared to control and inorganic treated plots. The use of VIPP, particularly in combination with BSFF, enhanced the abundance of bacterivorous and fungivorous nematodes, suggesting improved soil health and biological control potential. The findings demonstrate that VIPP and BSFF synergistically promote assemblages of beneficial nematode communities, providing a sustainable pathway for management of nematodes in agroecological farming systems.

Keywords: Cropping system, kale, maize, regenerative agriculture, soil health

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Gendered seeking behaviour of plant health advisory services in Kenya

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Plant health clinics are demand-driven initiatives that offer farmers plant health advisory services to minimize pre- and post-harvest losses caused by pests and diseases and increase food production. Therefore, the study aimed to assess gender differences in smallholder tomato farmers' plant health advisory service-seeking behaviour, focusing on gender-disaggregated data. Data on self-reported estimates of plant health advisory service-seeking behaviour were collected through a multistage sampling procedure using a pre-tested, electronically designed semi-structured questionnaire administered to 385 respondents in Kirinyaga County, Kenya. Overall, structural equation modelling results indicated farmers' service-seeking intentions did not significantly translate into actual behaviour. Multigroup analysis results indicated no gender differences in plant health advisory service-seeking intentions between male and female farmers, likely influenced by their attitudes, subjective norms, perceived behavioural control, and motivation. However, a gender difference was observed in actual service-seeking behaviour, with male farmers more likely to act on their intentions than their female counterparts. These findings underscore the need for policies that support evidence-based demonstrations, employ behavioural nudges, strengthen the presence of female extension staff, promote gender-sensitive training for plant health clinic personnel, expand awareness campaigns, and scale up digital advisory platforms to encourage the actual service-seeking behaviour among farmers.

Keywords: Kenya, plant health advisory services, plant health clinics, PLS-multigroup analysis, seeking behaviour

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Typology of smallholder farms adopting conservation agriculture in northern Benin's Sudanian zone

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The adoption of conservation agriculture (CA) practices among small farms remains heterogeneous, both in term of implementation and agro-ecological performance. This study aims to characterise small farms profiles according to their level of CA practices adoption. Data were collected through individual interviews with 322 farm managers, covering socioeconomic characteristics as well as practices such as intercropping, crop rotation, sowing under cover crops, and minimum tillage, including their combinations. A factor analysis of mixed data (FAMD) was used to identify the main dimensions structuring CA practices, followed by hierarchical ascending classification (HAC) using Ward's method and Euclidean distance to define homogeneous groups. Adoption rates were analysis using descriptive statistics. Our results identify three classes of producers according to their level of CA adoption. Institutional and human factors constitute the main determinants of this heterogeneity, with adoption trajectories more strongly associated with access to training, credit, and support mechanisms than with farm size or physical resources. Full adopters (Class 1) implement all practices in a combined manner, whereas partial adopters (Class 2) adopt a subset of practices, and moderate adopters (Class 3) exhibit an intermediate level of adoption. The chi-square test reveals significant differences ($p < 0.05$) in adoption patterns across class and municipality. Northern Benin's farms show a gradient from traditional to agroecological systems, with increasing legume integration, crop rotations, and soil conservation enhancing productivity, fertility, and sustainability. Overall, the findings highlight the diversity of CA strategies and underscore the need for target support mechanisms and policies to promote sustainable agriculture transitions.

Keywords: Adoption, conservation agriculture, hierarchical clustering, mixed data analysis

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How can we improve the adoption of sustainable agricultural practices in the developing countries: A perceived views of farmers in a community conservation area in northern Mozambique

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Successful project implementation to yields the desired results requires a context assessment, implying thus, understanding the needs of the target group; the points of divergency and complementarity; the strengths and opportunities to be leveraged and weaknesses and threats to be mitigated. For implementation of agroecological in the rural Protected Area (PA), this assessment requires, at least: i) outline the profile of the target group, including farmers; ii) knowledge on the current agriculture practices under implementation; iii) the main crops, and it destination (for consumption or sale); iv) the willingness of the local people in adopting some agroecological practices and, v) the incentives required to do so. This study provides those insights from the perspective of householder living inside Chipanje Chetu Community Conservation Area (CCCCA), a remote PA located in northern Mozambique, where shifting cultivation is the main threat to nature conservation and the livelihood of the local people. A survey was conducted with 270 heads of households living in five villages within CCCCA. Most of the heads of the householders (64 %) had primary education (5a - 7a grads). Agriculture was perceived as the most important source of livelihood and income and essentially employs slash-and-burn cultivation method (94.1 %). Nearly half of the households surveyed reported having heard or even receiving support on conservation agriculture practices. Although farmers have pointed out some disadvantages related to the adoption of conservation agriculture, such as costs with labour and delays in increasing yield. Most of them would be willing to adopt conservation agriculture practices, such intercropping 260 (96 %); crop rotation 237 (87.8 %); improved fallow 154 (57 %); incorporation of organic matter into the soil 223 (83 %); and use of botanical pesticides to combat pests and diseases 217 (80 %). The required incentive for adoption includes money to buy necessary inputs 134 (50 %), and in-kind incentives such as technical assistance 196 (73 %), inputs 154 (57 %); and training in agroecological practices 130 (48 %). There is a high probability of successfully incorporating agroecological and conservation agriculture into CCCCA farming systems, if necessary, precautions are taken into consideration.

Keywords: Conservation agriculture, livelihoods means and farming practices

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Efficiency of the adjuvant sure shot on increasing the efficacy of insecticides on the melybug

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The out-break of cotton mealybug *Phenacoccus solenopsis* (Tinsley) (Hemiptera: Pseudococcidae) on many crops belong to different families making a real worry for both farmers and research scientists. *P. solenopsis* belongs to the family Pseudococcidae which is the second largest family of scale insects. *P. solenopsis* is a major threat to agriculture and horticulture in many countries which was found to attack large number of plant species. As a result of *P. solenopsis* dispersal, reproductive and survival capacity, this invasive pest has the potential to damage or kill native plant species that could be displaced by other more aggressive plant This experiment was conducted at Gezira Research Station Farm, during summer season to evaluate the efficacy of the agricultural adjuvant Sure Shot, Sure shot is Silicon based Wetting & Dispersing Agent, on increasing the efficacy of the insecticides Hitcel 44 % EC (profenofos 40 % and cypermethrin 4 % EC) and Celenour for the control of cotton mealybug in the field and the laboratory. The product was tested at the different concentrations of the adjuvant solutions in addition to mixtures of the adjuvant with the insecticides under test.plus Untreated Control. A field experiment was conducted at Gezira Research Station Farm (GRSF) during the summer season 2018/2019, where the insecticide Celenour 720 EC (profenofos % EC) at a dose rate of 0.6 $^{L}/_{fed}$ was sprayed once with or without the adjuvant Sure Shot. The results indicate, that mixing of the adjuvant with insecticides had a positive effect in increasing the efficacy of the insecticides.

Keywords: Cotton mealybug, Gezira, Sudan, wetting and dispersing agent

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Deciphering the plant growth promotion potential of rice-associated bacteriomes from Chiang Mai, northern Thailand

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Synthetically assembled autochthonous bacterial communities containing locally adapted biofertiliser candidates are underexplored reservoirs for sustaining rice productivity and minimising external chemical fertiliser input towards sustainable agriculture. This study involved bioprospecting the bacteriome of three rice cultivars (RD-43, Riceberry and Bue Poh Loh) from representative agroecological zones in Chiang Mai, Northern Thailand. Specifically, the copiotrophic and oligotrophic bacterial communities from the rhizosphere and endosphere of each cultivar were surveyed to identify robust candidates for future bioinoculant development. Bacterial counts, oligotroph:copiotroph ratios, as well as qualitative and quantitative indices of plant growth promotion (PGP) potential, including N-fixation, indole acetic acid (IAA) production, P and K solubilisation were assayed using standard methods. PGP potentials were also statistically compared across bacterial types and rice cultivars. Of the 84 morphologically diverse isolates, 50 have PGP properties. Rhizospheric bacteria did not statistically outnumber endophytes (average: 6.20 vs 4.00×10^7 CFU g^{-1}, Mann-Whitney U: $p = 0.16$). Principal Component Analysis grouped the isolates into 17 oligotrophs, 16 facultative oligotrophs and 17 copiotrophs similarly distributed among rice cultivars (Chi square: $p = 0.35$). Copiotrophs statistically outnumber oligotrophs (average: 8.50 vs 1.60×10^7 CFU, Mann-Whitney U: $p = 0.037$). Oligotroph:copiotroph ratios (median range: 0.08–0.25) correlate with agroecological traits, but did not differ by sampling site (Kruskal–Wallis H: $p = 0.065$). No significant difference exists between qualitative PGP traits of oligotrophs and copiotrophs (pooled average: 1.36 vs 1.71, Welch's test: $p = 0.35$). However, oligotrophs produced higher IAA than copiotrophs (average: 12.95 vs 7.16 $\mu g\,mL^{-1}$, T-test: $p = 0.00$). Additionally, oligotrophs had higher P solubilisation potential compared to copiotrophs (mean: 145.80 vs 26.32 μg/mL, T-test: $p = 0.006$). Only two oligotrophic bacteria can solubilise K (range: 2.44–8.90 $\mu g\,mL^{-1}$). Conclusively, trophic strategy (copiotrophy vs oligotrophy) best determines the PGP potential of the rice bacteriome in the study area, rather than niche (rhizosphere vs endosphere). Further screenings, molecular assays, laboratory and field trials are envisioned to fully unravel the biofertilisation potential of carefully engineered synthetic bacterial communities from these PGP isolates on rice in the study area.

Keywords: Biofertiliser, rhizosphere, synthetic bacterial communities

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Molecular characterisation of *Solanum lycopersicum* L. accessions using simple sequence repeat (SSR) marker

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Solanum lycopersicum L. (tomato) is one of the most economically important climate-resilient crops cultivated globally and critical for nutrition and income of smallholder farmers in the tropics. Previous studies reported morphological and molecular characteristics of tomato with limited information on characterisation using Simple Sequence Repeat (SSR) marker. This study was therefore carried out to evaluate the genetic diversity of tomato accessions using SSR primers for breeding of climate-adapted accessions. Eight tomato accessions were obtained from the National Centre for Genetic Resources and Biotechnology (NACGRAB), Ibadan, and Technoserve, Kano, while one local accession from Oojo served as a check (control). A screen house experiment was conducted using complete randomised design with three replicates. Genomic DNA was extracted from three-week-old leaf samples using the Dellaporta method. Four SSR primers (LEga003, LECaa001, LETaa001, and LEAAT005) were employed, and PCR amplification products were analysed using gel electrophoresis. Genetic diversity was evaluated using PowerMarker software version 3.25. The SSR primers amplified polymorphic bands ranging from 100 to 1000 base pairs. Primers LETaa001 and LECaa001 exhibited the highest Polymorphic Information Content (PIC) of 0.56 and 0.52, respectively, with corresponding gene diversities of 0.64 and 0.58. The mean PIC of the primers was 0.45, indicating moderate genetic diversity. Phylogenetic results revealed two major clusters, and the Oojo accession formed an outgroup, suggesting a distinct genetic lineage. The NGB00752 and Rukuta Jubia accessions showed close genetic relationships. Primers LETaa001 and LECaa001 were highly informative and are recommended for molecular breeding programmes in tomato. A phylogenetic dendrogram was constructed using the maximum likelihood method implemented in PowerMarker software. Genetic distance matrices were calculated based on the binary data, and the dendrogram was generated to visualise genetic relationships among the eight tomato accessions. Bootstrap analysis with 1000 replicates was performed to assess the robustness of the clustering pattern. Therefore, genetic diversity provides valuable insights for germplasm conservation, improvement, and breeding of climate-resilient tomato cultivars for tropical farming systems.

Keywords: Climate resilience, genetic diversity, molecular breeding, Nigeria

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Effects of hot spring-derived photosynthetic bacteria on growth and quality of chinese kale (*Brassica oleracea* var. *alboglabra*) seedlings

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Photosynthetic bacteria have emerged as a promising biological approach for promoting sustainable agriculture, capable of enhancing plant growth through phytohormone production, nitrogen fixation, and improved stress tolerance. Bacteria isolated from extreme environments, such as hot springs, may possess unique physiological traits that further support plant growth promotion. The increasing demand for sustainable food production systems has driven interest in identifying effective microbial biostimulants that can reduce dependence on chemical fertilisers. This study evaluated the effects of photosynthetic bacteria isolated from San Kamphaeng hot springs, Chiang Mai, Thailand, on the growth performance and quality of Chinese kale (*Brassica oleracea* var. *alboglabra*) seedlings. Five isolates (H1–H5) were tested under a randomised complete block design (RCBD) with six treatments and four replications, including an uninoculated control, to evaluate growth performance, nutrient uptake, and photosynthetic pigment accumulation. Isolate H3 significantly enhanced plant height, root length, fresh weight, and dry weight across all observation periods (7, 14, 21, 28, and 35 days after sowing) ($p = 0.001$), and improved nutrient uptake, with values of 15.63 mg N plant^{-1}, 1.53 mg P plant^{-1}, and 1.45 mg K plant^{-1} ($p = 0.005$). Isolate H2 showed distinct advantages in photosynthetic pigment accumulation, with chlorophyll a, chlorophyll b, total chlorophyll, and carotenoid contents of 3.75, 2.00, 4.22, and 4.21 mg L^{-1}, respectively ($p = 0.001$). Additionally, inoculation enhanced microbial diversity in the growing medium compared to the control. These findings suggest that photosynthetic bacteria from hot spring environments have potential as microbial biostimulants that can enhance plant growth, nutrient use efficiency, and physiological attributes in Chinese kale seedlings. Isolates H3 and H2 are promising candidates for field-based applications, supporting sustainable and climate-resilient agricultural systems. Future studies should assess their efficacy under field conditions and soil microbiome interactions to validate their potential as bioinoculants in sustainable crop production.

Keywords: Microbial biostimulants, plant growth promotion, sustainable agriculture

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Agroecology as a dual strategy for drought resilience and sustainable N and P management: Mechanisms, evidence, and trade-offs

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Global agriculture faces interconnected challenges from climate change-induced drought and unsustainable nitrogen (N) and phosphorus (P) management. Conventional strategies, relying heavily on irrigation and synthetic fertilisers, have historically maximised short-term yields but are increasingly constrained by resource depletion, low nutrient use efficiency, environmental degradation, and economic inefficiencies. This review synthesizes contemporary evidence on how agroecological practices can simultaneously mitigate water scarcity and optimise N and P cycling, offering a holistic alternative to decoupled management approaches. We examine core agroecological strategies, including cover cropping, agroforestry, legume integration, organic amendments, diversified rotations, and conservation tillage. Mechanistically, these practices synergistically enhance soil organic matter, structural integrity, and belowground biodiversity. Consequently, improved soil architecture increases water infiltration and moisture retention, thereby buffering crops against drought stress. Simultaneously, rooting complementarity and stimulated microbial processes – such as biological N fixation, arbuscular mycorrhizal fungal (AMF) colonisation, and microbial P solubilisation – boost overall nutrient use efficiency. These biological pathways reduce reliance on synthetic inputs while mitigating N losses via leaching and nitrous oxide emissions, as well as P losses through surface runoff and erosion. Current evidence indicates that agroecological systems can sustain agricultural productivity and significantly improve long-term yield stability. However, outcomes are inherently context-dependent; the efficacy of these practices varies across climates, soil types, cropping systems, and management histories. Notably, transition periods can introduce complex trade-offs, including short-term yield penalties or delayed ecological benefits prior to realising long-term gains. Furthermore, widespread adoption remains hindered by

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critical knowledge gaps, technical and financial barriers, and entrenched policy frameworks that disproportionately subsidise conventional, linear nutrient supply chains. Ultimately, agroecology presents a robust, systems-based paradigm for advancing climate-resilient, resource-efficient, and ecologically sound agriculture. To fully operationalize this dual strategy, future research must prioritise long-term, multi-site studies that elucidate the complex, coupled dynamics of water, N, and P under shifting environmental conditions.

Keywords: Agroecology, crop diversification, drought resilience, nitrogen use efficiency, phosphorus use efficiency, soil organic matter

Drivers of push-pull pest management adoption among maize farmers in East Africa: A logit analysis

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The recurrent incidences of pest and diseases and predominance of soil fertility depletion, exacerbated by the prevailing impacts of climate change calls for ecological integrated pest management approaches. The push-pull integrated pest management (PPIPM) technology offers a sustainable, cost-friendly alternative to pesticides for controlling fall armyworm, Stemborer and *Striga* weed constraints in maize production.

This study used Logit regression to analyse the drivers of plot-level adoption of PPIPM amongst 740 smallholder maize households operating on 1680 maize plots across both Kenya and Uganda obtained using multistage random sampling. The pooled results indicated that male gender, perceived technology benefits, access to trainings, group membership, land size under PPT, access to credit and distance to input stockiest positively influenced adoption of PPT, while age of the farmer, and education had a negative effect. However, in Kenya PPT adoption was influenced by access to training, land size and perceived technology benefits while in Uganda, PPIPM was significantly influenced by age of the farmer, male gender, perceived technology benefits, perceived technology effectiveness, access to training, group membership, land size as well as distance to input stockiest. Notably, farmer's access to training emerged as a crucial driver for increasing the likelihood of adoption of PPT in the maize farming plots with its effect being more in Uganda compared to Kenya. Similarly, the perceived PPT benefits had higher influence in Uganda compared to Kenya.

The study therefore concludes that perceived technology attributes and training are crucial drivers of technology adoption. The findings give compelling recommendations to policymakers to enhance number of training on PPT giving emphasis on the perceived technology benefits while targeting young farmers in groups dealing with agricultural activities disaggregated by male and female gender respectively.

Keywords: Adoption, integrated pest management

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Impact of intercropping systems on farm productivity and welfare in Ghana

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The transition towards multifunctional agro-ecosystems is critical for enhancing climate resilience, productivity, and sustainability among smallholder farmers in sub-Saharan Africa. This study evaluates the impact of intercropping systems on farm productivity and welfare outcomes in Ghana using panel data from the Ghana Socioeconomic Panel Survey (Waves 2 and 3), comprising 4,156 households in a panel structure. To address potential selection bias and endogeneity in intercropping adoption, the study employs a combination of Multinomial Endogenous Switching Regression (MESR) and Inverse Probability Weighted Regression Adjustment (IPWRA) estimators, complemented by fixed effects models for robustness. Descriptive evidence indicates that monocropping remains dominant, although intercropping adoption varies across crop combinations, with cereal–tuber and cereal–legume systems exhibiting higher participation relative to cereal–tree crop systems. Econometric results reveal strong and consistent productivity gains from intercropping. MESR estimates indicate that the average treatment effect on the treated (ATT) is positive and substantial, suggesting that intercropping significantly increases farm yield relative to the counterfactual of monocropping. Similarly, IPWRA estimates confirm robust positive impacts, highlighting the effectiveness of intercropping even after correcting for observable and unobservable selection bias. Heterogeneity analysis across regimes shows that yield responses differ between adopters and non-adopters, reflecting structural differences in farm characteristics and management practices. Intercropping adoption is positively associated with farm size, soil management practices, and extension access, but negatively associated with rainfall variability, indicating that farmers use intercropping as a risk mitigation strategy under climate uncertainty. Despite strong productivity effects, welfare outcomes such as food consumption and income exhibit mixed results, suggesting incomplete transmission of productivity gains into household welfare. The findings underscore the role of intercropping as a climate-smart agricultural strategy that enhances productivity while contributing to agro-ecosystem multifunctionality. However, adoption remains constrained by resource endowments and institutional factors. Development interventions should therefore focus on improving access to extension services, credit, and climate information to promote equitable adoption. Scaling context-specific intercropping systems can accelerate the transition towards resilient and sustainable agricultural systems in Ghana and beyond.

Keywords: Climate resilience, multinomial endogenous switching regression

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Electrolysis-based nitrogen fertilisers: Opportunities for import substitution, sustainable and resilient food systems

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Commercial farmers and smallholders across the world are affected by price increases, especially for nitrogen fertilisers and the disruption of important international supply chains. The extent of the impacts depends on the duration of the disruptions, on the structure of the agricultural sectors and the intensity of land use. The differences among regions of Global South are significant. In America, an average of 187 kg is applied per hectare of arable land, in Sub-Saharan-Africa only 18 kg. In both regions, fertiliser usage is high in commercial and export-oriented production and lower related to food production. Thus, it is likely that prices for agricultural products, e.g. cocoa and pineapples from Africa or banana and melon from Latin America will increase if the crisis drags on. More severe are the impacts on food security, in Latin America because a large proportion of food production depends on synthetic fertilisers. In Africa, food insecurity and the prevalence of undernourishment reflects high indicators in comparison with Latin American ones.

Technological innovation may offer options to mitigate problems related to import dependency on the balance of payments and to food security. Increased maturity of electrolytic hydrogen and downstream technologies allow the production of hydrogen with local renewable energies and the ammonia synthesis as basis of nitrogen fertilisers. A number of industry-scale green ammonia projects are in the pipeline in both regions and a relevant project has recently achieved Final Investment Decision in Paraguay. In Uruguay, a key ammonia and green hydrogen project is under study, exports would be destinated to European countries.In Kenya, a first mid-sized green ammonia project is up and running. This second option of local ammonia production is highly relevant for Sub-Saharan-Africa, where the problems related to vulnerable international supply chains are exacerbated by deficient transport infrastructure, which raises the farm gate prices of fertilisers or even prevents the access of farmers.

Against this background, we examine the contexts in which projects are implemented, including resource availability, institutional set-up, and government policies. Based on expert interviews and comparative analysis, we want to understand the potential and readiness for decentralised hydrogen-based fertiliser production.

Keywords: Agricultural sector, ammonia, disruption, food production, food security, global South, nitrogen fertilisers, price increases, renewable energies, technological innovation

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Agronomic and economic performance of integrated soil fertility management across an organic matter continuum and climate variability

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We develop a hybrid dynamic Bayesian Network model to capture the probabilistic relationships among organic matter, soil fertility trajectories, climate variability, crop variety-specific responses, and socio-economic feasibility within a unified framework. We demonstrate the utility of this model architecture by applying it to smallholder systems in the Guinea Savannah of northern Ghana, where Integrated Soil Fertility Management (ISFM) recommends up to 5 tonnes ha□[1] of organic matter to restore fertility and sustain productivity on degraded lands. However, farmers relying on crop residues as primary organic inputs rarely achieve this rate due to competing uses of crop residues. Our model assesses the agronomic and economic performance of ISFM across an organic matter input continuum of 1–5 tonnes ha□[1] for locally relevant varieties of maize and soybean. For each organic matter input level, we assess how soil organic matter stocks change under current and projected climates, how these dynamics translate into crop productivity for each crop variety, and whether resulting yields are agronomically sufficient and economically viable given the labour and management costs of crop residue integration. Our results reveal that while 5 tonnes ha□[1] of organic inputs maximises absolute soil organic matter recovery, it is not the universal economic optimum for resource-constrained smallholders. Instead, our model identifies a threshold of diminishing returns, where the joint probability of achieving soil fertility recovery, agronomic sufficiency, and economic viability is maximised under climate variability. The work can guide extension and policy on pragmatic ISFM implementation. The model provides a decision-support framework tailored to real-world constraints. By aligning extension efforts with the dual goals of soil fertility restoration and economic viability, this methodology offers a robust, scalable framework for designing site-specific, resilient agricultural intensification pathways in the Guinea Savannah and beyond.

Keywords: Bayesian network, climate change, crop suitability, Monte Carlo simulation, soil organic matter

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Beyond single indicators: Composite indexing of soil fertility managements for maize intensification in northern Ghana

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Closing maize yield gaps in sub-Saharan Africa demands intensification strategies that are productive, profitable, ecologically sound, and socially acceptable. This study evaluated soil fertility management practices: a Control (no fertiliser), two inorganic nitrogen rates (30 and 60 kg N ha^{-1}), two sole organic manure rates (2.5 and 5.0 t ha^{-1}), and two integrated combinations (30 kg N+5.0 t manure ha^{-1} and 60 kg N+2.5 t manure ha^{-1}) across four sustainability pillars in three districts of Northern Ghana (Mion, Savelugu and Tolon), using APSIM simulations (1980–2024) for two maize maturity classes. Long-term climate data confirmed rising temperatures and declining rainfall across all sites, underscoring the urgency of resilient intensification pathways. Sole 60 kg N ha^{-1} maximised gross margins (GHS 14,821 ha^{-1}, a 70 % gain over the Control and 70 % over the sole 5.0 t manure ha^{-1}) yet recorded the lowest biodiversity score (0.2) across sites. Conversely, sole 5.0 t manure ha^{-1} scored highest on biodiversity, yet no single fertility management strategy consistently excelled across all dimensions. The longer-maturing Obatanpa outperformed Abontem by a mean gross margin of GHS 2,706 ha□^{1} across all treatments. Integrated treatments produced the lowest yield coefficients of variation, confirming their resilience under rainfall variability. Social acceptability diverged by location: Mion farmers favoured organic-inclusive treatments, Savelugu farmers preferred inorganic-dominant practices, and Tolon farmers showed the strongest aversion to high nitrogen without manure. A composite sustainability index aggregating all four pillar scores with equal weighting provided decisive resolution, with integrated treatments outperforming sole-input strategies across all sites. The 60 kg N+2.5 t manure ha^{-1} achieved the highest composite score at Mion (0.85), while 30 kg N + 5.0 t manure ha^{-1} excelled at Savelugu (0.79) and Tolon (0.80), far exceeding the Control (0.14–0.20). The score differential between these two integrated treatments suggests that, where inorganic fertiliser access is constrained, increasing manure to 5.0 t ha^{-1} while reducing mineral nitrogen to 30 kg N ha^{-1} can achieve equivalent sustainability outcomes. The composite index combines multiple performance indicators into one clear score, providing a site-specific tool to support farmers, extension agents, and policymakers in scaling integrated soil fertility management.

Keywords: Crop modelling, integrated soil fertility management, low-input systems

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Do long-term management practices impact tea soil properties and plant yield? Insights from Sri Lanka

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As the world's second-most-consumed beverage after water, tea is a perennial crop of major socio-economic importance in many countries. It is Sri Lanka's top agricultural export, bringing in a revenue of 1.3 billion USD annually. Here, young shoots are harvested regularly, making fertilisation vital for promoting growth and quality. Nevertheless, challenges regarding the high costs of fertilisers and their environmental risks persist. Further quantitative insights evaluating the long-term influence of different fertilisers on tea soil properties and subsequent aboveground plant yield are limited. Moreover, while organic production practices are considered an emerging solution for reducing nutrient losses, their effects on the tea soil-plant system remain underexplored.

To address these gaps, we assessed selected soil chemical properties and harvested tea flush yields in a long-term tea field trial (TRIORCON) in Sri Lanka. Each plot has received fertiliser inputs of either reclaimable tea (RT), neem oil cake (NOC), compost (COM), or a synthetic mixture of urea granules, rock phosphate and muriate of potash (MIN) since 2000. Despite differences in total carbon (C) added through fertilisation, topsoil C content did not differ significantly across treatments. Similar trends were observed for topsoil total phosphorus (P) and potassium (K), whereas total nitrogen (N) content may have been affected by varying inputs over time.

Annual tea flush yields were also analysed for the TRIORCON from 2007 to 2022. Yield differences were observed among the treatments: generally, COM yielded the highest, followed by RT and MIN, and finally NOC. Simplified soil surface budgets comparing fertiliser inputs with harvested tea outputs revealed positive nutrient balances. The N balances of the RT, NOC, COM, and MIN treatments were 224 $\pm$ 139, 142 $\pm$ 94, 272 $\pm$ 111, and 203 $\pm$ 50 kg N ha^{-1} yr^{-1}, respectively. High nutrient surpluses observed in the trial indicate inefficient fertiliser use for the tea plant and suggest potential nutrient losses. Ultimately, the findings offer a perspective on the nutrient use efficiency of the tea system and could contribute to more sustainable nutrient management in its cultivation.

Keywords: Long-term field experiment, nutrient balance, organic agriculture

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Malagasy smallholder farmers' understanding of soil quality processes: Understanding perceptions and adoption intentions by evaluating mental models

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Soil degradation poses a severe threat to smallholder livelihoods in Madagascar, yet farmers' perceptions of the processes affecting soil quality remain poorly understood. This study analyses the mental models of 1,007 smallholder farmers in south-eastern Madagascar, examining how environmental and socio-economic characteristics shape their understanding of soil quality. Additionally, we evaluate whether participating in a mental model elicitation task increases agronomic knowledge and technology adoption intentions. Using a representative survey with randomised assignment, we find that Malagasy smallholders hold complex, nuanced mental models of soil health. Manure, rainfall, and heat are identified as the most frequent drivers, with manure perceived as the most beneficial factor for soil quality. Regression analysis reveals that education is the strongest predictor of mental model complexity, with complexity increasing progressively across education levels. Furthermore, sex, age, and local climatic conditions significantly shape both the complexity of these models and the occurrence of specific environmental drivers. Experimental results indicate that the structured elicitation task itself serves as a cognitive intervention. Participation significantly increased agronomic knowledge test scores and was positively associated with intentions to adopt manure application. These findings underscore the complexity of farmers' systemic thinking and highlight the importance of taking into account the sociodemographic and ecological heterogeneity within local agricultural knowledge systems. Ultimately, this research suggests that structured mental model elicitation holds significant potential as a tool for targeted agricultural extension, particularly for reinforcing practices that are already salient and positively perceived within a community's cognitive framework. Our results provide a roadmap for future policies.

Keywords: Agricultural production, Madagascar, mental models, smallholder farmers, soil quality, system thinking

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Integrated farmers' perceptions and field evidence of land degradation and soil fertility decline in southwest Ethiopia

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Land degradation and soil fertility decline pose critical threats to agricultural sustainability in southwestern Ethiopia, yet few studies integrate local farmers' indigenous knowledge with empirical data. This research bridges that gap by combining farmers' perceptions with rigorous field-based assessments in Omo Nada district, Jimma Zone, Oromia Regional State. This study integrates farmers' perceptions with field-based evidence to assess land degradation and soil fertility status in Omo Nada district, Jimma Zone, southwestern Ethiopia. During the 2021 cropping season (October–November), we conducted reconnaissance surveys across four kebeles, interviewing 82 households via semi-structured questionnaires, personal observations, and open-ended discussions. Complementary soil sampling yielded 56 composite samples (0–30 cm depth) from cultivated lands, analysed for key fertility parameters. Nearly all farmers (99 %) attributed degradation to anthropogenic drivers, including continuous cropping, overgrazing, deforestation, and poor management. Red soils dominated perceptions (43–62 % across sites), followed by brown soils (20–36 %), with fields classified into four productivity categories – productive, moderately productive, degraded, and severely degraded – based on weed species, soil colour, and crop yields. Laboratory analyses corroborated these views: soils were strongly acidic (pH 4.8–5.4), with low CEC (12–18 cmol(+) kg^{-1}), TN (0.12–0.18 %), available P (3.5–7.2 mg kg^{-1}, limited by fixation and erosion), and exchangeable bases. OC and TN were medium (1.2–2.1 %) but insufficient for optimal yields. This synergy of perceptions and data underscores severe degradation, with acidity as the dominant constraint. We recommend site-specific interventions: liming to neutralize acidity, organic amendments for nutrient replenishment, and balanced fertilisers tailored to soil tests. Strengthening farmer-researcher linkages will foster scalable, participatory solutions for resilient agroecosystems in Ethiopia's highlands.

Keywords: Farmers' perceptions, integrated assessment, land degradation, soil acidity, soil fertility, Southwest Ethiopia

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Decoupling soil quality improvement from short-term crop productivity in tropical agroecosystems

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Soil quality improvement is commonly expected to enhance crop productivity, particularly where organic amendments are used to increase soil organic carbon (SOC) and restore degraded soils. However, field evidence often shows that improvements in soil properties do not immediately translate into higher crop biomass, especially under diverse crop sequences and contrasting site conditions. This study examined the extent to which improvements in SOC were associated with short-term biomass responses in two long-term field trials in Rwanda representing contrasting agroecosystems. The Huye trial involved compost and biochar combinations, while the Musanze trial consisted of different organic and mineral amendment strategies without biochar application. Due to differences in treatment structure, both sites were treated as independent experiments. Soil fertility indicators including SOC, total nitrogen, available phosphorus, potassium, and cation exchange capacity were evaluated alongside biomass data collected across sequential crops. Heatmaps, ANOVA, regression analysis, Tukey post-hoc tests, and mixed models were used to assess treatment effects and identify key drivers of biomass variation. Results revealed that amendment treatments improved SOC significantly in Huye ($F = 5.05$, $p = 0.00021$), with the highest treatment mean reaching 2.79 % SOC compared with 1.24 % in the control. Musanze showed weaker treatment responses and greater system stability, indicating stronger buffering by baseline soil fertility. However, biomass responses were not consistently aligned with carbon increases. Crop type explained most of the biomass variation, while potassium emerged as a stronger predictor of biomass than SOC in regression models. In particular, SOC was not a significant direct predictor after controlling for crop effects ($p = 0.901$), whereas potassium remained significant (coefficient = 18.87, $p = 0.001$). The final biomass model explained 87.6 % of variation ($R^2 = 0.876$). These findings indicate that soil quality improvement and short-term crop productivity can be partially decoupled in tropical agroecosystems. Sustainable soil fertility strategies should therefore move beyond carbon accumulation alone and incorporate nutrient-specific mechanisms and site-dependent responses to support multifunctional and climate-resilient agroecosystems.

Keywords: P-value, soil organic carbon

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Soil health responses to tillage, residues, and manure in potato rotation systems in Peru

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Soil degradation, salinity, and unsustainable management practices threaten potato production systems in the coastal region of Lima, Peru. Regenerative agriculture practices, including minimum tillage (MT), crop residue incorporation, and the application of organic manure, have been proposed as strategies to improve soil health under such conditions. This study evaluated the effects of these practices on soil physical, chemical, and biological indicators, and developed a Soil Health Index (SHI) to assess overall soil health in a potato rotation system. A field experiment was conducted using different combinations of tillage practices, residue management, and sheep manure application rates. Soil indicators including bulk density (BD), aggregate stability, penetration resistance, hydraulic conductivity, soil pH, soil organic carbon (SOC), electrical conductivity (EC), and biological activity (macrofauna abundance and diversity and decomposition rates) and potato yield were measured and integrated into a normalized SHI. Results showed that sheep manure application significantly improved several soil indicators, including SOC, aggregate stability, BD, macrofauna abundance, and SHI. Minimum tillage significantly reduced EC, while residue incorporation significantly improved aggregate stability. However, most soil indicators were not significantly influenced by tillage or residue management alone. SHI responses showed a general increasing trend with manure application, although differences among treatment combinations were not consistently significant. Potato yield was not significantly influenced by any of the management practices. Overall, manure application was the primary driver of soil health improvements in the short term, while the effects of MT and residue incorporation were limited. These findings highlight the importance of organic amendments for rapidly improving soil health in saline, sandy soils, and suggest that short-term changes in soil health may not directly translate into yield responses.

Keywords: Crop residue incorporation, minimum tillage, Peru, potato rotation, regenerative agriculture, sheep manure, soil health index, soil indicators, soil salinity

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From village to region: soil micronutrient dynamics across scales in northern Ghana

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A clear understanding of the spatial distribution of soil micronutrients is vital for addressing agricultural productivity and nutritional outcomes in Northern Ghana, where soil fertility limitations influence food quality, and high-quality soil data is lacking. The effectiveness of soil micronutrient assessment is strongly shaped by the scale of mapping, which determines the balance between cost, level of detail, and practical utility. At broader (regional) scales, mapping offers a cost-efficient means of identifying general patterns and priority zones of micronutrient deficiency. Such approaches are valuable for national planning, policy formulation, and targeting interventions. However, coarse-scale assessments often mask local heterogeneity, limiting their usefulness for site-specific management. Conversely, fine-scale (village to field-level) mapping captures detailed spatial variability, enabling precise recommendations for soil amendments. This level of detail enhances decision-making at the farm scale but comes with significantly higher costs. This study explores the utility of mapping scales for soil micronutrients in Northern Ghana. At medium scale, plant-available micronutrients (Zn, Cu, Mn, and Fe) were not significantly different across different geological formations of Northern Ghana, implying that cheaper, cost-efficient regional soil micronutrient data may be adequate for crop productivity management and nutrition security. This is more so for iron (Fe) and manganese (Mn) which are available in adequate amounts for proper crop growth and productivity across the entire region, and molybdenum (Mo), which was too low to detect. For Fe, Mn and Mo, costly, detailed, site-specific assessments may not be required as one management recommendation may be applied across the entire region. The situation is different for copper (Cu) and zinc (Zn), whose spatially variable amounts range from low to moderate. For both, the regional averages were also distinct from medium scale (by geological formations) and village averages. As such, applying the same treatment across the region would result in deficiencies arising from inadequate application in some areas and toxicities arising from over application in others. Consequently, to enable precise management recommendations for increased crop productivity and nutrition security, site-specific (medium to village-level) mapping is required to capture the spatial variability of Cu and Zn across Northern Ghana.

Keywords: Mapping, micronutrients, scale, site-specific, spatial variability

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The DecLaRe geospatial toolbox for West Africa: Land evaluation, micronutrients and more

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Within the BMFTR-funded project DecLaRe a geospatial toolbox was developed in order to provide basic GIS functionality that enables to present and to work with data collected in an inter-disciplinary framework. The toolbox is completely based on open-source software and delivered in an encapsulated format so that it can be installed on servers or personal computers elsewhere for programme development or teaching. Major components are a land evaluation tool that enables ex-ante evaluation of intervention zones for agricultural innovations and a micronutrient tool that allows to detect potential human micronutrient deficiency based on local diets. Available data sets include bio-physical (e.g. soil, climate) as well as socio-economical (e.g. household composition, nutrition behaviour). The tool is free for distribution and can be used in other regions of the world if respective data sets are available.
Included baseline data concern the ISRIC soil data sets interpolated to 250 m, modelled climate data at 5 and 50km raster resolution (PIK), open street map information, digitised historical maps (e.g. geology), historic project data (e.g. BenSOTER) and FAO crop parameterisation.
Within the DecLaRe project the toolbox additionally served as a data repository in a password secured environment. That way project internal data could be compared and new ideas developed in order to create interdisciplinary output. The toolbox has the potential to be used across project boundaries. In future it will be installed at WASCAL (Burkina Faso), University for Development Studies (UDS, Tamale, Ghana) and at the University of Parakou (Parakou, Benin).
For detailed information on the software environment please connect to Terra GIS.

Keywords: DecLaRe project, GIS, land evaluation, micronutrients, spatial tools

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Potential of perennial legumes for restoration and reutilisation of small-scale gold mined sites in Ghana

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The increasing small-scale gold mining activities in recent years have led to degradation of arable lands. This is projected to surge due to high demand driven by advancements in artificial intelligence, cloud computing, nanotechnology and among others. In view of this, the study explore how perennial legumes can support restoration and reutilisation of gold mined sites and to what extent the restored sites support crop productivity.

Five years field experiment was established using three perennial legumes species namely Pueraria, Leucaena and Gliricidia on a degraded surface gold mined site at Anumso in the Ashanti Region of Ghana. Notably, Pueraria and Leucaena were established via seeds while Gliricidia through stem cuttings. The plots were monitored for a period of five years and data was collected on soil fertility parameters including soil organic carbon (SOC) and nitrogen (N). Three years after establishment maize was planted in each plot without any external amendments including fertilisers to assess whether the restored fertility is enough to support crop production.

The results show that perennial legumes increased fertility relative to control by at least 60 % for soil organic carbon and 90 % for total nitrogen regardless of the species used. Surprisingly, after three years of establishment, the fertility level was not enough to support grain production despite substantial improvement in growth parameters. These highlight the potential of these legumes for the reutilisation of these sites for agricultural activities. However, future studies should explore the use of modelling approach to assess the long term benefits and optimise management practices that support better utilisation of these sites.

Keywords: Agroforestry, artisanal mining, productivity, revegetation

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Enhancing organic wheat productivity through land configuration and optimised nitrogen management in sub-humid Rajasthan

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As global agriculture shifts toward sustainable practices, optimising resource-use efficiency in organic systems becomes critical. This study investigated the impact of diverse land configuration methods and organic nitrogen optimisation strategies on the growth, productivity, and nutrient status of organic wheat (*Triticum aestivum* L.). A comprehensive field experiment was conducted over two consecutive rabi seasons (2022 and 2023) at the Organic Farming Unit, Rajasthan College of Agriculture, MPUAT, Udaipur. The experiment was laid out in a split-plot design with four replications, evaluating three land configuration methods Flat row sowing, Furrow Irrigated Raised Bed (FIRB), and Zero Tillagemas main-plot factors. The sub-plot factors comprised eight distinct nutrient management strategies utilising Farm Yard Manure (FYM) as a primary nitrogen source, supplemented with liquid bio-enhancers, specifically Jeevamrit and Panchagavya.

The pooled results demonstrated that the FIRB sowing method significantly outperformed both flat row and zero tillage systems. FIRB recorded superior growth attributes, including plant height, dry matter accumulation, and chlorophyll content, alongside a significant increase in the number of effective tillers. This enhancement is attributed to the creation of a favourable micro-environment, better moisture regulation, and reduced inter-plant competition. Furthermore, FIRB significantly improved the uptake of macro and micronutrients (N, P, K, Zn, and Fe), showing an increase of approximately 15.5 % to 22.4 % compared to other methods.

Among nutrient management practices, the application of 75 % Recommended Dose of Nitrogen (RDN) through FYM as a basal dose, combined with 25 % RDN at the first irrigation and supplemented with Jeevamrit and Panchagavya, yielded the highest growth and productivity. The integration of liquid organic manures acted as a catalyst, enhancing nutrient availability during critical growth stages. The study concludes that the combination of FIRB land configuration and integrated organic nutrient management offers a robust and sustainable strategy for maximising organic wheat yields and soil nutrient status under the agro-climatic conditions of sub-humid southern Rajasthan.

Keywords: FIRB, Jeevamrit, land configuration, nutrient management, organic wheat, sustainable agriculture

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Integrating tropical soil-calibrated pedotransfer functions with Sentinel-1 backscatter for soil moisture retrieval in soybean and maize systems in Zambia

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Accurate characterisation of soil hydraulic properties is critical for understanding and mitigating the impacts of precipitation variability in rainfed maize (*Zea mays*) and soybean (*Glycine max*) systems across sub-Saharan Africa (SSA), where soils act as the primary water reservoir. However, direct measurement of these properties is labor-intensive, time-consuming, and costly. Pedotransfer functions (PTFs) provide a practical alternative by estimating hydraulic parameters from readily available soil attributes. This study assessed the spatial variability of key soil hydraulic properties in soybean–maize systems in Lusaka, Katete, and Kalomo districts of Zambia. Clustered soil sampling was conducted using the Land Degradation Surveillance Framework across 10 fields per location. Locally calibrated PTFs were developed for tropical conditions using an Artificial Neural Network (ANN) trained on the tropical subset of the combined International Geosphere-Biosphere Programme and World Soil Information Service (IGBP-WoSIS/T) datasets. The ANN model demonstrated strong predictive performance, achieving a coefficient of determination (R^2) of 0.84 and a root mean square error (RMSE) of 0.064 $cm^3\ cm^{-3}$ on the test dataset. The PTF was used to estimate soil water retention at matric potentials corresponding to 10 pF values: 0.0, 1.0, 1.5, 2.0, 2.3, 2.5, 3.0, 3.4, 3.7, and 4.2. These estimates enabled the generation of continuous soil water retention curves (SWRCs) using the van Genuchten model, from which key hydraulic properties, including residual water content, porosity, and available water capacity (AWC), were derived. These parameters were subsequently used to normalise Sentinel-1 radar backscatter for soil moisture retrieval, reducing dependence on laboratory-based measurements. Soils across the three study sites exhibited substantial variability in texture, organic carbon, and bulk density, resulting in AWC values ranging from 0.15 to 0.25 $m^3\ m^{-3}$. Soil moisture estimates derived from normalised Sentinel-1 backscatter showed variable but meaningful agreement with *in situ* TMS-4 soil moisture probe measurements, with R^2 values ranging from 0.20 to 0.80 across the maize and soybean fields. This study demonstrates the potential of integrating locally calibrated PTFs with remote sensing data to improve soil moisture estimation in data-scarce, agricultural systems, supporting more informed water management and precision agriculture in SSA.

Keywords: Artificial neural network, pedotransfer functions, rainfed agriculture, Sentinel-1; tropical soils, soil moisture retrieval, soil water retention, Zambia

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Biochar-based fertiliser can decouple smallholder farm economy from global market disturbances

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About 41 % of Ethiopia's agricultural soils are affected by acidification and decreasing fertility. Smallholder farmers face the challenge that decomposition rates under tropical climate quickly consume soil organic carbon but crop residues need to supply various farm needs other than soil fertility management. On top, costs for imported synthetic fertiliser, e.g., Urea tripled from 2020 to 2025. The development project ETH-Soil embarked on sustainably improving soil conditions and thereby productivity through the application of biochar-based fertiliser (BBF). Concomitant soil monitoring in 2024 and 2025 compared plots in wheat fields treated with BBF (10 t/ha biochar) against plots treated business as usual (BAU: synthetic fertiliser recommended rates) at 24 farms located at different elevations and soil types in two regions, i.e., the Southwest and Southeast of Ethiopia. Regionally different BBF recipes were applied, i.e., co-composting of biochar with manure in the Southwest and vermicompost in the Southeast. In 2024, bare mean values of key soil quality indicators tended towards higher pH (up to +0.3 points), soil organic carbon content (SOC) (+0.15%−0.28 %) and available phosphorus (aP) (+0.78%−5.5 %) with BBF than with BAU across regions. However, none of the results attained a significance level ($p = 0.05$) except aP of Southeast sites (+5.5 %). Results in 2025 were similar, except a missing aP improvement even at Southeast sites. Overall, sampling soil parameters SOC, pH, and aP did not consistently indicate soil quality improvement across the regions. However, BBF application resulted mostly in similar or better dry grain yield (DGY) as compared to BAU. In 2024, DGY tended to be slightly higher though statistically not significant with BBF than with BAU at Southwest sites (+0.01−0.1 t/ha), whereas DGY increased significantly with BBF at Southeast sites (+1.3 t/ha). Conversely in 2025, DGY increases with BBF over BAU were not significant at Southeast sites (+0.4 t/ha) but significant at the Southwest sites (0.45−0.9 t/ha). While monitoring must continue to explain the soil data pattern along the soil-climate gradient, BBF helps smallholders to decouple their farm economy from global market disturbances. Reassurance in self-reliant grain crop production can encourage farmers to adopt additional agroecological practices including crop diversification and agroforestry.

Keywords: Biochar, cost-benefit ratio, pH, plant available phosphorous, soil fertility management, soil organic carbon

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Are farm households willing-to-pay for organic soil amendments? The case of biochar and compost in northern Ghana

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Organic soil amendments, particularly application of biochar and compost have been recommended as potential strategies for the adaptation and/or mitigation to climate change and weather variability in developing countries. However, the adoption of these organic soil products is extremely low, and this has necessitated researchers, development partners and policy makers' interest in understanding whether farm households in semi-arid regions are willing to pay for these agricultural inputs. Currently, the market for such inputs is at its infancy in many low-income settings, and this raises a policy relevant question on the demand for organic soil amendments. Using a contingent valuation approach, this study elicited the willingness to pay for organic soil amendments (i.e., biochar and compost) among 472 farm households in three semi-arid regions of Ghana. We found that the majority of farm households are willing to pay an amount lower than market prices for the organic soil amendments. Specifically, farm households in Northern Ghana are willing to pay an average of USD 6.43 and USD 6.06 for a 50-kilogram bag of compost and biochar, respectively. Therefore, a partial cost recovery approach would be beneficial in ensuring the demand for organic soil amendments in low-income settings. Employing the ordinary least squares (OLS) method, we also found that the correlates of the maximum willingness to pay include participation in capacity building initiatives on organic soil amendments and social protection programs, religion, education, distance to market and extension offices, risk attitudes, access to mechanisation and digital services including mobile phone, telephone masts and internet services, access to road network, and location of residence. We conclude that there is a demand for organic soil amendments albeit at a lower value than the market price, and this is influenced by socio-economic status and access to social capital, social networks, digital and physical infrastructure.

Keywords: Ccontingent valuation, economic valuation, willingness to pay

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Farmers' perception of low-cost biochar technology as a nature-based solution for improving soil health in southwest Nigeria

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The acceptance of organic food and general concern about the environmental impact of synthetic agrochemical use have prompted the search for an affordable and environmentally friendly approach to protecting our soils. Globally, biochar technology has been positioned to affect soil repellent and quality. However, its adoption in Nigeria is dependent on farmers' awareness and perception. Thus, this study examines how farmers perceive low-cost biochar technology as a nature-based solution for improving soil health in South-West Nigeria. A multistage sampling technique was employed to select 300 crop farmers across Ekiti, Ogun, and Oyo States. Data were collected using a structured questionnaire and analysed using descriptive statistics, a binary logit regression model, and Likert scale analysis. Descriptive results revealed variation in adoption, with Ogun State recording the highest adoption rate (45.0 %), followed by Oyo State (39.0 %), while Ekiti State had the lowest adoption level (23.75 %). Logit regression results showed that the variables "educational years, awareness of biochar technology, and cooperative membership positively and significantly influenced adoption. Results indicated that biochar application in cropping systems improves soil structure (4.12), nutrient availability (4.02), and reduces water percolation (3.97), thereby reducing vulnerability to drought stress. Findings also suggest that biochar aids the growth of soil microbes (3.86), thus contributing to increase on-farm biodiversity. Despite these advantages, adoption was constrained by limited awareness (4.23), high labour demand (4.09), competition between biochar use and household energy demands (4.05), and climate change–induced variability in biomass availability (3.96). The study emphasises the possibility of low-cost biochar as a climate-smart and scalable intervention for sustainable agriculture. For broader adoption among crop producers, this study recommends policy support, capacity building, and the promotion of targeted extension services that will help farmers to integrate this technology into their cropping systems.

Keywords: Biochar, farmers' perception, nature-based solutions, soil health, south-west Nigeria, sustainable agriculture

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From diagnosis to action: A bibliometric assessment of land degradation neutrality research and the gap in soil and land management solutions (2013–2026)

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Land degradation neutrality (LDN) was adopted as a global target under Sustainable Development Goal 15.3, and more than 130 countries have since committed to voluntary neutrality targets. Whether the science that has grown around the concept actually supplies the soil and land management knowledge needed to meet those targets has not been examined systematically. This study maps the LDN research field and asks how far it has moved from describing degradation toward delivering practical means of reversing it. Bibliographic records were retrieved from Scopus using a focused query centered on the concept of neutrality and its precursors, and 607 documents published between 2013 and 2026 were analysed after cleaning. Performance analysis and science mapping, including keyword co-occurrence and country collaboration networks, were carried out in Python, and each record was additionally classified as diagnosis-oriented, policy-oriented, or solution-oriented based on its title, abstract, and keywords. The literature expanded rapidly after 2015 at roughly 32 % per year and now spans 257 sources and 2,193 authors. China, India, and a small group of European countries produce most of the work, whereas the drylands of sub-Saharan Africa, which bear much of the global degradation burden, remain weakly represented. Assessment and monitoring accounted for 41.5 % of the corpus, and policy or conceptual framing for 35.4 %, while studies centered on management interventions such as restoration, conservation tillage, residue retention, and organic amendment accounted for only 22.4 %. The field has matured in its ability to measure and report degradation, but the evidence base for acting on it through soil management remains thin and geographically skewed. We outline a research agenda that places sustainable soil and land management at the center of LDN scholarship. Keywords: .

Keywords: Bibliometric analysis, land degradation neutrality, restoration, SDG 15.3, soil conservation, sustainable land management

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Biochar and covering as optimisation strategies for cattle manure composting: Trade-offs in gaseous emissions and safety

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Composting of livestock manure improves nutrient circularity and reduces health risks in smallholder farming systems of sub-Saharan Africa. Since composting requires regular turning and mixing of the manure for better aeration, this can lead to nutrient losses through greenhouse gas (GHG) and ammonia (NH_3) emissions. Given the importance of manure for farm productivity, developing optimised composting approaches and evaluating emissions, nutrient transformations, and compost safety is needed. A three-month outdoor composting experiment was conducted using cattle manure mixed with straw (4:1 $^{w}/_{w}$) and simulating conditions during solid manure storage in heaps. We evaluated five treatments: (i) unturned control (UC), (ii) turned (T), (iii) turned plus cover (TCov), (iv) turned plus 10 % biochar (TB), and (v) turned plus 10 % biochar plus cover (TBCoV). Mixtures of 200 kg were stored in 600 L plastic containers (n=3) that were equipped for gas measurements. Turning occurred three times during the thermophilic phase. Bacterial counts for Escherichia coli, coliforms, Enterococci and *Salmonella* were evaluated over the composting period.

Temperatures within the heap increased above the sanitisation threshold (50°C) in all composting treatments, and the biochar treatments had the longest thermophilic phase of 16 days. The UC treatment recorded the highest N_2O emissions, whereas emissions were reduced in TB and TBCoV by 61–77 %. Turning triggered high NH_3 emissions which were not reduced by covering or biochar addition, resulting in higher total NH_3 losses in the turned compost treatments. Changes in mineral N (NH_4^+ and NO_3^-) indicated that nitrification and denitrification dominated at different composting stages, while declining NH_4^+:NO_3^- ratios suggested progressive compost stabilisation during matu-

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ration. Composting treatments had CH_4 emissions during the thermophilic phase, indicating that anaerobic conditions developed inside the heap. Compared to the control, composting with biochar addition and covering reduced cumulative CH_4 emissions by 51–77 %. All composting strategies showed significant reductions in the four indicator pathogen species with temperature the main driver for pathogen reduction. We conclude that covering and biochar addition during cattle manure composting are promising low-cost interventions to reduce CH_4 and N_2O emissions, but not NH_3 losses, while producing a sanitary and safe organic fertiliser for sustainable crop production.

Keywords: Ammonia, crop-livestock integration, methane, nitrous oxide, nutrient circularity

Evaluating manure management interventions for fertiliser quality and zoonotic pathogens in pig manure, Uganda

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The expanding pig subsector in Uganda, particularly among smallholder farmers, has increased the production of pig manure. While this represents a valuable nutrient resource amid rising fertiliser costs, poor management reduces its fertiliser quality and increases risks of nutrient losses and zoonotic pathogen transmission. However, evidence on effective pig manure management strategies under Ugandan field conditions remains limited. This study assessed low-cost interventions aimed at improving fertiliser quality and reducing zoonotic pathogens. On-farm experiments were conducted using separated solid and liquid pig manure fractions. Solid manure was managed through heap composting for 85 days under shelter, while liquid manure was stored in plastic containers under covered and uncovered conditions. Solid manure treatments were arranged in a randomised complete block design and included: (i) covering and turning, (ii) covering, turning, and biochar addition, and (iii) an uncovered, unturned control. Solid manure heaps were turned every three days during the first 15 days. Regular sampling was conducted to assess nutrient composition (total nitrogen, potassium, phosphorus, dry matter, organic carbon, pH, and ammonium and nitrate nitrogen) and pathogen indicators (Escherichia coli, Enterococci, and Salmonella). Fertiliser quality was further assessed through percentage nutrient loss estimates, and maturity indices including C:N ratio, germination index, and ammonium-to-nitrate ratio.

Data were analysed using linear mixed-effects models, ANOVA, Tukey HSD tests, and non-parametric tests (descriptive statistics and linear regression) for pathogen data. By day 85, no significant differences were observed among treatments for most nutrient parameters, except dry matter content, which

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was significantly lower in the uncovered, unturned treatment ($p = 0.002$). In liquid manure, total nitrogen and ammonium nitrogen differed significantly ($p < 0.05$), with covered storage retaining higher total nitrogen and lower ammonium nitrogen than uncovered storage. No treatment achieved full compost maturity based on maturity indices. Pathogen loads declined across all treatments, with moisture and temperature significantly influencing pathogen concentrations. This study showed that covering and turning of manure during composting, with or without biochar addition, showed potential as low-cost strategies to improve nitrogen retention and reduce pathogen risks, thereby enhancing the agronomic value and biosafety of pig manure in smallholder systems in Uganda .

Keywords: Biochar, composting, nutrient cycling, nutrient losses, pathogen reduction

Multifunctional cover crops for sustainable intensification: Agronomic performance, weed suppression and soil quality in Cameroon

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Sustainable intensification in humid tropical smallholder systems requires technologies that stabilise yields, suppress weeds and regenerate soils, while reducing dependence on synthetic inputs. Against this backdrop, we evaluated the adaptability and multifunctional performance of five herbaceous cover crops – *Mucuna pruriens*, *Cajanus cajan*, *Stylosanthes guianensis*, *Crotalaria juncea* and *Crotalaria retusa* – in the Mount Cameroon Region, focusing on agronomic traits, weed suppression and soil chemical dynamics. Field experiment established in a Randomised Complete Block Design with five cover crop treatments plus a weedy fallow control. Measurements included nodulation, canopy development, fresh and dry biomass, weed density and biomass, diversity indices, and pre and post season properties (pH, organic matter and carbon, total N, available P, exchangeable K, Ca and Mg). Results revealed that *M. pruriens* exhibited superior nodulation (9.33 ± 0.33 nodules plant^{-1}) and rapid canopy closure (97.2 % ground cover by Week 12), while *C. retusa* produced the highest dry biomass (5.67 ± 0.40 t ha^{-1}; $p < 0.05$). Across species, cover cropping increased soil pH by about 7.1 % relative to weedy fallow and raised organic matter and organic carbon by 10.7 % and 16.1 %, respectively, with *S. guianensis* and *C. juncea* particularly effective in building soil C stocks. In contrast, available P declined by 25.3 % ($p < 0.001$) and exchangeable Ca, Mg and K decreased significantly ($p < 0.001$), reflecting strong nutrient uptake and possible leaching in high rainfall volcanic soils; notably, *M. pruriens* and *C. retusa* plots retained comparatively higher cation levels, indicating superior nutrient capture and banking. Weed suppression responses were species specific. *M. pruriens* reduced weed biomass by up to 100 % (ANOVA $p < 0.05$), driven by dense canopy cover and below ground competition, whereas *S. guianensis* was consistently the least effective suppressor, and problem weeds such as *Ageratum conyzoides, Eleusine indica* and *Cyperus rotundus* persisted mainly in non *Mucuna* plots. *C. retusa* and *M. pruriens* offered the most favourable trade offs between high biomass production, weed control and soil quality enhancement. We therefore recommend their combined integration as a complementary cover crop in resilient, low herbicide rotations for the Mount Cameroon Region and analogous humid tropical agro ecosystems.

Keywords: Cover crops, humid tropics, soil fertility, sustainable intensification, weed suppression

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Enduring gains in maize yield and soil hydraulic function from cocoa pod husk compost in Ghana

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Low soil fertility and poor soil hydro-physical properties limit crop productivity in tropical smallholder systems, with these constraints worsening under increasing climate variability. Ghana produces approximately 600,000 tonnes of cocoa beans annually, generating about 6,000,000 tonnes of cocoa pod husk (CPH) as a by-product. This abundant biomass represents a significant opportunity for nature-based soil amendment to enhance soil functions and support climate-resilient crop production systems. However, in most smallholder farming systems in Ghana, organic amendments are commonly surface applied without incorporation, leading to nutrient losses through runoff and volatilisation. Subsurface placement has been proposed to improve nutrient retention, but its effectiveness under tropical field conditions remains insufficiently understood. This study evaluated the effects of compost placement depth on maize yield and soil hydraulic conductivity over three growing seasons in Ghana. CPH compost was applied at 20 $^{t}/_{ha}$ and incorporated either into the topsoil (0–15 cm) or into a subsurface layer (15–30 cm), alongside an unamended control. Compost application significantly increased maize yield across all three seasons, regardless of placement depth. Seasonal grain yield increases ranged from 30–120 % under surface application and 45–100 % under subsurface application relative to the control. Over the three seasons, compost application produced an additional 14 $^{t}/_{ha}$ of total dry matter yield and 5 $^{t}/_{ha}$ of grain yield compared to the control. Temporal trends showed stronger early-season responses under surface application during the first two seasons, while subsurface placement produced more sustained benefits and outperformed surface application in the third season. Compost also significantly improved soil hydraulic conductivity. Surface incorporation increased hydraulic conductivity by approximately 280 % relative to the control, while subsurface application increased it by about 85 %. Surface application resulted in about 100 % higher conductivity compared to subsurface placement. These findings demonstrate that both compost use and placement depth critically influence crop yield and soil water dynamics. Optimising the use of locally available CPH compost can improve crop yield, soil hydraulic function, and support sustainable intensification and climate resilience in tropical smallholder agroecosystems.

Keywords: Soil fertility

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Can compost increase grain yield more than inorganic fertiliser in maize-sorghum rotational systems in southwestern nigeria?

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This study explored the potential yield-enhancing effects of compost and biochar in maize-sorghum rotational systems of southern Nigeria. To this end field trials were conducted on maize (*Zea mays* L.), followed by sorghum (*Sorghum bicolor* Moench.) to study residual treatment effects in the 2023 and 2024 cropping seasons in Ibadan, Nigeria. The experimental design was a split-plot, randomised complete block design, with six nutrient sources replicated four times. Composts made from poultry manure (PM), broadleaves (BL+PM), grasses (GR+PM), cassava peels (ME+PM), NPK and an untreated Control were main plot treatments into which +/- biochar application was nested as subplots.

In 2023, the maize grain yield of PM (1767 kg ha^{-1}) was 44 % higher ($p < 0.01$) than average maize grain yields of control, BL+PM and ME+PM. Maize amended with biochar attained 49 % (1682 kg ha^{-1}) ($p < 0.01$) higher grain yields than those without biochar. Maize grain yield in 2024 had a nutrient source and biochar interaction: in PM+BC (3335 kg ha^{-1}) and NPK+BC (2985 kg ha^{-1}) grain yields were 78 % higher ($p < 0.01$) than all other treatments. In 2023 and 2024, nutrient source influenced sorghum grain yield: sorghum amended with PM and BL+PM yielded three-times higher ($p < 0.01$) than control plots in 2023. In 2024, the grain yield of sorghum fertilised with PM was 27 % higher ($p < 0.01$) than the average of BL+PM, ME+PM and the control. In 2023 and 2024, biochar amendment increased sorghum grain yield by an average of 74 % compared with the no-biochar treatment.

Rainfall use efficiency (RUE) of maize displayed a nutrient source and biochar interaction, with PM+BC in 2023 and 2024 being 74 % ($p < 0.05$) and 69 % ($p < 0.01$), respectively, higher than other treatments. In 2024, fertiliser use efficiency (FUE) of maize fertilised with NPK was 4-fold higher ($p < 0.01$) than FUE of other nutrient sources. Biochar-amended maize plants had a 50 % higher FUE ($p < 0.01$) than no-biochar-amended maize plants.

We conclude that amending poultry manure with biochar increased the yield of maize and sorghum, thus recommend the production and inclusion of biochar in organic soil amendments.

Keywords: Agricultural residues, integrated fertiliser management, organic fertiliser, soil amelioration, sustainable farming

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Does integrated soil fertility management improve the food security of Ethiopian farmers? Empirical evidence in the context of climate change

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Integrated soil fertility management (ISFM) has been increasingly promoted as a sustainable, climate-smart agricultural solution. It jointly abates land degradation, climate shocks, productivity decline and food insecurity. At the smallholder level, adoption is still quite low despite its tremendous benefits. So far, there is insufficient evidence of the effect of ISFM on food security, especially at the household level. Therefore, we examine the drivers of smallholder farmers' adoption of ISFM and the impact of adoption on their food security outcomes based on two alternative food security measures (i.e., food consumption expenditure per adult equivalent and food insecurity experience scale). We use data obtained from the Ethiopian Socioeconomic Survey conducted in 2021/22. For our empirical analysis, we employ an endogenous switching regression (ESR) that accounts for both heterogeneity in adoption decisions and unobservable farm characteristics. As a robustness check, we also use pooled and fixed-effect instrumental variable models using additional data from the 2018/19 survey. The results from the first stage of the ESR model clearly show that land size, livestock size, access to credit, access to extension services, land tenure, off-farm activities and community watershed activities significantly enhance ISFM adoption. The treatment effect analysis reveals positive and significant gains in food security for both adopters and non-adopters, with the Average Treatment Effect on the Untreated (ATU) exceeding the Average Treatment Effect on the Treated (ATT). This indicates that overcoming adoption barriers yields the highest marginal returns to food security for current non-adopters. To unlock these benefits, policy interventions should prioritize formal credit access, tenure security, income diversification, and tailored extension training.

Keywords: Adoption, ESR, Ethiopia, food security, impact, integrated soil fertility management

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Agronomic practices and sugarcane biomass burning affect PM2.5 emission and soil fertility in Thailand

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Agronomic practices such as land preparation, harvesting, disease management, and crop residue management are among the leading causes of dust emissions in crop production systems. In Thailand, crop biomass burning has become a common practice, especially for sugarcane, rice, and maize. Pre- and post-harvest biomass burning during the dry season is a significant source of air pollution at the farm level, particularly particulate matter 2.5 (PM2.5). In addition, biomass burning reduces the return of organic carbon and nitrogen to the soil, thereby affecting soil fertility in agricultural lands. So far, very few studies have examined the effects of sugarcane farm management practices on PM2.5 emissions and the impact of sugarcane biomass burning on mineral nutrient composition in Thailand.

The research was conducted in Kamphaeng Phet Province, the largest sugarcane-growing in northern Thailand. In addition to secondary PM2.5 data, field measurement campaigns were carried out on sugarcane farms during the dry season (i.e., the harvesting period). Controlled in- field biomass-burning experiments were conducted using biomass samples from both organic and conventional farms, as well as from five commercial cultivars. The mineral nutrient content of dry biomass and ash samples was analysed, and the C/N ratio was evaluated. A farmer survey was also conducted to identify key farm activities contributing to PM2.5 pollution, the drivers of biomass burning, and the associated impacts on farmers' health.

PM2.5 concentrations at the Kamphaeng Phet monitoring station reached 120 $\mu g\,m^{-3}$ during the 2023 dry season. However, in-field sugarcane residue-burning experiments showed PM2.5 concentrations exceeding 999 $\mu g\,m^{-3}$, while PM > 0.3 μm reached 60,000 $\mu g\,m^{-3}$. Interestingly, biomass from organic sugarcane farms (cultivar KK3) emitted less PM2.5 than biomass from conventional farms. Nutrient analysis indicated that organic sugarcane crop residues contained higher levels of nitrogen(5.5 $g\,kg^{-1}$), phosphorus(0.85 $g\,kg^{-1}$), and potassium(10 $g\,kg^{-1}$) than conventional residues. Moreover, nitrogen and carbon were lost during combustion. The farmer survey indicated that sugarcane smut disease control was the primary reason for biomass burning.

These findings reveal narrow policy incentives for unburned cane, yet redirecting subsidies to pest-reducing cycles and valorising lignin-rich residue can yield superior ecological and economic outcomes, guiding future long-term soil assessments.

Keywords: Agronomic practices, C/N ratio, crop residue management, farm-pollution, mineral nutrients, *Saccharum officinarum*

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Dynamics of soil organic carbon, nitrogen, phosphorus, and aggregates stability under different grassland management types in the Central Rift Valley, Ethiopia

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Grassland management significantly influences soil organic carbon (SOC) and nutrient fluxes. This study investigated the effects of five distinct grassland management types on SOC, nitrogen (N), and phosphorus (P) in Ethiopia's Central Rift Valley. We collected soil samples from random grazing natural grasslands (random grazed); periodically mowed and grazed natural grasslands (mowed-grazed); cultivated, fertilised, and mowed grasslands (cultivated-mowed); periodically mowed area closure natural grasslands (mowed-closed); and protected native forest grasslands (protected forest). We analysed SOC, labile and stable C fractions, total N, total P, and soil aggregate indices using standard methods, also calculating the C management index and stability ratio. Our findings reveal significant variations ($p < 0.01$) in SOC fractions across management types. Protected forest grasslands exhibited the highest labile C (1.41 %), while random grazed grasslands showed the lowest (0.39 %). For stable C, mowedclosed grasslands had the highest (0.92 %) and random grazed the lowest (0.23 %). Total N ranged from 1.18 % in protected forest and cultivated-mowed to 0.04 % in random grazed, with total P highest in cultivated-mowed soils. SOC, total N, and total P levels also varied significantly ($p < 0.05$) with soil depth. The highest total SOC was observed in protected forest, followed by mowed-closed, cultivated-mowed, mowed-grazed, and random grazed. Overall, grassland management practices that minimise soil disturbance, such as protected forest and mowed-closed, proved most effective in enhancing SOC storage and total N content and the decreasing order of the five grassland management types is protected forest > mowed-closed > cultivated-mowed > mowed-grazed > random grazed. This study underscores the critical importance of implementing sustainable grassland management to maximise C sequestration in the region.

Keywords: Carbon sequestration, grassland management, nutrient dynamics, soil aggregate stability, soil organic carbon

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Determining the proportion of basal to topdress nitrogen that optimises maize yield in northern Ghana

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In northern Ghana, the average grain yield of maize is constantly lower than the potential yield. Poor N use efficiency has been reported as a key factor. Most farmers have therefore adopted the split method of N application. They use compound fertiliser (NPK) as the basal application and urea or sulphate of ammonium as the topdress, to make up for the crop's N supply. With this, the proportion of basal to topdress N amounts applied is basically determined by the grade of the compound fertiliser. It is against this background that this investigation was carried out to determine the proportion of basal to topdress N amounts that would produce optimum maize growth and yield in northern Ghana and subsequently, recommend an appropriate NPK grade. The investigation was carried out at the CSIR-SARI experimental field at Nyankpala in 2024 and 2025 growing seasons. The recommended rate of NPK fertiliser in the Guinea savannah (90–60-60) was used. All P and K were applied during the basal application in the form of TSP and MOP respectively. The N rate (90 kg) however, was splitted into two according to different ratios for basal and topdress applications. Urea was used as the source of the N. Eight treatments; (1) No fertiliser (control) (2) 20%-80 % (3) 30%-70 % (4) 40%-60 % (5) 50%-50 % (6) 60%-40 % (7) 70%-30 % (8) 80%-20 % were arranged in RCBD with three replications. SPAD and other growth parameters were taken at various growth stages and grain yield at harvest. Results for SPAD and other growth parameters revealed the optimum amount of basal N to be 45 kg/ha (50 % of the 90 kg required). Grain yield results further corroborated this finding, where the highest maize grain yields for both years (3.6 and 4.7 ton/ha) were recorded in the 50%-50 % treatment. These were 0.7 and 1.0 ton/ha higher than those of 70%-30 % treatment, which represents the most popular NPK grade on the Ghanaian market (15–15-15). The NPK fertiliser grade that would result in 50%-50 % basal-topdress applications is 15–20-20. It is therefore recommended that, fertiliser producing companies should consider the production of this grade of NPK fertiliser.

Keywords: Basal, fertiliser, grade, maize, nitrogen, rate, topdress, urea

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Comparative analysis of organic and inorganic soil amendments on microbial biomass and nutrient dynamics in maize-based systems of Wondo Genet, Ethiopia

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Soil degradation threatens agricultural sustainability in Ethiopia, necessitating effective fertilisation strategies to maintain productivity. This study systematically evaluated the effects of organic and inorganic fertilisers on microbial biomass and soil nutrients in Wondo Genet, Ethiopia. Using a randomised complete block design, three treatment rates of forest soil (organic fertiliser) and chemical fertiliser were applied alongside control treatments. Soil samples were collected from two depths (0–10 cm and 10–20 cm) and analysed for microbial biomass and key soil nutrients. Results demonstrated that both soil amendments significantly improved microbial biomass and soil nutrients compared to the control ($p < 0.05$). Organic treatments achieved the highest microbial biomass carbon (MBC: 1979.72 μg/g) and nitrogen (MBN: 141.92 μg/g), followed by inorganic and control treatments. Organic amendments increased soil organic carbon (SOC) and total nitrogen (TN) by 34.11 % and 34.04 %, respectively, while inorganic fertiliser increased these parameters by 21.44 % and 12.77 %. Additionally, organic fertiliser enhanced available potassium and phosphorus by 12.19 % and 25.7 % compared to inorganic treatments. Fertiliser application rates significantly influenced microbial biomass, with optimal rates of 0.75 kg/m^2 for organic and 4.9 g/m^2 for inorganic amendments. Soil depth critically affected microbial biomass distribution, with consistently higher values in topsoil, though soil nutrients remained unaffected by depth. Correlation analysis revealed strong positive relationships between MBC and MBN, and between SOC and TN. These findings demonstrate the superiority of organic fertilisers in enhancing soil microbial biomass and key nutrients, indicating greater potential for improving soil fertility and sustainability. The results advocate for organic-based soil management strategies to restore soil health and support sustainable crop production in the Ethiopian Rift Valley and similar vulnerable agroecosystems.

Keywords: Fertilisers, microbial biomass, soil degradation, soil nutrients, sustainable agriculture

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Effect of marabou (*Dichrostachys cinerea* (L.) Wight & Arn.) on soil properties in agricultural systems in Cuba

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The widespread expansion of marabou (*Dichrostachys cinerea*) in Cuban agricultural landscapes represents not only an ecological challenge but also a potential transformation of soil system dynamics. While traditionally considered an invasive species, its influence reveals a more complex role on the indicators that determine soil quality. Soil assessment in areas invaded by marabou using selected physical, chemical, and biological indicators can provide valuable information for monitoring soil quality in agroecosystems. This study evaluated agricultural systems invaded by marabou near the city of Santa Clara, in Villa Clara province, in central Cuba. The results obtained here suggest that marabou can contribute positively to soil quality, particularly through increased carbon (C) availability and alteration of the nitrogen (N) cycle. The elevated levels of potentially mineralisable carbon and nitrogen have indicated an increase in soil organic matter turnover, especially in agricultural systems previously cultivated and managed organically. Biological parameters show that soil mesofauna communities (specifically those related to mites and springtails) remained stable in both invaded and non-invaded systems, indicating that marabou promotes conditions conducive to soil life, likely through its role in nutrient cycling and organic inputs. This ecological stability challenges the assumption that invasion by this plant in agroecosystems necessarily decreases biodiversity or soil function. Overall, marabou invasion can be interpreted as a shift toward alternative but viable soil states where agronomic potential is preserved. Instead of being solely a target for eradication, marabou could be integrated as a soil improvement tool in agricultural systems and strategically in land management frameworks aimed at restoring or maintaining soil quality in degraded agroecosystems.

Keywords: Farming systems, marabou, mesofauna, soil quality

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Harnessing *Typha australis* biochar for enhanced soil fertility and pearl millet productivity in semi-arid systems

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In Senegal, agriculture, a key sector for economic and social development, faces major challenges, including climate change and soil degradation. Millet, the main food crop occupying 51 % of cereal acreage, is experiencing stagnant yields due in part to declining fertility. The objective of this study is to evaluate the effects of increasing doses of biochar made from *Typha australis*, an invasive plant, on soil chemical properties and millet productivity. The study was conducted in the Senegalese peanut basin using a completely randomised block design with five treatments, repeated four times: T0 = control; T1 = recommended dose of inorganic fertiliser (NPK + urea); and the recommended rate of mineral fertiliser rate combined with 10 t ha^{-1} (T2), 20 t ha^{-1} (T3), and 30 t ha^{-1} (T4) of biochar. The application of high rates of biochar, particularly T3 and T4, significantly increased pH, electrical conductivity, and exchangeable K. Soil organic matter content and organic matter increased consistently with biochar, while Ca, Mg, Na, and CEC were mainly influenced by year. Biochar application (T3 and T4) decreased time to heading, flowering, and maturity compared to the control treatment. Addition of higher rates of biochar (T3 and T4) also enhanced millet vegetative growth, particularly plant height (up to 249 cm) and biomass production. Grain yield was significantly influenced by treatments, with highest values recorded under T3 (2750 kg ha^{-1}), followed by T4, while T0 consistently had the lowest yields. These results highlight the potential of T. australis-based biochar as an alternative for the valorisation of an invasive plant to restore soil fertility and support more sustainable agriculture, particularly for smallholder farmers.

Keywords: Biochar, pearl millet, semi-arid systems, soil fertility, *Typha australis*

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Collaboration intercropping, PGPM fertilisation, and Cascara-compost on optimising productivity of sub-optimal land in the tropics

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Designing model cultivation system for sub-optimal land in the tropics to optimise productivity is a challenge due to limitations in soil physico-biochemical properties. The objective of this research is to obtain cropping system model in the sub-optimal land to optimise productivity through collaboration of intercropping, Plant Growth Promoting Organisms (PGPM) fertilisation, and application of Cascara-compost. The experiment was conducted in the field 2 m × 2 m plots using split-plot experimental design. The treatment were arranged with PGPM as the main plots and Cascara-compost as sub-plots with three replications, and it applied to the intercropping of sweet corn and peanuts. The treatments PGPM was consisted of 3 levels dosage as p0 = control, p1 = 49 mL/L water/plot, and p2= 67 mLL^{-1} water/plot. The kaskara-compost was applied as k0= control, k1=2.4 kg plot^{-1}, and k2=3.6 kg plot^{-1}. Statistical analysis of significant difference the experiment using ANOVA and the effect of different treatment analysed by Duncan's multiple range test. The result showed that collaboration of the treatment PGPM 67 mLL^{-1} water/plot and Cascara-compost 3.6 kg plot^{-1} have shown the significant result in vegetative stage at the 7th weeks after planting (WAP). The plant height of corn and peanut was 99.44 cm and 61.18 cm, cob diameter and number of pods/plant was 5.36 cm and 19.97 pieces. Analysis result in the generative stage has shown in the production as 14.68 ton ha^{-1} and 2.03 ton ha^{-1}. This study confirmed the potential model cultivation system that collaboration of PGPM and Cascara-compost could be used in optimising productivity of sub-optimal land in the tropics.

Keywords: Intercropping, Cascara-compost, peanut, plant growth promoting microorganisms (PGPM), sweet corn

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Humic acid and gypsum affect phosphorus speciation and rice yield in an acidic paddy soil

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Acidic paddy soils frequently exhibit low fertility because phosphorus (P) availability is restricted by fixation of aluminum and iron (hydr)oxides. Additionally, the essential element calcium (Ca) is low. While applying soil amendments such as humic acid (HA) and flue gas desulfurisation gypsum (FG) could address both P and Ca deficiencies, the effects of HA, FG, and their combination on phosphorus speciation and subsequent rice production in an acidic paddy soil remain poorly understood. This study employed X-ray absorption near edge structure (XANES) spectroscopy to quantify P speciation in an Aeric Kandiaquult under four different soil managements, including chemical fertiliser (CF) (1), HA (2), FG (3), and coapplication of HA and FG (4). The CF was applied pertaining to local farmer practices at rate of 75, 38 and 38 kg ha^{-1} for N, P_2O_5 and K_2O, respectively. The HA was applied at the optimum rate for rice cultivation in acidic paddy soil of Thailand (975 kg ha^{-1}), while FG was applied at rate of 636 kg ha^{-1}, based on the gypsum requirement for high-acidity soil. Findings of this study revealed that HA application maximised rice yield by enhancing P cycling, especially labile P. In addition, HA increased the proportion of archerite (KH2PO4). In contrast, either FG alone or combined with HA suppressed yield, as they induced the formation of stable brushite ($CaHPO4{\cdot}2(H_2O)$) mineral. Furthermore, the HA+FG application promoted the formation of non-labile P forms, including inositol hexakisphosphate and strengite ($FePO4{\cdot}2H_2O$). This result suggested that the sole application of HA is an effective approach for acidic paddy soil to enhance P availability and rice yield.

Keywords: Phosphorus cycling, soil amendment, tropical region, Ultisol, XANES

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Photosynthetic responses as indicators of potassium use efficiency in oil palm (*Elaeis guineensis* Jacq.) progenies

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Understanding photosynthesis's response to nutrient availability is essential for enhancing potassium uptake and use efficiency and maintaining oil palm productivity under resource-limited conditions. This study evaluated *in situ* photosynthetic responses of four 8-year-old oil palm progenies (C1, C2, C3: Deli × LaMé; C4: Deli × Yangambi) to a stepwise increase in irradiance (0–1100 µmol m^{-2} s^{-1}, in increments of 200 µmol m^{-2} s^{-1}) under field conditions in Ologbo, Nigeria. Three levels of KCl (K0, K1, K2 = 0, 1.5, and 3 kg KCl $palm^{-1}$), combined with 0.75 kg $MgSO_4$ $palm^{-1}$, were applied. Photosynthesis was measured under limited water-supply conditions during the dry season (between January and February) to simulate water-stress constraints, which are a major factor limiting oil palm production in West Africa. Significant differences among progenies were observed ($p < 0.05$). At the highest irradiance (1100 μmol m^{-2} s^{-1}), increasing KCl supply led to a marked rise in net photosynthesis in the high-yielding progeny C3, from 9.45 to 12.56 and 17.84 μmol CO_2 m^{-2} s^{-1} under K0, K1, and K2, respectively. A comparable but less pronounced trend was observed in C2, with values increasing from 12.24 to 16.25 μmol CO_2 m^{-2} s^{-1} between K0 and K1, and only a slight additional increase at K2 (18.09 µmol CO_2 m^{-2} s^{-1}). In contrast, progeny C1 exhibited similar photosynthetic rates under K0 and K1 (16.25 and 16.95 μmol CO_2 m^{-2} s^{-1}), followed by a significant decline at K2 (11.35 µmol CO_2 m^{-2} s^{-1}). For C4, photosynthetic activity remained relatively stable across all K levels. These contrasting responses suggest that photosynthetic performance can effectively differentiate oil palm progenies in terms of potassium uptake and use efficiency, underscoring its value for guiding targeted fertilisation strategies to optimise productivity under nutrient-constrained environments.

Keywords: K uptake and use efficiency, oil palm, photosynthesis, radiation

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Modelling the effects of water and nitrogen fertiliser management on irrigated rice production

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This study assessed the effect of climate change on grain yield, water and nitrogen use efficiencies in rice production using DSSAT-CERES-Rice model. The experiment was conducted on-farm during wet and dry seasons using a split-split-plot design with three replications. The main plots were four irrigation regimes including continuous flooding (CFI), alternate wetting and drying (AWD) method with a water depth fluctuating above and below the soil surface at 5 cm (AWD $\pm$ 5 cm), at 10 cm (AWD $\pm$ 10 cm), and at 15 cm (AWD $\pm$ 15 cm). The sub-plots were 4 nitrogen (N) fertiliser rates (kg N ha^{-1}: 0, 76, 114 and 133). The sub-sub-plots included 2 cultivars (IR841 and Jasmin85). Wet season data were used for model calibration while that of the dry season were used for model validation. Model performance was evaluated using Root Mean Square Error (RMSE) and d-statistics (d). The validated model was used to assess long term (2025–2050) effects of the above treatments on grain yield, water and nutrient use efficiency. The model accurately simulated straw, grain yield, total biomass (RMSE = 492.65–2550.00 kg ha^{-1}, d = 0.60–0.91) but performed fairly good for leaf area index (RMSE = 1.82–2.27, d = 0.35–078), water use efficiency (WUE) and crop water productivity (CWP) (RMSE = 1.41–5.53 kg ha^{-1} mm^{-1}, d-stat = 0.35–0.88), partial factor N productivity (PFNP) and agronomic N efficiency (ANE) (RMSE = 3.76–17.87 kg kg^{-1}, d-stat = 0.35–0.89) for both cultivars. The long-term simulation results revealed that the AWD methods, especially $\pm$5 cm with increasing N fertiliser rate recorded higher ($p < 0.01$) CWP relative to that of CFI in both seasons. However, there was no significant effect of the irrigation regime on grain yield, WUE, PFNP, ANE during the wet season. In the dry season, the CFI with increasing N fertiliser rate recorded higher ($p < 0.05$) grain yield, WUE, PFNP and ANE compared to the AWD methods. The results suggest that smallholder rice farmers in Togo and similar agro-ecology could use the AWD $\pm$ 5 cm with 114 kg N/ha in the wet season and CFI with 114 kg N ha^{-1} in the dry season for improved grain yield, water and nutrient use efficiency.

Keywords: Nitrogen use efficiency, *Oryza sativa*, Togo, water productivity, yield

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Soil management shapes plant responsiveness to rhizosphere bacterial inoculation: Single strains versus consortium

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Soil management drives plant–microbe interactions, affecting the outcome of microbial inoculation strategies. In this study, we evaluated the effects of oat (*Avena sativa*) seed inoculation with rhizosphere bacterial inoculants. A five-week greenhouse experiment was conducted using a randomised complete block design (6 repetitions), with three soils and five seed coating treatments. Soils were obtained from a long-term field experiment at INIA Las Brujas – Uruguay, with contrasting management histories (CTMF -conventional tillage and mineral fertilisation, RTOF - reduced tillage and organic fertilisation, and UND - undisturbed soil as control). Seed coating treatments were single bacterial isolates (*Agrobacterium fabrum* (3IV10), *Pseudomonas umsongensis* (4IV7), *Ensifer adhaerens* (5II23)), a consortium (CON) composed with the three isolates, and a non-inoculated control. We assessed plant growth and chlorophyll content, root growth, rhizocompetence (bacteria cfu) and rhizosphere microbial community composition using amplicon sequencing. Plant responses were strongly soil-dependent. UND behaved distinctly, with lower chlorophyll content but higher root biomass and greater responsiveness to inoculation compared to CTMF and RTOF. This soil, characterised by higher biological activity and favourable structure, appeared to enhance soil–plant–microbe interactions, suggesting a shift towards root development. Inoculant performance varied, with 3IV10 showing the most consistent positive effects on root volume and chlorophyll content. CON did not outperform single isolates despite higher cfu, indicating that colonisation alone does not necessarily translate into plant benefit. CTMF behaved as a more restrictive system, while RTOF showed intermediate and stable responses. Inoculants 3IV10, 5II23, and CON were most affected by soil management, showing strong soil-dependent responses, with effect sizes reaching up to ~60 % variation in root volume, ~50 % variation in shoot biomass, and ~16 % variation in chlorophyll content across soils. Overall, soil management was a key factor shaping plant responses to inoculation, and microbial establishment alone was not a reliable predictor for plant benefit.

Keywords: Consortium, microbial inoculation, plant–microbe interactions, soil management

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Soil fertility management practices and yield of nutrient dense crops in refugee settlements in Uganda

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There are currently over 120 million refugees globally with Uganda as a leading host country due to its open-door policy. Though substantial investment has been made in refugee food provision, nutrition security remains a pressing challenge for the majority. Cultivation of nutrient dense crops such Orange Fresh Sweet potatoes (OFSP), Iron Rich Beans (IRB) and green leafy vegetables (GLV) has been promoted in refugee settlements to enhance nutrition security. This study aimed to investigate the influence of soil fertility management (SFM) practices on yield of nutrient dense crops in refugee settlements in Southwestern Uganda. A cross-sectional survey was employed to collect sociodemographic and production data from a sample of 171 refugees across two case study refugee settlements (i.e. Rwamwanja RS and Kikuube RS). Descriptive statistics and logistic regression were performed using JASP software. Results showed that 64 % of refugees in Kibuube RS had stayed for less than 5 years while the majority in Rwamwanja RS (57 %) had stayed between 5 to 10 years. Generally, most refugees (85 %) perceived their soils as having declined in fertility, with 82.5 % of the refugees adopting at least one SFM practice majorly through the utilisation of crop residues. Logistic regression results indicated that location of the refugee settlement was a significant predictor for adoption of SFM practices (Wald=4.23, OR=3.022, $p = 0.04$), with refugees in Rwamwanja RS three times more likely to adopt SFM practices than those in Kikuube RS. Productivities for IRB, GLV, and OFSP were 540 kg ha^{-1}, 277,1 kg ha^{-1}, and 186 kg ha^{-1}, respectively. Overall, the productivities of the nutrient dense crops were far below reported potential yields probably due to the cultivation on nutrient depleted soils. These results are essential to inform strategies to narrow the huge existing yield gap of nutrient dense crops in refugee settlements amidst the diminishing donor support to refugees. Implementation of affordable soil fertility management practices in refugee farming systems will be necessary to ensure sustainable food production and nutrition security in refugee communities.

Keywords: Nutrient dense crops, nutrition security, refugees

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Effect of bio-inputs on potato (variety: Kufri Himalini) grown in rice fallow under agro ecology based farming system in Assam, India

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Being one of the most important non-cereal food crops, potato serves as a vital source of nutrition for millions of people worldwide. Globally, potato is cultivated on about 18–19 million hectares, with an annual production exceeding 370 million metric tons. Owing to its high yield potential and rich nutritional composition particularly carbohydrates, vitamins, and minerals, potato plays a key role in ensuring food and nutritional security. An experiment was conducted at Assam Agricultural University, Jorhat, India under the GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit) - sponsored project titled "Assessment of Agro-Ecology-Based Cropping Systems and Natural Bio-Inputs for Soil Health Improvement and Product Quality Enhancement in Assam, India." aimed to evaluate the performance of the potato variety Kufri Himalini grown in rice fallow conditions during the Rabi season of 2024, under natural farming system using different combinations of bio-inputs made out of cow dung and cow urine–based concoctions. The experiment was laid out in a Randomised Block Design (RBD)with three replications and eight treatment combinations. The treatments included applications of various natural bio-input concoctions such as Jeevamrit, Beejamrit, Ghanajeevamrit, Dravajeevamrit, and Panchgavya. Among the different treatment combinations treatment T4viz., Ghanajivamrit (1.5 t ha^{-1}) + Dravajeevamrit @ 3 % in 15 days interval + Panchgavya @ 4 % in 15 days interval demonstrated the best performance in terms of both growth and yield parameters. In case of tuber yield treatment T4 showed highest yield (16.05 t ha^{-1}) which was statistically at par with treatment T6. T4 also significantly improved soil health including decreased bulk density (1.48 to 1.21 gcm^{-3}), increased water holding capacity, and increased organic carbon content (0.75 %). Nutrient availability improved, with nitrogen reaching 283 kg ha^{-1}, along with enhanced micronutrient content. Biological activity is also improved, indicated by higher microbial biomass carbon (194 μg/g), enzyme activities, and microbial populations (bacteria-47 × 10^6 CFU g^{-1} and fungi 19 × 10^4 CFU g^{-1}). These results highlight the effectiveness of integrating multiple natural bio-inputs in improving the productivity of potato crops in rice fallow systems. The findings also suggest that such practices can contribute to sustainable agriculture by enhancing soil health and crop performance).

Keywords: Assam, bio-inputs, India, potato, soil health

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Integrating homemade botanicals and companion cropping improves soil fertility and vegetable productivity under tropical conditions

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Vegetable production in sub-Saharan Africa greatly contributes to food security and rural incomes but face persistent soil degradation, pest pressure, and climate variability. These constraints reduce soil fertility, limit water retention, and weaken ecological functions that support stable production. We evaluated sustainable ecological management practices within a cabbage-garden pea cropping system in crop rotation cycles in the upper midland agroecological zone of Central Kenya. Four treatments were assessed, including Botanicals, Intercrop, Intercrop + Botanicals, and a sole crop Control. The experiment was based on a randomised complete block design, under field conditions across ten consecutive seasons from 2020 to 2024. Soil properties and crop performance were measured to examine changes in soil fertility and productivity. The Intercrop + Botanicals treatment recorded higher soil nitrogen (0.5 %), organic carbon (5.28 %), and available phosphorus (45.49 ppm). As a result, the improvements were associated with increased cabbage head size (185.9 mm) and marketable yield (61.6 Mg ha^{-1}), as well as higher garden pea height (64.8 cm) and grain yield (2.7 Mg ha^{-1}) in the same treatment. In contrast, the sole crop treatment recorded lower soil carbon and phosphorus and lower crop performance. Our results show that crop diversification combined with nature-based inputs can strengthen soil functions and support more stable vegetable-legume production under variable rainfall conditions. This approach contributes to soil conservation, improved water retention through increased organic matter, and enhanced on-farm biodiversity through diversified cropping. Our results provide a practical solution for developing multifunctional agroecosystems that sustain productivity while maintaining ecosystem services in smallholder landscapes.

Keywords: Agroecological practices, nature-based solutions, nutrient cycling, soil fertility, water retention

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Crop responses to abiotic stress in field and controlled environments

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Foliar nutrients enhance physiological responses and yield of maize (*Zea mays* L.) under drought at tassel initiation

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Drought stress at the reproductive stage significantly reduces the yield and quality of maize. Thus, this study aimed to evaluate the physiological responses and yield of maize following foliar applications of K, Ca, and Zn under drought stress conditions, prior to the critical tassel initiation stage. The experiment was arranged in a Randomised Complete Block Design (RCBD) with four replications. The eight treatments were as follows: T1: Well-watered control; T2: Drought stress at tassel initiation; T3–T4: Foliar K^+ at 2 % and 4 %; T5–T6: Foliar Ca^{2+} at 0.1 % and 0.2%; and T7–T8: Foliar Zn^{2+} at 0.3 % and 0.6 % at the critical tassel initiation stage under drought conditions. Physiological responses, including net photosynthetic rate (Pn), transpiration rate (E), and stomatal conductance (g_s) were maintained under drought stress conditions through foliar applications of T3 and T4 treatments. Furthermore, T3 and T4 treatments significantly increased the total soluble sugar content in the silks, while decreasing proline content in the silks under drought stress conditions. Moreover, compared to the well-watered control (T1), yield under drought stress was effectively maintained in the T3, T4, T7, and T8 treatments. Correlation analysis revealed that yield was significantly and negatively correlated with proline content in the silks. Specifically, an increase in yield, g_s, and E was associated with a decrease in silk proline content. In conclusion, T3 and T4 treatments effectively induced physiological responses in maize under drought conditions, thereby maintaining yield. These treatments reduced the proline content in the silks. Furthermore, they maintained g_s and E under stress.

Keywords: Drought stress, foliar nutrient application, maize, physiological responses, yield

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Leaf position dependent hyperspectral responses to drought in wheat

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Understanding how drought alters plant physiological functioning across canopy positions is critical for improving phenotyping of drought resilience in wheat. Most spectral studies focus either on the flag leaf or on the canopy, assuming uniform responses and overlooking informative variation associated with leaf age and microclimate variation. This study tested the hypothesis that integrating spectral measurements from two canopy positions, flag leaf (FL) and bottom sixth leaf (BL; counting from the top), provides additional insight into drought responses not captured by flag leaf measurements alone. Twenty-four wheat genotypes from CIMMYT's Best Physiological Traits panel were evaluated under irrigation and drought conditions during the 2023–2024 growing season. Spectral reflectance (400–2500 nm) was measured during grain filling using an ASD FieldSpec hyperspectral spectroradiometer. A series of indices was derived, representing chlorophyll content and canopy greenness, pigment composition and senescence, photosynthetic efficiency, canopy water status, and structural and biochemical traits. Drought reduced grain yield by 53.8 % ($p < 0.001$) and significantly increased reflectance across all regions of the spectrum, indicating reduced pigment content and water status compared to irrigated plants. Under irrigation BLs showed higher reflectance than FLs, particularly in the visible range (400–700 nm). However, under drought, reflectance of FL and BL in the visible range could not be distinguished, indicating that the drought induced pigment degradation was much faster in FL than in BL. After a two-way ANOVA (leaf position × environment), 77 of the 100 reflectance indices showed significant responses, mainly those related to chlorophyll pigments, vegetation greenness, water status, and epicuticular waxes were identified. Twenty-two were significant only in BLs and 55 only in FLs. Spectral responses in wheat were leaf-position dependent. While the flag leaf is widely reported to be associated with yield formation, bottom leaves can also provide valuable information on drought response in wheat, as around 40 % of indices were statistically significant. These results suggest that leaf-position-specific spectral information can provide additional insight into the characterisation of drought responses in wheat.

Keywords: Canopy physiology, drought, leaf responses, physiological indices, spectral phenotyping, wheat

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Modelling response of wheat genotypes to combined nitrogen × water stress at critical growth stages in contrasting environments

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Nitrogen shortage and water deficit at critical crop growth stages (CCGS) disrupt physiological processes and yield formation, consequently reducing wheat yield. Most crop growth models are not yet fit for accurately estimating yield during booting and grain-filling stages. This may partly be due to the fact that many models are constrained by source-sink capacities as influenced by G×E×M interactions. There are few studies investigating the interactions of N×W stress with genotype-specific responses. Here, we hypothesise that the simulation models CERES-Wheat (v4.8.2) and APSIM-Wheat (v7.10) can potentially reproduce genotype-specific responses to combined N×W stresses at CCGS in different environments.

Multi-year and multi-location field experiments were conducted in the arid climate of Punjab-Pakistan with varied soil conditions. The models were calibrated and evaluated under a diverse range of multi-factors (treatments: 4-irrigation regimes × 3-N rates (90, 140, 190 kg ha^{-1}) × 2 genotypes). Drought stress imposed at tillering, stem elongation, booting, and grain formation (25, 35, 45, and 65 BBCH). The models were parameterised with temperature functions, thermal time, base temperature, and leaf senescence functions adjusted before genotype-specific calibration. Systematic model sensitivity-analyses and seasonal-analysis were performed with historical climate (1991–2023) to test the genotype-specific yield potential for combined N×W stress at CCGS across different environments.

Overall, the models reproduced genotype responses to N×W stress interactions, showing acceptable statistical performance; for grain yield, RMSE= 486–717 kg ha^{-1} and d-index = 0.56–0.86, which are both satisfactory. LAI in CERES-Wheat was sensitive to SLAS, PHINT, and PARUE parameters, reflecting its use of a simple thermal-time threshold rather than APSIM-Wheat.

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Both models simulated TDM reasonably well (RMSE = 572–1395 kg ha^{-1}; d-index = 0.72–0.92), with CERES-Wheat closer to observed values than APSIM-Wheat. Genotype Akbar-2019 yielded 14–21 % more than FSD-2008 across treatments and locations. Multi-year climate interaction with G×N×W demonstrated that Akbar-2019 had a higher potential production than FSD-2008. In combination with four irrigations at CCGS, 140 kg N ha^{-1} significantly enhanced yield, and Akbar-2019 performed well, suggesting that it could be further cultivated even under combined stress conditions in this region. These results can also guide breeders in developing wheat ideotypes for high-yield production under multiple abiotic stress conditions.

Keywords: APSIM, climate analysis, DSSAT, genotype potential, G×E×M, model-sensitivity, N×W interactions

From transcriptomics to the field - improving screening for salinity tolerance in quinoa (*Chenopodium quinoa*)

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Salinisation of agricultural land poses a threat to global food security. Quinoa (*Chenopodium quinoa*) is a salt-tolerant crop, which provides highly nutritious seeds and exhibits a broad genetic diversity and adaption to saline and arid environments. Identifying quinoa accessions adapted to salinity and elucidating the respective tolerance mechanisms is critical to improving quinoa breeding for marginal environments. Phenotyping for salinity tolerance in field conditions is challenging due to heterogeneous soil conditions, unpredictable extreme weather events, cost- and labour requirements. Phenotyping therefore often relies on small-scale systems and younger plant stages, with relevance to field conditions remaining unclear. In this study, we screened 150 quinoa genotypes for their response to salinity in a soil-based pot experiment in the greenhouse and conducted transcriptomic analyses on leaf samples of 29 contrasting genotypes. Additionally, 6 genotypes were investigated in a multi-year field experiment in Uzbekistan. Physiological parameters, such as stomatal conductance, leaf ion contents and osmolality were assessed after the treatment period and plants were harvested after seed maturity. As a measure for salt tolerance, a salt tolerance index was calculated based on the maintenance of biomass and seed yield under salinity, between control and treatment group. The screening revealed differences in salinity tolerance across genotypes and suggests K+-dynamics and shoot water relations in early stress phases are important traits for seed biomass maintenance. Transcriptome analyses provide insights into the underlying molecular pathways. Also, genotypes which had a high salt tolerance index in the greenhouse pot experiment also performed well in saline field conditions, suggesting the screening system in the greenhouse indeed had relevance for plant performance in the field. The presented results will help identify genetic markers for physiologically important traits for salinity tolerance in quinoa and facilitate selection of genotypes for breeding quinoa for saline environments.

Keywords: Abiotic stress, phenotyping, quinoa, salinity

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How does UVB seed priming affect agronomic and yield traits of rice genotypes under UVB-stress?

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Rice cultivation has shifted to higher altitudes, up to 3000 m a.s.l. in Nepalese highlands, increasing cultivar exposure to higher ultraviolet-B (UVB) radiation. UVB-seed priming enhances abiotic-stress defense in some crops, but its genotype-specific effect on rice under UVB stress remains unexplored. This study investigated how UVB-seed priming affects agronomic and yield-related traits of selected rice genotypes and quantified the trade-offs between priming and UVB-stress exposure.

The experiment was conducted in a UV-climate chamber and greenhouse. Seeds of four rice genotypes, IR29 (sensitive, lowland), Marshi (highland, UV and cold-tolerant), CH1 and DBB (highland, stress response - unknown), were exposed to a UVB dose (22 kJ m^{-2} day^{-1}) as priming before germination. Primed and non-primed seedlings were transplanted into 2.5 L soil pots and grown under UVB-stress (22 kJ m^{-2} day^{-1}) for two weeks. After two weeks of UVB treatment, rice plants were grown in a greenhouse until harvest. Agronomic and yield traits were evaluated among four different UV-treatments (-UVp/-UVB, -UVp/+UVB, +UVp/-UVB, +UVp/+UVB). Tiller number, shoot height, physiological stress response indices (chlorophyll, anthocyanin, flavonoids, NDVI, PRI), shoot biomass and yield traits (panicles, grains) were assessed.

Chlorophyll content and yield increased with UVB-seed priming in IR29 and Marshi, with potential yield increased about 14% in IR29. Interestingly, grain yield increased by 18 % under primed (seed) and UVB (seedling) treatment for genotype CH1. However, about 44 % yield reduction was observed for Marshi under UVB-priming treatment. NDVI was higher in CH1 under combined treatment (+UVp/+UVB), and photochemical reflectance index (PRI) was higher in CH1 and DBB under primed treatments, showing a stronger stress tolerance response. Overall, these genotype-dependent responses suggest that UVB-seed priming may enhance stress resilience and can reduce yield loss under high UVB-stress growing conditions.

Keywords: Abiotic stress, highlands, NDVI, *Oryza sativa*, ultraviolet radiation

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Transpiration dynamics of quinoa for controlled environment agriculture: Interactions of light, salinity and nitrogen

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Transpiration rate regulates plant water use, nutrient transport, and evaporative cooling – processes critical for plant growth and air humidity control in controlled environment agriculture (CEA). Complementing water requirements from marginal sources such as municipal or saline groundwater requires high water through-put in plant growing systems. High transpiration rates as well as highly efficient nutrient uptake increase the volume of water that can be potentially purified through plant production in CEA deep water hydroponics. Quinoa (*Chenopodium quinoa* Willd. cv. Titicaca), a stress-tolerant halophyte with growing global importance, remains poorly studied in hydroponic CEA, particularly regarding transpiration responses and nutrient uptake under suboptimal nitrogen nutrition.

In this study, quinoa cv. Titicaca was grown under two light sources (LED and metal halide, MHL) with contrasting spectral PAR, combined with two salinity levels (0 and 150 mM NaCl) and two nitrogen ratios (NO_3^-:NH_4^+ = 50:50 and 100:0) at 3.0 mM total N. Over 30 days, five harvests quantified biomass and leaf area, while daily transpiration and nutrient solution measurements enabled estimation of water flux. The system was nearly sealed, so water loss occurred only via transpiration. Daily water loss was recorded at a fixed time, calculated per plant, and normalised by leaf area to derive transpiration rates (mmol $cm^{-2}day^{-1}$).

Maximum cumulative transpiration (21.33 L $plant^{-1}$) occurred under non-saline, no-ammonium conditions with MHL, followed by LED (18.45 L $plant^{-1}$), corresponding to 17.6–18.0 mmol $cm^{-2}day^{-1}$. Salinity reduced transpiration by 29.85 % under MHL (18.12 to 12.71) but only 1.52 % under LED. Without ammonium, transpiration declined by 28.62 % with salt, while cumulative loss decreased by 53.60 % under MHL and 61.65 % under LED. Overall, 150 mM NaCl reduced transpiration by 16.38 % and stomatal conductance by 44.36 %.

Under LED without ammonium, stomatal conductance increased by 172 % and shoot biomass by 36.87 % compared to MHL. Salinity reduced leaf area by 51 % under LED and 36 % under MHL. Under salinity, transpiration was 47 % higher under LED than MHL, whereas under non-saline conditions, MHL showed 39 % higher transpiration. Quinoa transpiration is strongly influenced by light, salinity, and nitrogen form, offering opportunities to optimise water use and system efficiency in hydroponic CEA.

Keywords: Controlled environment agriculture, hydroponics, LED, MHL, nitrogen form, quinoa, salinity, stress, transpiration

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Interactive effects of white led light, vapour pressure deficit, and root zone salinity on growth and nutrient uptake of hydroponically grown quinoa

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To date, little is known about the suitability of white light emitting-diodes (LEDs) for the plant production in controlled-environmental agriculture. The objective of this study was to evaluate the suitability of white LEDs for hydroponic quinoa production under moderate salinity (100 mM NaCl) at contrasting vapour pressure deficit (VPD) regimes, using ceramic metal halide lamps (CMH) as a reference. Quinoa (*Chenopodium quinoa* Willd., cv. Vikinga) was grown hydroponically in a greenhouse at two different salinity levels (0 and 100 mM NaCl) and two contrasting VPD levels (high 3.4 and low 0.6 kPa). Plant dry biomass and leaf area were measured alongside evapotranspiration and SPAD. Sodium (Na^+), and Potassium (K+) concentrations of the plants were analysed. Biomass allocation (leaf:stem ratio) and K+/Na^+ ratios under salinity were calculated.

Plants grown under LED lights produced similar biomass to CMH light under high VPD conditions at both salinity levels, indicating that LED lighting can sustain quinoa growth under dry atmospheric conditions. Salinity of 100 mM did not reduce the plant biomass under both light sources showing the plant's tolerance to root zone salinity of 100 mM NaCl. Leaf area under LED light was smaller than under CMH light, however leaf mass per area was higher and leaves were greener under LED illumination. Plants grown under LED light produced bushy plant types with shorter stems than under CMH light which was reflected in the higher leaf-stem ratio for the plants grown under LED light. Evapotranspiration and sodium uptake were lower under LED light, whereas potassium uptake was similar under both light sources. K+/Na^+ ratios did not show any differences across plant parts (root, stem, and leaves) under high VPD. Under low VPD conditions, plants grown under LED light showed a significant reduction of evapotranspiration, K+ uptake, and growth compared to CMH light conditions. This underlines the importance of atmospheric humidity for plant growth under LED lighting. Overall, the results show that LED lighting is suitable for hydroponic quinoa production under moderate salinity in greenhouse cultivation, provided that dry conditions are maintained to support the potassium nutrition and growth stability.

Keywords: Biomass, CMH, greenhouse, hydroponics, K+/Na^+ ratio, LED, quinoa, salinity, VPD

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Effects of light quality and nitrogen form on reproductive growth in hydroponic quinoa

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Hydroponic grain production currently represents only a minor share compared to leafy vegetable cultivation. However, increasing climate change, soil degradation, and water scarcity underscore its potential role in future food security. In controlled environment agriculture, maximising reproductive biomass accumulation is essential to optimise resource-use efficiency and reduce operational costs per unit of yield.

We evaluated the effects of light quality and nitrogen form on generative growth in quinoa (*Chenopodium quinoa* Willd., 'Titicaca'). Plants were grown in deep water flow systems under blue-dominated LED and metal halide (MHL) lighting, combined with two nitrogen ratios (NO□□-N:NH□+-N = 50:50 and 100:0) at a total N concentration of 3.0 mM. Additionally, two root zone salinity levels (0 and 150 mM NaCl) were applied to exploit quinoa's salt tolerance. Nutrient solutions were renewed every five days and regularly analyzed. Five destructive harvests were performed at six-day intervals over the 30-day experimental period to assess biomass partitioning, focusing on inflorescence and shoot dry mass (DM).

Shoot DM showed significant interactions between light and time ($p = 0.018$) and salinity and time ($p < 0.001$), whereas nitrogen ratio had no significant effect on the Shoot DM. In contrast, inflorescence DM was significantly influenced by the interaction between light and N ratio ($p = 0.005$). After 25 days, LED-50:50 (2.24 ± 0.51 g), LED-100:0 (1.92 ± 0.24 g), and MHL-50:50 (1.84 ± 0.49 g) treatments produced significantly higher inflorescence DM than MHL-100:0 (0.70 ± 0.17 g). This trend persisted at the final harvest, although not statistically significant ($p = 0.059$). However, the analysis of the inflorescence absolute growth rate confirmed a significantly higher growth performance ($p = 0.005$) for LED-50:50, LED-100:0, and MHL-50:50 over the entire observation period, independent of salinity.

These findings demonstrate that light quality and nitrogen form interactively influence reproductive growth in quinoa. While nitrogen form had no significant effect under LED lighting, ammonium supply significantly enhanced inflorescence growth under MHL. Optimising light spectra and nitrogen ratios may increase inflorescence mass and thus the yield in grain crops in controlled environment hydroponics, making it a viable option for the future of agriculture.

Keywords: Controlled environment farming, hydroponics, light quality, nitrogen form, quinoa

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Temporary nutrient depletion in hydroponics: Tomato growth response and recovery potential

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Finite phosphorus reserves and the energy-intensive production of synthetic nitrogen fertilisers are placing increasing pressure on global nutrient supplies. At the same time, nutrient-rich wastewater discharged into aquatic environments drives eutrophication, highlighting the need for circular resource management. By treating nutrient-rich effluents as a resource rather than a waste, wastewater-based hydroponic systems enable simultaneous nutrient recovery and crop production. However, realising this potential requires understanding the operational boundaries under which plants can function productively. Nutrient supply in these systems is inherently dynamic, fluctuating due to variable treatment efficiency and system dynamics. Nutrient depletion events may arise from technical faults, inconsistent influent quality, or deliberately through feed-and-deplete strategies, in which renewal is delayed until nutrients are substantially depleted to maximise removal. Beyond nutrient availability itself, vapour pressure deficit (VPD), the evaporative gradient between plant tissue and air, regulates transpiration-driven nutrient fluxes, making it a key environmental driver of plant performance. To determine the limits of plant productivity under interrupted nutrient supply, tomato plants (*Solanum lycopersicum*) were cultivated in recirculating deep-water culture systems under two VPD levels (0.8 and 2.0 kPa), with solution renewal delayed by 0, 2, 4, or 8 days once nitrogen fell to 5 mg N L^{-1}, followed by replenishment and a 7-day recovery period. After two days, deprivation had only minor effects on biomass, with high VPD showing greater compensatory capacity. From four days onwards, losses increased substantially, reaching 15 % after four days and 31–32 % after eight days, indicating a threshold beyond which recovery remains incomplete. Following replenishment, net CO□ assimilation recovered rapidly and transiently exceeded control levels, yet lost biomass was not fully regained. These results establish a practical tolerance window for nutrient supply interruptions in wastewater-based hydroponic systems, providing guidance for operational management strategies that balance treatment efficiency with crop productivity.

Keywords: Deep water culture, nutrient recovery, vapour pressure deficit

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Grain yield and quality trait responses of Bambara groundnut (*Vigna subterranea* (L.) Verdc) to drought stress

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Bambara groundnut (BG) is an underutilised legume crop with the potential to provide a nutritious food in drought-prone areas. It is valued for its protein and oil content, which contribute to dietary energy and essential fatty acids. This bean is prepared by boiling, roasting, or processed into flour. It is a climate-resilient crop but research is needed to determine drought effects on its oil and protein content, as these are its exceptional nutritional qualities. The experiment was carried out at the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria, in the derived savanna agroecological zone, with slightly acidic sandy-loam soil. We investigated the effects of drought on the grain yield, seed oil and protein content of BG. Ten accessions of Nigerian origin with similar flowering times were evaluated in a field trial under two water treatments; well-watered (WW) and drought-stressed (DS) using a split-plot design with three replicates. The split plot treatments in the DS plot had different watering based on different plant growth stages; vegetative, flowering, and pod-filling. All DS treatments were watered three times weekly until they reached the designated growth stage, at which point drought stress was imposed by withholding irrigation for 21 days. Thereafter, normal watering resumed and maintained until plant senescence. The WW treatment received water three times weekly until plant senescence. Irrigation was applied to achieve field saturation, with soil moisture monitored using a Hydrosense II probe in both WW and DS plots. Plants were harvested, weighed and analyzed for oil and protein. All data were subjected to ANOVA and correlation analysis. Grain yield reduced in the DS vegetative (13.8 %) and flowering (23.0 %) treatments. Drought stress significantly increased protein content in the vegetative (7.8 %) and pod filling (26.5 %) stages and had no significant effect on seed oil content. Grain yield had a significant negative correlation with seed oil content but not with seed protein content. Accessions TVSu-2, TVSu-8, TVSu-2094, and TVSu-2089 showed great yield potential, while TVSu-2093, TVSu-2090, and TVSu-2091 combined low to moderate grain yield with high seed protein and oil content and may be good sources of germplasm for improvement programs.

Keywords: Bambara groundnut, critical stage of water stress, drought stress, grain yield, oil and protein content

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Radiation-use efficiency, cumulative light interception, and crop senescence dynamics as physiological traits for wheat resilience under heat and drought stress

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Radiation-use efficiency (RUE) is the amount of above-ground biomass produced per unit of photosynthetically active radiation (PAR) intercepted by a crop. It is a central integrative trait of canopy photosynthetic performance and a key driver of genetic yield gains in wheat under optimal growing conditions, although its importance under heat and drought stress remains uncertain. In addition, canopy-level determinants of radiation capture, namely total intercepted PAR (IPAR), and post-heading senescence dynamics, play critical roles in crop productivity under abiotic stress. However, the contribution of these traits to RUE and wheat performance under drought and heat has not been established. This study aims at filling this knowledge gap using 50 elite wheat genotypes from three CIMMYT nurseries targeting specific environments: ESWYT (well-watered, WW), SAWYT (drought-stressed, DRT), and HTWYT (heat-stressed, HT). Genotypes were grown during the 2024–2025 season in Cd. Obregón, Mexico. WW received full irrigation, DRT was restricted to two irrigations (sowing and tillering). HT was sown in late February to impose heat stress and was fully irrigated. Normalised difference vegetation index was measured at canopy level as a proxy for greenness using a GreenSeeker at weekly intervals from post-heading to physiological maturity. An ACCUPAR ceptometer was used to estimate the fraction of IPAR. Above-ground biomass was determined through destructive harvest at physiological maturity to calculate total RUE. Multivariate regression analysis showed strong environment-dependent associations between physiological traits and grain yield. RUE explained yield variation with R^2 values of 0.50 (WW), 0.57 (HT), and 0.25 (DRT). Post-anthesis senescence dynamics accounted for R^2 values of 0.24 (WW), 0.44 (H), and 0.20 (DRT), whereas total IPAR showed R^2 values of 0.43 (WW), 0.47 (H), and 0.004 (DRT). Stepwise regression further confirmed RUE as the primary determinant of yield under WW and HT (WW: R^2_adj = 0.63; HT: R^2_adj = 0.64), while under DRT, yield variation was modestly explained by a combination of RUE and crop senescence dynamics (R^2_adj = 0.32), indicating a marginal contribution of canopy persistence under drought. These findings demonstrate RUE as the main driver of yield across environments, with a weak complementary contribution of senescence dynamics under drought.

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The contribution of ecosystem restoration and agroforestry practices to biodiversity conservation in Ethiopia: A systematic literature review

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Ethiopia faces significant biodiversity loss due to deforestation, land degradation, and agricultural intensification. Ecosystem restoration and agroforestry practices have emerged as potential strategies for biodiversity conservation while supporting rural livelihoods. However, a comprehensive synthesis of empirical evidence on their effectiveness in the Ethiopian context is lacking. We conducted a systematic literature review following PRISMA 2020 guidelines. We searched Google Scholar, PubMed, and SciSpace databases for studies published between 2012 and 2026. Eligibility criteria included studies conducted in Ethiopia reporting quantitative biodiversity metrics for ecosystem restoration or agroforestry interventions with comparative assessments. Two-stage screening (abstract and full-text) was performed using predefined criteria with score thresholds of $\geq$4.0 and $\geq$4.5, respectively. Data extraction focused on study design, intervention types, biodiversity metrics, key findings, geographic location, recommendations, and risk of bias assessment using the ROBINS-I tool. From 1,484 identified records, 335 studies met inclusion criteria after removing 472 duplicates and screening 1,012 unique records. Studies covered diverse agroforestry systems (home gardens, parkland systems, coffee-based agroforestry, boundary plantations, woodlots) and restoration interventions (exclosures, reforestation, soil and water conservation) across multiple Ethiopian regions. Home gardens consistently showed the highest species diversity (Shannon-Wiener index: 2.5–3.8), followed by coffee agroforestry systems. Ecosystem restoration interventions, particularly exclosures and area closures, demonstrated significant increases in species richness (40–150 % compared to degraded sites) and diversity indices. Native species composition was higher in traditional parkland systems and forest coffee compared to intensively managed systems. Policy integration of traditional ecological knowledge with scientific approaches emerged as critical for sustainable biodiversity conservation.

Both ecosystem restoration and agroforestry practices contribute significantly to biodiversity conservation in Ethiopia, with effectiveness varying by intervention type, management intensity, and ecological context. Home gardens and coffee agroforestry systems serve as important repositories of plant diversity, while restoration interventions effectively rehabilitate degraded ecosystems. Integration of indigenous and exotic species, maintenance of structural complexity, and supportive policy frameworks are essential for maximising biodiversity outcomes. Future research should address geographic gaps, long-term monitoring, and socio-ecological interactions.

Keywords: PRISMA, species diversity, systematic review

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Food sovereignty across a rural–peri-urban gradient: Transformations of traditional agroforestry systems in the High Atlas of Morocco

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Traditional agroforestry systems in mountain regions support livelihoods, biodiversity, and local food systems. However, urbanisation, market integration, and climate stress are reshaping these systems and their contribution to food sovereignty. This study examines how food sovereignty is configured across a rural–peri-urban gradient in the High Atlas Mountains of Morocco and how these transformations interact with traditional agroforestry landscapes. The research compares three communities representing different socio-economic contexts: Isslk (remote rural village), Ait Blal (rural town), and Imi Nifri (peri-urban town). Data were collected through 45 semi-structured interviews with farmers, cooperative members, local leaders, and traders. The analysis applies six food sovereignty dimensions – resources, production models, commercialisation, food consumption and the right to food, agrarian policies and civil society organisation, and gender – to assess how agroforestry systems contribute to autonomy, food provision, and livelihood resilience. Results reveal differentiated configurations along the gradient. In Isslk, relatively open access to land and pastoral resources supports culturally embedded food systems, yet infrastructural constraints and climate stress limit productivity and increase reliance on external food sources. Ait Blal exhibits comparatively strong food sovereignty, where diversified agroforestry, terraced farming, and communal labour practices sustain ecological multifunctionality and partial food self-sufficiency. In Imi Nifri, proximity to markets enhances income opportunities and food availability but drives specialisation, mechanisation, and reduced diversification, increasing dependence on external markets. Across all sites, climate stress, market integration, labour migration, and policy incentives emerge as key drivers shaping agroforestry systems and food sovereignty dynamics. These drivers generate both adaptive transformations, such as diversification and local processing, and erosive changes, including declining communal practices and increasing market dependence. The findings highlight a structural tension between food security and food sovereignty, underscoring the need for policies that strengthen diversified agroforestry systems and sustain local knowledge in rapidly transforming mountain regions.

Keywords: Food system governance, mountain agroecosystems, rural–urban gradient

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Farmer responses to market liberalisation: The role of cooperatives in the Rwandan coffee sector

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Food value chains involve multiple actors, yet research has largely focused on small-scale farmers. In contrast, the role of primary buyers remains comparatively under-explored, particularly in contexts undergoing regulatory change, such as processes of market liberalisation.

This study investigates how producer-buyer relationships shape farmers' intentions in the Rwandan coffee value chain following the repeal of the zoning policy, which liberalised cherry procurement nationwide. We focus on the role of cooperatives, as evidence shows they form the strongest producer-buyer relationships.

Introduced in 2016, the zoning policy aimed to reduce side-selling and improve service provision by requiring farmers to sell cherries to a designated Coffee Washing Station (CWS). In June 2023, the policy was repealed, allowing unrestricted purchasing and trading of coffee cherries. The policy shift is expected to intensify competition among CWSs, particularly through price adjustments. While price remains the primary determinant of CWS choice, we hypothesise heterogeneous responses: farmers supplying private CWSs may be more willing to switch than cooperative members, who often value loyalty, non-monetary benefits, community belonging, and participation in decision-making. Such differentiated responses would imply possible uneven effects across farmers and could place competitive pressure on cooperatives.

Using a mixed-methods design, we combine primary data from a socio-economic survey of 834 farmers with insights from 12 semi-structured interviews. We analyse the association between cooperative membership and farmers' willingness to switch CWSs using an inverse probability weighted regression adjustment model. The qualitative interviews triangulate and complement the quantitative findings.

Findings show that cooperative members are 9 percentage points less likely to intend to switch CWSs.However, considerable heterogeneity among cooperative members emerged: those who had to sell to private CWSs are 14.6 pp more likely to intend to switch than members selling to their cooperatives. Interviews reveal that, while farmers value higher prices, cooperative members prioritise loyalty, trust, and access to services such as credit, training, and input provision. However, increased price competition may disadvantage cooperatives, potentially threatening their sustainability.

These results underscore the importance of considering relational dimensions when designing market reforms.

Keywords: Coffee, cooperatives, Rwanda, zoning policy

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Distribution, use, and governance of wild mango stands in north-eastern Pakistan

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Mango (*Mangifera indica* L.) is an important commercial fruit crop in Pakistan providing a substantial income source for farmers. Mango trees are cultivated on large scale commercial farms, and the stands consist mainly of modern varieties. Despite much research on the genetic diversity of mango trees and on effects of management practices on their yield and quality, there is, to date, little information on the ancient belt of wild mango stretching along the foothills of the Karakoram/Himalayan Mountains in the districts of Gujrat and Bhimber (Kashmir) of north-eastern Pakistan. Exploring these old landraces helps in generating a basis map for further genetic distribution mapping. This study therefore aims at identifying the extension and use of these wild mango stands. To do so, the geographic coordinates of individual trees were collected between August and September 2025 using a handheld Global Positioning System (GPS) and were integrated in a Geographical Information System (GIS) to analyse the geo-morphological determinants of the stand density. A manual classification of the trees was done in QGIS using Google Earth satellite image. In addition to that, we conducted a questionnaire to collect data on the age and use of the trees. As a result of the classification, a total of 2,747 trees were mapped. These were located in the eastern part of the Bhimber district, across 128 km^2, and an elevation gradient between 290 to 890 m above sea level (m a.s.l.) whereby the majority (68 %) was found in the lower areas (360 to 460 m a.s.l.). Primary results furthermore reveal that the majority of the trees (78 %) are over 100 years old and are under communal ownership and use. Together with the crops cultivated by farmers, the trees form an agroforestry system and their management is strongly linked to cultural and religious beliefs. Further classification work will target the automation of the process using deep learning models and a larger area, covering both districts, where we expect a total number of >26,000 trees. Future research will also focus on the analysis of ecological determinants of the stand density.

Keywords: Fruit crops, GIS, indigenous varieties, Kashmir, traditional knowledge

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Linking agroforestry and soil conservation practices: Shaping soil fertility in smallholder coffee systems of Africa

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Smallholder coffee systems in the humid tropics of Central Africa are increasingly vulnerable to soil degradation, necessitating a transition towards regenerative agroecology. This study investigated how agroforestry shade levels and soil conservation practices interact to shape soil fertility across two Agroecological Living Labs (ALL): Kabare-Biega, DR Congo (n = 75), and Giheta, Burundi (n = 90). Using the Land Degradation Surveillance Framework (LDSF), topsoil (0–20 cm) was sampled with the Y-frame technique. Samples were analysed for soil organic carbon (SOC), total nitrogen (TN), available phosphorus (P), and soil pH. Statistical significance was determined using ANOVA and Tukey's HSD tests ($p < 0.05$).

Results showed that agroforestry structure and management practices significantly differentiated soil health outcomes between the two sites. In Kabare-Biega, shade intensity was the primary driver of fertility; SOC content was significantly higher in high-shade plots (4.2 %) than in low-shade systems (2.8 %). Available P also increased under high-shade conditions, while soil pH remained stable across the shade gradient (5.4). In the Giheta ALL, the synergy between canopy cover and mulching was decisive. The combination of high agroforestry levels and mulching yielded the highest SOC (4.01 %) and TN (0.29 %), significantly outperforming the bare soil plus low agroforestry control (SOC: 1.98%; TN: 0.14 %). In Giheta, however, available P and soil pH showed no significant variation across treatments, with P ranging narrowly from 2.1 to 3.8 mg kg^{-1} and pH fluctuating between 5.1 and 5.7. These findings suggest that while canopy shade provides a baseline for organic input, ground-level conservation such as mulching is essential to double carbon and nitrogen stocks in degraded landscapes. We conclude that sustainable intensification in Central African coffee systems requires site-specific agroecological packages: optimising shade canopy in DR Congo to drive P availability and SOC, while integrating intensive mulch management in Burundi to overcome nutrient limitations. These insights are vital for transitioning towards resilient, climate-smart smallholder food systems in the humid tropics.

Keywords: Central Africa, coffee agroforestry, mulching

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Assessing zero deforestation agreements outcomes in Colombia's beef and dairy and cocoa supply chains

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Zero Deforestation Agreements (ZDAs) are market-oriented, voluntary, and non-legally binding initiatives to reduce deforestation from key agricultural supply chains in forested countries, involving private, public, and civil society actors that promote market opportunities for agricultural commodities while addressing deforestation. These agreements align with the global concerns arising from the Paris Agreement to reduce deforestation and forest degradation to curb greenhouse gas emissions associated with climate change. This study assesses the outcomes of Zero Deforestation Agreements in Colombia, initiatives that have been implemented since 2017 to reduce deforestation across key agricultural supply chains. The analysis is situated in a post-conflict context characterised by accelerated deforestation driven by frontier expansion, land grabbing, and weak enforcement, which poses a challenging setting for voluntary sustainability initiatives. We applied a mixed qualitative and institutional analysis grounded in a theory-of-change framework, drawing on stakeholder interviews, document review, and comparative sectoral analysis to examine governance, coordination, and behavioural outcomes of ZDAs in the beef and dairy, and in the cocoa supply chains. Results show that in high-risk and fragmented sectors such as beef and dairy, ZDAs main contributions have been institutional, including improved coordination, information sharing, learning processes, and emerging norms around deforestation-free production. However, weak traceability, misaligned incentives, and strong frontier dynamics continue to constrain their effectiveness. In contrast, in the cocoa sector, characterised by high organisational coverage and agroforestry-compatible production systems, ZDAs have been more effective in consolidating low-deforestation pathways, reinforcing sustainable production models, and facilitating alignment with emerging international due diligence and traceability requirements. These results highlight that ZDAs function best as governance instruments embedded within broader environmental and agricultural policy frameworks rather than as stand-alone solutions. Their effectiveness depends on complementary regulatory baselines, credible economic incentives, and long-term financial commitments. When matched to sector-specific realities, ZDAs can either remain limited to pilot impacts or consolidate sustainable, deforestation-free production trajectories.

Keywords: Beef and dairy, cocoa, Colombia, outcomes, zero deforestation agreements

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Silvopastoral systems in Brazil's Cerrado: Motivations and abilities of farmers

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The Cerrado is one of the world's most biodiverse ecosystems and an important agricultural frontier. Rapid agrarian transformation, driven by agricultural intensification and expansion, has reinforced its role in global food production while simultaneously generating environmental and socio-economic challenges, which put the Cerrado under increasing pressure. In this context, sustainable food systems offer pathways to address environmental issues while supporting food security and rural incomes. One such approach are silvopastoral systems (SPS), a traditional land use practice in the Cerrado. We collected data from 204 households in two rural regions in the Cerrado, Rio Pardo and Urucuia. Through the MOTA (Motivation and Ability) framework, we quantified farmers' motivations and abilities to use SPS. We separated the analysis across regions, SPS adoption status, and farm sizes. The results show that farm size is the main factor influencing ability: smallholders have lower levels of ability, especially in terms of income, knowledge, and machinery. Regional differences are also evident, with lower income and knowledge levels in Rio Pardo, and lower access to machinery, workforce, and external funding in Urucuia/Arinos. When separating SPS adopters and non-adopters, motivation shows as the key difference between the groups. These findings suggest that promoting SPS should focus on strengthening motivation and shaping farmers' perceptions, rather than solely capacity building. At the same time, ability differences reflect underlying structural inequalities, indicating that socially just SPS promotion must address both motivation and ability.
The MOTA framework proved valuable for comparing different farmer groups and identifying the central role of motivation in shaping SPS adoption. Building on this, further research could explore the underlying perceptions and decision-making processes that shape farmers' motivations.

Keywords: Agrarian transformation, agroforestry, Cerrado, ecosystem services, MOTA, motivation and abilities, silvopastotal systems

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Economic, environmental, and social impacts of silvopastoral systems: Evidence and scaling pathways from Colombia

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Colombia's cattle sector is a cornerstone of rural livelihoods and national agricultural output, yet it is also a major driver of deforestation, land degradation, and greenhouse gas emissions. Silvopastoral systems (SPS), which integrate trees, forage, and livestock, have emerged as a promising pathway toward more sustainable and climate-resilient cattle production. This study assesses the potential of SPS to transform Colombia's cattle sector by synthesizing evidence on their economic, environmental, and social impacts, as well as the enabling conditions required for large-scale adoption. A systematic literature review of 185 sources published between 2000 and 2025 was conducted, including peer-reviewed articles, institutional reports, and policy documents. The analysis applies frameworks on technology adoption, scaling of innovation, and sustainable finance to evaluate SPS performance and identify barriers and opportunities for expansion. Results show that SPS can significantly enhance productivity and profitability, with reported internal rates of return often exceeding 20 % and reduced payback periods compared to conventional systems. Documented environmental benefits include carbon sequestration, reduced methane emissions, improved soil health, and increased biodiversity, positioning SPS as a climate-smart land-use strategy. Socially, SPS support rural livelihoods, strengthen resilience among smallholders, and contribute to food security and inclusive development. Despite these advantages, adoption remains limited due to persistent barriers such as high upfront investment costs, long and uncertain payback periods, insecure land tenure, limited access to tailored financing, and weak institutional support. The findings highlight the importance of integrated scaling strategies that combine financial innovation, policy alignment, technical assistance, and market development. Promising mechanisms include blended finance, payments for ecosystem services, carbon markets, and sustainability-linked value chains. Colombia's experience provides valuable insights for scaling sustainable livestock systems across the tropics. Unlocking the full potential of SPS requires coordinated public–private action, targeted investments, and enabling policy environments that address systemic constraints. By aligning economic incentives with environmental and social outcomes, SPS can contribute to transforming cattle production into a more sustainable, productive, and inclusive sector.

Keywords: Agroforestry, climate-smart agriculture, ecosystem services, scaling innovations, sustainable cattle farming, sustainable finance, technology adoption

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The impact of on-farm fuelwood production on collection time in agroforestry systems: panel evidence from Rwanda

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Agroforestry systems offer a promising pathway to building resilient and multifunctional landscapes, enhancing provisioning services and reducing dependence on off-farm resources such as natural forests particularly in sub-Saharan Africa. This study examines whether integrating trees into smallholder farming systems reduces household fuelwood collection time, thereby improving provisioning service efficiency, easing the labour burden on households, and reducing pressure on natural forests where extraction is unsustainable. We use a two-wave primary panel dataset from rural households in the Eastern province of Rwanda. A random effects (RE) model combined with a control function approach (CFA) is employed to estimate the impact of on-farm fuelwood harvesting on monthly collection time, while addressing potential endogeneity in the decision to harvest farm fuelwood. Exposure to agroforestry practices is used as an instrument to capture variation in tree adoption and management intensity. Results indicate that harvesting fuelwood from on-farm trees significantly reduces collection time by 27–37 % ($p < 0.01$), depending on model specification. Instrumental variable estimates show that exposure to agroforestry practices increases the likelihood of tree planting and enhances both the density and functional diversity of on-farm tree stocks. This strengthens the case for on-farm biomass supply and reflects a shift toward internalised energy provision within agroforestry systems. These findings highlight that agroforestry systems can contribute to multifunctionality by simultaneously providing fuelwood, reducing related household time burdens, and enhancing tree-based ecosystem functions. By reducing reliance on common-pool forests and increasing tree cover within agricultural landscapes, agroforestry systems support more sustainable and resource-efficient smallholder production systems in Rwanda and similar contexts.

Keywords: Agroforestry systems, biomass and energy, collection time, fuelwood production, panel data, Rwanda, smallholder households

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Forest conservation practices: Insights of local communities near wildlife-protected areas in Ghana

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Effective forest conservation depends on active community participation, however, local communities in Ghana are often excluded from policy development and decision-making processes. This study explored community perspectives on forest conservation by identifying practices that local inhabitants believe could help preserve and sustainably manage two wildlife-protected areas within the forest–savannah transition zone of Ghana: Boabeng-Fiema Monkey Sanctuary (BFMS) and Kogyae Strict Nature Reserve (KSNR). A cross-sectional survey of 300 respondents was conducted using semi-structured questionnaires to gather insights into conservation practices suggested by the local populace. A Multinomial Logistic Regression (MLR) model was employed to assess whether socio-demographic variables such as age, sex, education level, occupation and residential status influenced these perspectives. Results indicate that wildfire prevention was the most emphasised conservation strategy in BFMS (38.6 %), reflecting concerns over increasing fire incidence and its ecological impacts, whereas, respondents in KSNR (37.2 %) emphasised the need for increased staffing and improved monitoring and enforcement capacity. Socio-demographic variables did not have a statisti-

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cally significant influence on conservation preferences ($p > 0.05$), indicating that direct interaction with the forest, as experienced by local communities, is one of the key drivers of knowledge on how to sustainably preserve and manage it. These findings highlight the important role of local knowledge and community-driven strategies in shaping sustainable land-use practices and improving governance of protected landscapes. Integrating such perspectives into formal conservation policies can enhance ecosystem resilience, strengthen landscape multifunctionality and support equitable resource management. The study contributes to ongoing discussions on participatory governance and policy innovation in tropical landscapes and aligns with global sustainability goals, particularly SDG 13 (Climate Action) and SDG 15 (Life on Land).

Keywords: Biodiversity conservation, forest-savannah transition zone, sustainable forest management

Enhancing landscape multifunctionality in a biosphere reserve through agroforestry and non-timber forest product domestication

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Biosphere Reserves (BR) are a tool to achieve multifunctionality in landscapes, but a policy-implementation gap remains. The Hangzhou Strategic Action Plan as the major guiding document for the next decade of BR development (2026–2035) calls for science-practice partnerships, through demonstration projects and sustainable resource management approaches tailored to the local context that integrate local and scientific knowledge. This study documents the transdisciplinary research process for species identification for agroforestry and non-timber forest product (NTFP) domestication in Lake Bosumtwe Biosphere Reserve (LBBR), a mosaic landscape in the high-forest zone of Ghana. The study included a combination of structured surveys, botanical inventory and focus group discussions with local farmers. Joint site visits and excursions to agroforestry plots in Ghana allowed stakeholders to exchange local and scientific knowledge on management practices, yields and suitable species as well as on processing and marketing opportunities. A prioritisation process for species suitable to the social-ecological context included farmers' species preferences, current market demand, potential for value-chain development, conservation value and environmental suitability. The species finally selected for cultivation in local farmers' demonstration plots were *Aframomum melegueta, Piper guineense, Terminalia superba, Tetrapleura tetraptera*, *Triplochiton scleroxylon*, *Milicia excelsa, Khaya grandifoliola, Terminalia ivorensis, Pericopsis elata* and *Tieghemella heckelii*. Their potential to enhance the three functions of a biosphere reserve is examined, finding that they can strengthen conservation and development function, while the demonstration plots as collaborative learning platforms enhance the logistic support function of a BR. The demonstration plots enable farmers and stakeholders to observe performance, exchange scientific and local knowledge, and refine management approaches. The agroforestry plots allow to further adapt and co-develop agroforestry systems that strengthen multifunctionality of the LBBR.

Keywords: Agro-forestry, NTFP, transdisciplinary research

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Agroforestry for promoting climate-resilient future and building pathways for food security & sustainable livelihoods

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With growing environmental challenges, agroforestry systems are emerging as a vital solution for food, nutrition, ecological and economic sustainability. Beyond their role in carbon sequestration, these systems enhance soil fertility, improve water retention, mitigate climate change, and provide diverse livelihood opportunities for farmers. By integrating trees with crops, horticulture, and livestock, agroforestry systems offer multiple benefits by boosting biodiversity, enhancing resilience against extreme weather, and ensuring long-term food and nutritional security towards achieving green growth and net zero transition. These systems build resilient multifunctional landscapes.

Agroforestry, combined with tree-based food systems and horticulture, also offers a transformative solution for drylands which cover nearly 45 % of our planet's land area and are often seen as challenging environments. However, they hold immense potential for sustainable food systems, biodiversity conservation, and climate resilience.

Integrating right trees, crops and animals in functional agroforestry and horticulture reduce vulnerabilities in rainfed agriculture. Resilient tree-based cropping systems diversify farm income and reduce climate-related risks. These systems restore source sustainability by soil health and carbon sponge capacity to hold more green water (rainwater where it falls).

Additionally, agroforestry leverages for achieving Net Zero goals, carbon sequestration, and restoring degraded lands. Further, these systems unlock opportunities for smallholder farmers through tree-based sustainable value chains.

Here we discuss how to harness the infinite potential of agroforestry and tree-based food systems to achieve a green economic transition, ensure good food security, and build climate-resilient landscapes. Land fragmentation, biodiversity loss, species exemptions, transit regulations, revenue regulations and disputes are some of the key challenges that need to be addressed. Additionally, we need to explore innovative solutions like tree tracking, geotagging, and technology driven conflict resolution to support tree growers on agricultural lands while fostering sustainable and profitable land management practices. This article highlights the role of multifunctional agro-eco-systems towards a greener future.

Keywords: Agroforestry, climate resilience, economic sustainability, food security, green growth, sustainable livelihoods

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Diversity, synergies and trade-offs between stakeholders' demands towards tree-related ecosystemic services

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Agroforestry is widely promoted as a land-use option that can alleviate the environmental pressures of agriculture while enhancing the livelihoods of vulnerable rural households through the development of multifunctional landscapes. While a significant body of literature reveals existing ecosystemic services (ES) and disservices related to agroforestry practices, fewer studies explore the diversity of tree-provided ES demands among stakeholders. Understanding this diversity of demand and the potential synergies and trade-offs that may appear between diverging stakeholders is crucial for assessing tree-based practices attractiveness and designing multifunctional landscapes. This study aims to enhance the state of knowledge on local demands related to trees and their translation into land management within a case study in semi-arid zone of Embu County in Kenya.

We conducted 80 surveys with a panel of stakeholders to examine, the relationship between (i) stakeholders' demands for ecosystem services supplied by trees (e.g., soil fertility, water regulation, fuelwood, fruit production), (ii) their opportunities and constraints related to their socio-economic and agro-environmental characteristics, and (iii) their current agroforestry practices. Using cluster analysis, respondents are grouped according to their ecosystemic-service-demand profiles to generate a typology. These profiles reveal that stakeholders with similar characteristics may prioritise different ecosystem services, leading to divergent strategies concerning trees, and resultant trade-offs across space (plot, farm, landscape) and time (short- vs. long-term) scales.

The results highlight that the perceived importance of specific ES is central in shaping agroforestry decisions, potentially outweighing conventional socio-economic predictors. A multiscale, systems-based approach that adapts incentives, technical assistance, and institutional support to diverse demand-type groups is required to reconcile competing interests and promote AF uptake across heterogeneous rural landscapes.

Keywords: Agroforestry, ecosystemic services, multifunctional landscape, stakeholders demands, trade-offs

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Optimising harvesting frequency of *Moringa stenopetala* for biomass yield, nutritional quality and food security in Ethiopia

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Moringa stenopetala is a high-value multipurpose tree with exceptional potential to strengthen multifunctional agroecosystems in arid and semi-arid Africa by simultaneously addressing malnutrition, supporting livestock productivity, and enhancing climate resilience. Yet evidence-based harvesting protocols that balance biomass productivity with nutritional quality and long-term plant vigour remain lacking. This study determined the optimal harvesting frequency for *M. stenopetala* across early developmental stages in Bena-Tsemay District, South Omo Zone, southern Ethiopia – one of Ethiopia's most food-insecure dryland regions. Five harvesting intervals (15, 30, 45, 60, and 75 days) were evaluated in a factorial Randomised Complete Block Design (RCBD) with three replications. Key indicators included growth parameters (plant height, root collar diameter, branch number, and recovery rate); biomass yield (g/plant, kg/ha, and kg/ha/year); proximate composition (protein, ash, crude fiber, fat, carbohydrate, and energy); and fat-soluble vitamins (A, D, E, and K). Harvesting frequency significantly affected all measured parameters ($p < 0.05$). The 30-day interval maximised fresh biomass yield (3,566 g/plant), achieving the best balance between productivity and plant recovery – making it the recommended protocol for smallholder farmers prioritising leaf output. Longer intervals (60–75 days) supported superior vegetative growth (tree height up to 2.33 m, branch number up to 18) but yielded fewer harvests annually. Crucially, protein content (24–27 %) and fat-soluble vitamins remained high and largely stable across all intervals, confirming that nutritional quality is robust to harvesting management. These results establish that M. stenopetala can serve as a reliable, year-round source of human nutrition and livestock feed under optimised management, even in nutrient-poor dryland soils. By providing scientifically grounded harvesting guidelines, this study supports the integration of M. stenopetala into climate-resilient agro-ecosystems – contributing to food security, dietary diversity, and sustainable land use across the semi-arid Horn of Africa.

Keywords: Harvesting frequency, *Moringa stenopetala*, nutritional quality, proximate composition, vitamin content

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Apricot farming and processing in Central Asia: Challenges and perspectives

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Apricot (*Prunus armeniaca* L.) remains one of the key fruits of temperate zones, with Central Asia serving as a major centre of its origin and genetic diversity. The study aimed to evaluate the economic potential of fresh and dried apricot production and trade worldwide, with a special focus on Central Asian countries, and to assess the efficiency of various drying technologies. Data from FAOSTAT, WITS, Tridge and WTO for 2020–2025, along with a systematic review of scientific literature on drying technologies (Scopus, Web of Science, etc.), were used; return on investment (ROI) and gross profit were calculated for traditional sun drying, convective, infrared and freeze-drying methods assuming an annual output of 50 tonnes of dried apricots. It was established that global apricot production reached approximately 4.5 million tonnes in 2024; Turkey, Uzbekistan and Iran remain the leading producers, but in 2025, catastrophic spring frosts in Turkey (particularly in Malatya province) reduced output, causing a sharp rise in global prices for fresh and dried apricots. In Central Asia, Uzbekistan (~526–540 thousand tonnes in 2024), Tajikistan (~313–348 thousand tonnes in 2024–2025), and Kyrgyzstan (~57 thousand tonnes in 2023–2024) demonstrate substantial export potential; Turkey exported dried apricots worth USD 404.5 million in 2024, yet regional suppliers (especially Uzbekistan and Tajikistan) gain competitive advantages in 2025. ROI calculations showed: sun drying – 7.3 %, convective – 23.4 %, infrared – 28.5 %, freeze-drying – 33.9%; infrared and freeze-drying provide the highest product quality. The findings can be applied by farmers, processors and investors in Central Asia (primarily Kyrgyzstan) to select appropriate drying technologies, reduce post-harvest losses and access premium export markets (EU, USA, Russia).

Keywords: Drying technology, equipment, harvested area, operating costs, return on investment, yield

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Benefits of agroecological agroforestry systems as perceived by family farmers for adding value to products

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A major challenge to overcome in order to maintain and expand the scale of production of agroecological agroforestry systems is the marketing of their products at a fair price that remunerates family farmers who produce healthy food in systems that promote positive socioeconomic and environmental impacts. The project "Design for biodiversity: co-design as a participatory tool for the consolidation of agroforestry systems in the state of São Pauloäims to build, in a participatory manner, using co-design process tools, design solutions to improve the communication of benefits generated by agroecological agroforestry systems and improve the presentation to consumers through a new visual identity of their products. This summary presents one of the stages of this project, which aimed to define these benefits in the perception of family farmers from four organisations in different regions of the state of São Paulo that have implemented, produce, and market products from their agroforestry systems. Three workshops were held in each region to define and prioritise the benefits, with the participation of farmers from the Cooperativa da Agricultura Familiar de Sete Barras – Coopafasb (southern region); From the Rural Producers Cooperative of Ipanema and Region - Coprir and the Association of Agroecological and Biodynamic Producers of Family Farming in the Sorocabana Region - APBio (south-central region) and the Association of Agroforestry Farmers of the Sepé Tiaraju Settlement (northeast region). The definition of benefits was guided by five dimensions: ecological; social; productive; immaterial/ethical and economic. Farmers were invited to record up to three benefits for each dimension on cards, later grouping similar benefits and naming a single benefit. After systematizing the results of the workshops in the three regions, farmers were invited to prioritise benefits, resulting in 17 benefits. Among these, seven benefits were selected for communication to consumers, in the dimensions: ecological - conserving nature; productive: polyculture, knowledge on the plate, produced without pesticides, living soil; and immaterial/ethical: cultivating happiness and beauty. The next step involved developing a protocol with parameters for identifying these benefits being promoted by the agroforestry systems of these and other organisations that wish to add value to their products.

Keywords: Socioeconomic and environmental impacts, value addition

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The cocoasoils core trials: Setup and early growth in 10 large-scale on-station cocoa nutrient response trials

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Cocoa is a key source of income for millions of farmers in West Africa, Latin America and South-East Asia. Dry cocoa bean yields of up to 4 t ha−1 are achievable, but actual yields in major producing regions are often far less due weather, pests and diseases, aging plantations, and poor farm management practices such as insufficient or imbalanced nutrient application. Quantifying the nutrient requirements in perennials such as cocoa is challenging, and requires long-term large-scale experiments. The CocoaSoils programme (www.cocoasoils.org) brought together the major actors from the local to global cocoa supply chain (national and international research institutes, universities, cocoa traders and processors, and fertiliser suppliers) to set up a network of 10 large-scale long-term cocoa nutrient response trials (Core Trials) in six countries (Cameroon, Côte d'Ivoire, Ecuador, Ghana, Indonesia and Nigeria). Here, we present the set-up of the trials and the key findings from the first four years of trial implementation. The Core Trials are NPK response trials with a reduced factorial design and four nutrient rates (0 %, 50 %, 100 %, 150 % of the estimated nutrient requirement). They were planted between 2019 and 2022 using the best available planting material, on suitable sites with slight slopes. Trees and plots were barcoded, to facilitate the collection of data on vegetative growth and yield using ODK. The data are collected in an online database, with the dataset now including >180000 data points. Cocoa trees responded to the application of N from the first year after application onwards by increased vegetative growth (basal area and height), irrespective of the availability of P and K. Vegetative growth increased in response to K

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application in some of the trials, yet not in the majority. We did not observe a response to P in any of the trials. There was an inflection point (at 50 to 100 % N and K rates) after which responses decreased, indicating economic fertiliser rates. We observed a strong negative relationship between elevation and vegetative growth in most trials, even when elevation ranges were small, suggesting strong effects of soil and water on cocoa tree growth.

Keywords: Elevation, integrated soil fertility management, trial design, vegetative growth

Climate-resilient cacao: The role of innovation channels and long-term research, insights from a Bolivian case

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This research aims to understand the role of long-term research as an innovation channel to enhance the adoption of tested agroforestry management practices among smallholder cacao farmers in Bolivia and to learn which elements farmers identify as enablers or obstacles to mirror the management practices.

In 2008, a unique long-term experiment (LTE), a cocoa field trial, was established in Alto Beni, Bolivia, within the SysCom project. It is the result of a cooperation between a cacao farmers' cooperative, national and international research and academic partners. At the trial, cacao agroforestry has shown potential for sustainable production in terms of biodiversity enhancement and improved farmers' livelihood, food security and diversified incomes. Besides, these systems have proven to have better environmental performance and competitive yields than cocoa monocultures, with no external inputs. This study adopts a transdisciplinary approach, combining scientific knowledge and local expertise, with a strong emphasis on stakeholder participation and the co-creation of tailored solutions. As part of the methodology, participatory workshops, focus groups discussions and feedback loops with cooperative members of 16 cooperatives randomly selected in each zone of Alto Beni, staff of the LTE, members of a local university research station and technical assistants of the cooperative, took place between October 2024 and December 2025. The scope was to document their perspectives, experiences, and ideas on the role of available innovation channels related to cacao farming considering socioeconomic characteristic of the farmers such as the location of the farm, cacao yield, time as a cooperative member, etc. Participants identified obstacles such as the lack of criteria for selecting suitable forest species, high labour costs, and challenges in accessing technical services (e.g., shade tree pruning) to implement agroforestry. Opportunities were pointed out, including the simplification of agroforestry systems to reduce farmers' workload, the use of beneficial fruit trees to improve productivity and resilience, and strengthening local capacities via innovation channels such as technical training and visits to demonstration plots and real farms, which successfully practice agroforestry. The role of the LTE was also discussed and recommendations by farmers about knowledge gaps it could address are highlighted.

Keywords: Cacao agroforestry, knowledge co-creation, participatory research

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Agroecological agroforestry system designed for more efficient use of irrigation water by family farmers

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One of the main difficulties faced by family farmers, especially those settled through agrarian reform, is the low availability of water for food production. Crop diversification and intercropping are traditional practices in family farming, and agroforestry systems have become one of the most promising productive strategies to improve food sovereignty and security and generate income for this category of farmers, while simultaneously preserving biodiversity and natural resources. This study aimed to design an agroecological agroforestry system to reduce waste and optimise the management of irrigation water use by family farmers. This design was conceived by the agroecology team of Embrapa Meio Ambiente and the Non-Governmental Organisation Mutirão Agroflorestal in conjunction with family farmers from the Sepé Tiraju Agrarian Reform Settlement (Serrana and Serra Azul, São Paulo state, Brazil) within the scope of the Public Policy of the Sustainable Rural Development Program, implemented by the São Paulo State Secretariat for the Environment. Thirty-five agroforestry systems were implemented in the Sepé Tiaraju Settlement, totaling 25.4 ha, in 2014. The design differs from the most widespread and adopted ones by featuring rows of trees for economic production, including fruit trees and some timber trees, interspersed with rows of native trees from various ecological groups for biomass production, with a spacing of 5 m between rows and 4 m between trees within the row. Adopting this design, in which only the rows of economically productive trees are irrigated because the native trees are better adapted and resistant to low soil moisture conditions, reduced water consumption by 50 % and irrigation material costs by 37.6 %. Another advantage of this design is the optimisation of labour use in the sequential pruning of native trees along the same line, aiming to generate biomass for distribution as ground cover in the economically important production lines. This helps conserve soil moisture, reduces labour in controlling spontaneous species, reduces soil erosion, provides nutrients for economically important species, and ensures less dependence of family farmers on external inputs, promoting greater self-sufficiency of the system, as advocated by the principles of agroecology.

Keywords: Agroecology, agroforestry, arrangement, water economy

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Growth, yield and water use of vegetable cowpea (*Vigna unguiculata*) grown in bucket lysimeters for crop coefficient determination

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As rainfall patterns become unpredictable and water resources increasingly become strained due to climate change, efficient irrigation scheduling becomes critical to maximise yields while conserving scarce water resources. This requires precise knowledge of overall water consumption by the crop which is often obtained through weighing lysimeters. However, standard lysimeters are expensive, therefore not readily available for use. This creates need to develop low-cost lysimeters to make them available at an affordable price and thus contribute to improvement of management of water resources. A simplified lysimeter was therefore made using two buckets. One bucket full of soil with perforations at the bottom to allow water to drain was inserted inside a slightly larger bucket. Excess drainage from inner bucket was collected inside the larger outer bucket. Lysimeters were installed flush with the soil surface and surrounded with rows of plants to allow normal crop growth. Plants in lysimeters and surrounding were allowed to grow optimally. A comparison between plants growing within the lysimeter and those outside was done to determine the effect of the lysimeter on cowpea plant growth. Growth was determined in terms of plant height, number of leaves and number of branches which were used to calculate relative growth rate parameters. Fresh weight and dry weights were estimated. The amount of water used was determined from water balances. All growth parameters did not differ significantly between lysimeter plants and non-lysimeter plants. While relative change in height was 3.623 for lysimeter plants, it was 3.6156 for non-lysimeter plants. Relative change in number of branches was 0.907 for both lysimeter and non-lysimeter plants. Relative change in number of leaves was 7.148 for lysimeter plants, 9.75 for non-lysimeter plants. The Fresh weights were 50g for lysimeter plants and 60g for non-lysimeter plants while dry weight was 6g for lysimeter and 8g for non-lysimeter. The amount of water added to the lysimeter was 3.032 kg, resulting in a water use efficiency of 1.98 g/l water. The results show that bucket lysimeter has no effect on plant growth and therefore may be used providing an easy set up for estimating water use.

Keywords: Climate change, crop water requirements, irrigation, water resources management

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Shade effects on okra and eggplant growth and productivity in fruit-tree agroforestry systems, Kenya

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Smallholder vegetable production in coastal Kenya faces growing climate pressure from elevated temperatures and high evapotranspiration, threatening crop productivity and food security. Fruit tree–based agroforestry systems offer a promising pathway toward multi-functional agro-ecosystems buffering climatic stresses through shade-induced microclimate regulation while diversifying farm output. Yet crop-specific responses to shade remain poorly understood, limiting evidence-based design of climate-resilient agroforestry arrangements. This study evaluated growth and yield of okra (*Abelmoschus esculentus* L.) and eggplant (*Solanum melongena* L.) under four shade levels (full light, partial, intermediate, and full shade) in mango (*Mangifera indica* L.)- and baobab (*Adansonia digitata* L.)-based systems in Kilifi County, Kenya. A factorial randomised complete block design was implemented across three sites with three replications. Plant height (PH), total fruit number (TF), and summed-up fruit weight (FW) were recorded from eight plants at crop maturity and analysed using ANOVA with Tukey HSD tests. Shade significantly affected all parameters ($p \leq 0.05$), with responses varying by crop and tree system. In the mango-based system, okra PH was greater under full light than shaded conditions (46 vs. ~32 cm; $p = 0.002$), while TF and FW were higher under full light and partial shade than full shade (3.5–3.6 vs. 1.3–1.8 and 55–60 vs. 10–24 g, respectively; $p < 0.001$). Eggplant yielded higher TF and FW under full light than shaded treatments (4.2 vs. 1.1–2.2 and 145 vs. 24–64 g, respectively; $p < 0.001$). Under baobab, okra showed highest FW under partial and lowest under full shade (90 vs. 38 g; $p < 0.001$). Eggplant remained shade-sensitive with higher TF and FW under full light than shaded conditions (8.1 vs. 1.9–3.5 and 506 vs. 128–167 g, respectively; $p < 0.001$). These findings confirm that tree–crop interactions in agroforestry systems are crop- and system-specific. Eggplant requires full light for optimal productivity, while okra benefits from partial shade under baobab. Strategic matching of vegetables and fruit trees based on crops' shade tolerance can enhance agro-ecosystem functionality and sustainability, support smallholder livelihoods, and may strengthen climate resilience of horticultural farms in Kilifi County and beyond.

Keywords: Agro-ecosystem, climate resilience, horticulture, shade tolerance, vegetables

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A global coffee drought index monitor

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Global coffee production is increasingly threatened by climate change, with drought emerging as one of the most critical hazards affecting yield stability and supply reliability. Drought impacts are often telecoupled, with climate anomalies in key producing regions affecting prices and thereby distant livelihoods and food security. Improved insights into the spatial and temporal prevalence of drought in coffee-growing regions are therefore essential for both agronomic management and financial risk mitigation. We developed a globally consistent, near-real-time monitoring framework to quantify drought characteristics across major coffee-producing areas using the Standardized Precipitation-Evapotranspiration Index (SPEI). SPEI has been identified to be more appropriate for climate impact research because it captures both precipitation and temperature variability, and decreased cloud cover. First, we spatially disaggregated FAOstat national production statistics by combining subnational harvested area statistics with probabilistic agroecological suitability masks and land cover constraints to approximate the global distribution of coffee cultivation. Second, we computed SPEI at 3-, 6-, and 12-month timescales for the baseline (1981–2020), aligned with region-specific phenological calendars based on the timing of the rainy season. Climate inputs were derived from near-real-time reanalysis data provided by Copernicus Climate Data Store (ERA5), enabling continuous updates of drought conditions. Third, we defined a Global Coffee Drought Index (GCDI) as the area-weighted sum of drought intensity (SPEI < -1) across all coffee-growing regions. The resulting system produces a monthly updated global drought indicator that quantifies the proportion of coffee area currently affected by water deficits. This monitoring approach provides actionable information for stakeholders, including producers, traders, and policymakers, by identifying emerging drought risks and supporting timely interventions such as adaptive management, financial planning, and targeted support measures.

Keywords: Climate change, climate services, coffee, drought

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Macaúba: Multi-criteria spatial assessment of alternative oil crop production systems in Brazil

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The macaúba palm (*Acrocomia aculeata*) is increasingly recognised as a promising alternative oil crop in Brazil due to its ecological adaptability, high oil yields, and potential to generate co-products such as proteins and fibers. Unlike conventional tropical oil crops like African oil palm, macaúba can be established on degraded pasturelands in Brazil's Cerrado biome, offering opportunities for ecological restoration and rural development while reducing deforestation pressure on tropical forests. The cultivation of macaúba is currently in implementation phase in Brazil. This study applies an integrated multi-criteria decision analysis (MCDA) framework to three municipalities in the State of Minas Gerais, each hosting distinct macaúba cultivation and value chain initiatives. Spatial datasets were selected and organised into three MCDA pillars: (i) Biophysical-environmental feasibility combines a macaúba suitability map with pasture degradation layer, after masking protected areas to ensure legal compliance while avoiding conflicts with biodiversity conservation priorities; (ii) Techno-economic viability is represented by an infrastructure proximity index based on distances to warehouses, urban centers, and highways; (iii) Socio-institutional desirability is captured through a community rural density index as proxy for rural labour and social presence. Land-use and land-cover data are used to distinguish pasture and crop systems and assess where macaúba can be integrated via silvopastoral, agroforestry, or plantation configurations. From these layers, a composite implementability index and a production system typology map were developed, classifying map cells as plantation, community silvopastoral, commercial silvopastoral, or agroforestry with coffee, soybean, or other annual crops. Results indicate that the municipality of João Pinheiro offers large contiguous areas suitable for plantation-oriented models, the region of Montes Claros supports a hybrid pattern combining plantations and community silvopastoral systems, and the territory of Patos de Minas presents a diversified mosaic where agroforestry and community silvopastoral typologies align with existing land-use and rural settlement patterns. The study shows that macaúba expansion and value chain development in Brazil should be guided by typology-aware spatial analysis rather than climate suitability or investment opportunity alone. The three municipalities offer transferable templates for matching production models to territorial conditions and for designing regionally differentiated, socially inclusive, and environmentally robust macaúba value chains in Brazil.

Keywords: Agroforestry, degraded pastures, diversification, GIS, innovative decision support approach, MCDA, novel perennial oil crop, silvopastoral systems

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Baseline complexity shapes multifunctional trade-offs in Latin American tropical crops

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Biodiversity loss and agricultural production are frequently cast as competing demands, yet the conditions under which trade-offs are severe, moderate, or avoidable remain poorly quantified at scale. This meta-analysis examines 1,940 pairwise management comparisons drawn from 88 studies across coffee, cacao, and banana systems in Latin America, three crops that differ systematically in their baseline system complexity and thus constitute a natural experiment for testing whether starting conditions shape trade-off severity.

We propose the Baseline Intensity Hypothesis: the degree to which diversifying management generates a biodiversity-yield trade-off depends on how intensified or simplified the reference system already is. Crops with complex baselines (coffee and cacao in multi-strata agroforests) show limited room for gain; crops with simplified baselines (banana in monocultures) retain recovery potential. Consistent with this hypothesis, trade-off outcomes differ markedly by crop: 82 % of coffee comparisons and 75 % of cacao comparisons fall in the biodiversity-gain/yield-loss quadrant, while banana comparisons split more evenly (50 % trade-off, 50 % win-win). Abundance benefits span multiple taxa – arthropods (+41 %), vertebrates (+44 %), and plants (+64 %) – but management pathway matters: input reduction most favours arthropods, while shade management most benefits non-crop vegetation.

Applying a yield-threshold framework (<15 % loss as the safe-transition criterion), seven transitions qualify as safe pathways, including three win-wins: cacao monoculture to low-complexity agroforestry (+52 % biodiversity, +21 % yield), banana conventional to lower inputs (+54 %, +11 %), and banana monoculture to cover crops (+526 %, +1.5 %). Total carbon storage emerges as a universal win-win: all nine measured transitions record carbon gains of 41–305 %. Economic outcomes remain a persistent challenge: income reductions are recorded across all five measured transitions (3–37 % decline), requiring financial support mechanisms to be viable at farm level.

These findings provide a quantitative basis for crop-differentiated management recommendations. The Baseline Intensity Hypothesis suggests that conservation policy and agroecological transition strategies should not apply uniform guidance across crop types but instead account for where a given system sits on the intensification gradient, a distinction with direct consequences for resource allocation, subsidy design, and voluntary certification schemes across Latin American agricultural landscapes.

Keywords: Biodiversity-productivity frontier, meta-analysis

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Drought tolerance of dominant tree species in mixed deciduous forests of Myanmar

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Mixed deciduous forests are the most dominant forest type in Myanmar, with 38.2 % of the total national forested area, representing a substantial proportion of the global teak forest distribution. Despite their importance in providing forest products and ecological services, Myanmar has consistently been listed among the top 10 countries for global annual net forest loss due to agricultural expansion and excessive logging. This has led to frequent occurrences of droughts, forest fires and carbon emissions, finally accelerating climate change. Additionally, climate change projections indicate mean temperatures will increase by 1–4°C by the end of the 21st century, which is also expected to intensify drought stress. Consequently, restoring these mixed deciduous forests is critically important. At this point, the selection of drought-adapted tree species is crucial for the effective restoration of mixed deciduous forests, as well as supporting the broader ecological goals. Therefore, the study aimed to assess the drought tolerance of dominant tree species in mixed deciduous forests to identify site-matching tree species for forest restoration. Vegetation surveys were carried out in 1-hectare (25 plots of 20m × 20 m) in each type of mixed deciduous forests: moist upper mixed deciduous forest, dry upper mixed deciduous forest and lower mixed deciduous forest. Diameter at breast height, total height and species were recorded. Also, sapwood samples of 20 dominant tree species were collected from each forest type. To assess drought tolerance and water use efficiency of dominant tree species, osmotic potential, stable carbon and nitrogen isotope ratios (δ^{13}C and δ^{15}N) of sapwood samples were analysed across species using the freezing point depression (cryoscopy) method and mass spectrometry. The results showed that *Gmelina arborea*, *Millettia pendula, Terminalia tomentosa, Terminalia chebula* and *Adina cordifolia* exhibited relatively high drought tolerance and water use efficiency. These species can be proposed as potential drought tolerant tree species for forest restoration activities in mixed deciduous forests of Myanmar, contributing to broader ecological restoration goals at both regional and global levels.

Keywords: Mixed deciduous forests, osmotic potential, restoration, δ^{13}C, δ^{15}C

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From monoculture to regeneration:evaluating regenerative oil palm systems in Côte d'Ivoire

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Oil palm production is a key livelihood for smallholders in Côte d'Ivoire, but conventional monoculture systems are increasingly associated with declining soil fertility, reduced biodiversity and vulnerability to climatic variability. Regenerative practices, based on increased plant diversity, soil cover and organic matter recycling, are proposed as more sustainable alternatives, yet field-based evidence from West African smallholder systems remains limited. This study evaluates regenerative and monoculture oil palm systems in an experimental plot in Aboisso, Côte d'Ivoire.

A total of 56 young palms were monitored using a balanced experimental design across three observation waves under contrasting climatic conditions, from drought to high rainfall. Agronomic, environmental and sanitary indicators were assessed, including palm growth, biodiversity, soil conditions and plant health.

The regenerative system showed consistently stronger agronomic performance, with higher palm growth and more active leaf development. Biodiversity indicators were clearly higher, with greater plant species richness, vegetation cover and soil macrofauna presence. Soil conditions also differed, as the regenerative system maintained higher litter cover and lower soil temperatures, suggesting improved soil protection and microclimatic buffering, as well as enhanced biological activity, including greater earthworm presence.

Sanitary observations indicated that both systems remained exposed to pest, disease and nutrient-related constraints, highlighting that regenerative practices do not eliminate stress factors but modify system dynamics.

Overall, the regenerative system demonstrated improved agronomic performance, enhanced biodiversity and more favourable soil conditions, along with greater stability under variable climatic conditions. These findings provide field-based evidence supporting the potential of regenerative practices to improve the sustainability and resilience of smallholder oil palm systems in Côte d'Ivoire.

Keywords: Monoculture, regenerative practices, sustainable alternatives

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Blockchain-enabled sustainability certification in coffee: Assessing opportunities and risks via expert consensus

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Small coffee producer organisations, cooperatives, and traders in the Global South face compounding pressures: volatile prices, persistent power asymmetries, and tightening regulatory demands such as the EU Deforestation Regulation (EUDR). Sustainability certification has long been promoted as a pathway to more equitable market participation, yet existing certification systems are frequently criticised for high costs, limited transparency, and inadequate benefit distribution to producers.

Blockchain-enabled sustainability certification (BESC) is increasingly being discussed as a means to address these structural deficiencies by enhancing traceability, reducing fraud risks, and strengthening accountability across agri-food value chains. However, empirical evidence on its practical value and, critically, on its implications for equity and smallholder inclusion, remains limited.

This Delphi study investigates the feasibility, stakeholder acceptance, economic, and social implications of blockchain for sustainability certification in the coffee value chain. A two-round qualitative Delphi study was conducted in 2025 with 12 experts representing exporters, roasters, certification bodies, technology providers, and sustainability researchers. Data were analysed by qualitative content analysis and quantitative measures.

Results indicate strong expert consensus that blockchain can enhance traceability, data integrity, and regulatory compliance, including under frameworks such as the EUDR. However, experts expressed limited confidence that blockchain will substantially reduce certification costs or replace third-party certification systems, viewing it instead as complementary within hybrid models.

Over the past decade, there have been several BC projects and Pilots in the coffee sector, but still, the empirical evidence is minimal. Insights from this study provide a deeper understanding of how blockchain can be successfully implemented in coffee sustainability certification. It further addresses challenges related to the proliferation of existing power imbalances and governance requirements.

The findings have direct implications for policymakers, development practitioners, and technology designers working on digital innovation in tropical agricultural value chains, and contribute to ongoing debates on how governance and institutional conditions shape whether digital tools serve as tools of empowerment or exclusion.

Keywords: Blockchain adoption, coffee value chain, sustainability certification, technology for sustainability

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EUDR and Ghana's cocoa value chain: Its implication for smallholder farmer livelihoods and cocoa production

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Deforestation driven by agricultural expansion remains a critical global challenge, with cocoa cultivation in West Africa identified as a major contributor. The research investigates how the European Union Deforestation Regulation (EUDR) may affect cocoa production and smallholder farmers in Ghana, a leading cocoa exporter. The study aims to assess stakeholders' knowledge of the EUDR, its potential implications for smallholders, and the strategies being implemented to ensure compliance. The research is academically significant as it situates the EUDR within debates on the Brussels Effect, global supply chain governance, and sustainability transitions, while practically addressing Ghana's readiness for deforestation-free trade. A qualitative case study design was adopted, combining in-depth interviews and focus group discussions with key actors across the cocoa value chain including government agencies, licensed buying companies, farmer cooperatives, CSOs and individual farmers. Data were thematically analysed to identify common patterns and diverging perspectives. Findings show that while regulatory bodies and buying companies demonstrate high awareness of the EUDR, most smallholder farmers have limited knowledge of its requirements and implications. The study finds that although Ghana's National Cocoa Traceability System (NCTS) and other readiness efforts have been accelerated by the EUDR, the regulation does not amount to a full Brussels Effect but rather reflects negotiated adaptation shaped by local agency. Importantly, the study highlights unintended risks such as potential farmer exclusion, land tenure conflicts, and possible shifts in deforestation pressures. This research contributes to literature by bridging the gap between theoretical discussions of extraterritorial regulation and on-the-ground realities in cocoa-producing regions. It underscores the need for robust local support systems, fair trade practices, and inclusive policy design to protect vulnerable farmers. The findings have practical implications for policymakers, EU regulators, and industry actors seeking to balance global sustainability goals with local livelihoods and socioeconomic development in Ghana's cocoa sector.

Keywords: Brussels effect, cocoa, deforestation, EUDR

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Utilisation of cocoa pod husks for the generation of renewable energy in Ghana

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This study sought to assess whether, at a 70 % recoverable rate for waste cocoa pod husks (CPHs), rural communities in Ghana can be provided with electricity using this waste as a feedstock for a small-scale gasifier system. The energy potential of CPHs in the Edwenase community was therefore measured. A total of 12 samples were collected, comprising four predominant species, each represented by three samples. The sample batches were characterised through ultimate and proximate analysis. An assembly of licensed buying companies and local farmers was also held to collect data on annual cocoa production and other socioeconomic factors that may influence the production, availability, and management of cocoa.

Using a social class system and an energy consumption model, the electrical power requirements for Edwenase at a household level were estimated. The study showed that the CPH possesses a high heating value of 18.28 MJ kg^{-1}, which is comparable to that of widely used feedstocks, such as wood, bagasse, rice husk, and straw. With fewer heritage farmers, the total electricity that can be generated per year is 80,772 kWh, with an average contribution of 198.12 kWh per participating farmer. The low levels of nitrogen and sulfur observed, together with the high heating value, suggest that CPHs are eco-friendly feedstock that can be used to power rural communities in Ghana, which can help bridge the poverty gap between urban and rural areas.

Categorized as low-income users, CPHs produced in Edwenase have three times the potential to supply the community with electricity annually, as they only require 24,300 kWh at the household level. It is a green approach that will be effective in managing and controlling the waste residue problem in Edwenase.

Keywords: Biochemical process, biopower, valorisation, waste management

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The cocoasoils core trials: Early yields and pod counts

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Cocoa is a key source of income for millions of farmers in West Africa, Latin America and South-East Asia. Dry cocoa bean yields of up to 4 t ha−1 are achievable, but actual yields in major producing regions are often far less due weather, pests and diseases, aging plantations, and poor farm management practices such as insufficient or imbalanced nutrient application. Quantifying the nutrient requirements in perennials such as cocoa is challenging, and requires long-term large-scale experiments. The CocoaSoils programme (www.cocoasoils.org) brought together the major actors from the local to global cocoa supply chain (national and international research institutes, universities, cocoa traders and processors, and fertiliser suppliers) to set up a network of 10 large-scale long-term cocoa nutrient response trials (Core Trials) in six countries (Cameroon, Côte d'Ivoire, Ecuador, Ghana, Indonesia and Nigeria). Here, we present cocoa bean yield data from the first five years after trial establishment. Results of the first five years following trial establishment indicate that nitrogen is the most consistent driver of yield. However, once 50 % of the modelled nitrogen off-take was reached, yields tended to plateau or decline, suggesting diminishing returns at higher nitrogen rates. Responses to potassium and phosphorus were site-specific. Phosphorus-limited sites showed linear yield responses to increasing phosphorus rates, whereas high potassium rates negatively affected yields in sites responsive to potassium. The timing of nutrient application also influenced yield responses: potassium predominantly affected early harvests (years 1 to 3), while phosphorus effects were more pronounced in later harvests (years 3 to 5). During the first

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four years after establishment, site characteristics exerted a stronger influence on dry bean yield than N, P, or K application. These site effects were associated with early vegetative vigour, which emerged as a strong predictor of subsequent reproductive development. In conclusion, we observed strong but plateauing yield responses to N and site-specific responses to P and K. Early growth traits appear as useful indicators of future productivity. With the available data, we can generate site-specific fertiliser recommendations for P and K application, and general recommendations for N application in the first five years after cocoa establishment.

Keywords: Cocoa

Unveiling drivers of cocoa agroforestry adoption intensity and ecological and socio-economic outcomes in West Africa

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To address climate change, biodiversity loss and social inequities in rural areas, transitions toward sustainable agricultural practices are urgently needed. In the West African cocoa sector, efforts to promote cocoa agroforestry, the integration of trees on farms, often assume that the factors motivating farmers to adopt agroforestry are the same as those shaping the extent to which they integrate shade trees into their farms. However, policy debates rarely interrogate these distinctions or the ecological and socio-economic trade-offs that arise once farmers move beyond initial adoption. Drawing on 305 household-level data from smallholder cocoa producers and 122 biomass plot surveys, this study investigates whether the drivers of agroforestry adoption are similar to the drivers of agroforestry adoption intensity and subsequently assesses how the socio-economic and ecological outcomes are affected by these adoption decisions within existing complex agroforestry systems in South-east Côte d'Ivoire. The findings reveal that distinct processes drive adoption and adoption intensity. Labour availability and perceived agroforestry knowledge encourage farmers to adopt agroforestry practices in the first place. However, the degree to which farmers subsequently increase shade levels is shaped primarily by the household head's education and perceived environmental benefits. These results underscore that initial uptake does not necessarily translate into deeper engagement with agroforestry, and that different capabilities, knowledges, and expectations influence farmers' decisions across adoption stages. The analysis also demonstrates that adoption intensity produces both synergies and trade-offs. High shade cover can reduce cocoa revenues, revealing the economic constraints farmers face when pursuing ecologically beneficial outcomes. However, higher adoption intensity simultaneously yields substantial carbon and biodiversity benefits, showing that cocoa agroforestry holds considerable potential for broader environmental governance agendas. Despite these ecological gains, the contribution of shade-tree product sales to household incomes remains marginal, pointing to underdeveloped markets and the suboptimal configuration of existing agroforestry systems for income diversification. Taken together, the results highlight the need for policies that move beyond recommendations limited to shade cover and instead support diversification of shade species, development of high-value tree markets, and integration of smallholders into emerging climate and biodiversity market schemes, such as carbon markets and payment for ecosystem services.

Keywords: Adoption, agroforestry, cocoa, Cote d'Ivoire, intensity, trade-offs

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Determinants of cacao agroforestry practices adoption in Colombia and implications for technical assistance programs

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Understanding the factors associated with the adoption of agroforestry practices is key to adequately designing programmes that promote such practices among smallholder farmers, to increase the likelihood of success of such programs. This study examines the determinants of adoption of agroforestry management practices in Cesar and Caquetá – two of Colombia's most rapidly expanding cacao-producing departments. We use data of 3,091 farmers collected in late 2024 and estimate multivariate probit models for five practices of interest: organic fertilisation, chemical fertilisation, cover crop use, cacao pruning, and cacao sanitary control. This multivariate approach explicitly accounts for the interdependence of adoption decisions, a methodological strength that allows for the detection of complementarities and substitution effects across practices. Results reveal that adoption decisions are jointly determined by household socioeconomic characteristics, resource endowments, institutional access, and farm-level biophysical conditions. Statistically significant cross-equation correlations confirm that chemical fertilisation, pruning, and sanitary control tend to be adopted as a cluster of input-intensive practices, driven primarily by access to credit, liquidity, and agricultural extension services. Conversely, organic fertilisation and cover crop use exhibit a substitution dynamic with chemical inputs, being more prevalent among resource-constrained farmers with limited financial access – suggesting these practices serve partially as low-cost alternatives rather than purely agronomic choices. Farm-level characteristics further affect adoption probabilities, as the presence of clonal cacao materials is positively associated with adoption across nearly all practices, likely reflecting the higher management requirements and yield potential of improved genetic materials. Additionally, the type of shade tree integration significantly increases the likelihood of doing some of the practices, highlighting the role of agroforestry system composition in shaping management decisions. These findings carry direct implications for extension design and practitioners. First, interventions that promote individual practices in isolation risk achieving low levels of adoption if they fail to account for labour and liquidity constraints, practice complementarities, and the heterogeneity of farming systems. Second, addressing some of the limiting factors may require coordination with other programs, for example, financial assistance to ease liquidity constraints. The results highlight the need for differentiated, systems-oriented extension approaches to achieve higher adoption rates.

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Mature, diverse shade tree communities are needed to reap broad biodiversity benefits in cocoa agroforestry systems

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Efforts to improve the sustainability of cocoa production seek to maximise benefits to farmer livelihoods and minimise impacts on biodiversity. We surveyed 168 cocoa farms in four West and Central African countries, and assessed the diversity of shade tree community composition, structure, and functioning. We then modelled the relationship between shade trees communities and ecosystem services, including cocoa yield, and identified the most important traits of trees and shade tree communities from the perspective of cocoa farmers. We found that tree-level traits can be used to predict benefits and disbenefits as perceived by farmers. Taller trees were considered more useful for construction, and fruiting trees for food. Traits such as evergreen leaf habit were linked to trade-offs between food provision and competition with cocoa. Farms with more trees, and larger trees, were more likely to provide provisioning ecosystem services like timber for construction or sale, as well as cultural services like recreation. Farms with more fruiting trees were most useful in providing food both for farmers and for the market. When shade tree diversity was low, maximum yields were predicted at low shade tree density, in line with current recommendations of 20 trees ha^{-1}. When shade tree communities were more diverse, maximum yields could be achieved at higher tree densities of up to 100 trees ha^{-1}, though yields were lower overall. Typical agroforestry recommendations such as 30–40 % shade cover can be achieved in a variety of ways, using tree communities that promote different values to famers. But this standard alone does not always accommodate benefits to yield and ecosystem service provision. Within these boundaries, compositional, structural, and functional traits of shade communities could be optimised to maximise yield and a number of ecosystem services simultaneously. However, most yield and highly-valued ecosystem service benefits are dependent on large, mature trees, which can take longer than the productive lifespan of cocoa trees to grow. Guidance should move beyond shade cover alone to accommodate farmer preferences and the role of structure and function in supporting ecosystem services, including a steady supply of the most important types of trees to ensure sustainable production.

Keywords: Ecosystem services, farmer preferences, shade tree biodiversity

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Spatial nutrient dynamics in Ecuadorian cacao agroforestry

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Agroforestry systems represent a sustainable alternative to conventional land-use systems, particularly in tropical regions affected by deforestation, soil degradation, and nutrient losses. This study investigated the spatial variability of nutrient dynamics in an Ecuadorian cacao agroforestry system established on volcanic ash-derived Andosol. The study focused on two shade-tree species, *Cedrelinga cateniformis* and *Erythrina amazonica* – and their influence on soil carbon, nitrogen, phosphorus, and alkaline nutrient pools. A standardised transect-based sampling design was applied to capture spatial gradients between cacao trees (*Theobroma cacao*) and the respective shade-tree species. Soil samples were collected at two depths, 0–20 cm and 20–40 cm, and analysed for carbon and nitrogen stocks, C/N ratios, phosphorus fractions, Mehlich-3 extractable nutrients, total concentrations of K, Mg, and Ca, and soil pH. Statistical analyses were performed using linear mixed-effects models and principal component analyses. The results showed only weak and inconsistent spatial differentiation of carbon and nitrogen stocks. This was likely caused by the high background nutrient levels due to strong organo- mineral stabilisation typical of Andosols, which may have masked species-specific effects. In contrast, phosphorus dynamics displayed more pronounced spatial patterns. Local increases in labile and moderately labile P fractions were observed particularly near *E. amazonica* and, to a lesser extent, near cacao. Alkaline nutrients, especially K, Mg, and Ca, also showed partially elevated total or extractable concentrations near E. amazonica and cacao. *C. cateniformis*, however, showed no clear measurable effects on the investigated soil parameters. Overall, the study demonstrates that transect-based sampling designs are suitable for detecting fine-scale biotic influences in tropical agroforestry systems. The findings also highlight the dominant role of Andosol properties in shaping nutrient dynamics. Nevertheless, *E. amazonica* appears to have potential to enhance local phosphorus and nutrient cycling, providing valuable insights for shade-tree selection and nutrient management in cacao agroforestry systems.

Keywords: Shade-tree species

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Spatial mapping of associated trees in cocoa agroforestry systems using remote sensing: Evidence from Côte d'Ivoire

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Côte d'Ivoire cultivates cocoa either as monoculture or in association with forest trees within cocoa agroforestry. Cocoa agroforestry offers important advantages in terms of long-term sustainability, biodiversity conservation and climate resilience. Furthermore, the adoption of the EU Deforestation Regulation (EUDR), which restricts the import of products linked to deforestation into the EU market, may enable farmers to negotiate premium prices for sustainability produced cocoa. The aim of the study was to propose a Earth Observation (EO)-based approach for mapping associated trees in cocoa plantations. This work contributes to improving the economic situation of local farmers while supporting sustainable cocoa production in Côte d'Ivoire. The study area was conducted in the Gueyo region in southern Côte d'Ivoire, characterised by a Guineo-Congolian climate. Sentinel-1 and Sentinel-2 data (10 m spatial resolution) together with high resolution NICFI Planet imagery (4.7 m spatial resolution). Reference data consisted of field polygons from farmers in the study area. The classification workflow was implemented in two stages. First, a binary cocoa/non-cocoa map was generated using Sentinel data. Vegetation indices and texture metrics were derived and used to train a Random Forest classifier (RF). The resulting cocoa map was then used as a mask for the Planet imagery. In the second stage, sampling points representing tree/non-tree areas were collected with the cocoa boundaries, and a tree/non-tree classification was performed using RF. Tree cover percentage was estimated and adjusted for each farmer's plot. The proposed approach achieved an Overall Accuracy (OA) of 0.87 for cocoa mapping, while the associated tree classification reached an OA of 0.91. Tree cover percentages were reported successfully for each farmer plot, and a spatially explicit tree cover density map of cocoa agroforestry systems was produced for the study area. The study demonstrates the potential of combining Sentinel and high resolution Planet imagery to generate 10 m resolution products capable of identifying cocoa agroforestry systems. Such information can support farmers, research institutions, and local authorities by improving the monitoring and spatial characterisation of sustainable cocoa production landscapes.

Keywords: Agroforestry, cocoa mapping, Côte d'Ivoire, planet, Sentinel, tree cover density

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Inclusive governance and smallholder readiness for new regulatory requirements in Côte d'Ivoire's cocoa value chains

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Côte d'Ivoire, the world's leading cocoa producer and heavily dependent on this sector for its national economy, has long followed a model of extensive agricultural expansion. This trend has led to massive land conversion and a loss of over 90 % of forest cover since the 1960s. Against an international backdrop marked by tightening policies to combat deforestation, the European Union, responsible for around 16 % of imported deforestation, adopted the European Union Deforestation Regulation (EUDR) in 2023, banning imports of products linked to deforestation and requiring full traceability to the plot level. For Côte d'Ivoire, with 60 % of its cocoa exports destined for the EU, these regulatory changes are reshaping market access conditions. At the same time, Côte d'Ivoire has adopted the African Regional Standard (ARS-1000), reflecting domestic and regional efforts to regulate sustainability practices through agroforestry, traceability, and improved farm management.

While these regulations aim to promote sustainable land use, they also introduce significant costs and institutional requirements, raising critical questions about smallholder inclusion. This study analyses how these governance frameworks are transforming the cocoa sector and reshaping farmers' access to markets. Using a mixed-methods approach based on surveys with 235 farmers and 34 qualitative interviews, the study compares cooperative and non-cooperative producers regarding their readiness for new regulatory requirements.

The findings highlight the central role of cooperatives as key governance intermediaries. They facilitate compliance by providing access to information, training, and traceability systems, effectively integrating farmers into regulated value chains. In contrast, non-cooperative farmers face significant barriers to compliance, including limited access to information and institutional support, placing them at risk of exclusion from formal markets. More broadly, the study identifies a gap between regulatory ambition and local implementation capacity, driven by structural constraints such as limited financial resources, land tenure insecurity, and competing livelihood priorities.

These findings underline the need for more inclusive governance mechanisms and policy innovations that balance environmental objectives with livelihood realities. Ensuring equitable access to compliance support, while integrating non-member farmers, and aligning incentives across the value chain are critical to achieving sustainability and social inclusion.

Keywords: Cocoa value chains, smallholder farmers, sustainability governance

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The role of certifications in enhancing cocoa exports from Trinidad and Tobago to Switzerland

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Cocoa production in Trinidad and Tobago is internationally recognised for its fine-flavour quality and cultural significance; however, it remains marginal in global supply due to structural constraints and limited scale. Despite strong reputational advantages, smallholder producers face persistent barriers to accessing premium markets, including weak export coordination, high transaction costs, and limited institutional support. At the same time, demand for certified and traceable cocoa is increasing in Switzerland, a key hub for high-value chocolate production, positioning sustainability standards as potential instruments for market integration.

This study examines the role of certification schemes, Fairtrade, Organic, and Rainforest Alliance, in shaping market access, price formation, and value chain coordination. A mixed-methods design combines survey data from 21 cocoa farmers with 18 semi-structured interviews with exporters and institutional stakeholders in Trinidad and Tobago, and 4 interviews with Swiss market actors, complemented by desk-based analysis.

The findings reveal a substantial gap between awareness and adoption: while most farmers are familiar with certification, only 2 out of 21 farmers (9.5 %) are currently certified. Certification facilitates access to niche markets and improves traceability; however, economic benefits remain limited and uneven. The most significant constraints are financial costs, administrative requirements, and uncertainty regarding returns. Exporters and institutional actors confirm that certification functions primarily as a market entry condition rather than a driver of price premiums, with quality consistency, traceability, and supply reliability identified as more decisive factors by Swiss buyers.

The results indicate that certification alone is insufficient to enhance export competitiveness. Effective market integration requires complementary institutional support, improved coordination, and targeted measures to reduce financial and administrative burdens.

Keywords: Certification, cocoa, exports, Fairtrade, market access, smallholders, sustainability

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Yield and yield response monitoring in on-farm trials: Implications for cocoa yield improvement

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Smallholder farmers in West Africa produce more than 60 % of the world's cocoa (*Theobroma cacao*), yet average yields remain low at about 500 kg ha^{-1} year^{-1}. Reliable yield measurements are essential to assess productivity trends, evaluate management interventions, and understand climate impacts. However, measuring cocoa yields in farmers' fields is challenging because cocoa produces pods year-round, requiring repeated harvests to capture total annual production. Consequently, collecting full-year harvest data through direct harvest is usually feasible only in small-scale studies, limiting its application in large-scale and long-term research. At the same time, farmers' reported data remains unreliable, highlighting a fundamental trade-off between accuracy and feasibility. Despite these well-documented challenges, no standardised, scalable approach currently exists to derive comparable annual yield estimates from the irregular harvest data that dominate large on-farm networks. In this study, we developed a statistical methodology to derive standardised annual yield estimates from irregular on-farm harvest data. The approach was applied to harvest data collected over five years (2020–2025) from a large on-farm trial network established under the CocoaSoils programme in Cameroon, Côte d'Ivoire, Ghana, and Nigeria. Harvest observations, which were recorded at irregular intervals due to logistical constraints, were analysed using a linear mixed model that accounted for temporal dynamics within seasons and spatial variation among trials. The model was used to generate harvest predictions at equally spaced time points within the main and light seasons, which were subsequently aggregated to estimate annual yields. Uncertainty in yield estimates was quantified using a simulation-based approach in which the model was repeatedly refitted to simulated datasets to derive confidence intervals. Our analyses showed that most variation in harvested quantity is driven by treatment and country effects, while harvest dynamics variables (i.e. number of harvest rounds and harvest intervals) contribute significantly but with relatively small effect sizes. Our study demonstrates that cocoa yields can be estimated from incomplete and irregular on-farm harvest data using robust statistical methods, while remaining transparent about their limitations. Finally, our modelling approach can be applied to assess yield differences under alternative management scenarios, potentially offering a practical tool for decision-making in the cocoa system.

Keywords: Cocoa yield estimation, irregular harvest data, on-farm trial network, smallholder farms, standardised yields

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Assessing land use and land cover (LULC) dynamics and future change in a cocoa landscape (Côte d'Ivoire)

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A better understanding of the land use and land cover (LULC) dynamics of the cocoa landscape in Côte d'Ivoire is essential for meeting sustainability initiatives, such as European regulations aimed at zero deforestation. This study assesses the land-use dynamics of the cocoa landscape in Aboisso, Abengourou, and Divo (Côte d'Ivoire) for the years 2002, 2015, 2024, 2035, and 2050. Satellite Landsat images are used to classify 9 LULC dynamics for the years 2002, 2015, and 2024 using the Random Forest classifier. The LULC predictions of 2035 and 2050 were simulated using the Markov chain and Multi-Layer-Perceptron neural network in Land Change Modeler. Classification accuracy for 2002, 2015, and 2024 was 89.6 %, 90 %, and 93.6 % for Abengourou, 90 %, 87 %, and 86.8 % for Aboisso, and 89.6 %, 90 %, and 75.15 % for Divo, respectively. The results show spatial agreement between the classified maps and those produced by the model, demonstrating the model's ability to accurately replicate dynamic land use processes with 74.38 % in Abengourou, 75.25 % in Aboisso, and 87.51 % in Divo. In Abengourou and Divo, 19 % of the cocoa full sun area has been converted to agroforestry, and 10 % in Aboisso from the transition matrix of 2002 to 2024. According to predictions, an increase in agroforestry cocoa will be observed in Abengourou, Aboisso, and Divo, as well as an increase in the area of full-sun in Divo. In Abengourou, an increased area of rubber trees will be observed, while the palm area will increase in Aboisso and Divo. Nevertheless, factors such as the expansion of the more economically advantageous industrial crops, agronomic factors linked to the ageing of cocoa orchards, poor soils, and social limitations are influencing the decline in cocoa acreage.

Keywords: Cocoa, Côte d'Ivoire, deforestation, land change modeler, Markov chain, TerrSet

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Effects of harvesting methods and frequency on biomass production and growth of *Afzelia africana*

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In tropical regions, the dependence of livestock systems on fodder trees during the dry season leads to the scarcity of woody species and threatens the sustainability of these resources. Producing forage biomass in nurseries using woody species offers a sustainable alternative for supplying fodder while preserving mature trees. This study aimed to evaluate the influence of harvesting techniques and frequencies on biomass production, growth, and leaf regeneration of *Afzelia africana* in the nursery. We conducted a nursery experiment at the Baka farm (Faculty of Agronomy, University of Parakou) using a completely randomised factorial design combining two harvesting methods (clear cutting after the first three leaves and on-plant harvesting while sparing the terminal buds) and two cutting frequencies (monthly and bimonthly), with three replicates per treatment. Harvesting technique had no significant effect on total biomass, although on-plant harvesting produced slightly more biomass than clear cutting. Plant height growth was significantly influenced by harvesting technique: on-plant harvesting resulted in a more moderate decline in growth over time, whereas clear cutting caused a more pronounced reduction. No significant effect of harvesting technique was observed on stem diameter growth. Cutting frequency significantly affected leaf regeneration only under the on-plant harvesting method, with bimonthly cutting promoting higher regeneration. The combination of on-plant harvesting and bimonthly cutting frequency optimised leaf regeneration without reducing biomass production or plant growth in *A. africana*. These results provide useful insights for the sustainable management of fodder woody species, helping to reconcile forage production with the conservation of threatened woody species.

Keywords: Harvesting frequency, harvesting technique, leaf regeneration, livestock feeding, tree pruning

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Analysing the economics of agroforestry within land use and land cover change: The case of the Baga-Kisimagonja ecological corridor of Tanzania

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Deforestation poses significant ecological, economic, and social challenges globally.Tanzania, in particular, faces an alarming annual loss of 469,000 ha of forest, primarily driven by unregulated agricultural expansion. The magnitude of deforestation is, however, spatially heterogeneous, arguable to be higher in the productive agro-ecological landscapes such as in ecological corridors. Agroforestry systems and specifically Silvo-arable, offer a promising solution by balancing agricultural productivity with conservation goals. Their adoption, however, remains restrained due to limited awareness on economic viability and perceived risks among farmers. This study assessed the land use land cover changes of Baga Kisimagonja ecological corridor (BKG) in Tanzania between 1992 and 2022. The study further employs a probabilistic cost-benefit analysis (PCBA) to assess the economic viability of traditional agroforestry practices in comparison to conventional crop farming. The findings indicate that over the study period, crop land expanded at an annual rate of about three to six percent while agroforestry grew at a rate of less than three percent. Forest land decreased by an average of two percent per annum. Such land use dynamics is associated to a net carbon loss of 2.3 to 3.5 kt C year^{-1}, valued at approximately 18,771 to 32,681 USD year^{-1}. Additionally, our analysis showed that agroforestry systems are economically viable compared to conventional crop farming and more so when carbon benefits are integrated. We conclude that agroforestry has the potential to mitigate deforestation and enhance long-term land-use resilience if implemented effectively. The findings of this study are important to guide policymakers, farmers, and conservation organisations in making informed investments in agroforestry technologies and practices to restore the degraded ecosystems.

Keywords: Agroforestry, carbon sequestration, conventional farming, deforestation, PCBA

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Sustainable forest management model (Brawijaya smart people & sustainable forest/BSPSF) in Indonesia (case study on mangrove forest)

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Sustainable Forest Management Model (Brawijaya SPSF) in Indonesia (Case Study on Mangrove Forest)was as a form of integration between forest resources, stakeholders involved, and regulations in forest management performance. Brawijaya SPSF is a term for the concept of forestry science found on the Brawijaya Campus, which manages a 544.74 ha forest called UB Forest in Karangploso, Malang Regency and has a Forestry Study Program along with lecturer and student resources. The Brawijaya SPSF model completes a holistic discussion of the performance of forest area managers oriented towards the rules of the game, social, economic, and forest characteristics. The weaknesses of this model require detailed observation and holistic analysis of forest characteristics, actors, and rules of the game as well as the interaction between these three elements in providing management performance.
The advantage of the Brawijaya SPSF concept and theory is that it thoroughly understands the characteristics of forests that provide different performance from the others, compared to previous concepts and theories that view forests as still the same from one forest to another in the ecosystem landscape. The rules of the game and their implementation provide colour in measuring performance between actors and forest resources in their various interactions. The weaknesses of the theory and concept presented require detailed observation and holistic analysis related to the integration of three institutional elements of forest management, namely: forest characteristics, actors, and rules of the game as well as the interaction of these three elements in providing management performance.

Keywords: Actors, forest management, institutions, sustainability

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Why agency matters for tackling food security and rebuilding legitimacy in multi-scale cocoa governance

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Smallholder cocoa farmers produce over 90 % of the world's cocoa, but are in a paradoxical position in global food systems. Across Ghana, the world's second-largest producer and exporter of bulk cocoa, nearly half of cocoa farmers experience moderate to severe food insecurity, while 91 % do not earn a living income. Using a multi-sited ethnography and a tripartite understanding of agency involving voice, choice, and power, I examine this paradox, paying attention to how cocoa governance across global, national, and landscape levels strips farmers of the ability to make meaningful choices over their production systems. I show how state- and corporate-dominated cocoa governance undermines cocoa farmers' agency by extracting higher taxes from them than other workers, while (re)producing asymmetrical dependency relations that demand accountability of farmers without itself being accountable. The erosion of cocoa farmers' agency not only contributes to persistent food insecurity among cocoa farmers but also undermines the legitimacy of multi-level cocoa governance. Cocoa sector actors need to invest in more inward-looking initiatives to strengthen cocoa farmers' ability to influence cocoa farmgate pricing and integrate locally relevant crops in cocoa if they are to break out of the interacting food, liquidity, and risk-dumping lock-ins inherent in the current system. Overall, this paper contributes to reimagining global agro commodities governance not as instruments for extractive growth but as mechanisms for engendering food security, agency, and equity. It also supports the High-Level Panel on Food and Nutrition Security's call to expand the dimensions of food security beyond the availability, access, utilisation, and stability by revealing why agency matters if stakeholders are to make food security a non-negotiable aspiration in the multi-level governance of cocoa landscapes deliberately.

Keywords: Agro-commmodities, food security, food systems governance, forest-farm nexus

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Irrigation, biochar, and fertiliser management shape cadmium accumulation in cacao beans: Long-term agroforestry field study

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Cacao (*Theobroma cacao*) is a globally traded commodity and a key export for small-scale farmers in Latin America. However, many countries struggle to meet European cadmium (Cd) thresholds for chocolate and its derivatives. This makes field-scale mitigation strategies essential. Biochar shows promise for ameliorating Cd and improving soil fertility. Nevertheless, knowledge remains limited on how biochar and fertilisers interact to balance Cd mitigation under field features and their heterogeneity. To address this, a four-year randomised trial was conducted in a cacao agroforestry system in Piura, northern Peru. The trial tested commercial biochar (produced at 650–859 °C from pruning and poultry manure, and composted with trace $FeSO_4$), fertiliser, and their combinations. The site featured clay loam soil (1.2 % organic matter, pH 5.7, 1.7 ± 0.6 mg Cd kg^{-1}) and initial bean Cd of 7.7 ± 2.1 mg kg^{-1}. Multivariate modelling revealed key findings as follows: (1) proximity to irrigation channels consistently increased bean Cd levels, likely due to Cd influx from upper-valley mining and irrigation-driven erosion; (2) presence of *Cedrela odorata* trees and higher local soil pH both moderately reduced bean Cd levels; (3) Biochar application led to a reduction in bean Cd by up to 26 %, primarily by liming and enhanced adsorption, but levels still exceeded the critical threshold for trade ($\geq$1.2 mg kg^{-1}); (4) Fertiliser application increased bean Cd, likely due to soil acidification, competitive sorption, and increased root uptake, and diminished the positive effects of biochar. Overall, field-irrigation conditions and plot heterogeneity exerted a stronger influence on bean Cd content than treatments alone, indicating the necessity for integrated water and soil management. Improved fertilisation regimes and exploration of biochar optimisation, including coated and functionalized variants, are necessary to achieve Cd compliance in cacao beans for international trade.

Keywords: Circular economy, crop modelling, *Theobroma cacao*, watershed

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Resilient cocoa agroforestry innovations under climate disturbance: Comparing Loum, Tombel and transcontinental pilot regions

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This research examines resilience and agroforestry innovation in cocoa-based systems in Loum and Tombel, Littoral Region of Cameroon. The area is highly exposed to climate disturbances, and Cocoa, a strategic crop for the national economy, faces severe impacts including drought, temperature increases, rainfall irregularity and diseases that affect productivity and farm sustainability. The objective of this study is to understand how producers mobilise endogenous practices to strengthen their resilience. This research employs a mixed-method approach integrating quantitative and qualitative surveys. A sample of 83 producers (31 in Loum and 52 in Tombel) was selected through stratified and snowball sampling. Data were collected using structured questionnaires and semi-structured interviews, processed using XLSTAT and SPSS, and analysed through triangulation. The survey revealed that farms contain an average of 36 trees, with a landscape dominated by safou (*Dacryodes edulis*) and avocado trees (*Persea americana*). The main manifestations of climate disturbances identified include plant desiccation (65 %), yield decline (58 %), and increased disease incidence (46 %). Endogenous innovations implemented include the use of foliar fertilisers and phytosanitary products known as "Lavage" (57 %), tree diversification (29 %), varietal replacement, and participatory knowledge management. Constraints encountered by stakeholders are technical, financial, and institutional. In summary, the resilience of cocoa-based agroforestry systems relies on the diversity of tree species introduced into farms, endogenous innovation, and community organisation. To extend the comparative scope of this research, transcontinental pilot regions in Latin America – notably cocoa-producing hubs in Ecuador, Peru, and Colombia – are considered as reference frameworks for assessing analogous agroforestry resilience strategies under similar climatic pressures. These West Africa–Latin America cross-regional comparisons provide a broader empirical basis for assessing the transferability of endogenous innovations and informing global policy frameworks for sustainable cocoa systems.The study recommends strengthening institutional support, promoting regional scaling-up, and integrating digital platforms to enhance the dissemination of sustainable practices.

Keywords: Agroforestry innovation, climate disturbances, cocoa systems, Loum and Tombel, resilience, West Africa-Latin America

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Agroforestry as a nature-based solution for water-scarce drylands: Ecological and economic outcomes from a Melia Dubia-based system in Karnataka, India

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Water scarcity and land degradation pose mounting threats to smallholder farming in dryland regions of South Asia, where conventional irrigation-dependent agriculture is increasingly unviable under climate stress. However, agroforestry can act as a multi-thronged approach to improve soil organic matter, regulate microclimate and on-farm biodiversity along with increasing farm income. The paper supports this through a case study-based approach where a Melia Dubia (Hebbevu)-based agroforestry system established on one hectare [2.5 acres] of dryland in Davanagere district of the state of Karnataka, India, delivered integrated ecological and economic outcomes over a nine-year period. In addition to field-based observations, the study incorporates geospatial satellite-based monitoring to assess changes in tree cover and plantation development over the period 2016–2026, enabling spatially explicit evaluation of vegetation growth, canopy expansion, and landscape-level ecological transformation. The study also includes greenhouse gas estimation to examine the climate mitigation potential of the agroforestry system through above-ground biomass accumulation, carbon sequestration, and avoided land degradation pathways.

After nine years, the plantation yielded approximately 300 tonnes of timber, generating gross returns of 2.0–2.5 million Indian Rupees (approx. €18,000–23,000), translating to an estimated net income of 50,000–60,000 Indian Rupees per acre annually, substantially outperforming conventional dryland cropping systems in the region.

Beyond economic outcomes, the system demonstrates the multi-functional character of tree-based agricultural systems. The case also highlights how strategic species selection, intercropping sequencing, and institutional support can enable resource-poor dryland farmers to adopt nature-based solutions that simultaneously enhance soil health, water-use efficiency, and ecosystem services.

This case study contributes evidence for the scalability of agroforestry as a policy-relevant, low-external-input land-use strategy in water-stressed tropical and subtropical dryland contexts, with implications for livelihood resilience and climate adaptation across similar agro-ecological zones in peninsular India and the broader Global South.

Keywords: Carbon sequestration, climate resilience, geospatial monitoring

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Socioeconomic changes and local communities' attitudes towards forest use in the Zagros, Iran

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The aim of this study was to analyse the consequences of recent socioeconomic changes on the behaviour and attitudes of forest dwellers towards their traditional forest territory in the northern Zagros forests of Iran. We also examined the extent to which local livelihoods depend on forest-related products compared to previous years. Data were collected from 42 households in the Armardeh forests using semi-structured interviews with family heads. Current household income was compared to 2012 values after adjustment to constant prices. Results showed that most respondents were aged 30–40 years and had elementary-level education. Animal husbandry accounted for the largest share of household income (47.8 %), followed by labour work (25.5 %), forest-related products (18.6 %), and agriculture (8.5 %). Among forest products, edible and medicinal plants contributed the most (22.6 %), while tree fodder, forest floor fodder, and forest farming followed. Comparison with 2012 revealed that forest-related income increased significantly, from 6.5 % to 18.6 % of total household income. Despite this rise, respondents perceived that overall forest utilisation had declined. They emphasised continuity in their attitudes toward traditional practices such as Galazani (traditional forest management regulating forest mainly to produce fodder from oak trees), controlled grazing, and forest farming. Cutting was limited to dead trees, and households expressed willingness to participate in government-supported conservation and restoration programs, citing both material and cultural values of the forest landscape. Our findings show that the share of forest-related income in household livelihoods has nearly tripled since 2012, reflecting a growing reliance on forest ecosystem services. While this strengthens rural economies, it also creates a dual challenge: sustaining livelihoods while preventing overexploitation and degradation of the Zagros oak forests. Strengthening community participation in forest management will be critical to balancing economic reliance with long-term sustainability. Social forestry initiatives that regulate forest–people relations can integrate traditional practices with modern conservation strategies, ensuring both livelihood security and ecosystem health.

Keywords: Ecosystem services, forest-related income, livelihood dependency

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From forest conversion to climate-resilient agroecosystems: Impacts of land-use change on ecosystem services and local well-being in the Hyrcanian forest region of Iran

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Forest conversion to agricultural land as a form of forest land use change (FLUC) is one of the main drivers of biodiversity loss, ecosystem service degradation, and changes in human–nature relationships. Although agricultural expansion can provide short-term economic benefits and livelihood opportunities, simplified land-use systems may reduce ecological functions and increase the vulnerability of forest- dependent communities to environmental and socio-economic changes.The purpose of this research was to investigate the effects of forest conversion into agricultural systems on biodiversity ecosystem services (BECS) and human well-being (HWB) in the Hyrcanian Forest region of northern Iran. The research was conducted using a human ecological approach through a mixed-methods design, including semi-structured interviews with forest rangers, local resource users, and government officials, household surveys, and participatory assessments of perceived changes in ecosystem services. The results showed that the conversion of Hyrcanian forests to croplands and orchards was perceived as a major factor contributing to the decline of regulating, supporting, and cultural ecosystem services. Water regulation, soil protection, environmental quality and cultural connections with forests were the most affected elements of these services. The increased provisioning benefits from agricultural conversion were unevenly distributed among households. Communities dependent on forests, particularly those with limited access to land, forest resources and alternative livelihoods, had larger declines in perceived well-being and adaptive capacity. Results also indicated that FLUC effects were not only mediated by ecological changes but also by social inequities, such as unequal resource access and limited participation in land use decision-making. The results of the research confirm the strong links between FLUC, BECS and HWB and emphasise the importance of considering forest conversion as a coupled social-ecological process. Thus, post- logging-ban policies such as Iran's Forest Rest Plan should address not only the restriction of timber extraction but also the issues of livelihood security, equitable access to resources, and community participation in forest governance. An integrated approach of ecological restoration and social justice can lead to improvements in ecosystem recovery and the long-term well-being of forest-dependent communities.

Keywords: Ecosystem services, forest land use change, human ecology, human well-being, Hyrcanian forests, social–ecological systems

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Large ruminant systems and dairy

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Genetic introgression as a conservation challenge in the endangered wild camel (*Camelus ferus*) in Mongolia

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The endangered Wild Camel (*Camelus ferus*; Mongolian: *khavtgai*; Chinese: *ye luo tuo*) is the only surviving wild species of the Camelini tribe. Restricted to remote regions of the Gobi deserts of Mongolia and China, it faces significant threats from climate change, habitat disruption and small population size. The species can hybridise with domestic Bactrian Camels (*Camelus bactrianus*), but the extent and origins of genetic introgression have remained poorly understood.

We analysed DNA from 257 individuals, using predominantly non-invasive samples collected from *in situ* and *ex situ* Wild Camel populations in Mongolia. Nuclear marker genotyping and mitochondrial DNA sequencing were used to investigate the extent and origins of introgression and assess genetic diversity within these populations.

Our results show evidence of nuclear, mitochondrial and historical Bactrian Camel introgression in the *in situ* population, as well as in some individuals within the *ex situ* herd. Nuclear introgression was detected in approximately 10–22 % of the *in situ* population. Combined nuclear and mitochondrial analyses indicated that paternal introgression was the predominant source in both *in situ* and *ex situ* populations. The *in situ* population also exhibited reduced heterozygosity and elevated inbreeding, with similar patterns observed in the *ex situ* herd.

Although hybridisation is commonly viewed as a threat to species conservation, it can contribute positively to population viability. This presents a complex challenge for conservation management, particularly where thresholds for acceptable introgression remain largely arbitrary. A detailed understanding of genetic diversity and the direction and extent of introgression is therefore crucial in evaluating the conservation consequences of hybridisation and informing evidence-based management strategies for threatened species, such as the Wild Camel.

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Mechanisms behind persistent smallholder dominance in the livestock sectors of Tajikistan and Uzbekistan

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Livestock production in Tajikistan and Uzbekistan remains overwhelmingly smallholder-based three decades after independence, with household herds accounting for more than 90 % of cattle in both countries. This paper examines tenure security as a key variable shaping livestock investment and feeding strategies in two countries that share a Soviet institutional baseline, similar agro-ecological constraints, and politically protected cotton and wheat sectors, but pursued different forms of incomplete land reform after 1991. Both face persistent feed bottlenecks, limited formalisation, and constrained herd intensification despite continued policy attention to livestock sector upgrading.

Drawing on household survey data and semi-structured interviews conducted in Sughd, Tashkent, Jizzakh, Sirdaryo and Samarkand provinces between 2022 and 2025, I distinguish formal land tenure from the security producers experience in practice. In Tajikistan, formally heritable use rights coexist with presidential directives that override land-use decisions while in Uzbekistan, long-term lease arrangements remain revocable through administrative discretion and crop placement requirements.

The empirical focus is whether this distinction between formal and effective tenure security predicts livestock-specific outcomes: artificial insemination uptake, fodder cultivation on accessible land, herd dynamics by farm type, and the prevalence of informal arrangements such as sub-leasing and labour-for-feed exchange. Preliminary findings indicate that aggregate convergence in smallholder dominance masks substantive divergence in mechanism: crop mandates concentrate the binding constraint on land for feed in Uzbekistan, while dispersed enforcement gaps produce a comparable constraint profile in Tajikistan through different institutional channels. The paper closes with implications for livestock-relevant tenure reform under conditions where formal codification alone proves insufficient.

Keywords: Institutional constraints, land tenure security, livestock value chains, post-soviet agriculture

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Land reform and agropastoralism in northern Benin: Reconfiguring resource access and mobility

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Benin's land reform, particularly formalisation processes, aims to improve tenure security and incentivise long-term agricultural investment. However, the implementation processes intensify competition over land and disrupt traditional land use systems, often to the disadvantage of communal grazing resources and pastoral mobility. Moreover, recent policy measures, including the national prohibition on transhumance, further complicate mobility and heighten land use conflicts. This study examines the interactions between formalisation processes and local land-use relations in Tchaourou commune. We analyse how these processes shape land use, mobility, and communal resource management among agropastoral communities. This contribution is based on extended ethnographic fieldwork that utilises qualitative methods such as participant observation (including visits to the farm, homes of the study group, and involvement in herding activities), informal interviews, focus group discussions, and engagement with state and non-state actors. By combining narrative and document analysis, we examine how statutory land reforms are experienced, contested, and negotiated in everyday land use practices. The findings show that formalisation processes reconfigure local land use arrangements, shifting access and management from shared and open systems toward fragmented, privatised holdings. These enclosures prompt ongoing renegotiation of access and are associated with declining herd sizes within the commune. Additionally, the loss of open corridors compels herders to move livestock through public roadways and cultivated fields, increasing the risk of crop damage and resource conflict. Despite these, agropastoralists adapt by growing forage, purchasing crop residues, and negotiating mobility. However, the growing importance of cash crops in the region, such as cashew, and new local regulations on rice farming along riverbanks further constrain access to land and water resources. Reflecting on these findings, we discuss how land reform as an institutional innovation produces differentiated outcomes shaped by local contexts and practices.

Keywords: Agropastoral systems, formalisation processes, land reform, land use, northern Benin

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Effectiveness of institutional conflict resolution strategies on farmer-herder disputes: Implication for sustainable livelihoods in Nigeria

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Conflicts between crop farmers and herders are common in nearly every part of Nigeria. This menace poses a formidable challenge to socioeconomic development and a serious threat to food security and the sustainable livelihood of the agrarian communities. While various institutions were involved in conflict resolution, there is a dearth of information empirically on their operational efficacy based on strategies employed. Therefore, this study assessed the effectiveness of conflict resolution strategies employed by institutions in crop farmers- herders dispute in Oyo State, Nigeria.
A multistage sampling technique was used in selecting 107 farmers, while snowball sampling was used to select 53 herders in Oyo State. Data were collected through a validated structured interview schedule and were analysed using descriptive and inferential statistical tools. The findings revealed that the mean age of farmers was 43 years while that of herders was 32 years. The causes of conflicts between farmers and herders include crop damages by herders (89.7 % and 60.4 %,) competition for available land (67.3 % and 62.3 %), sexual harassment (82.2 % and 34.0 %), droughts and climate change (desertification) (87.9 % and 73.6 %), respectively. Amotekun (Western Nigeria Security Network) was the most involved institution in conflict resolution between farmers and herders in the study area. The most effective strategies employed by the institutions include peace-building initiatives that promote social cohesion, payment of fines, police arrest, and reconciliation programmes for promoting forgiveness and reintegration. The result of Pearson Product Moment Correlation (PPMC) revealed that there exist positive and significant relationships between age (r=0.204, $p < 0.05$), years of herding experience (r=0.171, $p < 0.05$) and the effectiveness of various conflict resolution strategies. The observed effectiveness of social cohesion initiatives supports a shift toward restorative justice frameworks rather than purely punitive measures. The study recommends that there is a need for scaling up peace-building initiatives and restorative local programmes to complement formal security measures in safeguarding agrarian livelihoods.

Keywords: Conflict, conflict resolution strategies, effectiveness, farmers-herders, institutions

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Reading the landscape, reading the herd: Local ecological knowledge and livestock mobility in the Himba pastoral system, Namibia

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Pastoralism in arid and semi-arid environments depends on livestock mobility to track highly variable rangeland resources. In northern Kunene, Namibia, Himba pastoralists sustain livestock production through strategic movements across heterogeneous landscapes, yet the factors shaping these movements – and the knowledge systems that guide them – remain poorly understood. This study examines what drives livestock mobility among Himba herders in northern Kunene, and how animal characteristics, landscape conditions, and local ecological knowledge jointly shape herding decisions across seasons. Data were collected through participatory mapping, GPS livestock tracking, and semi-structured interviews. Ten community mapping sessions were conducted using large-scale satellite imagery, and nine cows were fitted with GPS devices between February 2024 and January 2026. Fifteen semi-structured interviews were conducted with Himba herders about their seasonal grazing itineraries, complemented by interviews with the herders of the tracked livestock. The study investigates how herders distinguish grazing units by vegetation type and seasonal suitability, differentiating between wet and dry-season pastures governed by shared access rules. GPS movement data are interpreted alongside herders' accounts of seasonal decision-making to reveal the logic underlying observed mobility patterns. Findings show that herd movement is not purely reactive to forage availability, but structured by a combination of customary access rules, water availability, and animal-terrain interactions – particularly when using the mountainous dry and drought reserves that function as critical refuges. Alongside institutional and environmental factors, herders continuously read animal behaviour and condition to calibrate movement decisions e.g grazing routes, and home return times. Body condition, milk yield, coat appearance, and dung condition all serve as real-time indicators of rangeland quality and herd welfare. The study demonstrates that livestock mobility in the Himba system is best understood as an adaptive, knowledge-intensive practice shaped by the ongoing integration of landscape signals, animal feedback, and community norms. Understanding livestock mobility in this context requires moving beyond spatial pattern analysis to engage with the local ecological knowledge and institutional norms that give those patterns their meaning and resilience.

Keywords: Adaptive decision-making, common-pool resource management, drought reserves, GPS livestock tracking, grazing itineraries, landscape heterogeneity, seasonal grazing systems

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Institutional arrangements and livestock mobility in communal rangelands: Evidence from Kavango East and Omaheke, Namibia

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Namibia's communal rangelands support agropastoral livelihoods, but access to grazing and water is shaped not only by ecological variation, but also by crop calendars, local authority, and water infrastructure. This study examines how decisions over grazing and water access are made in communal lands and how those arrangements shape livestock mobility across two contrasting regional settings in Kavango East and Omaheke. The analysis draws on three complementary methods applied across Muduva Nyangana, George Mukoya, and Eiseb Conservancies participatory mapping (n=25), net-mapping sessions (n=23) and GPS tracking data from 26 tagged cattle net-mapping identified the actors involved in grazing governance and the coordination linkages though which decisions are made. GPS data are analysed using 95 % Minimum Convex Polygon to estimate home-range size, Kernel Density Estimation to identify core use areas, and seasonal movement paths examined in relation to water points, kraals, and mapped grazing areas. The findings reveal a clear contrast between the two regional settings. In the conservancies Muduva Nyangana, George Mukoya in Kavango East, livestock movement is organised through layered decision-making that links herders' daily route choices to traditional leaders, crop farmers, and conservancy actors. During the crop season, cattle are kept out of cultivated fields, traditional authorities coordinate when unsupervised grazing may resume, and and sanctions are applied for violations. After harvest, movement expands as animals access crop residues and wider communal grazing areas. In the Eiseb conservancy in Omaheke, by contrast, grazing decisions are made mainly at household or family level, with considerably less coordination at village level. Movement is more tightly constrained by borehole access water infrastructure conditions, and the need to secure agreement to use camps or temporary grazing posts associated with other families. GPS tracking data add a spatial dimension to this comparison, examining whether these institutional differences are reflected in home-range size, concentration of use around water points and kraals, and seasonal route shifts. The study shows that livestock mobility in communal rangelands cannot be understood from pasture conditions alone, but must be analysed alongside with the rules, permissions, and decision-making structures that govern access to grazing and water.

Keywords: Agropastoralism, communal rangelands, governance, livestock mobility

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Antibiotic stewardship and antimicrobial resistance profiles in livestock farming in South Kivu (DRC)

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Antimicrobial resistance in livestock farming is a major challenge for global health. The excessive and inappropriate use of antibiotics in animal production contributes to the development of resistant bacterial strains in animals, which can be transmitted to humans through the food chain or environmental contamination. Based on the One Health approach, this study aims to evaluate antibiotic use practices in cattle farming and their impact on the emergence of antibiotic-resistant organisms.
A descriptive, cross-sectional study was conducted from April 2024 to January 2025 in three territories of South Kivu province, including the Kalehe, Walungu and Kabare territories. The study consisted of 140 farms, for which samples were taken from cattle (128 rectal swabs and 28 milk samples), soil (78 samples) and farmers (134 throat swabs). In all samples, bacterial species were isolated and sensitivity tests were carried out using the diffusion method on antibiotic discs. A survey was conducted interviewing cattle farmers to evaluate their antibiotic use practices.
Results of laboratory testings revealed that 137 bacterial strains were isolated from rectal swab samples, with Escherichia coli as the most prevalent species. 21 bacterial strains were isolated from milk samples, including 9 species of *Klebsiella pneumoniae*, followed by 4 species of *E. coli*. A high oropharyngeal carriage rate of *K. pneumoniae* was shown in throat swab of farmers followed by *E. coli*. The *E. coli* strains were also the most isolated from soil samples, followed by *Staphylococcus aureus*. It was observed that certains germs isolated from throat swab and soil samples were multidrug-resistant. A proportion of 2.69 % bacterial strains were found to be multidrug-resistant, including one of *Staphylococcus aureus*, *Klebsiella pneumoniae, Enterobacter* spp, *Salmonella* spp, and two strains of *Escherichia coli* and *Proteus mirabilis*. Significant levels of resistance were observed to Piperacillin, Cefuroxime, and Amoxicillin-Clavulanic acid. Regarding antibiotic use, 59.3 % of farmers used antimicrobials and disinfectants for prophylactically.
To limit the emergence of antibiotic-resistant bacteria and the misuse of antibiotics, mass awareness campaigns and rigorous monitoring of antibiotic use must be implemented in livestock farming. Besides, it important to improve rational use of antibiotic

Keywords: Antibiotic use, cattle breeding, drug resistance

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Regenerative rangeland management in practice: Evidence from a commercial cattle farm in central Namibia - A case study

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Namibia's commercial farming sector relies on cattle and sheep production from the vast savannah rangelands. However, many farmers face challenges such as rangeland degradation, climate change, and insufficient profitability. Not only farmer-led initiatives but national policy and the Namibian Agricultural Union have advocated for sustainable and/or regenerative rangeland management. But theses approaches do not prescribe certain practices or standard procedures a farmer can just implement and "be regenerative". Scientific knowledge on how farmers operationalise the approach remains limited. The aim of this case study is to understand how regenerative management is developed and implemented on a 11.000-hectare cattle farm in central Namibia. We conducted in-depth interviews with the farmer couple and practical aspects were demonstrated in farm drives. We present objectives, strategies and practices regarding grazing management and cattle breeding; and we report challenges they experienced while transitioning towards regenerative management over the past decade. The farmers pursue two interrelated objectives and corresponding strategies: (1) improve forage quality and quantity and overall rangeland ecology through targeted animal impact (i.e. grazing, browsing, trampling, manure distribution) and (2) improve reproduction and (meat) production through improved herd genetics that ensure early mature and locally adapted animals.
To create the envisioned animal impact, the previous grazing scheme has been altered towards a new system rooted in Holistic Grazing Planning™. Additionally, it incorporates ultra-high-density grazing using electro fencing. To improve the herd genetics, the farmers are shifting from a Bonsmara-dominated herd towards African native breeds (e.g Nguni) but rather they look for a "type" and therefore observe various phenotypical indicators. They select males accordingly, but heifers are actually "selected by the bull", i.e. through early conception. The system and tradeoffs are managed through (1) functional herd divisions (i.e. certain herds get to graze more selectively to ensure performance or less selectively to ensure animal impact) and (2) targeted interventions at the level of individuals or small groups, guided by continuous monitoring of e.g. dung consistency and vegetation composition. The case shows how farmers tailored regenerative management to their objectives and site-specific conditions and reveals a knowledge-intensive system shaped by continuous observation, experimentation, and adaptive decision-making.

Keywords: Cattle breeding, grazing planning, Namibia, rangeland management, regenerative farming

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Factors affecting the success of community based bull breeding programs: Evidence from the regional pastoral livelihood resilience project in Uganda

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Community-Based Breeding Programs (CBBPs) have emerged as a promising strategy for improving livestock productivity among smallholder farmers in sub-Saharan Africa. However, their effectiveness remains inconsistent, with many programmes failing to achieve sustained outcomes. This study examines the factors influencing the success of CBBPs in Uganda, using evidence from the Regional Pastoral Livelihood Resilience Project (RPLRP). Success is conceptualised through two key indicators: the survival of distributed breeding bulls and their reproductive performance, measured by the ability to sire offspring and the intensity of siring.

The study employs a quantitative approach, utilising primary data collected from 225 bull-hosting households across pastoral and agro-pastoral regions. A double-hurdle econometric model is applied to simultaneously analyse the determinants of both the likelihood and intensity of success outcomes. The results reveal that the drivers of bull survival and reproductive performance are related but largely distinct. Bull survival is positively associated with host-level human capital and institutional factors, including education, literacy, livestock farming experience, prior community consultations, and access to local government technical support. In contrast, reproductive success is primarily influenced by herd structure and management practices, particularly the number of reproductive female cattle, ownership of improved breeds, and the use of controlled grazing systems such as tethering.

The findings further highlight the critical role of animal health interventions, including regular spraying and vaccination, as well as collective financing mechanisms, in enhancing programme sustainability. Conversely, competing livelihood activities, particularly crop farming as a primary occupation, negatively affect programme outcomes. These results underscore the importance of aligning breeding interventions with local production systems and strengthening institutional support frameworks.

The study concludes that the success of CBBPs depends on an integrated approach that combines technical, institutional, and socio-economic considerations. Policy recommendations include strengthening extension services, promoting participatory programme design, enhancing animal health systems, and encouraging management practices that optimise breeding efficiency. These insights provide valuable guidance for scaling sustainable livestock genetic improvement initiatives in similar contexts.

Keywords: Based breeding program, community, factors, success

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Rangeland governance, grazing access and livestock management in semi-arid Namibia: Evidence from Eiseb communal conservancy

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Rangelands are critical for sustaining rural livelihoods in semi-arid Namibia, where pastoralism remains a dominant land-use system. However, colonial, post-colonial, and formal legal influences have reshaped patterns of land use and access, disrupting long-standing relationships with the land, while in some cases, resettlement has reconnected communities to areas of ancestral significance. This has resulted in a complex landscape of both historical ties and fragmented tenure and governance systems. This study examined how changes in rangeland governance particularly through land redistribution post independence, introduction of communal conservancy policies and customary systems have influenced rangeland and livestock management, grazing access, and local communities' perception of these changes. The study was conducted in the Eiseb Communal Conservancy, Omaheke Region of eastern Namibia, using a qualitative case study approach. Data collection was conducted over four months combining document analysis, 4 key informant interviews, and 20 semi-structured narrative interviews with community members, thereby capturing both institutional perspectives and lived experiences. The study found that rangeland governance in the Eiseb Conservancy is supported by a comprehensive policy and legislative framework. However, multiple actors, including government institutions, traditional authorities, and conservancy structures operate with weak coordination, overlapping mandates, and limited enforcement capacity. At the community level, increasing challenges in accessing rangeland resources are driven by a growing human population, expansion of legal and illegal fencing, land grabbing, and informal land allocation. This seems to be intensifying competition among livestock owners and the conservancy structures. These access constraints have reduced livestock mobility, fragmented grazing areas, and undermined traditional flexible grazing and herd management practices. The findings point to a disconnect between policy intent and rangeland reality in the Eiseb Communal Conservancy: frameworks sound in conception are rendered ineffective by weak coordination and enforcement, while communities absorb the consequences through reduced access, constrained mobility, and growing livelihood insecurity.

Keywords: Fencing, institutional challenges, land fragmentation, livestock mobility, local knowledge, tenure insecurity

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Can climate-smart livestock practices increase milk yield of dairy cattle in the Tropics? Evidence from sub-Saharan Africa

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Climate-smart livestock (CSL) practices have the potential to boost milk yield (MY) and mitigate greenhouse gas (GHG) emissions in sub-Saharan Africa (SSA). However, the extent to which various CSL practices increase MY and mitigate GHG emissions in the dairy sector remains unclear. To address this knowledge gap, the present study estimated the effects of CSL practices on MY and on enteric methane (CH_4) emission intensity (EI) of dairy cattle in SSA using meta-analytical methods. Study identification and selection were conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. Seventy-one publications identified through searches in the Web of Science database and the Google Scholar search engine met the inclusion criteria and were used for the analysis. The CSL practices identified and considered for this study using a random-effects model were feeding of i) silage, ii) concentrate feed, iii) hay, iv) forage legumes and v) fodder cereals. CSL practices led to a significant ($p < 0.001$) overall positive effect size on MY of 1.30 (95 % CI: 1.07–1.53; N=77). Use of silage had the biggest effect size (2.64; N= 8), followed by concentrates (1.33; N=44) and fodder cereals (1.21; N=7), while feeding hay (1.11; N= 9) and forage legumes (0.68; N= 9) showed smaller and more variable effects. Substantial heterogeneity was observed, whereby dry matter intake and days of experiment duration were identified as significant moderators in meta-regression. CSL practices reduced enteric CH_4 EI by 41.5 % compared to the usual feeding practices that were based on natural pasture. The mean EI per kilogram of fat and protein-corrected milk (FPCM) was significantly lower under CSL practices (0.91 vs. 1.55 kg CO_2-eq; $p < 0.001$), with variation across practices (0.73–1.30 kg CO_2-eq). The results indicate that CSL practices have a big potential to increase MY and reduce enteric CH_4 EI in SSA, supporting their integration in Nationally Appropriate Mitigation Actions for dairy production systems so as to meet the Nationally Determined Contribution obligations of the Paris Agreement for SSA countries.

Keywords: Climate change mitigation, enteric methane, low emissions dairy, meta-regression, Paris agreement

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Gender, labour, and sustainable technologies in Amazonian dairy systems: Evidence from Colombia

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Gender norms strongly shape labour distribution, access to resources, and decision-making within livestock systems, often resulting in the invisibility and undervaluation of women's contributions. In the Colombian Amazon, these dynamics intersect with the introduction of sustainable livestock technologies, raising important questions about their effects on women's workload and well-being. This study examines gendered labour dynamics and analyses how the adoption of new technologies influences women's work burden and participation in dairy systems. The research was conducted in Puerto Rico, Caquetá (Colombia), within the framework of the Rutas PDET program. A mixed-methods approach was applied, combining ethnographic fieldwork, participant observation, and four gender-focused participatory workshops involving 80 farmers across 25 households. Qualitative data on household labour division, perceptions, and technology use were complemented with quantitative analyses, including Principal Component Analysis (PCA) and Multiple Correspondence Analysis (MCA), to explore associations between gender roles and farm activities. Results reveal a pronounced gendered division of labour, with women performing up to 80 % of daily tasks, including both domestic and livestock-related activities such as milking, feeding, and cleaning. Men are more involved in physically demanding and occasional tasks, as well as in financial decision-making. Despite women's central role in farm operations, their participation in decision-making remains largely indirect. The introduction of sustainable technologies generated mixed outcomes: innovations such as water collection systems and paddock division reduced women's time burdens and physical strain, while others, such as mixed forage banks, increased their workload through additional tasks. Furthermore, women's limited rest time, compounded by domestic responsibilities and male absence, highlights a persistent condition of disproportionate workload. The study concludes that technological innovation alone is insufficient to achieve gender equity in livestock systems. Without addressing underlying gender norms and intra-household power dynamics, new technologies may reproduce or even intensify existing inequalities. A gender-transformative approach is therefore essential, integrating labour considerations, promoting shared responsibilities, and strengthening women's decision-making power to ensure more equitable and sustainable outcomes in rural development.

Keywords: Gender inequality, gender norms, labour division, livestock, sustainability, technology adoption, work burden

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Crop–livestock integration and smallholder livelihood resilience in South Asia

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Smallholder livelihoods in South Asia are increasingly vulnerable to climate change, driven by rising temperatures, erratic rainfall, droughts, and extreme weather events. Integrated crop–livestock systems offer a critical pathway to enhance resilience by diversifying income sources, improving resource-use efficiency, and supporting ecological sustainability. Despite a broader trend toward agricultural specialisation, mixed crop–livestock systems remain widespread, with varying levels of intensification across agro-ecological contexts, resulting in uneven livelihood outcomes. This study examines how crop–livestock integration sustains smallholder livelihoods under changing climatic conditions and evaluates the role of sustainable intensification in strengthening resilience. The analysis draws on a trans-regional survey of 480 households across three sites in two countries: India (Udaipur and Karnal) and Bangladesh (Dinajpur). These sites represent distinct levels of crop–livestock intensification under contrasting agro-ecological and socio-economic conditions. Udaipur represents a low-intensity system, characterised by limited institutional support, poor irrigation, weak market access, and low adoption of improved technologies, with nearly 70 % of land under forest or pasture. Karnal reflects a high-intensity system, supported by robust irrigation infrastructure, strong institutional linkages, efficient market access, and widespread use of modern technologies. Dinajpur represents a medium-intensity system, with moderate access to markets, irrigation, and technologies, alongside high population density. Results show that higher levels of crop–livestock intensification are associated with improved livelihood outcomes, including higher farm incomes, diversified income portfolios, and lower poverty incidence. In high-intensity systems such as Karnal, farmers derive substantial returns from both crop and livestock enterprises. In contrast, in low-intensity systems like Udaipur, nearly 60 % of household income originates from off-farm activities. Livestock plays a crucial buffering role, particularly during crop failure, when households sell animals (e.g., goats) and reinvest in farming, including irrigation improvements. In Dinajpur, crops and livestock contribute nearly equally to household income, reflecting balanced integration. Non-farm income also supports gradual intensification across systems. Overall, the findings highlight the need for context-specific crop–livestock integration pathways that enhance livelihood resilience while maintaining ecological sustainability under climate change.

Keywords: Crop-livestock farms and livelihood, intensification

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Governing the new pastoral commons: Property rights and institutional dynamics in Kenya's transforming rangelands

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Kenyan pastoral rangelands are undergoing profound transformations owing to fragmentation and privatisation, resulting in shifts from communal to individual resource systems. These transformations undermine the structural foundation – like mobility and resource access – that make pastoralism viable systems in challenging environments. In response, pastoralist communities are establishing institutional arrangements through negotiations, overlapping authorities, and bricolage, creating what are termed "new pastoral commons."

Despite their growing prominence, critical research gaps remain in our understanding of new pastoral commons. Existing scholarships lack shared vocabularies and indicators to rigorously analyze, compare, and scale these emerging systems of shared resources. Additionally, we lack a systematic analysis of the institutional performance metrics that frame these commons. Importantly, how governance functions – like boundary definition, rulemaking, monitoring, and sanctioning – are executed, how institutional qualities – like legitimacy and enforcement capacities – shape the execution of governance functions, and the consequences of emerging institutional arrangements. Furthermore, while traditional pastoral commons historically relied on shared values, there is limited research into how new moral community can be established to support the emerging commons.

To bridge these gaps, this study adopts a mixed-methods approach incorporating rapid ethnographic assessments, case studies, household surveys, and experimental economics. This framing explores pastoralist strategies, fine-grained institutional processes, and behavioral responses within two Kenyan pastoral regions facing distinct rangeland transformations. The study identifies two pathways through which new pastoral commons unfold.

"Reasserted commons" arise when communities revive and reinterpret traditional norms and practices that had been weakened or replaced by more formal governance structures. Essentially, they re-establish customary authority and legitimacy within landscapes that had shifted towards privatized,

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enclosed, or externally regulated usage. It serves as a form of contestation against formal arrangements that fail to reflect community interests.
"Reconfigured or bricolage commons" emerge when communities recognize that neither customary nor formal arrangements alone can adequately address the rapidly changing realities of rangelands. Consequently, they assemble hybrid arrangements that blend traditional institutions, state regulations, market mechanisms, and non-governmental interventions.
The study's findings are particularly pertinent to understanding how layered and overlapping rights can be configured to overcome the paradox of pastoral tenure, which has challenged the implementation of Kenya's Community Land Act (CLA).

Keywords: Kenya, new pastoral commons, pastoralism, rangeland transformations

Grazing management on communal land: Information and decision-making in an agro-pastoral system in northern Namibia

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Pastoral and agro-pastoral systems in semi-arid regions are increasingly exposed to climate variability and resource constraints, particularly in mixed crop-livestock landscapes where competing land uses create tensions between grazing and crop production. However, how information systems and decision-making processes shape grazing practices in northern Namibia remains poorly understood.

This study examines how herders and livestock owners in a Miombo woodland agro-pastoral system in northern Namibia use information to guide grazing management decisions. Drawing on an exploratory qualitative case study conducted in Muduva Nyangana conservancy (Kavango East Region), the analysis is based on three months of fieldwork. Data collection combined participant observation, participatory seasonal resource mapping sessions (n=30), semi-structured interviews (n=52), and one focus group discussion on digital communication practices.

Herd mobility in the study area is primarily shaped by information on pasture availability and quality, water access, and seasonal dynamics, making these the most critical information needs influencing rangeland use. Herders draw on a combination of ecological, social, and institutional information to navigate these conditions, with additional key information including crop field status and livestock health, alongside risks of conflict with crop farmers. Although decisions are made at the individual level, they are strongly shaped by the spatial proximity of crops, the associated risk of crop damage and institutional sanctions. Information flows rely primarily on direct observation and face-to-face communication, with public meetings playing a central role in disseminating community-level information. Mobile phone use remains selective and functionally limited to calls and SMS, while smartphones and internet-based applications remain limited due to cost, connectivity, and unequal access.

Beyond current practices, the findings reveal substantial unmet information needs, particularly regarding animal health, disease outbreaks, predator pres-

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ence, livestock theft, and locating lost animals. Existing communication channels are often too slow, spatially limited, or poorly coordinated to support timely responses.
The findings highlight that understanding existing information systems is central to explaining grazing management decisions in agro-pastoral contexts. They further suggest that digital tools may offer opportunities to strengthen information access, but only if aligned with existing practices, socio-institutional contexts, and structural constraints such as unequal access and limited digital literacy.

Keywords: Communal conservancy, crop-livestock integration, herd mobility, Kavango, local knowledge, unmet information needs

Competition or complementarity? Institutional arrangements and interactions in rangeland carbon projects

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This study explored how rangeland carbon projects interact with and transform resource governance in pastoral landscapes. Longstanding debates on pastoralism have shaped interventions aimed at sustainable rangeland management. While some of these interventions support restrictive approaches such as sedenterisation, others recognise the role of mobility and customary governance as adaptive strategies. Recently, rangeland carbon projects have emerged as a tool to strengthen governance and provide financial incentives to improve rangeland management for climate change mitigation. However, the structure of these projects is likely to reinforce existing governance tensions and debates that characterise this ecosystem. Drawing on qualitative data from 19 pastoral communities and other stakeholders, the study analysed the institutional arrangements and actor interactions in the world's largest rangeland carbon project situated in northern Kenya. Findings show that the project operates largely through institutional layering by building on existing community rangeland governance structures rather than replacing them. The project introduces new objectives for collective rangeland management, new actors, and monitoring requirements while maintaining core elements of pastoral governance such as negotiated mobility, reciprocity, and community-based rangeland rule-setting within the project area. This suggests a degree of complementarity. However, our results also indicate that compliance with standard requirements in the project may alter existing reciprocal arrangements between project and non-project communities. These findings highlight that the effectiveness of carbon projects in supporting sustainable rangeland management is not dependent only on financial incentives from the sale of carbon credits or formalised rules but also on the project's continued alignment with the fluidity inherent in pastoral systems.

Keywords: Carbon projects, institutions, pastoralism, rangeland governance

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From readiness to scale: Financing climate-resilient livestock systems in Africa

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Livestock play a critical role in food security, rural livelihoods, and climate resilience across Africa, yet they remain sidelined within global climate agendas. Despite supporting more than one billion people worldwide and offering substantial potential for both climate adaptation and methane mitigation, less than 1 % of global climate finance is directed to the sector. At the same time, growing evidence demonstrates that sustainable intensification, e.g., through improved forages, grazing and manure management, and herd optimisation, can simultaneously reduce emission intensity, increase productivity, and enhance farm incomes and resilience. The key challenge is therefore not only technical, but financial and institutional, raising the question on how livestock interventions can be translated into bankable, scalable, and verifiable investment opportunities. This study develops an investment-readiness framework to mobilise climate finance for livestock transformation in Africa. It synthesizes key financial instruments, including grants and concessional loans, blended finance, voluntary carbon markets, and green or climate bonds, and identifies conditions required for their effective deployment. We propose a four-stage pathway for livestock finance readiness: (1) policy alignment, (2) piloting and cost validation, (3) scaling through robust investment logic, and (4) long-term expansion supported by monitoring, reporting, and verification (MRV) systems and diversified financing mechanisms. Drawing on emerging experiences, such as climate-smart dairy initiatives and livestock-related carbon projects, we illustrate how tailored financing approaches can deliver gains in productivity, mitigation, and resilience simultaneously. Results indicate that grants and concessional finance are essential in early stages to reduce risk and build institutional capacity and markets, while carbon finance can provide performance-based revenues, provided that MRV systems are robust and upfront financing needs are met. Green and climate bonds, in turn, are better suited for larger, aggregated livestock investments with stable and

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predictable cash flows. However, significant barriers persist, including limited project preparation capacity, weak prioritisation of livestock in national climate strategies, underdeveloped MRV systems, high transaction costs, uncertainty, and low smallholder bankability. We conclude that livestock can become a viable and investable pathway toward climate-resilient and multifunctional rural landscapes in Africa – provided that financial mechanisms are sequenced with policy reform, institutional coordination, and credible data systems.

Keywords: Climate-smart agriculture, investment readiness, livestock transformation

Predicting methane emission from dairy farms in southwest Bangladesh: Steps toward supporting data-driven decision model

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Enteric methane (CH_4) from ruminants is a significant contributor to anthropogenic greenhouse gas emissions (GHG). The amount of CH_4 lost through enteric fermentation is strongly impacted by the quantity of ingested feed and composition of the diet. However, limited access to advanced methods to measure CH_4 especially in developing countries, including Bangladesh, necessitates the use of modelling approaches, which require constant validation against biological measurements. Therefore, the objective of this study is to estimate and compare enteric CH_4 emission using a) International Farm Comparison Network (IFCN) partial life cycle assessment (LCA) model, which applies IPCC Tier 1 and Tier 2 methodologies to estimate farm-gate GHG, and b) a laboratory-based approach using in-vitro gas and CH_4 production measurements generated by Hohenheim Gas Test for farm specific diet ingredients. The input data for the IFCN model were collected from nine typical farms selected through a survey of approximately 400 dairy farms from the southwest region of Bangladesh. Feed samples were collected from these farms and analysed at the University of Göttingen. The daily dry matter intake (DMI; 8.6-13.6 kg/cow) and concentrate proportions of the diets (40.8-62.5 % DM) varied across farms. The NDF content of the diets was between 41.9 and 57.1 % DM. Among other factors, this likely contributed to the variability in CH_4 emissions. Annual *in-vitro* CH_4 emissions associated with DMI ranged from 1,705-2,676 kg CO_2-equivalent/cow, with emission intensities between 0.83 to 1.11 kg CO_2 equivalent/kg solid corrected milk (SCM). Model predictions differed in their agreement with *in-vitro* values, with farm level deviations. Emission intensities estimated by IFCN Tier 1 approach ranged from 0.78-1.13 kg CO_2 equivalent/kg SCM, with deviations of -15.90 % to +12.06 %, and an overall mean deviation of -1.20 $\pm$ 8.15 %, while the Tier 2 approach resulted in 0.84 – 1.20 kg CO_2 equivalent/kg SCM, with deviations between -18.2 % and +16.9 % (mean deviation -5.0 ± 10.14 %). Overall, both laboratory and model-based approaches showed similar trends depending on the specific farm conditions, indicating that the IFCN framework can serve as a viable alternative to laboratory-based estimation under certain conditions.

Keywords: IFCN, *in vitro*, LCA, methane emission, milk production

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Smallholder exit under structural change: Long-run evidence from Punjab's dairy sector

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Agrifood supply chains across developing countries are rapidly changing. Rising demand for dairy products and quality standards is associated rapid structural transformation of the sector and the exit of smallholder farmers, raising important questions about the distributional and efficiency implications of this transition. This papers examines the drivers of smallholder exit from milk markets in Punjab, India, over a 15-year period of rapid dairy sector transformation. Leveraging a unique, detailed three-round panel dataset of 762 farming households spanning 2008–2023, we analyse the drivers of exit out of milk sales over time. We estimate the determinants of exit across two sub-periods, 2008–2015 and 2015–2023, using OLS, logistic regression, and instrumental variable (2SLS) approaches. To address the endogeneity of market participation with respect to sales to dominant buyers, including a private multinational and a state cooperative, we employ distance to buyer locations and village-level agricultural wages as instruments.

Our findings reveal marked temporal shifts in the drivers of exit. In the earlier period, initial household endowments – including the number of female adult cattle, availability of male labour, and landholding size – are significant predictors of exit from milk sales. In contrast, in the later period, land size emerges as the sole robust determinant. These results suggest that as the dairy sector undergoes structural transformation, the constraints shaping market participation become more concentrated, with scale increasingly governing smallholder viability. By documenting time-varying exit dynamics using long-run panel data, this study highlights the importance of accounting for structural change in designing policies aimed at sustaining smallholder participation, improving supply chain efficiency, and promoting inclusive rural development.

Keywords: Dairy, India, inequality, structural transformation

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Biomass production and nutritional value of natural rangelands under two management systems in northern Benin

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In Benin, grazing management of communal rangelands is undergoing changes linked to the sedentarisation policy towards livestock keepers. This study, conducted within the DecLaRe project (https://www.uni-kassel.de/forschung/declare/home), aimed to evaluate how two contrasting rangeland management systems (innovative versus traditional) affect herbaceous biomass production and nutritional quality of rangelands in northern Benin. While the innovative management includes soil fertility management, tree-integration, and supplementary livestock feeding practices, supported by local institutions, research, and cooperatives, the traditional management has fewer or no of these elements. From July 2023 to April 2025, 20 actively grazed rangelands were monitored across four villages that represented the two management types. Data were collected every other month and included vegetation height, species richness, the percentage of bare ground, and aboveground biomass. A total of 180 vegetation samples were collected and analysed for dry matter, ash, carbon, nitrogen, phosphorus, calcium, and fiber fractions. Differences in species composition were assessed using PERMANOVA. Differences in aboveground biomass production were evaluated using a linear mixed model, and forage quality was assessed using MANOVA. All analyses were conducted using RStudio version 4.5.1.

Eighty-one herbaceous plant species were recorded, mainly belonging to the families Poaceae (26 %), Fabaceae (20 %), and Cyperaceae (18 %). Species composition differed significantly among management systems ($p = 0.001$). The mean biomass production exhibited clear system-dependent patterns. Across all measurements, the traditional management yielded significantly ($p = 0.004$) more biomass (725 $\pm$492 kg DM ha^{-1}) than the innovative one (606 $\pm$519 kg DM/ha). However, for the proximate components (g kg^{-1} DM), the innovative system yielded significantly higher concentrations of N (12.9 $\pm$2.91; $p < 0.001$), P (1.46 $\pm$0.702; $p < 0.05$), and Ca (9.33 $\pm$3.65; $p > 0.05$) than the traditional system that yielded 11.6 $\pm$2.92, 1.35 $\pm$0.630, and 9.1 $\pm$3.12 respectively for N, P, and Ca. Although forage yield was lower, the higher share of nutrient-rich functional groups suggests that under the innovative system, grazing livestock may ingest more nutrients than under the traditional system. This highlights the importance of species diversity for forage quality.

Keywords: Forage quality, herbaceous biomass, seasonal dynamics

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Mapping the red meat market system to inform pastoral livestock breeding programmes in Kenya

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Pastoral systems in Kenya occupy approximately 80 % of the total landmass, support over 20 % of the human population, and host nearly 75 % of the national ruminant population. These systems contribute over 80 % of domestically consumed beef, yet productivity and profitability remain low due to recurrent droughts, disease burdens, and inadequate feed quality and availability. Although growing market opportunities present significant potential for sectoral transformation, structural inefficiencies, limited infrastructure investment, high transaction costs, and weak actor integration undermine the pastoral red meat sector. This study assessed the inclusivity and performance of the red meat market system in Kenya's arid and semi-arid lands using a market systems development framework conceptualising markets as multi-actor arrangements comprising core exchange functions, supporting services (inputs, infrastructure, and service provision), and enabling environment (standards, regulations, and norms). Through a facilitated multi-stakeholder engagement with 50 representatives across the value chain, including producers, aggregators, traders, processors, consumers, input and service providers, and institutional enablers, a participatory market-system mapping was implemented. System blockages affecting actor groups were identified, and a root cause analysis was implemented to determine underlying systemic constraints in the red meat value chain. Findings revealed a high multiplicity of actors concentrated within the core value chain, with weakly defined linkages that limited effective coordination. The actor mapping presented groups comprising; six actors within the enabling environment, six within the core value chain (condensed from 19 sub-actor categories), and five within the supporting services. Limited capacity of livestock producers emerged as the primary systemic blockage affecting all actor groups. Additional bottlenecks included insufficient capacity to meet demand for inputs, services, and technologies; inadequate financing of market actors; and weak policy frameworks and compliance mechanisms. These bottlenecks create systemic inefficiencies that limit market integration, value addition, and overall sector performance. The importance of a systems-oriented approach to understanding actor interdependencies and strengthening linkages across value chain nodes was evident. Integrating market system insights into the design of livestock breeding and genetic improvement programmes could stimulate changes in pastoralist livestock productivity, reinforcing stakeholder mapping as a foundational step toward sustainable transformation of pastoral red meat systems in Kenya.

Keywords: Livestock, market-systems, pastoralists, value chain mapping

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Agroecology in motion: Driving sustainable transitions in peri-urban cattle farming in Benin

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Cattle farming plays a pivotal role in ensuring food security and sustaining livelihoods in Benin. Yet, its long-term viability is challenged by environmental pressures, economic constraints, and social dynamics, particularly in rapidly expanding peri-urban areas. While agroecological practices are increasingly promoted as pathways to resilience, their actual integration at farm-level remains underexplored, limiting insights into system-wide transformation. This study applies the Food and Agriculture Organisation's Tool for Agroecology Performance Evaluation (TAPE) to assess the degree of agroecological transition among cattle farms in three municipalities in southern Benin (Grand-Popo, Ouidah, and Abomey-Calavi). Using a snowball sampling, 130 cattle farmers were surveyed through semi-structured questionnaire interviews with data analysed via descriptive statistics and multivariate methods. Findings reveal an overall modest agroecological performance (47.6 %) with the Characterisation of Agroecological Transitions (CAET) distinguishing two farm types: (i) non-agroecological farms, (62 %, CAET score of 44.4 %), characterised by limited tree cover (40.7 % without trees), low crop diversification (82.7 %), and minimal recycling of crop residues; and (ii) transitioning farms (38 %, CAET score of 53.2 %), showing stronger tree integration, greater production diversification and reliance on local varieties (55.1 %), and improved nutrient cycling through crop residues (34.7 %) and manure use (55.9 %). Across agroecological dimensions, diversity, synergies, and human and social values scored lowest (<44 %), indicating weak systemic integration. Conversely, higher scores (> 50 %) for culture and food traditions, circular and solidarity economy, and knowledge co-creation and sharing highlight strong cultural and community embeddedness of practices. These results position peri-urban cattle farming in Benin at an early but promising stage of agroecological transition. To accelerate progress, targeted interventions are needed, particularly in crop-livestock diversification, integrated agroforestry, and enhanced nutrient recycling. Strengthening extension services and improving farmers' access to technical and institutional support will be critical to foster resilient peri-urban cattle farming systems.

Keywords: Crop-livestock integration, TAPE, tropical livestock systems

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Land-use conflicts and trade-offs between mining, pastoralism, and crop production in Mongolia: A perspective

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Mongolia's rapid economic growth has been largely driven by the expansion of the mining sector that currently accounts for 25.3 % of the GDP. Yet, mining increasingly overlaps with traditional pastoral systems and, in some regions, emerging crop production areas. This spatial overlap has intensified land-use competition. Despite extensive research on individual sectors, integrated assessments that jointly examine environmental change, livelihood impacts, and land-use trade-offs among miners, herders, crop farmers, and local communities are rare. This study aims to advance knowledge on land-use conflicts in Mongolia using a combined methodology that includes a literature-based SWOT analysis, a NDVI-based assessment of vegetation dynamics (2010–2025), and stakeholder perspectives gathered in the Zaamar Soum gold mining area during September and October 2025. The SWOT results indicate that interactions among mining, pastoralism, and crop production generate both synergies and trade-offs, yet ultimately lead to land-use conflicts. Mining contributes positively to local livelihoods, national income, and infrastructure development. However, it also imposes substantial negative impacts on environment and society, including water depletion, ecosystem degradation, restricted livestock mobility, and health risks for animals and humans, including, for example, noise and dust impacts that have been underexplored so far. Pastoralism supports socio-cultural values, and income generation but

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is increasingly constrained by land degradation and reduced access to grazing areas. In the study region, NDVI data points to 17 % to 45 % lower vegetation production in mined areas compared to non-mined regions over the period 2016–2025. Stakeholder perceptions support these findings, indicating that mining is linked to pronounced environmental degradation, disruption of seasonal migration, and health risks. Regarding the distribution and magnitude of mining-related benefits, uncertainties remain about their effects on employment generation and infrastructure development, which are rarely quantified, particularly for herders. Limited transparency in benefit-sharing mechanisms between the relevant stakeholders, unclear post-mining rehabilitation practices, and insufficient consideration of mine closure costs during licensing are governance gaps that also are rarely explored. Currently, the Trans-Net project (https://www.uni-kassel.de/forschung/trans-net/home.html) is addressing these trade-offs to gather more detailed data and inform reflection on governance options that eventually can support both mining-related economic gains and the long-term viability of pastoral and agricultural livelihoods.

Keywords: Land-use conflicts, mining governance, pastoral livelihoods

A farm-level financial framework for sustainable cattle intensification: Evidence from Colombia's Altillanura

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Sustainable intensification is promoted as a pathway to reconcile productivity growth with environmental sustainability in cattle systems, particularly in frontier regions where low-productivity ranching coexists with land degradation and climate pressures. In Colombia's Altillanura, these challenges are especially acute, yet farm-level evidence on the private economic performance of integrated intensification packages remains scarce. This study presents a pilot economic assessment designed to validate a financial evaluation framework using two case studies in Puerto Gaitán, Meta: Alejandrera and Altamira. Since 2021, both farms have implemented a sustainable intensification package promoted by the NGO GANSO, including improved pastures, silvopastoral components, good cattle practices, water infrastructure, and technical assistance. These interventions aim to increase stocking rates and animal productivity through enhanced forage availability and more efficient resource use. The primary contribution of the study is methodological. A discounted cash flow framework is applied to assess private profitability over the 2022–2031 period, complemented by a Monte Carlo simulation (5,000 iterations) to explicitly incorporate uncertainty. Four standard financial indicators are estimated: Net Present Value (NPV), Internal Rate of Return (IRR), Benefit-Cost ratio, and Payback Period. Uncertainty is introduced through key variables, including stocking rate, daily weight gain, cattle prices, and the opportunity cost of capital. Two financing scenarios are evaluated: a baseline reflecting standard agricultural credit conditions in Colombia, and a preferential scenario incorporating subsidised lending terms. This design enables both estimation of expected returns and assessment of downside risk and key profitability drivers. Results show that the framework produces economically consistent and policy-relevant insights at the farm level. Under baseline financing, NPV reaches US$43,634 (Alejandrera) and US$25,156 (Altamira), with IRRs of 61 % and 41 %, respectively, and benefit-cost ratios above one. Preferential financing substantially improves returns. The probability of negative NPV is zero in Alejandrera and remains low in Altamira, while sensitivity analysis identifies daily weight gain and cattle prices as the main drivers of profitability. Although illustrative rather than generalisable, these findings demonstrate the usefulness of the framework for structuring farm-level evidence, quantifying uncertainty, and informing adoption decisions. Future research should scale this approach and integrate environmental and ecosystem service valuation.

Keywords: Discounted cash flow, financial analysis, livestock economics, Monte Carlo simulation, silvopastoral systems, sustainable intensification

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Interactive effects of soil restoration strategies on nutrient dynamics in the tropical savannah

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Grassland soil degradation poses major environmental challenges, with nutrient depletion and disruption of microbial communities limiting ecosystem recovery. However, restoration often relies on natural regeneration (i.e, passive restoration), which is often insufficient, and thus active intervention is necessary. We established a full-factorial field experiment to test whether soil inoculum, organic amendments (manure), and physical disturbance (tillage) interact to affect soil nitrogen dynamics and microbial properties in a degraded grassland of Kenya.

The three-way treatment interaction increased NH_4^+ ($p < 0.05$), though the soil inoculum alone increased NH_4^+ even more ($p < 0.01$). Combining soil inoculum with manure reduced NH_4^+ ($p < 0.05$) while increasing microbial biomass nitrogen (MBN) ($p < 0.05$). Tillage eliminated both effects, resulting in intermediate NH_4^+ levels, an increase in NO_3 ($p < 0.05$), and a reduction in microbial biomass carbon (MBC) ($p < 0.01$). Manure alone increased MBN, while tillage consistently increased NO_3 and decreased MBC.

These results suggest three nitrogen dynamics pathways: i) mineralisation (inoculum-enhanced organic matter breakdown), ii) immobilisation (manure + inoculum-driven microbial sequestration), and iii) physical override (tillage-induced disruption of biological processes). Since the inoculation effect depended on whether manure was applied, restoration outcomes are context-dependent, so strategies should target specific goals: tillage for immediate nutrient availability, inoculation for enhanced mineralisation, or inoculum + manure for long-term biological soil development.

Keywords: Grassland restoration, nitrogen dynamics, organic amendments, soil microbes

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Impact of village livestock promoter on buffalo milk productivity in Nepal: A cluster randomised controlled trial

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This study evaluates the effectiveness of the village livestock promoter (VLP) extension approach in improving buffalo milk productivity in Nepal's eastern Terai region. We conducted cooperative-level cluster-randomised controlled trial involving 27 cooperatives. All of these had identified VLP candidates, but only 14 randomly selected VLP candidates were offered the training and mentoring treatment during the observation period. VLPs are locally selected youth trained by experts in animal husbandry. They serve as community-based extension agents, providing advisory services, technical support, and facilitating input linkage. Using data from a 2-round panel survey of 1092 farmers and difference-in-differences estimates, we find that farmers in VLP-treated cooperatives experience a statistically significant increase in milk productivity of approximately 12 % relative to the control group. The interaction effects further indicate that the effectiveness of the VLP intervention varies across farms and seasons. We observed a consistent and significant impact of the VLP approach among medium-scale farmers, in terms of herd size, but not among small- or large-scale farmers. Similarly, the interaction with seasonal conditions shows that the treatment effects are larger during the good production season compared to the less favourable season. This implies that VLPs work best with farmers having moderate resource endowments and when agro-climatic conditions are favourable. Our analysis further shows that the observed productivity gains are primarily driven by increased investment in animal health and higher technology adoption scores in households linked to treated VLPs relative to those served by non-treated VLPs. From a policy perspective, we recommend scaling up the VLP approach to provide farmers with efficient support for increased technology uptake and targeted training opportunities. These efforts enhance technology adoption and farmers' investment in animal health, thereby sustaining milk productivity in the buffalo sector.

Keywords: Livestock extension, milk productivity, technology adoption, village livestock promoter

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Information access, seed market systems and forage adoption: Evidence from smallholder dairy farmers in Kenya

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Forage seed markets in developing countries are fragmented and underdeveloped. In Kenya, uptake of new improved forages is constrained by limited seed availability, high seed prices and limited information. The study assesses uncommon connections in research on seed market perceptions (quality, availability, and affordability), information access, and forage uptake, while controlling for socioeconomic, farm, and market access factors. To investigate these relationships, a household survey was conducted among 424 dairy farmers growing Napier grass (informal system), forage maize (formal system) and Oats (semi-formal system) in Nyandarua and Uasin Gishu counties in Kenya, between July and August 2025. Data was analysed using a linear probability model and a multivariate probit regression. The results show that Napier grass adoption was associated with higher quality perceptions of planting material ($p = 0.021$). Forage maize adoption was associated with higher perceptions of availability ($p = 0.000$), affordability ($p = 0.000$), and quality ($p = 0.002$), while oats adoption was associated with availability ($p = 0.000$) and affordability ($p = 0.000$). Higher seed quality perceptions were associated with market information and membership in farmer groups. Interestingly, an increased availability perception was reported by farmers who encountered counterfeit maize seeds, indicating engagement with multiple seed sources. Increased affordability perceptions were associated with access to market information and greater trust in seed sellers. Adoption of the three crops was considerably influenced by access to market information. In addition, participation in forage projects influenced the adoption of Napier grass and oats. The adoption of forage maize was also linked to training, extension services, trust in seed sellers, prior experience with counterfeit seeds and the distance to agrovet shops. In conclusion, forage adoption across crops is closely linked to seed market perceptions, which in turn are associated with access to market information, membership in farmer groups, and trust in seed sellers. The results highlight the need for specific seed system interventions to improve forage adoption and boost milk productivity: quality-declared planting materials in informal seed systems; enhancing seed availability and lowering seed prices in formal and semi-formal systems; and expanding access to market information and extension services.

Keywords: forage seed systems, adoption, dairy farmers, information access, seed market perceptions

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Rangeland management under pressure – strategies for safeguarding livelihoods and savannah ecosystems in Namibia

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Rangeland management in Namibia is under increasing pressure from climate change, economic challenges, policy constraints, and ongoing degradation dynamics. Savannah ecosystems, which have long supported human livelihoods through diverse and interdependent land-use systems, are undergoing significant degradation. This places both ecology and livelihoods at risk. This contribution presents findings from the NamTip project, focusing on a case study in the Waterberg area in Namibia, and examines strategies of freehold farmers to restore ecosystems and maintain livelihoods under changing environmental and socio-economic conditions.

The project adopts a multi-methods approach that integrates social and ecological perspectives, combining conceptual frameworks with empirical data and analytical work. The concepts of social-ecological systems and social-ecological tipping points serves both as the subject of analysis and as an integrative framework linking different disciplinary perspectives.

The findings of this study point to a growing risk of a tipping-point dynamic emerging within the social-ecological rangeland system, particularly in the form of the loss of perennial grasses, the bush encroachment and the resulting decline in carrying capacity. This leads to lower household income and the loss of the socio-economic viability of farming. This development leads to a reduced ability to manage situations of stress caused by droughts or market changes, as well as a reduced capacity for investments. In view of this, farmers are employing a range of coping strategies that reflect the multifunctional nature of savannah ecosystems. Livestock farming is combined with or replaced by wildlife management – often better adapted to climatic fluctuations and having lower risk of environmental degradation – as well as forms of tourism-related activities. Strategies also include bush thinning and woody biomass use, as well as diversifying into off-farm income.

These coping strategies modify key feedback loops to strengthen resilience in rangeland management. By implementing them, farmers aim to interrupt adverse dynamics and prevent downward spirals that would otherwise constrain their decision-making capacity.

The study concludes that effective coping strategies require strong local knowledge and practical experience, supported by adequate infrastructure and robust institutional and policy frameworks to enhance long-term resilience of the rangeland system.

Keywords: Climate change, coping strategies, farming, Namibia, social-ecological systems, sustainability, tipping points

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Climate -resilience dairy in Asia: Implications for economic and environmental sustainability

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The ongoing climate change and economic uncertainty across the globe are considered as tremendous challenges for meeting future demand of consumers for milk and milk products and ensuring food security in Asia. Therefore, the objective of this study was to quantify economic and environmental sustainability for developing a data-driven monitoring system for climate resilient production system in Asia. This study utilises the International Farm Comparison Network (IFCN) Typical Farm Database from 174 farms from 58 countries which were the extracted only for Asia (37 typical farms from 9 Asian Countries) consisting of three from Middle east (Turkey, Iran and Israel; three from South Asia (India, Pakistan, Bangladesh) and three from South east Asia (Indonesia, Japan and China). The sustainability criteria were adopted from Dairy Sustainability Framework (DSF) and IFCN sustainability Metrics. The Cost of milk production only (COMPO) and milk price represent the Economic Sustainability and Carbon Footprint (kg CO_{2e} kg^{-1} Solid Corrected Milk -SCM) represent Environmental sustainability. As regards farm resilience (buffer capacity to withstand and/or bounce back from sudden or acute shock) which includes Liquidity (measure the cash flow higher than cash expenses), Financial Profit Margin (measure the efficiency of the dairy enterprise) and Operating Profit Margin (measure as the ability to cover all opportunity costs) were used for the farm resilient factors. The results revealed that Turkey is economically Sustainable as the COMPO for Turkey is the lowest among all Asian Counties (18.8 USD/100 kg SCM). The highest milk price for Iran (75.43 USD/100 kg SCM) clearly showed highly sustainable while the lowest milk price is observed for Bangladesh (44.46 USD/100 kg SCM). The carbon footprint was found the lowest for Japan (0.91 kg CO_{2e} kg^{-1} SCM) and the highest was found for Bangladesh (2.90 kg CO_{2e} kg^{-1} SCM) which implies that Bangladesh is the least climate resilient compared with other Asian Countries. Considering the farm resilience criteria, all South Asian countries fall under risk to cope with shocks. The results of this study are highly beneficial for dairy farm monitoring system to make the sustainable in the era of extreme climate resilient dairy production in Asia.

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VEFS: focus-aware dual-spectrum vegetation isolation for rangeland monitoring across rangelands

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We present VEFS, a focus-aware framework for isolating the main plant visible in dryland rangeland images. The aim is to extract the individual vegetation speciments which are most clearly in focus from field RGB photographs, even when the scene is visually complex. This remains difficult in rangelands because when plants are often proximally photographed against bright sandy backgrounds, parts of the image may be blurred, and vegetation may include both green, living material and dry components such as stems, litter, and thorns. In such conditions, standard vegetation extraction methods often fail, especially due to spectral overlap and overexposure of sunlight. This lead to the dry plant material looking similar to bare soil.
Our approach combines prompt-based YOLOE instance segmentation with both text and visual guidance and introduces a new scoring system called the Vegetation Ecological Focus Score (VEFS) to identify the main vegetation target in each image. VEFS is defined as VEFS = αC + βS + γT + δD, where C describes how centrally the object appears, S captures whether its shape and structure resemble a shrub, T measures how well green and dry plant parts are grouped together as one coherent object, and D estimates how strongly the object is in focus using image sharpness information. Rather than selecting vegetation only by colour or size, VEFS is designed to choose the plant that is both visually dominant and ecologically meaningful.
The dataset consists of rangeland images collected from Marsabit County, Kenya, and the Kavango region, Namibia, including varied shrub forms, different focus conditions, and diverse dryland backgrounds. Performance will be assessed against largest-object, centre-bias, green-threshold, and default YOLOE baselines using IoU, mIoU, precision, recall, VEFS agreement with expert interpretation, and species-agnostic focus-selection accuracy. We expect VEFS to better preserve dry woody structures, reduce background leakage, and produce more ecologically meaningful masks for applications such as rangeland monitoring, biomass-related assessment, and smart agricultural decision support.

Keywords: Focus-aware segmentation, open-vocabulary AI, photosynthetic and non-photosynthetic heterogeneity, shrub isolation

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From trade-offs to synergies: Sustainable intensification pathways in the global cattle sector

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The global cattle sector plays a central yet paradoxical role in achieving the Sustainable Development Goals (SDGs) of the 2030 Agenda. While it contributes significantly to poverty alleviation, food security, and economic growth, it is also a major driver of deforestation, greenhouse gas emissions, water pollution, and biodiversity loss. We examine these dual dynamics by systematically analysing the synergies and trade-offs between cattle production and selected SDGs through a systems theory lens. A systematic literature review following PRISMA guidelines was conducted, covering peer-reviewed studies, global datasets, and empirical case studies published after 2016. The analysis focused on key SDGs linked to cattle systems and mapped their interrelations using a framework that distinguishes between synergy multipliers, trade-off multipliers, and buffers. In addition, three sustainable intensification (SI) practices, namely wastewater treatment, biogas production from manure, and silvopastoral systems, were assessed for their potential to mitigate trade-offs and enhance synergies. Results show that SDGs 1 (No Poverty), 2 (Zero Hunger), and 8 (Decent Work and Economic Growth) function as primary synergy and trade-off multipliers. While these goals benefit from cattle production through income generation, employment, and food provision, they often exert negative pressures on environmental and health-related goals, particularly SDGs 3 (Good Health and Wellbeing), 6 (Clean Water and Sanitation), 12 (Responsible Consumption and Production), 13 (Climate Action), and 15 (Life on Land). These trade-offs manifest in land-use change, water contamination, and increased emissions, reflecting a pattern of systemic suboptimisation in current production models. The evaluated SI practices demonstrate strong potential to rebalance these interactions. Wastewater treatment improves water quality and public health outcomes; biogas production transforms waste into renewable energy while reducing emissions; and silvopastoral systems enhance carbon sequestration, biodiversity, and farm resilience. However, their adoption remains uneven due to financial, technical, and institutional barriers. We conclude that transitioning toward sustainable cattle systems requires not only technological innovation but also integrated governance, cross-sectoral coordination, and context-specific policy frameworks. By proposing an SDG interaction framework tailored to the cattle sector, we provide actionable insights for policymakers, researchers, and development practitioners seeking to align livestock production with the holistic vision of the 2030 Agenda.

Keywords: Biogas production, SDGs, silvopastoral systems, trade-offs and synergies

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Co-design of agroecological innovations in the dairy value chain based on consumer expectations and the business models of processors and dairy farmers: Case studies in Burkina Faso and Senegal

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In West Africa, meeting growing consumer expectations for dairy product quality and quantity requires prioritising agroecological intensification in dairy value chains to strengthen food sovereignty and promote sustainable production. This transition relies on implementing innovations aligned with agroecological principles at the levels of production, collection, processing, and distribution. For effective and sustainable scaling, we argue that co-designing these innovations should start from consumer expectations and integrate them into operators' business models, rather than focusing solely on production without considering markets. Since 2022, we have been testing this demand-driven approach with stakeholders of the Bobo Dioulasso Dairy Innovation Platform in Burkina Faso and, more recently, with actors in Senegal's Fatick dairy sector. The work combined analysis of consumer expectations, workshops to characterise business models of value chain operators (mainly processors and dairy farmers), and sessions to design agroecological innovations within these models. These activities were complemented by cost-benefit analyses, field trials, and assessments of resulting changes. In Burkina Faso, the consumer study showed strong demand for fresh dairy products made from local milk and flavored with local ingredients. Processors targeting this market incorporated such products into their models, producing yogurts flavored with monkey bread, néré, moringa, and other local ingredients. To ensure year-round supply of quality fresh milk at acceptable cost, dairy farmers adopted agroecological practices such as cultivating high-quality forage, improving feeding systems, and producing organic manure. These practices reduced dependence on costly industrial feed, sustained milk production during the dry season, and maintained soil fertility. Milk production increased by more than 80 % for crossbred cows and over 12 % for zebu. Consumer expectations were better met, and value chain actors benefited overall. For dairy

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farmers and collectors, benefits exceeded costs, while for processors costs remained higher than benefits. This approach is now being introduced in Fatick, Senegal. The consumer and business model-based co-design of agroecological innovations appears transferable to other value chains and agricultural products. Its impact could be strengthened through greater involvement of policy actors responsible for agricultural strategies and sector support measures.

Keywords: Agroecology, Burkina Faso, business models, co-design, consumption, dairy value chain, Senegal

Economic growth and emissions in cattle systems: Evidence from developing regions

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The projected increase in global demand for livestock products presents both an opportunity for economic development and an environmental challenge. From an environmental economics perspective, the Environmental Kuznets Curve (EKC) provides a useful framework to examine the relationship between sectoral growth and environmental impact. The EKC hypothesis posits an inverted U-shaped relationship, whereby environmental degradation initially increases with economic growth, reaches a turning point, and subsequently declines as higher income levels enable cleaner technologies and stronger regulatory frameworks. We estimate the EKC for the cattle sector (meat and milk production) by analysing the relationship between economic growth and greenhouse gas emissions (CO_2-eq) across countries in Latin America, Africa, and Southeast Asia over the period 2000–2020. Using panel data econometric methods applied to 66 countries, the analysis incorporates a comprehensive set of socioeconomic and institutional variables derived from FAO and World Bank databases, including governance quality, energy efficiency, and development flows. The results confirm a strong and statistically significant positive association between cattle sector growth and environmental degradation. While the estimated coefficients support the theoretical inverted U-shaped EKC, the calculated turning point is exceptionally high and remains far beyond current production values. Consequently, none of the countries in the sample has reached the income threshold at which emissions begin to decline. Instead, cattle systems remain in the initial phase of the EKC, characterised by rising emissions alongside increasing production. Further findings highlight the critical role of institutional and structural factors in shaping environmental outcomes. Improvements in governance quality, political stability, and energy efficiency are associated with lower emission intensities and can accelerate progress toward the turning point. In contrast, development flows directed toward agriculture may reinforce emission-intensive production systems, while targeted environmental funding contributes to emission reductions. This suggests that economic growth alone is insufficient to reduce environmental degradation in the cattle sector. A transition toward sustainable intensification, e.g., through practices such as improved forages and silvopastoral systems, is essential to decouple production from emissions. Achieving this transition will require coordinated policy support, including instruments such as Nationally Appropriate Mitigation Actions (NAMAs), to align livestock development with long-term environmental sustainability.

Keywords: Environmental degradation, panel data analysis, sustainable intensification

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Carbon finance potential for climate-smart pastoral livestock systems in Mongolia

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Pastoral livestock systems are central to livelihoods, land stewardship, and ecosystem functioning in Mongolia, but they are increasingly challenged by climate change, rangeland degradation, and rising greenhouse gas emissions. Identifying viable financing mechanisms to support sustainable transitions in therefore critical. This study evaluates the potential of carbon finance to support climate-smart transformation in Mongolia's livestock sector by linking mitigation practices in pastoral systems with voluntary carbon markets, carbon accounting frameworks, and projected economic returns. The analysis integrates three components. First, it reviews Mongolia's evolving carbon market and policy landscape. Second, it maps priority mitigation practices identified in the Mongolia Green Livestock Action Plan (GLAP), including sustainable grassland management, improved feeding strategies, silvopastoral approaches, and herd management, against existing carbon accounting methodologies under leading standards such as Verra, Gold Standard, and Plan Vivo. Third, using GLAP-based business-as-usual and intervention pathways for cattle, goats, and dairy systems over 2025–2040, it estimates mitigation potential and the associated market value of carbon credits. Emissions are compared at the production level achieved under intervention scenarios to isolate productivity effects, while revenue projections vary according to carbon price trajectories and the share of mitigation that can be commercialised. Results indicate that several priority interventions are already compatible with recognised carbon accounting frameworks, providing a strong basis for market integration. Total annual mitigation potential is projected to increase from 5.24 Mt CO_2-eq in 2025 to 13.14 Mt CO_2-eq by 2040. Goats account for the largest share (59.9 %), followed by cattle (39.5 %) and dairy systems (0.6 %). Depending on carbon price trajectories and commercialisation assumptions, annual carbon revenues could range from US$13–210 million by 2040. These findings suggest that voluntary carbon markets could become a meaningful complementary source of finance for climate-resilient pastoral development in Mongolia. However, realising this potential will require strengthened monitoring, reporting, and verification systems, clearer regulatory frameworks, and market designs that account for pastoral mobility, communal land governance, and ecosystem co-benefits. Carbon finance offers a promising pathway to align climate mitigation with sustainable pastoral livelihoods, provided that enabling institutional and technical conditions are in place.

Keywords: Carbon credits, greenhouse gas mitigation, voluntary carbon markets

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Gender transformative approaches in pastoral systems in Africa: Lessons and reflections for equitable resilience

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Pastoral systems across Africa are commonly characterised by mobility, adaptability to climate variability, and communal tenure and resource governance. Navigating uncertainties in the face of compounding shocks and stresses is key to pastoral livelihoods and resilience. Resilience capacities, however, are uneven. Intersecting inequities along gender, generation, marital status, education and other axes shape differential access to and ownership of livestock, resources, services and decision-making agency, deepening vulnerabilities for women, girls and marginalised groups. Gender transformative approaches (GTAs) can play a vital role here by addressing restrictive norms and harmful practices underpinning these inequities. By strengthening community-led efforts toward sustainable social change, GTAs offer pathways to make resilience of pastoral systems more equitable. We examined the status of GTAs in pastoral areas across 13 countries in East and West Africa, using multiple methods including a literature review, 11 key informant interviews and 5 stakeholder workshops. We applied the Reach–Benefit–Empower–Transform (RBET) framework and identified 18 interventions that demonstrate transformative impacts in pastoral contexts. Key findings indicate GTAs are typically layered or embedded within broader programmes on livelihoods, resilience, health, and land and natural resource governance rather than implemented as standalone interventions. Interventions targeting adolescent girls show a socially differentiated approach, accounting for marital status and literacy levels while engaging multiple generations and customary institutions. Transformative impacts are more consistently documented in women's decision-making, reductions in harmful practices, and women's participation and leadership in natural resource management and governance – domains central to pastoral resilience. Key mechanisms driving these outcomes include collective action, community dialogue, and deliberate engagement of men, elders and local champions. To unlock the full potential of GTAs, design must go further in integrating unique characteristics and challenges of pastoral systems related to mobility, conflict and peacebuilding, and polygynous household arrangements. Rigorous, context-sensitive monitoring and evaluation that extend beyond programme life cycles are needed to build evidence on what works, where, for whom, how and under what conditions. We conclude with actionable recommendations for tailoring GTAs to complex pastoral realities. This can help generate critical insights around equitable resilience relevant for diverse contexts in and beyond rangelands.

Keywords: Rangelands, social norms

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Pastoralist commons and contestations: Enclosure of Pokot land as a gendered project of accumulation

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Recent processes of enclosure in the pastoralist region of West Pokot in Kenya are transforming land use and gendered socio-economic relations. Although scholarship on enclosure in pastoralist societies is well established, its gendered implications are often sidelined or oversimplified. This contribution argues that enclosure operates as both a material and a social process, reconfiguring gender identities, deepening women's structural dependency, and producing new arenas for contestation. As part of my MSc, I conducted three months of ethnographic fieldwork in West Pokot, involving participant observation and 65 semi-structured interviews. My analysis examines how enclosure, primitive accumulation, and the confinement of women to the domestic sphere are reproduced through gendered norms, ideals, and performativity and 'the myth of the patriarchal pastoralist'. At the same time, it demonstrates how women are challenging these emerging dynamics by creating new commons. Focusing on the double burden of income generation and care work, as well as the new forms of dependency arising from the enclosure of land, social relations, and women's bodies, I challenge the widespread policy assumption that women's economic empowerment leads to gender equality in a linear way. Economic participation alone is insufficient; for women to be truly emancipated, they must also be free from conjugal dependency. I conclude that emerging practices based on commons, such as autonomous women's savings groups and fundraisers – termed 'money commoning' – tackle enclosure, primitive accumulation, and confinement at their roots, constituting a more promising step towards emancipation. Thus, the study illuminates locally rooted alternatives to dominant rural development paradigms. Specifically, the findings contribute to debates on the politics and governance of rural development by showing how women negotiate, resist and reconfigure interventions that seeks to reshape pastoralist livelihoods.

Keywords: Commoning, commons, enclosure, gender, pastoralism, primitive accumulation

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Livestock forages, feeds and feeding

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Seeds of hope during the 2020-23 drought: Collective fodder production saved livestock in Kajiado, Kenya

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For thousands of years, pastoralists have been adapted to seasonal changes in water and pasture supply by migrating with their livestock. However, this strategy is under threat due to land fragmentation and exacerbated by a higher frequency of extreme weather events, such as droughts. Collective action in fodder production could enhance sufficient production and conservation of forages, addressing these challenges. In October 2025, an observational study using a qualitative case study design was implemented in Kajiado County, Kenya. Five out of 9 fodder-producing pastoralist groups in the county were selected to better understand drivers for group formation, collective action strategies, group governance as well as challenges and opportunities in addressing fodder and forage deficit. Five semi-structured interviews and one key informant interview were conducted, recorded, transcribed, translated and analysed using thematic analysis. Findings show that most of the groups actively started organising themselves in fodder production following the 2020–2023 drought, when – despite the nationwide livestock losses – none of them lost any animals. Fodder is produced for group members' own livestock and the local market; commercialisation is affected by a lack of consistent demand and price-quality mechanisms. Additionally, results indicate that pastoralists pool and share resources (i.e. labour, land, equipment) to grow, harvest and store hay, using traditional pasture preservation areas (Olepololi). Existing institutional arrangements include paid membership and shares; group leadership and enforcement of group rules (i.e. fines and expulsion vs. discounts); strategies for fodder production such as mechanisation; benefits from collective action include risk reduction and economic benefits as well as interactions with national and international stakeholders on improved seeds and management practices. Major constraints identified are access to seeds, capital for mechanisation, storage facilities, as well as capacity on management of pests, and post-harvest losses. Socio-cultural constraints revolve around women's access to land to grow fodder on their own, unpaid time put towards the groups, and concerns about the role of the next generation in the Maasai society. Despite reported challenges, collective action increases the self-efficacy of fodder production and the capacity for crisis management in Maasai communities in Kajiado County.

Keywords: Climate change adaptation, livestock feed conservation, Maasai pastoralists

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Economic-environmental evaluation of silvopastoral systems in Colombia

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Colombia's cattle sector holds considerable socioeconomic importance but also generates significant environmental impacts, particularly due to greenhouse gas (GHG) emissions. However, it can also support climate change mitigation through the adoption of low-emission cattle systems like silvopastoral systems (SPS). Compared to monoculture pastures (M), SPS can maintain cattle productivity while increasing GHG removal and reduction. Nevertheless, high initial investment costs limit SPS adoption, underscoring the need to assess their profitability and promote financial mechanisms that support their implementation. The objective of this contribution was to evaluate the economic-environmental performance of an SPS and compare it with M in cattle fattening systems in Colombia. Experimental plots were established using the grasses Urochloa brizantha cv. Toledo and U. hybrid cv. Talismán alone (M) and in association with the tree *Leucaena diversifolia* (SPS). Plots were grazed by crossbred cattle (Brahman × Simmental × Charolais). A financial analysis compared the profitability of both systems, considering revenues from cattle sales and the economic valuation of carbon sequestration and methane emission reduction. Cattle revenues were estimated from liveweight gain measured at the beginning and end of the trial. Carbon sequestration was determined from carbon stocks in woody biomass and Soil Organic Carbon, which were derived from a vegetation inventory and soil sampling. Methane emission reduction was estimated using emission factors for both diet systems. The market price method was used to value these ecosystem services. Results indicate that the SPS achieved higher animal productivity, reaching higher profitability indicators compared to M, even without considering revenues from Payments for Ecosystem Services (PES). Moreover, SPS achieved an estimated carbon sequestration of 4 tCO_2eq ha^{-1} $year^{-1}$ and methane reduction of 0.5 tCO_2eq ha^{-1} $year^{-1}$, representing a potential additional income of approximately 45 USD ha^{-1} $year^{-1}$. The GHG reductions and removals associated with the SPS not only contribute to climate change mitigation, but also generated additional income through PES. This further improved the SPS's financial indicators, diversified income sources, and reduced economic risk. These findings indicate that SPS are a profitable alternative and that PES can be a key mechanism to promote their adoption and scale up low-emission cattle systems.

Keywords: Carbon markets, low-emissions cattle systems, market price method, methane emission reduction, payment for ecosystem services

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Degradation of gossypol from cottonseed meal for monogastric livestock feeding in West Africa

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Benin is the largest cotton producer in Africa, with cottonseed meal (CSM) as an underutilised agricultural byproduct. CSM has a nutritional value comparable to soybean meal and is therefore a potential alternative protein-rich source for feed formulations, making it an appropriate solution for addressing the competition between feed and food for human consumption. To date, CSM is not a major feed ingredient because it contains gossypol, which severely limits its suitability as a feed for monogastric animals such as poultry and pigs. The purpose of this study is to detoxify CSM using the process of Yinyinkou, which is a local starter used to ferment the seeds of *Parkia biglobosa* into Sonrou, a popular condiment used in North Benin. First, we surveyed and monitored 12 Yinyinkou producers and 35 Yinyinkou users (producers of Sonrou) in Northern Benin to document the process and practices. The subjects surveyed were sampled using the snowball method. Data were collected using digital questionnaires, supplemented by individual interviews and focus groups for triangulation of information. Next, the Yinyinkou process was used to process CSM. Next, 9 female processors were provided with 5 kg CSM for processing according to their own preferred and tested practices. Afterwards, samples were collected for analysis of nutrient content and free gossypol by Mérieux NutriSciences, an accredited, commercial lab in Ede, the Netherlands. Laboratory analyses showed that fermentation and cooking led to an increase in pH as well as a significant reduction in free gossypol. Particularly, cooking proved to be very effective in decreasing free gossypol from CSM. Overall, the Yinyinkou process caused a reduction of more than the targeted 50 % of free gossypol in CSM. It seems that alkaline fermentation alone is less effective, whereas the combination of cooking and fermentation is more efficient. The nutritional composition of the processed CSM was not affected. This detoxification method constitutes an effective and accessible approach for valorising CSM for potential use as a nutritious ingredient for monogastric animal feeding.

Keywords: Benin, cottonseed meal, detoxification, fermentation, gossypol, Yinyinkou

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Olive biochar supplementation in small ruminant feeding: Contrasting methane mitigation and productivity in lactating goats

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Mediterranean agriculture is under increasing strain due to resource scarcity, inefficient waste management, and climate change. Circular economy strategies offer a promising pathway toward sustainable agro-ecosystems by transforming waste streams from one sector into valuable inputs for another. This study investigated the conversion of solid waste from olive mills into biochar enriched with olive phenolic compounds, intended for use as a dietary supplement in small ruminants. The objective was to enhance integration between the economically important olive and small ruminant sectors while mitigating methane emissions from the latter. Two trials were conducted, each involving two groups of lactating goats: a control group receiving a standard diet and a treatment group receiving the same diet supplemented with polyphenol-enriched olive biochar at 2 % of the total mixed ration.
Individual data on milk production and methane emissions were collected over a 5-week period in both trials, while body weight was recorded at the beginning and end of each trial. Additionally, feed intake and milk composition were monitored weekly during the 5-week period in Trial 1. Data were statistically analysed using SPSS, applying the general linear model for repeated measures, with data from the first week used as a covariate. The biochar treatment did not have a significant effect on animal weight, feed intake (Trial 1), milk production, nor milk composition (Trial 1). In contrast, methane emissions, measured using a handheld laser methane detector, were lower in the biochar-supplemented groups in both trials, with a statistically significant reduction observed in Trial 2 ($p < 0.05$). These findings support the safety of biochar supplementation and highlight its potential for methane mitigation in small ruminant feeding systems. However, the overall sustainability of this approach requires further evaluation, particularly with respect to the environmental and economic costs associated with the production and application of olive waste-derived biochar.

Keywords: Circular economy, lactating goat, methane emission, olive waste

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Black-soldier-fly larvae in Kenya: Evaluating waste-based production systems for safe and climate-resilient protein value chains

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The escalating global population and increasing demand for protein have placed immense pressure on conventional food and feed sources. This challenge is exacerbated by environmental concerns associated with traditional livestock farming, including greenhouse gas emissions and land degradation. In this context, insect farming, particularly the rearing of Black Soldier Fly Larvae (BSFL), *Hermetia illucens*, has the potential to convert various organic waste streams into high-quality protein and fat. Despite significant global interest in adoption, substantial knowledge gaps and ongoing challenges exist regarding how different waste streams and manufacturing processes ultimately affect the nutritional content and safety of BSFL products, especially in practical situations in Africa. This study describes and assesses the performance and safety of BSFL reared on two waste streams in Kenya from December 2025 to March 2026. The study adopts an experimental design that integrates production system-level data with laboratory analyses of BSFL and its derived products. For this, the BSFL were produced in two systems, namely local (uncontrolled temperature and humidity, UC) and industrial (controlled temperature and humidity, CC). Parameters assessed were growth performance (gram per day), feed conversion efficiency (FC, %), proximate and amino acid composition, as well as microbiological hazards, mainly Enterobacteriaceae and *Salmonella* spp, which are prominent in local feeds. Preliminary results show that BSFL effectively transforms organic waste into useful biomass. However, marked variability in nutritional composition and safety parameters was observed between the systems. The UC provided 8.2$\pm$0.75 % ash, 13.05$\pm$0.82 % fat and 19.34$\pm$1.48 % moisture content compared to 17.84$\pm$0.26 %, 6.31$\pm$1.39 % and 8.6.3$\pm$0.1 % in the CC, respectively. Similarly, FC varied between the two systems, 3.51 % for UC and 3.06 % for CC. These preliminary findings highlight the need for standardised production systems to ensure consistent productivity, quality and safety in emerging BSFL value chains. Our ongoing analysis will provide further insights into the effect of genetic variation, feed ingredients, and processing methods on the efficiency, quality and safety of the BSFL.

Keywords: Alternative protein, black soldier fly, feed conversion efficiency, food safety, food systems, Kenya

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Effects of circular food resource inclusion in diets on ruminant productivity: A mixed-effects meta-regression analysis

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Considering their availability (132 kg per capita per year) and relevance to the circular bioeconomy prospects, circular food resources (CFRs) - including surplus crops, food processing by-products, and discarded plant-based materials - have strong potential as ruminant feed. However, evidence remains limited regarding the levels at which CFRs can be included without compromising productivity or whether they provide additional benefits. To address this, we synthesized data from two literature-based datasets on average daily gain (ADG) and milk yield. The compiled dataset comprised 735 animals (cattle, sheep, and goats) across 32 dietary treatments incorporating food leftovers, by-products, and unsold vegetables, alongside 33 treatments based on conventional feedstuffs, under diverse management conditions from 20 global studies. Descriptively, energy-corrected milk (ECM) was higher in diets including CFRs (10.1 ± 3.6, mean $\pm$ SD) compared to no inclusion (8.24 ± 3.4). Similarly, ADG expressed per kg body weight was slightly higher under CFR inclusion (6.52 ± 4.14 vs. 5.04 ± 4.33 g kg^{-1} BW day^{-1}). For analytical assessment, CFR inclusion levels were categorised as no (0 %), low (>0–30 %), and high (>30 %). Linear mixed-effects models were applied, with study as a random effect and inclusion level (continuous and categorical) and species as fixed effects. Model results showed that CFR inclusion was positively associated with ECM ($\beta = 0.021$ per %, $p = 0.023$), with no significant species effect. Specifically, low inclusion increased ECM by 1.27 kg TLU^{-1} day^{-1} compared to no inclusion ($\beta = 1.27$, SE = 0.36, t = 3.53, $p = 0.003$), whereas high inclusion showed no additional benefit ($p = 0.437$). In contrast, CFR inclusion did not significantly affect ADG, irrespective of whether it was modeled as a continuous ($p = 0.757$) or categorical variable ($p > 0.63$). Species, however, significantly influenced ADG, with higher values observed in sheep compared to cattle ($\beta \approx 6.1$, $p < 0.02$). Overall, moderate inclusion of CFRs can enhance milk productivity without compromising growth performance, supporting their role in sustainable ruminant feeding systems.

Keywords: Co-products, feed sources, food leftovers, inclusion level, sustainability

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Winter is coming – supplementary feeding of cashmere goats as an adaptive strategy of Mongolian herders

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Winter disasters, named dzud in Mongolian, represent a major threat to Mongolian nomadic livestock production, causing high animal mortality. Its frequency is expected to increase due to climate change and long-term rangeland degradation driven by overgrazing. Herders have developed adaptive strategies over centuries, like supplementary feeding of livestock during winter and collaborative action. However, quantitative evidence on feeding management remains limited. This study examines how Mongolian herders use supplementary feeding as a coping strategy for poor forage availability during winter and how herder cooperatives can provide support during winter feed preparation. Data were collected in autumn 2022 from 21 households in two regions in Mongolia: Galuut Sum (GS), where livestock numbers exceeded rangeland carrying capacity (CC), and Khulunbuir Sum (KS), where CC was not exceeded. The collected data encompassed semi-structured interviews, feed sampling, laboratory nutrient analyses, and focus group discussions in both regions. During the time of the visit, herders in KS had nearly completed preparations (5-point scale from 0–100 %, median: 100 %), while households in GS had only just begun (median: 25 %, $p < 0.01$). Herders in KS prepared more hay per Mongolian Sheep Unit (MSU) (median: 38.4 kg MSU^{-1}) than those in GS (7.4 kg MSU^{-1}, $p < 0.01$), while wheat bran provision did not differ (2.1 kg MSU^{-1} in both regions). Hay quality was generally low, characterised by low crude protein (mean $\pm$ SD, 62 $\pm$ 13 g kg^{-1}) and high aNDF contents (715 $\pm$ 32 g kg^{-1} DM). The focus group discussions showed that herders in GS faced constraints for feed preparation, such as degraded rangelands, limited financial means, weak collaboration among herders, and poor market access. In contrast, herders in KS collaboratively harvested hay before winter and had no exceeding CC. Across both regions, prepared feed quantities were insufficient to sustain livestock throughout the winter, leaving pasture as the primary feed source. However, the study revealed great differences in adaptive capacity for winter hazards between the regions. Strengthening collaborative action among herders, improving access to input markets and aligning livestock numbers with rangeland CC are critical to enhancing resilience against winter disasters, particularly in overgrazed regions.

Keywords: Climate resilience, feed preparation, forage scarcity, pastoralism

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From feed deficits to opportunities: The role of forage seed systems in transforming livestock systems

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Ruminant livestock systems across Sub-Saharan Africa and Southeast Asia face persistent and widening feed deficits that constrain productivity, limit smallholder incomes, and undermine the sustainability of food systems. This study synthesizes evidence from multi-country analyses in Sub-Saharan Africa (Burundi, Ethiopia, Kenya, Malawi, Mali, Mozambique, Nigeria, Rwanda, Senegal, Somalia, South Sudan, Sudan, Tanzania, Uganda, Zambia, Zimbabwe) and Southeast Asia (Cambodia, Laos, Timor-Leste, Thailand, Vietnam) to quantify forage gaps and evaluate the role of improved forages and seed systems in addressing them. Across regions, feed deficits remain substantial. In Eastern Africa alone, nearly 40 % of annual feed demand – equivalent to 136 million tons of dry matter – is unmet, with over 31 million tons potentially addressable through cultivated forages. Comparable deficits are observed in other parts of Sub-Saharan Africa and Southeast Asia, highlighting a systemic constraint to livestock intensification. Bridging these gaps would require large-scale transformation, including 3.2 million hectares of forage cultivation and the engagement of over 2.6 million farmers in Sub-Saharan Africa alone. Scenario analyses suggest that gradual adoption pathways are more realistic than rapid scale-up. Under conservative adoption scenarios, forage seed demand reaches tens of thousands of tons over a decade across regions, with substantial economic opportunities emerging. The forage seed market alone could generate hundreds of millions of USD, while the value of cultivated forages could reach several billion USD, reflecting strong incentives for private sector engagement. Despite this potential, adoption remains limited by systemic constraints, including underdeveloped and import-dependent seed systems, high seed costs, weak distribution networks, limited extension services, and land competition. Informal practices such as vegetative propagation play an important but insufficient role for scaling. Policy frameworks increasingly recognise feed constraints, yet implementation gaps persist, particularly in seed system development and regional harmonisation. The findings highlight that closing the feed gap is not merely a technical challenge but a systems-level issue requiring coordinated action. A systems-oriented approach to forage development offers a transformative pathway to enhance livestock productivity, strengthen climate resilience, and create inclusive opportunities for rural communities to participate in and benefit from a robust, multi-billion-dollar sector across the Global South.

Keywords: Climate resilience, feed gap analysis, forage deficit, seed policy

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Forage innovations for resilient livestock systems in northwest Vietnam

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Livestock production plays a critical role in the mixed farming systems of Vietnam's Northwest Highlands, where smallholder livelihoods depend heavily on cattle, pigs, and buffalo. However, persistent feed shortages, low-quality forage resources, and socio-economic and institutional constraints limit productivity and resilience, particularly among ethnic minority communities. This study synthesizes evidence from two participatory research-for-development initiatives implemented in Mai Son district, Son La province – Li-chăn (2017–2021) and Chăn-henh (2022–2024) – to assess the performance, adoption, and scaling potential of improved forage technologies in upland systems. Using a mixed-evidence synthesis approach, the study integrates quantitative data from forage trials and adoption studies with qualitative insights from gender-sensitive diagnostics, farmer interviews, and stakeholder consultations. Results demonstrate that high-yielding tropical grasses such as Green Elephant, Mombasa, and Mun River significantly improved biomass production and enhanced year-round feed availability, particularly during critical dry-season periods. Participatory on-farm trials confirmed strong farmer preference for these species due to their productivity, adaptability, and palatability. Adoption analysis revealed that 155 households integrated improved forages, with cultivated areas increasing by up to 66 % across farm types. Gender-responsive approaches, including inclusive training and labor-saving feed technologies, enhanced women's participation and reduced workload burdens. Capacity-building initiatives, particularly Training-of-Trainers and farmer-led extension models, proved effective in promoting knowledge diffusion and sustaining adoption. Despite these gains, several barriers continue to constrain broader uptake. Limited access to quality seed, financial resources, and extension services, especially in remote upland communities, restricts equitable adoption. Institutional challenges, including weak seed systems

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and fragmented market linkages, further hinder scaling efforts. The study highlights the importance of integrated, participatory, and gender-sensitive approaches in accelerating forage innovation uptake. Strong co-investment with local institutions and farmer-led dissemination models emerged as critical enablers of sustainable scaling. To achieve long-term impact, coordinated efforts are needed to strengthen seed systems, improve access to finance, institutionalize extension services, and embed forage development within policy frameworks. These findings provide valuable insights for designing inclusive and scalable livestock development strategies in upland regions, with broader relevance for similar smallholder systems globally.

Keywords: Adoption and scaling, gender-responsive approaches, improved forages, livestock productivity, participatory research, seed systems

From forage surplus to dry season feeding: Evaluating strategies for ruminants in central Cameroon

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Livestock plays an important role in rural areas. In Cameroon, 54 % of the meat consumed is beef. In most sub-Saharan countries, forage is abundant during the rainy season but gets poorer in quality and quantity during the dry season. This affects the animal productivity through weight loss, slower growth rates for calves, and low or no milk production. Improved feeding strategies, like fodder conservation, may help to maintain the productivity of ruminants and improve their resilience to dry season scarcity and climate change.

This study aimed to optimise ruminant feeding strategies using locally available resources at Bilone Farm, Central Cameroon, a training facility of the Agricultural Institute of Obala. Its role is to allow students to gain practical knowledge about different agricultural sectors, and to show them how to create a profitable agricultural business. Multi-nutrient blocs (MNBs) were produced using wheat bran, molasse, and either *Tithonia diversifolia* or *Stylosanthes guianensis*. Their physical and chemical characteristics, feasibility (from production to distribution), and palatability were evaluated in a 30-day feeding trial with nine calves. In addition, silage was produced from locally available grasses, *Tithonia diversifolia*, banana leaves, and molasse.

Both types of MBNs were readily accepted by calves, with no significant difference in consumption and an average consumption of 523 g per animal per day. The tithonia MNB shows greater practical potential because of a shorter production process and the better physical characteristics. Storage during the rainy season proved challenging because of high humidity, highlighting the importance of appropriate storage room and timing of production. The silage production in a concrete compartment of 0.8 m^2 was successful, and the product was accepted by both cattle and sheep. However, termites infested one corner of the compartment, showing the importance of using adequate materials like thick plastics and 100 % airtight conditions.

Ensuring sufficient production of conserved fodder during periods of forage surplus is critical to enable feeding during the dry season. While silage has a lot of potential, MNBs production is more time consuming, and both require further research including controlled feeding trials to quantify their effects on animal performance and productivity.

Keywords: Cameroon, fodder conservation, forage, multi-nutrient blocs, palatability, ruminant nutrition, silage

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Exploring the productivity of underutilised grassland forage C3 species under temperate and sub-tropical climatic conditions

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Temporary grasslands are not only a source of forage but also play a role in soil health, environmental protection, and sustainable agriculture. However, climate change is threatening the productivity and resilience of grasslands. Increasing interspecific and intraspecific diversity is suggested to counteract this development. In order to achieve this, the yield potential of species and accessions, including so far underutilized ones, under different climatic conditions has to be explored in order to find locally adapted functioning species. A field experiment was conducted in Germany and Brazil using a randomized block design, evaluating six forage species grown in pure stands differing in intraspecific diversity, i. e., one vs. two to three accessions. The selected species – two grasses (*Dactylis glomerata* and *Festuca arundinacea*), two legumes (*Onobrychis viciifolia* and *Lotus corniculatus*), and two non-leguminous dicotyledonous forage herbs (*Achillea millefolium* and *Plantago lanceolata*) – are representative of multispecies grasslands. Mineral fertiliser (CAN, 27% N) was applied at a rate of 120 kg N ha^{-1} yr^{-1} to non-legume plots in Germany and across all plots in Brazil. For Germany, the mean yield across two main production years, whereas for Brazil annual yield was derived from one experimental year. The data was analysed using linear mixed-effects models, with Tukey's HSD tests employed for pairwise comparisons of means. Species significantly affected productivity, with responses varying between sites ($p \leq 0.001$). In Brazil, *O. viciifolia* showed significantly lower productivity than all other species likely due to poor establishment. In contrast, in Gemany, *O. viciifolia* showed the highest production and *P. lanceolata* the lowest. While accessions had no main effect, its influence depended on the specific species-site combination, as indicated by the significant three-way interaction ($p < 0.05$). More accessions significantly increased productivity of *Festuca arundinacea* at both sites and of *L. corniculatus* and *P. lanceolata* in Germany. In contrast, there was no significant difference among accessions in Brazil. This pattern may reflect local adaptation and environmental filtering, with less-adapted accessions diluting the performance of an otherwise superior accession and reducing productivity in mixtures with more accessions. These findings show accession diversity benefits depend on context, emphasizing region-specific selection and breeding for sustainable grasslands.

Keywords: Accessions, grasses, herbs, legumes, productivity

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Adaptability of grazing Bunaji and Gudali cattle to stall feeding in a tropical university environment

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The changing dynamics in feed availability, herder conflicts, and increasing land pressure make a shift from traditional extensive cattle management systems increasingly necessary. This study evaluated the adaptability of grazing cattle to stall feeding at the Teaching and Research Farm, University of Calabar, over seven weeks. Nine White Fulani (Bunaji) and Sokoto Gudali cattle were used in a longitudinal observational cohort design. Animals were fed Napier grass hay supplemented with *Nymphaea lotus* leaf meal (NLLM). Body weight (BW) was recorded weekly, while temperature and relative humidity (RH) were measured daily at 8 am, 11 am, 2 pm, and 5 pm. Temperature-humidity index (THI) was computed. Data were analysed using repeated measures ANOVA and correlation analysis. Body weight increased steadily from 178.74 kg (Week 2) to 199.63 kg (Week 7), indicating positive growth. Ambient temperature declined from 31.89°C (Week 2) to 29.04°C (Week 4), while RH increased from 70.25 % to 80.75 %. The highest THI (84.42) occurred in Week 2, coinciding with the highest temperature and lowest RH, when BW was lowest. Diurnally, peak temperature (33.63°C) and THI (87.27) occurred at 2 pm, significantly higher ($p < 0.05$) than morning values, indicating severe heat stress. Despite declining temperatures at 5 pm, THI remained elevated (83.45) due to high RH, suggesting delayed thermal relief. Correlation analysis showed a strong positive relationship between THI and temperature (r = 0.943). BW had a weak positive relationship with time (r = 0.220), indicating gradual acclimation. BW showed negligible relationships with THI (r = -0.031), temperature (r = −0.074), and RH (r = 0.142), suggesting that moderate heat stress did not impair growth. Overall, cattle gained approximately 20 kg over the study period, likely due to improved nutrition, compensatory growth, and inherent heat tolerance. Nighttime cooling (THI = 78.80 at 8 am) may have supported feed intake and rumination. The results showed that stall feeding supported weight gain and could serve as a viable alternative to extensive systems. However, heat mitigation strategies, such as shade, ventilation, and cooling, should be implemented, particularly between 2 pm and 5 pm, to reduce thermal stress and optimise productivity.

Keywords: Adaptability, cattle, Nympha lotus, stall feeding

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Grass-*capoeira* pastures teem with the megadiversity of the NE-Amazon, Brazil

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Grass-*capoeira* pastures (GCP), consisting of partly tolerated secondary vegetation (*capoeira*) on humid tropical pastures, have been shown to be ecologically sustainable in smallholder agro-silvo-pastoral systems, as browsing cattle do not alter fallow species composition. Beyond enhancing soil fertility, hydrological regulation, and biogeochemical cycles, GCP represent an economically viable and ecologically sound alternative to low-input cattle husbandry and notorious pasture degradation. Even more, GCP encompass a considerable part of the local fauna and flora for nature conservation aspects. We investigated vascular plant and bird diversity on four experimental farms with GCP in Igarapé-Açu, Bragantina Region, NE-Pará. The flora on GCP was determined using 100 m^2 plant relevés (n=39) and compared to the complete phytodiversity of the respective farms (n=42). Also, bird counts of up to 50 m around these GCP were compared to the total richness of the Bragantinian avifauna. Results indicate that 277 vascular plant species (78.9 % of known *capoeira* species), 174 genera (81.3 %), and 55 families (91.7 %) were found on GCP plots. Furthermore, 124 bird species (64.6 %), 101 genera (66.9 %), and 35 families (79.5 %) were detected around GCP, respectively. This means that smallholders could contribute to a high extent to nature conservation on their pasture plots, for which they should be financially acknowledged. While many feared pasture weeds or even poisonous plants are also present on GCP, they also contribute to total biomass production of the fallow vegetation. As a prime example of multi-functional land use, GCPs operationalize Nature-based Solutions by integrating Regenerative Agriculture into low-input farming. This makes them a vital blueprint for Climate-Smart Agriculture in humid tropical forest margins.

Keywords: Birds, climate-smart agriculture, low-input farming, multi-functional land use, nature-based solutions, phytodiversity, regenerative agriculture, smallholdings

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Scaling sustainable livestock: Adoption and impacts of *Urochloa* hybrids in Latin America (2001–2024)

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Sustainable intensification of cattle systems is essential to meet the growing demand for animal-sourced foods while reducing environmental impacts in tropical regions. This study assesses the adoption and multi-dimensional impacts of interspecific *Urochloa* (syn. *Brachiaria*) hybrids across 27 countries in Latin America and the Caribbean (LAC) over the period 2001–2024. Using an innovative mixed methodology, we quantify adoption patterns and evaluate social, economic, and environmental outcomes. Results indicate that *Urochloa* hybrids have been adopted by approximately 1.2 million farmers on 1.9 million hectares, benefiting nearly 9 million people across the region. Adoption is strongly driven by smallholders, who represent about two-thirds of adopters, and generates significant rural employment beyond farm households. Despite rapid growth, adoption remains highly concentrated geographically and represents only a small fraction of total grassland area, highlighting substantial untapped potential. Economically, the hybrids are projected to generate cumulative forage value of US$9.2–12.2 billion by 2033, reflecting increased forage productivity and cattle performance. Environmental analysis suggests that adoption significantly reduced greenhouse gas emissions – by an estimated 16 to 146 Mt CO_2-eq – and could have potentially spared up to 5.5 million hectares of land, particularly when integrated into silvopastoral systems. These findings underscore the role of improved forages as a key lever for climate mitigation and land-use efficiency in the cattle sector. However, widespread adoption is constrained by systemic barriers, including limited access to quality seed, weak seed systems, insufficient extension services, and policy and regulatory challenges. Addressing these constraints will require coordinated investments in seed supply chains, inclusive financing mechanisms, knowledge dissemination, and supportive policy frameworks. Overall, this study demonstrates that *Urochloa* hybrids offer a scalable, science-based solution to enhance productivity, resilience, and sustainability in tropical cattle systems. Scaling their adoption could play a critical role in aligning cattle development with climate goals, food security, and rural development objectives in LAC and beyond.

Keywords: Greenhouse gas mitigation, impact assessment, improved forages, seed systems, sustainable intensification, technology adoption

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Intensive silvopastoral systems as a pathway to sustainable cattle transformation in the Peruvian Amazon

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Intensive silvopastoral systems (iSPS) are increasingly recognised as important option for the sustainable transformation of cattle farming, particularly in deforestation-prone regions such as San Martín, Peru. By integrating high-quality forages, legumes, and multi-strata woody perennials, iSPS enable a transition from extensive, low-efficiency grazing toward a model of sustainable intensification. These systems enhance biomass availability, increase stocking rates, and improve productivity in both milk and meat production. At the same time, they deliver substantial environmental benefits by acting as carbon sinks, reducing greenhouse gas emissions, and lowering dependence on synthetic fertilisers and agrochemicals through biological nitrogen fixation and improved nutrient cycling. Beyond their environmental advantages, iSPS offer important economic opportunities. Their diversified structure allows ranchers to internalise key production costs while generating additional income streams from timber and non-timber forest products. Given that technology adoption is largely driven by profitability expectations, this study evaluates the economic performance of an iSPS configuration in San Martín using a discounted cash flow approach. The analysis compares a conventional monoculture pasture system (*Urochloa brizantha* cv. Marandú) with a diversified iSPS comprising *Centrosema macrocarpum*, *Tithonia diversifolia*, and timber species such as *Brosimum alicastrum* and *Guazuma crinita*. To account for uncertainty and market variability, probabilistic indicators, such as Net Present Value (NPV) and Internal Rate of Return (IRR), were estimated under pessimistic, base, and optimistic scenarios. The results show a substantial difference in economic performance between systems. The conventional system generates a modest IRR of 8.09 %, whereas the iSPS exhibits significantly higher and more resilient returns of 26.62 %, 29.03 %, and 30.33 % across the respective scenarios. These gains are primarily driven by increased milk productivity and higher stocking densities enabled by improved forage quality and system design. These findings highlight iSPS as a financially viable and environmentally sustainable alternative to conventional cattle systems. Scaling up these systems could play a critical role in improving smallholder livelihoods, enhancing food security, and decoupling livestock expansion from deforestation in tropical regions.

Keywords: Cattle ranching, climate-smart agriculture, deforestation, discounted cash flow, economic analysis, silvopastoral systems, sustainable intensification

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Integrating anti-methanogenic plants into silvopastoral mosaics: Lessons from the tropics

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Ruminant production contributes to climate change by its enteric methane emissions, leading to some mitigating strategies. In tropical regions, incusing anti-methanogenic plants within silvopastoral mosaics is gradually gaining place, and offers a promising, ecologically grounded strategy to reduce enteric methane emissions thank to their metabolite compounds. The aim of this review is to explores the current evidence of the inclusion of anti-methanogenic plants into silvopastoral systems; underlying the main species, biochemical mechanisms, and environmental outcomes. We hypothesised that these plants in ruminant diets can hamper methane synthesis during the digestion process thank to their metabolite compounds particularly phenols.
The PRISMA method has been used to look for pertinent papers, obtained from tree academic databases (Google Scholar, Scopus, Research Gate), using a combination of keywords, without any publication year restrictions. Then, documents have been filtered and screened for information extraction.
Several researches have focused on anti-methanogenic plants, global tropical regions; Latin America and East Africa being the areas with more researches. Species like *Acacia nilotica* (503 g kg^{-1} DM), *Dichrostachys cinera* (386.5 g kg^{-1} DM), *Monechma incanum* (307 g kg^{-1} DM), *Grewia flava* (233.7 g kg−*1* DM) and *Rhus lancea* (226.6 g kg^{-1} DM) have demonstrated a high mitigating effect on methane emissions, thanks to their high phenol contents. Phenolic compounds are catabolised by rumen microorganisms using hydrogen or formate to form volatile fatty acids, inhibit methane production within ruminant, thus highlighting their potential in reducing methane emissions from livestock. More the plant phenolic compound (hydroxyl groups) amount is, less the methane is produced. However, the concentration, bioactivity, and the seasonal variability of phenol compounds are highly dependent on species, edaphoclimatic zone, and plant maturity.
The use of trees and shrubs in feeding tropics seems appropriate for reducing methane production in tropical areas. Further studies will allow to determine the trade-offs between methane mitigation and animal performance when using these plants.

Keywords: Ligneous, metabolite compounds, methane, phenol, ruminants, tree-livestock integration, tropics

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Camelids and small ruminants

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From trap to transition? The food-feed biomass battle under climate variability in Ethiopian enset-sheep farming systems

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In mixed crop-livestock systems of sub-Saharan Africa, trade-offs typically occur between competing uses of crop biomass. In central Ethiopia's enset farming systems, farmers face a "food-feed biomass battle" over enset (*Ensete ventricosum*), a drought-tolerant perennial crop. This battle reflects a tension between food security insurance and income from feeding livestock. The objectives of this study are to diagnose whether this battle constitutes a socio-ecological trap and evaluate the extent to which the Small Ruminant Value Chain Technology Pack (SmaRT Pack) intervention alters system feedback processes. Using a mixed-methods design comprising a structured household survey (n=100), focus group discussions (n=6), and key informant interviews (n=21) in the Doyogena region of Ethiopia. Data were analysed using the binomial with effect size quantified using Cohen's d. The feed-to-food ratio (R) is calculated, where R = 1.0 indicates equal allocation between food and feed as a diagnostic threshold. Enset biomass was allocated to food (64 %), feed (20 %), and sale (16 %). The system shows no directional shift toward equal allocation dry-to-wet (40.5 % toward vs. 55.7 % away) from R=1.0; sign test $p = 0.9$. This pattern is observed among sheep-fattening farmers, as biomass yields more income when used as feed than when sold as food. This systemic distance from R=1 shows the system is structurally trapped. The 85 % of households would increase feed if sheep prices rose 50 %, but 95 % would prioritise food during a prolonged dry season. This indicates a battle sustained by risk aversion driven by chronic climate variability. The SmaRT Pack intervention increased livestock holdings ($d = 1.7$, $p = 0.001$) and shifted livelihoods but did not change biomass allocation ($d = 0.3$, $p = 0.16$). The intervention targeted livestock productivity, while the trap functions at biophysical and behavioural feedbacks regulating biomass trade-offs. Without addressing self-reinforcing feedback, a component-based intervention alone can't break the trap. We conclude that escaping this socio-ecological trap requires not just increasing biomass but also improving resource-use efficiency, especially livestock feed conversion efficiency. This approach reduces climate pressure on biomass while ensuring food security. The study offers insights for designing a climate-resilient, sustainable livestock transition pathway.

Keywords: Biomass battle, climate variability, enset (*Ensete ventricosum*), smallholder farming systems, socio-ecological traps

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Antimicrobial use and knowledge among camel pastoralists in Ethiopia

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Use of antimicrobials among pastoralists is essential for maintaining livestock health and livelihoods in the arid and semi-arid regions of East Shewa and Borana zones in Ethiopia. However, limited access to veterinary services and lack of formal training strongly influence how these drugs are used. This study examines the knowledge and practices related to antimicrobial use among Ethiopian camel herder pastoralists.
A baseline survey was conducted among 386 camel pastoralists to assess camel health management practices. This was followed by a larger antimicrobial use survey combining structured interviews with herders in Borana (1,829 herd of camels) and East Shewa (5,185 herd of camels). The aim was to evaluate pastoralists' knowledge, practices, and sources of information regarding antimicrobial drug use.
The results revealed a higher camel population in East Shewa (73.92 %) compared to Borana (26.1 %). Antimicrobial use was widespread, with nearly all herders (98.71 %) using these drugs to manage camel diseases, often without professional prescription. Only 10.4 % of respondents in Borana and 2.1 % in East Shewa reported seeking advice from veterinary professionals.
Pastoralists demonstrated strong practical experience in identifying common camel diseases. However, there were significant gaps in knowledge related to appropriate drug selection and dosage. Only 2.6 % of herders reported receiving dosage information from veterinarians, while 12.76 % relied on other herders. In contrast, 52.34 % and 30.99 % obtained information from private drug vendors and veterinary pharmacists, respectively.
Awareness of drug withdrawal periods was very low. About 84.50 % of herders were unaware of withdrawal times and reported consuming camel milk immediately after antibiotic treatment. Additionally, 91.99 % lacked awareness of drug residues and their role in antimicrobial resistance. Informal drug sourcing and self-administration practices were highly prevalent, reported by 97.67 % of respondents.
These findings highlight critical gaps in knowledge and practice regarding antimicrobial use among pastoralists. There is a clear need for targeted awareness creation, improved access to veterinary services, and community-based education programs. Promoting responsible antimicrobial use is essential to reduce the risk of antimicrobial resistance and to improve both animal and public health outcomes.

Keywords: Antimicrobial drug use, camel herders, pastoralist community

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Livestock keepers' objectives and performance of dairy camels under two contrasting management systems in Ethiopia

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Dromedary camels are essential to pastoral and agro-pastoral livelihoods in Ethiopia's arid and semi-arid regions, yet their reproductive and dairy performance across management systems remains poorly understood. This study evaluated dairy camels in extensive pastoral (EP) and peri-urban agro-pastoral (PUAP) systems in the Borana and East Shewa region, respectively. Data on herd characteristics, herders' production objectives, reproductive performance, and lactation performance were collected from 48 camel herds and 135 lactating camels between November 2024 and October 2025 using structured questionnaires, direct observations, and on-site measurements. Milk production was the primary reason for keeping camels in both systems, more frequently reported in PUAP (83.3 %) than in EP (70.8 %). Income generation was reported only in EP (29.2 %), while religious purposes were exclusive to PUAP (16.7 %). All herders in PUAP prioritised milk yield, whereas EP herders considered milk yield alone (29.2 %) or in combination with milkability (70.8 %). Camels in PUAP were significantly older (188.7 $\pm$ 42.5 vs. 135.1 $\pm$ 38.0 months; $p < 0.001$) and had higher reported ages at first heat (55.2 $\pm$ 4.4 vs. 47.3 $\pm$ 4.4 months), first mating (56.3 $\pm$ 9.2 vs. 48.5 $\pm$ 3.8 months), and first conception (61.2 $\pm$ 8.7 vs. 50.8 $\pm$ 4.8 months), as well as a higher age at first calving (73.1 $\pm$ 8.6 vs. 62.0 $\pm$ 5.1 months) (all $p < 0.001$). Despite shorter lactation (10.6 $\pm$ 1.3 vs. 16.4 $\pm$ 4.1 months) and milking periods (9.1 $\pm$ 1.6 vs. 16.7 $\pm$ 4.2 months), PUAP camels showed better reproductive efficiency, with fewer matings per conception (1.8 $\pm$ 1.0 vs. 2.3 $\pm$ 0.9), higher numbers of calves born (4.8 $\pm$ 2.1 vs. 3.1 $\pm$ 1.3), and fewer abortions (0.3 $\pm$ 0.8 vs. 1.2 $\pm$ 0.7) (all $p < 0.001$). Differences in performance show that production systems strongly shape camel productivity. PUAP systems achieve higher reproductive efficiency and calf output despite delayed reproductive onset and shorter lactation periods. EP systems benefit from earlier reproduction and longer lactation but are limited by lower reproductive efficiency and higher losses. Results highlight need for system-specific interventions, improving reproductive management in pastoral systems and optimising lactation in peri-urban systems.

Keywords: Agro-pastoral systems, dairy production, dromedary camel, pastoral systems, performance, reproduction

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Camel milk value chain structure, functionality, and income generation in pastoral areas of Borana and East Shewa, Oromia regional state, Ethiopia

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Camel milk contributes substantially to the livelihoods, food security, and income generation of households in arid and semi-arid regions. However, its potential is constrained by weak institutions, limited market access, and inefficient value chain linkages. This study examines the organisational structure, functional performance, and income generation along camel milk value-chain in the Borana and East Shewa zones of Oromia regional state, Ethiopia. Using a cross-sectional, multistage sampling study design. This study targeted 386 producers and key value chain actors, including 20 collectors, 20 retailers, 2 cooperatives, 30 consumers, and 10 institutional stakeholders. Data were collected using structured questionnaires, key informant interviews, and focus group discussions in the main wet and dry seasons 2025. Marketing margin analysis, and others descriptive statistics as well as econometric modelling (multinomial logit models) were used to analyse the milk value chain structure, functionality and income generation .The findings reveal that the camel milk value chain in both study zones is largely informal, characterised by weak coordination, inadequate infrastructure, and limited institutional support. Significant differences were observed between the two zones, with Borana herders producing an average of 817 liters and East Shewa producing 2,160 liters of marketable milk per day. Market participation was reported by 47 % of herders in Borana and 69 % in East Shewa. Income distribution (GMMp) ranged from 55.60 % to 63 % in Borana and from 61 % to 71 % in East Shewa. This implies that East Shewa captures a greater value share, indicating a more efficient and equitable chain, while Borana reflects inefficiencies and lower producer returns. Producers receive a relatively small share of the final consumer price due to the dominance of intermediaries and limited value addition practices. The data analysis indicates that age and family size have a negative effect on market outlet choice, whereas farmland holding size, total livestock units, milk price, and cooperative membership had a positive effect. In conclusion, improving the camel milk value chain efficiency and inclusiveness requires strengthening institutions, infrastructure, cooperatives, and market linkages to increase income and livelihood resilience.

Keywords: Camel milk, econometric analysis, Ethiopia, income generation, pastoral livelihoods

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Maternal nutrition, offspring performance and alpaca resilience in Andean agroecosystems

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Introduction: Alpacas are central to livelihoods and food security in Andean pastoral systems, where regional variation in natural pasture quality may affect maternal condition, neonatal performance, and adaptive capacity in extensive livestock systems. In these extensive systems, protein availability and forage composition fluctuate markedly, potentially influencing colostrum quality and offspring development. This study evaluated the relationship between protein nutrition from natural pastures, colostral immunity, and dam–cria performance in primiparous and multiparous alpacas from three regions of Peru.
Materials and methods: A descriptive observational study was conducted in Junín, Cusco and Puno using 150 pregnant Huacaya alpacas (50 per region; 25 primiparous and 25 multiparous). Colostrum, maternal blood and cria blood samples were collected around parturition to assess immunological and nutritional indicators, including serum metabolites associated with protein status. Diet quality was characterised through hand-plucked pasture simulation and proximate analysis, including crude protein and neutral detergent fiber. Maternal body condition, neonatal vigour indicators, and productive variables of the dam–cria pair were recorded. Cria growth was monitored during the first month of life through repeated weight measurements.
Results: Marked regional and parity-related differences were observed. Multiparous alpacas, particularly in Junín, showed greater body weight and body condition, while their crias presented higher birth weights and shorter time to first suckling, indicating greater neonatal vigour. Pastures from Junín also had higher crude protein content, reflecting superior nutritional quality. In addition, cria follow-up during the first month indicated more favourable weight gain under better maternal nutritional conditions. Overall, improved nutrition was associated with enhanced dam–cria performance and indicators consistent with improved passive immunity potential.
Conclusions: Nutritional quality of high-Andean pastures influenced maternal condition, neonatal performance and early cria growth, with better outcomes in multiparous alpacas under superior feeding conditions. These findings highlight the relevance of nutritional management for productivity, offspring survival, resilience and sustainability in extensive pastoral livestock systems. They further support the contribution of pastoral livestock management to multifunctional Andean agroecosystems.

Keywords: Alpacas, maternal nutrition, passive immunity, pastoral systems, regional variability, resilience

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Alpaca production in climate-stressed Andean agro-ecosystems: Insights from milk composition, pasture quality and management practices

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Alpaca production plays a central role in sustaining livelihoods in the high-altitude Andes, where agro-ecosystems are increasingly affected by climate variability, pasture degradation and resource scarcity. In these marginal environments, alpaca systems are often considered inherently resilient; however, their capacity to sustain productivity under changing climatic conditions remains insufficiently understood. It is therefore essential to better understand factors affecting productivity in order to develop climate-resilient and multifunctional agro-ecosystems. This study evaluated how alpaca milk composition varies between primiparous and multiparous females across three lactation stages in three high-Andean regions of Peru (Cusco, Puno, Junín). A total of 158 milk samples were analysed using FOSS MilkoScan and nine pooled native pasture samples were analysed using AOAC, and ANKOM methods. Additionally, ten semi-structured interviews were conducted with local farmers to understand feeding, breeding, and rearing practices under different conditions. Multiparous females (n = 80) produced milk with higher fat and protein contents (median 4.46 % and 5.43 %, respectively), while primiparous females (n = 78) showed slightly higher lactose levels (median 5.19 %). Across lactation, fat content increased and lactose decreased consistently, whereas protein and non-fat solids remained relatively stable. Regional differences were minor, indicating that physiological factors outweigh environmental variation under extensive grazing conditions. Pasture analyses revealed declining crude protein and increasing fibre (NDF) from early to late lactation, suggesting seasonal nutritional constraints. In combination with interview data, these findings highlight key challenges, including feed scarcity, climatic stress, and limited management resources, all contributing to high cria mortality. Overall, results indicate that while alpaca systems are well adapted to marginal environments and contribute to the sustainable use of native rangelands, their productivity remains highly sensitive to nutritional and climatic limitations. Strengthening feed availability and management practices is therefore critical to enhance resilience, improve animal performance, and support the multifunctionality of Andean agro-ecosystems under changing climatic conditions.

Keywords: Alpaca milk, Andean agro-ecosystems, climate resilience, lactation stage, native pasture

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Thyroid hormones and hematological profiles of goats in contrasting agroecology: Indicators of physiological adaptation

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The hematological parameters and thyroid hormones have vital roles in monitoring and evaluating the health, nutritional, adaptation, and physiological status of animals. Normal thyroid gland function and hematology profiles are essential to sustain productivity. The study was conducted to examine the hematological and thyroid hormones of indigenous goats reared in three agroecological zones. Blood samples were collected from a total of 184 adult goats of both sexes from the jugular vein, using tubes with and without anticoagulant. The blood samples were collected in two seasons, viz., wet and dry. Hematology parameters were analysed from the blood collected in an anticoagulant-containing tube, while thyroid hormones (T3 and T4) were estimated from anticoagulant-free serum. Agroecological zone, season, and sex showed a significant ($p < 0.05$) effect on hematology parameters, while the effect of season was not significant ($p > 0.05$) for thyroid hormone concentration. The highland goats displayed higher values for LYMP, RBC, Hb, and RDW-CV, while the lowland goats exhibited larger values for WBC. The WBC, NEU, MON, EOS, RBC, Hb, HCT, MCV, and MCHC were significantly ($p < 0.05$) higher in the wet season. The RBC and HCT were higher in female goats, while the RDW-CV was higher in male goats. The female goats had higher concentrations of T3 and T4 than males. The highest concentrations of T3 (1.80 ng mL^{-1}) and T4 (8.33 μg dL^{-1}) were found in highland goats. The deviation of some hematology parameters from the normal range is due to the extensive management system. Thus, to validate the nutritional, health, and adaptive status of the goat, further research with more frequent blood data and complemented physiology is required.

Keywords: Adaptation, agroecological zone, hematology, thyroid hormones

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Breeding schemes integrating health, nutrition and reproduction services boosts small ruminants' productivity across African landscapes

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Multifunctional landscapes (MFLs) are designed to support diverse land uses while sustaining ecological functions generating social and economic benefits. Small ruminants are an important commodity across various African landscapes and Community-Based Breeding Programs (CBBPs) offer a framework for sustainable preservation of local genetic resources and productivity improvement while aligning with MFL principles e.g. harnessing local production objectives and ecosystem sustainability. The benefits from CBBPs are further amplified by the adoption of smart practices in health, nutrition and reproduction, and this framework guides the work of ICARDA and its partners in Ethiopia, Tunisia, and Mali. The practical implementation of CBBP is facilitated by two pillars. The first is the digitalisation of pedigrees and performances using "Dtreo" platform to generate a productivity dashboard and breeding values, that may consider methane emissions, for selection of next-generation animals. In Ethiopia, annual reproductive rates of 2.1, 2.2 and 2.5 were respectively achieved in Bonga, Horro and Doyogena sheep breeds; this gain was associated with 22.2 % reduction in methane emissions. The second pillar focuses on the dissemination of genetic gain while ensuring farmers have access to health, reproduction and nutrition services. In Ethiopia, the widespread use of certified rams yielded annual genetic gains in six-months weight of 0.14, 0.18 and 0.21 kg in Menz, Washera and Bonga breeds, respectively. In Tunisia, best-to-best mating schemes using artificial insemination in the local goat achieved a 34.7 % conception rate; further adoption of non-invasive ultrasound pregnancy diagnosis yielded a 7.6 % improvement in fertility. Additionally, circular practices using mixed forages to flush ewes increased litter size by 23 %. Furthermore, preventive health practices over 3 years lessened morbidity in Ethiopian highlands from 6.3 % to 3.02 % while in Mali, a similar scheme reduced the prevalence of gastrointestinal parasites and improved flocks' productivity. In Tunisia, ongoing health interventions are informed by baseline assessments of sheep welfare and antimicrobial resistance (AMR) levels, revealing that 51.5 % of animals had depressed body condition and that AMR levels reached alarming 32 % for streptomycin and 26 % for tetracycline. These findings, across various African Landscapes, underscore the necessity for integrated innovations to improve small ruminant productivity within an MFL approach.

Keywords: Africa, community-based breeding program, goat, sheep

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Impacts of community-based sheep breeding programme to household adaptive capacity towards climate change under extensive livestock production system of Ethiopia

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Adaptive capacity in the context of climate change is a system's, institution's, or household's ability to adjust to current and future climate variability, reduce impacts, seize opportunities, and cope with consequences. It entails building conditions and capabilities to address the social, economic, and environmental effects of climate change, integrating social, economic, and human capital to enable efficient adaptation. This study examines the contribution of a community-based sheep breeding program (CBBP) to enhancing household adaptive capacity in response to climate change within Ethiopia's extensive livestock production system. A cross-sectional study with a multistage sampling technique was used to select 213 sheep producers for household interviews across the selected three districts. Menz Mama district for Menz sheep producers and Adiyo-Kaka and Telo districts for Bonga sheep producers. The respondents were sampled from CBBP participants and non-participants to examine the net impact of the CBBP intervention. Besides the household interview, 14 key informant interviews and 6 focus group discussions were conducted. The Local Adaptive Capacity (LAC) framework followed the data collection and analysis for adaptive capacity. The analysis was done through the Propensity Score Matching model of STATA 14. Households participating in the CBBP program have significantly ($p < 0.05$) higher adaptive capacity compared to the non-participants. The participants have a higher average treatment effect (ATE) on adaptive capacity across various LAC indicators, including financial assets, human assets, social assets, institutions and entitlements, knowledge and information, innovation and technology, and flexible and forward-looking decision-making. The positive contribution of CBBP for adaptive capacity is due to the presence of integrative

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activities such as capacity building through trainings, market linkage, and improved feed and animal health interventions that have a positive relationship with LAC indicators. In conclusion, community-based breeding programs in Menz and Bonga sheep enhance the adaptive capacity of smallholder farmers rearing these animals. Hence, it is recommended to integrate CBBP and its interventions into Ethiopia's future climate change adaptation and mitigation strategies.

Keywords: Cross-sectional, local adaptive capacity, sheep

Goat crossbreeding for sustainable production and livelihoods in West Africa: Empirical evidence from Benin

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Goat production is a cornerstone of rural livelihoods and food security in West Africa, where smallholder systems dominate. The West African Dwarf (WAD) goat is widely kept in Benin and across the humid coastal regions of West Africa, valued for its adaptability and low-input requirements, yet its productivity (kid growth and doe reproductive efficiency) is often perceived as limited. Crossbreeding this valuable indigenous genetic resource with breeds from the drier Sahelian region has emerged as a strategy to improve performance, but it is frequently practised without regulation or empirical evidence, raising concerns about sustainability. This study evaluated reproductive and growth performance of purebred WAD, Red Maradi (RMG), Long-Legged Sahelian (LLG) goats, and their crossbred progenies under semi-intensive management. A total of 48 goats (15 females and one male per breed) were included in a reciprocal crossbreeding scheme. Reproductive traits and kid growth were analysed using Generalized Linear Models and Linear Mixed-Effects Models, with parity, litter size, and sex as fixed effects. Results indicated no significant ($p > 0.05$) breed effects on parturition rate ($68.5 \pm 30.51\,\%$) and abortion incidence ($13.4\,\%$), though abortion reduced kidding performance ($p < 0.05$). Rates of prolificacy ($149.5 \pm 57.66\,\%$) and fecundity ($212.4 \pm 135.53\,\%$), increased with parity, while the average kidding interval was 210.3 ± 23.77 days. Kid mortality ($43.3 \pm 46.72\,\%$) varied significantly with litter size and genotype ($p < 0.05$), largely due to nutritional deficiencies and parasitic infections. WAD kids had the lowest birth weight ($1.3 \pm 0.45\,\mathrm{kg}$) and average daily gain at 90 days ($46.3 \pm 31.72\,\mathrm{g/day}$), whereas crossbreds with Sahelian breeds showed superior growth ($p < 0.05$). Growth was further influenced by sex, parity, and specific Sahelian genotype. In conclusion, WAD goats demonstrate strong reproductive aptitude but limited growth potential. Crossbreeding with Sahelian genotypes enhances growth traits without compromising reproduction, offering a viable pathway to strengthen rural livelihoods and promote sustainable goat production in West Africa. These findings underscore the need for structured, evidence-based genetic improvement programmes to guide sustainable goat production in West Africa.

Keywords: *Capra hircus*, genetic improvement, reproductive efficiency

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Hematological and hormonal profiles of indigenous sheep populations in contrasting agroecological zones of the Sidama region, Ethiopia

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Hematological and hormonal parameters are widely used indicators of health and physiological adaptation in livestock and are essential for optimised flock management and productivity. This study was conducted to evaluate hematological characteristics and thyroid hormone profiles in indigenous sheep raised across contrasting agroecological zones in the Sidama region. A total of 180 apparently healthy sheep of both sexes were sampled from three districts, including 87 animals during the wet season and 93 in the dry season. Blood samples were collected aseptically using disposable syringes. Two milliliters of blood were drawn into EDTA-coated vacutainer tubes for hematological analysis, and the remaining three milliliters were drained into a clot activator tube for thyroid hormone analysis. The effects of agroecological zone, sex, season, and their interactions on hematological and thyroid hormone parameters were analysed using the General Linear Model procedure in SAS. Agroecological zone had a significant effect ($p < 0.05$) on total white blood cell count, with higher values observed in sheep reared in highland areas, followed by lowland agroecological zones. Sex had a significant ($p < 0.05$) effect on the proportions of lymphocytes, eosinophils, and basophils, whereas neutrophils and monocytes were not affected. Seasonal variation significantly influenced hematocrit, mean corpuscular hemoglobin concentration, and platelet counts, indicating a physiological response to environmental and nutritional changes. The interaction between agroecological zone and sex affected only red cell distribution width, while the interaction between sex and season showed no significant effect on any of the studied hematological parameters. Thyroid hormone levels were not affected by agroecological zone or sex but showed significant seasonal variation. The results of this study provide useful baseline information for improving the interpretation of laboratory data and support accurate clinical diagnosis and treatment in indigenous sheep. Further study is recommended to establish standardised hematological reference values for healthy indigenous sheep using the reference value estimation method.

Keywords: Agroecological zone, hematology, hormones, indigenous sheep, season, sex

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The effect of non-genetic factors on reproduction traits of Indonesian Etawah Grade goats

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Reproductive traits are important determinants of efficiency, productivity, and the economic viability of livestock production systems. Several reproductive traits in goats, commonly used as indicators of productivity and with a significant impact on profitability, are age at first kidding, kidding interval, prolificacy, and pre-weaning mortality. The Etawah Grade (EG) goat is a local Indonesian breed, classified as a dual-purpose breed (milk and meat production). This study aimed to analyse the influence of non-genetic factors on reproduction traits and the correlation between reproduction traits in Etawah Grade (EG) goats. A total of 11,344 reproduction performance records from 2699 animals were used in this study. The effects of non-genetic factors (parity, season, year, and type of birth) on litter size (LS), age at first kidding (AFK), kidding interval (KI), and pre-weaning mortality (PM) were analysed using a General Linear Model (GLM). The overall mean and standard error of PM, LS, KI, and AFK in this study were 13.776$\pm$0.004 %, 1.797$\pm$0.660 kids, 279.988$\pm$1.155 days, and 598.671$\pm$3.229 days, respectively. PM was significantly affected ($p < 0.05$) by year of kidding, parity of dam, type of birth, and season of kidding. Parity, season, and year of kidding had a significant effect ($p < 0.05$) on LS. AFK was significantly affected ($p < 0.05$) by year and season of kidding. KI was only affected by the year of kidding ($p < 0.05$). The present findings suggest that non-genetic factors predominantly affect reproduction performance in EG goats. The information obtained from this study provides an important basis for implementing breeding programmes of EG goats, as well as support the improvement of production strategies, enhance selection accuracy, and optimise breeding programmes for EG goats.

Keywords: Correlation, Etawah Grade goat, non-genetic, phenotypic, reproduction

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Nomadic and indoor concentrate-based production systems: Impacts on growth, reproduction and hemato-biochemistry of goat bucks

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This study aimed to evaluate the effects of four different production systems on the growth, reproductive effectiveness, and health indicators of goat bucks. A total of 40 yearling bucks (10 bucks per treatment) were randomly allocated to nomadic grazing (T1) and three different levels of concentrate (CN): roughage/ concentrate ratio 60:40 % (T2), roughage/ concentrate ratio 50:50 % (T3), and roughage/ concentrate ratio 40:60 % (T4) on a DM basis for a period of 90 days. CN-fed bucks had greater average daily gain (ADG), scrotal circumference, number of mounts, ejaculation frequency, and courtship behaviour scores (CBS), particularly in the T3 and T4. The nomadic grazing bucks exhibited longer reaction times and refractory periods compared to the CN-fed bucks. The semen volume, sperm cell concentration, semen motility, and testosterone levels were also considerably improved in CN-fed animals; however, the production systems had no significant effect on semen pH, colour, and viscosity. CN-fed bucks had also exhibited a greater hemoglobin concentration, red blood cell (RBC) count, packed cell volume (PCV), and glucose concentrations compared to nomadic grazing, but the difference between T1 and T2 was not significant. Serum protein, albumin, and testosterone concentrations increased progressively with increasing concentrate levels. In contrast, white blood cell count, mean corpuscular volume, mean corpuscular hemoglobin concentration, red blood cell distribution width indices, globulin, and albumin-globulin ratios remained unaffected. Calcium levels were significantly improved in the CN-fed groups, while the levels of K, Na, Cl, and P remained unchanged. The correlation matrix revealed strong positive correlations between dry matter intake (DMI), scrotal circumference, and semen volume. The ADG was also strongly correlated with semen volume, motility, and scrotal circumference. Correlation analysis also revealed significant positive correlations between PCV and RBC, protein and testosterone, and testosterone and glucose. The result of this study indicated that bucks fed CN (particularly T3 and T4) had better ADG, scrotal development, reproductive, and hemato-biochemical profiles than the nomadic grazing group. Increased DMI, along with enhanced energy and protein supplies, could explain this improvement. In conclusion, concentrate feeding at 50−60 % (T3−T4) of the daily requirements could improve the growth, reproductive, and health conditions of goat bucks.

Keywords: Average daily gain, health indicators, reproduction effectiveness

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Seasonal vegetation dynamics, goat foraging selectivity, and climate-resilient grazing strategies in semi-arid woodlands, northwestern Zimbabwe

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Extensive goat production systems are central to rural livelihoods and ecosystem functionality in semi-arid rangelands, yet seasonal climate variability increasingly threatens forage availability, biodiversity, and pastoral sustainability. This study investigates how seasonal shifts in vegetation accessibility influence goat dietary selectivity, spatial foraging patterns, and adaptive grazing strategies within the teak woodlands of Lupane District, Zimbabwe.

Using a mixed-methods design across seven wards, farmer surveys, vegetation quadrat assessments, GPS-based foraging site mapping, and direct behavioural observations were integrated to evaluate wet- and dry-season changes in browse/ graze availability and goat feeding responses. Vegetation selectivity was quantified using Ivlev's Electivity Index, dietary diversity through the Shannon–Wiener Index, and seasonal dietary overlap via the Morisita–Horn Index.

Results demonstrated significant seasonal differences ($p < 0.05$) in vegetation composition, forage accessibility, and goat behavioural responses. Wet-season conditions supported greater forage abundance and dietary diversity, with goats strongly selecting nutrient-rich browse species such as *Flueggea virosa* while primarily utilising open grassland habitats. In contrast, dry-season forage scarcity reduced accessible vegetation, prompting adaptive responses including intensified woody browsing, exploitation of fallen leaf biomass, and vertical foraging behaviours such as tree climbing, particularly on *Terminalia sericea*. Moderate dietary diversity ($H' = 1.0457$) combined with low seasonal dietary overlap (0.235) revealed substantial flexibility in forage utilisation under climatic stress. These findings position goats as highly adaptable components of multifunctional agro-silvo-pastoral landscapes, capable of sustaining livelihoods under variable environmental conditions while simultaneously

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exerting pressure on woodland biodiversity. The study highlights the importance of climate-smart grazing management, dry-season forage enhancement, and integrated rangeland governance to strengthen livestock resilience, conserve ecosystem services, and support sustainable land-use transitions in semi-arid regions. This research contributes practical evidence for designing resilient agro-ecosystems that align livestock productivity with biodiversity conservation and climate adaptation goals in the Global South.

Keywords: Behavioural plasticity, dry-season adaptation, ecosystem services, pastoral systems, rangeland governance

Sustainable and resilient poultry production

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Impact of drinking water acidification in broilers: A continental performance analysis

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The use of acidifiers in drinking water is a relatively recent development in poultry production, propelled by cost-efficiency and the implementation of various antibiotic reduction strategies. Organic acids, in particular formic acid and its salts, are well known to improve productivity in animal nutrition. The potential for organic acids to improve the water quality lies in their ability to protect against microbial contamination. This is especially crucial in rural tropical areas, often the centre of local poultry production. The use of acidifiers via drinking water will not only create hygienic conditions in the water itself but also lead to improved performance parameters in the birds. Various trials using a drinking water acidifier based on formic acid and sodium formate (ADDCON XL2.0) have been carried out under a wide range of tropical and sub-tropical conditions across Asia. This study analysed the average impact of the additive, from all data collected, on the performance parameters weight gain, feed efficiency, mortality and production index from commercial and academic trials. The final data-set contained the results of 8 trials in broilers at inclusion rates ranging from 350 ml to 1000 ml per 1000 L water. These studies were carried out between 2012 and 2023 in Indonesia, Pakistan, Philippines, Thailand and Turkey and included more than 223,000 broilers. The results are expressed as the percentage difference from the negative control and given as means. A confidence level of 95 % was defined for these analyses. The average dosage of XL2.0 in all treated broilers was 740 ml/1000 L. Average daily gain of birds was significantly ($p = 0.007$) increased by 5.0 %, while feed efficiency was significantly improved by 3.7 % ($p = 0.009$). An immensely reduced mortality rate was noticed (-17.1%; $p = 0.02$). The resulting overall productivity index was highly significantly ($p = 0.0001$) increased by 10.2 %. This study demonstrates that, under a wide range of different broiler production conditions throughout Asia, including water acidification in broiler production has beneficial effects on the performance of chickens and may be considered a low-cost sustainable option to improve production parameters with no or lowered antibiotic usage.

Keywords: Acidifier, broiler, drinking water, formic acid and formate, livability, productivity

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Effect of hydroponic maize fodder supplementation on growth performance, carcass traits, and economic value of Sasso T44 chickens in Shire, Tigray, Ethiopia

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This study was conducted to evaluate hydroponic maize fodder (HMF) as a cost-effective and sustainable alternative to conventional poultry feed, in response to rising feed costs. The effects of different inclusion levels of HMF (0 %, 10 %, 20 %, and 30 %) on growth performance, carcass characteristics, and economic returns of Sasso T44 chickens were investigated.

A total of 192 birds, aged 28 days, were randomly assigned to four dietary treatments in a completely randomised design, with three replicates of 16 birds per treatment. Parameters measured included body weight gain, average daily gain (ADG), feed intake, feed conversion ratio (FCR), dressing percentage, and economic indicators such as net return and marginal rate of return.

Highly significant differences ($p < 0.001$) were observed among treatments. Birds fed 10 % (T2) and 20 % (T3) HMF performed better than those in the control (T1) and 30 % (T4) groups. The highest final body weight was recorded in T2 (1726.25 g), followed by T3 (1615 g). Similarly, T2 and T3 showed higher weight gain (1308.54 g and 1193.61 g) and ADG (37.39 g day^{-1} and 34.10 g day^{-1}), respectively. Feed efficiency improved in these groups, with lower FCR values of 2.27 (T2) and 2.36 (T3), compared to 2.60 (T1) and 2.79 (T4).

Carcass traits followed a similar trend, with significantly higher slaughter and carcass weights observed in T2 (1913 g and 1120.28 g) and T3 (1886.33 g and 1037.17 g) ($p < 0.01$). Economic analysis indicated that increasing HMF levels reduced feed costs, with the 10 % inclusion level yielding the highest profitability. T2 generated the highest total return (840 ETB per bird) and net income (515 ETB per bird), with a net return of 180 ETB/bird based on partial budget analysis.

In conclusion, moderate inclusion of HMF, particularly at 10 %, significantly enhanced growth performance, carcass yield, and economic efficiency of Sasso T44 chickens. Further studies are recommended to evaluate its effects on digestion, health, and long-term productivity.

Keywords: Carcass yield, feed conversion ratio, growth performance, hydroponic maize fodder, poultry economics, Sasso T44

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Developing a herbal alternative to solve the problem of antimicrobial resistance in broilers production

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The ban on use of antibiotics as a common poultry health control measure, due to its end implication on the users, is a call for replacement in poultry production. This study was conducted to see the effect of replacing synthetic antibiotics with herbal one in broiler production during the dry and wet seasons.A total of ninety-six,21 day-old Abor Acres broilers were randomly allotted to four groups, four replicates and 6 birds per replicate in a completely randomised design. Group 1 (G1) was the positive control group not infected with a culture of Pseudomonas aeruginosa (PA) and no antibiotics, group 2 (G2) was the group with oral administration of PA and treatment with synthetic antibiotic, group 3 (G3) was group infected with PA and 10 ml of herbal antibiotics per litre of water, group 4 (G4) was the group infected with PA plus 20 ml L^{-1} of herbal antibiotics. The experiment lasted for 5 weeks while data on performance, haematology and serum parameters were taken and subjected to one way analysis of variance (ANOVA). Air temperature and relative humidity data were collected via Govee Bluetooth Hygrometer Thermometer and processed using Microsoft 365 Excel. Significant differences ($p < 0.05$) were observed in the performance parameters evaluated with G1 having the lowest final body weight (1692.63g) while the highest final body weight was obtained from birds in group 4 (1977.44 g). Body weight change followed the same pattern as in final weight as we had the highest weight change in group 4 (1731.19 g) while the lowest was found in group 1 (1448.99 g). Significant decrease ($p < 0.05$) were also recorded in feed intake across the group with G1 having the highest feed intake (2259.84 g) while the lowest feed intake (2165.39 g) was recorded in group G3. Serum biochemical parameters showed no significant difference ($p > 0.05$) in this study, but a numerically high serum protein (4.60 %) was recorded in G4. It can be concluded from this study that herbal antibiotics administered at the level of 20ml per litre gave the best results in terms of performance, therefore can perfectly replace synthetic antibiotics in broilers production.

Keywords: Antibiotics, antimicrobial resistance, broilers, humidity, temperature

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Improve chicken feeding with local resources in The Gambia

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Poultry production is vital for livelihoods in the Gambia, particularly in rural and peri-urban areas where chickens contribute to food security, income generation, and cultural practices. However, high feed costs, seasonal shortages, disease, and dependence on imported commercial feed constrain both backyard and commercial systems. The Tanji Education Center for Permaculture (TEC) seeks to strengthen local chicken production by experimenting with sustainable, low-cost feeding strategies using locally available resources.

This study evaluated two home-formulated, low-cost rations – one with (RB) and one without bloodmeal (RTEC) – that were balanced using a formulation software to ensure nutritional adequacy. Their effects on body weight, feed intake, feed conversion ratio (FCR), feed costs per kilogram body weight, and body condition score (BCS) were compared with those of a commercial feed.

A seven-week feeding trial was conducted at TEC using fifteen chickens, five per treatment, individually housed in cages within a randomised block design.

The commercial diet outperformed both local formulations across all parameters. Birds fed the commercial feed achieved significantly the highest weekly weight gain (160 g), whereas RB (73.3 g) and RTEC (62.0 g) supported less than half. Feed intake was greatest in the control group (125 g/day), slightly lower in RB (116 g/day), and significantly lower in RTEC (104 g/day). FCR and feed costs per kilogram body weight followed the same trend, with the commercial diet showing the most favourable FCR (5.84) and lowest cost (263 GMD), compared with RB (11.43; 604 GMD) and RTEC (19.54; 968 GMD). BCS values confirmed significantly better growth in birds fed the commercial diet. Post-trial feed analysis revealed that RB and RTEC were deficient in metabolisable energy, crude protein, and essential amino acids, and contained higher crude fiber. These nutritional limitations likely explain their reduced performance.

Overall, while locally produced poultry feeds are relevant for improving feed autonomy in the Gambia, the evaluated rations did not meet the nutritional needs of chickens and commercial feed remains the most effective option under current conditions. Nevertheless, this study provides a foundation for refining local feed formulations, improving nutrient balance, and assessing ingredient palatability and acceptance.

Keywords: Feed intake, growth performance, local feed formulation, poultry, The Gambia

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Agricultural extension training needs on climate smart practices among poultry farmers in Ebonyi State Nigeria

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This study looks at the agricultural extension training needs of poultry farmers in the Ebonyi State Nigeria for adopting climate-smart practices. The study sampled 80 poultry farmers across the various part of Ebonyi State using a purposive sampling technique and gathered primary data with structured questionnaires. They summarised socioeconomic characteristics using descriptive statistics, including frequency, percentages, mean, and standard deviation. For the establishment of need gaps of these poultry farmers mean scores helped to identify training needs in feeding, housing, and biosafety. A multivariate probit regression model was used to examine factors influencing these needs. The findings revealed that most respondents were male (60 %), married (85 %), and from polygamous households (70 %). Many had limited farming experience (33.8 %). A large portion had no formal education (63.7 %) and had not attended previous training (63.7 %). However, over half were members of poultry associations (53.8 %). Farmers indicated strong training needs in poultry housing (ventilation, insulation, and siting), feeding (use of local ingredients, ration formulation, and feed preservation), and biosafety (disease surveillance, vaccination, biosecurity measures, and waste management), along with emergency response and farm access control. Key challenges included lack of funds, weak extension services, high costs and scarcity of feed and vaccines, poor access to water, unfavourable weather, limited market access, poor transportation, and insufficient skills in managing disease and nutrition. The results also showed that education, farming experience, age, household size, type of labour, gender, marital status, association membership, and prior training significantly affected training needs. The study therefore recommends focused, need-based training programmes to help poultry farmers in the adoption of climate-smart poultry production practices.

Keywords: Agricultural extension training needs, climate smart agriculture, climate smart practices, poultry farmers

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Roselle powder (*Hibiscus sabdariffa*) improves performance and nutrients digestibility in weaner rabbits

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This study was carried out to assess the effect of graded levels of dried roselle powder (*Hibiscus sabdariffa*) on performance and nutrient digestibility of weaner rabbits. In an eight-week feeding trial, sixteen Hyla breed of weaner rabbits were allotted to 4 dietary treatments, 4 replicates and one rabbit per replicate in a completely randomized design (CRD). Dried roselle calyces meal was prepared and fed in graded levels of 0.0 %, (control diet), 0.5 %, 0.75 %, and 1.0 % in g/100 g of the diets. Feed and water were given to the rabbits *ad libitum*. Performance metrics, including feed intake, body weight gain and feed conversion ratio, were measured. Digestibility of dry matter, crude protein, crude fibre, ash, nitrogen free extract and ether were also determined. The data collected were subjected to analysis of variance (ANOVA). The results showed that dietary inclusion of roselle powder had significant ($p < 0.05$) effect on these parameters. Treatment 2 with 0.5 % roselle supplementation recorded the highest final body weight (1539.50 g) and body weight change (817.75 g) compared to other groups. Feed intake was highest in treatment 2 with 0.5 % reselle supplementation (2623.00 g), while the control group (T1) with no roselle had the least (2147.25 g). Feed conversion ratio was most favorable in treatment 3 with 0.75 % roselle powder supplementation (3.08) while the control group had the least favorable FCR of 4.34. Digestibility of nutrients was better for rabbits fed with control diet (0 % roselle) and diet 2 (0.5 % roselle) as they both have higher percentage of the nutrients digested in them. It was concluded that inclusion of roselle powder at 0.5 % improved performance and digestibility of the weaner rabbits.

Keywords: Digestibility, Hyla rabbit, nutrients, performance, roselle

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Promoting poultry bird performance using phytogenics as a healthy modulator of gut morphometry in broiler birds

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In light of growing concerns about antimicrobial resistance and regulatory restrictions on the use of antibiotic growth promoters, there's increased exploitation of natural feed additives as alternatives. This study investigated the effect of dietary supplementation of broiler chicken with pawpaw seed (*Carica papaya*) and black pepper seed (*Piper guineense*) at inclusion levels of 1 % and 2 %, alongside a control group and an antibiotics-supplemented group, on the small intestinal (ileum) morphology responses in broiler chickens.

A total of 240, day-old AHBOR acre broiler chickens were distributed into six treatment groups, having four replicates and ten birds per replicate. The duration of the experiment was a 42-day feeding trial, based on a completely randomised design. On day 42, two birds per replicate were selected and slaughtered. The small intestine (ileum) was excised and placed in a sterile container having 10 % formalin for histomorphological analysis. Parameters measured include villus height, villus width, crypt depth, crypt width and muscle thickness. Data collected on gut morphometry measures were subjected to a one-way analysis of variance (ANOVA), and means were compared using the Duncan multiple range test.

Gut morphometry results revealed that villus height differed significantly ($p < 0.05$) amongst treatments, with birds fed 2 % *Carica papaya* (2.92) exhibiting the highest values, followed by *Carica papaya* 1 % (2.85) and the control group (2.79). Birds fed *Piper guineense* showed moderate values (2.582 % and 2.441 %), while the antibiotic (2.24) treated group recorded the lowest villus height. A similar trend was observed for crypt width, where the 2 % *Carica papaya* (2.80) had the highest values, followed by the control group (2.74) and birds fed *Carica papaya* 1 % (2.71), *Piper guineense* 2 % and *Carica papaya* 1 % showed moderate values. In comparison, the antibiotics group and *Piper guineense* 1 % showed comparatively lower values. No significant differences ($p > 0.05$) were observed in villus height, crypt depth and muscle thickness.

In conclusion, dietary supplementation with *Carica papaya* seed, particularly at 2 % inclusion level, improved gut morphometric parameters in broiler chickens and may serve as a more effective natural alternative to antibiotics in broiler diets.

Keywords: Broiler chicken, gut morphometry, phytogenic, poultry diet

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Dates in poultry nutrition: Effects on growth, carcass yield, blood traits, and immune response to Newcastle disease and infectious bronchitis in Saudi cockerels

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This study evaluated the effects of dietary inclusion of date fruit (*Phoenix dactylifera*) as a sustainable alternative feed ingredient on growth performance, carcass traits, blood biochemical indices, hematological parameters, and humoral immune responses in Saudi native cockerels. A total of 200 cockerels were allocated to four dietary treatments consisting of 0 %, 5 %, 10 %, and 15 % dates using a completely randomised design. Each treatment had five replicates, with 10 birds each. Parameters assessed included growth performance (body weight gain, feed intake, FCR), carcass characteristics (dressing percentage, cut yields), relative organ weights, hematological indices, serum biochemistry, and specific antibody titers against Newcastle Disease (NDV) and Infectious Bronchitis (IBV) viruses. The data were analysed by ANOVA using SPSS v. 21.0. Body weight gain, feed intake, and feed conversion ratio were not significantly affected ($p > 0.05$) by date inclusion up to 15 %. Carcass yield, organ weights, and gastrointestinal lengths also remained comparable among treatments. Blood biochemical analysis revealed significant improvements in the lipid profile, with decreased triglycerides and very low-density lipoprotein levels, and increased high-density lipoprotein levels in birds fed diets containing 15 % dates. Hematological analysis showed a progressive decline in hemoglobin and lymphocyte percentages with higher date inclusion, while other parameters remained unchanged. Notably, dietary inclusion of dates at 10 % markedly enhanced antibody titers against Newcastle disease virus, emphasising the immunostimulatory potential of dates. In conclusion, dietary incorporation of date fruit up to 15 % is safe. It may improve lipid metabolism and humoral immunity, particularly at the 10 % level, supporting its use as a sustainable feed ingredient in poultry production systems.

Keywords: Dates (*Phoenix dactylifera*), growth performance, hematological and biochemical parameters, humoral immunity, Saudi native chickens, sustainable feed ingredient

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Risks and impacts of climate change

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Climate change and tropical crops: Disruption in the geography of coffee and cocoa

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Assessing the impact of climate change on high-value tropical crops such as coffee and cocoa is essential for long-term pro-active adaptation planning. A coherent approach which integrates analysis of change, hazards, risks and potential impacts enables the development of adaptation strategies for the coming decades, while acknowledging that climate-driven impacts will vary significantly across different geographical regions and require differentiated adaptation measures. In this study, we identified the most and least suitable areas for coffee and cocoa production over a 30-year horizon, employing an agroclimatic zones approach and the latest CMIP6 climate projections. This analysis was supported by the integration of Random Forest models with occurrence data, bioclimatic variables for precipitation, temperature and evapotranspiration; and key agro-climatic indices- such as the Number of Dry Days (NDD), Number of Days with Temperature above 30°C (NTx30), and Number of Water Logging Days (NDWL0). These variables were focused on their behaviour relative to presence points through a categorical data reclassification process. These variables act as vital indicators for crop distribution, providing the scientific evidence needed to prioritise climate resilience interventions and steer the transition of perennial production systems over the coming decades.

NDD showed more dry days in Southeast Asia and Oceania, but fewer in Andean and Central American mountains. NTx30 projections revealed widespread warming, especially in the Andes and North-Central Africa. Meanwhile, NDWL0 indicated increased waterlogging in Central and South America, while West Africa's cocoa regions faced a slight reduction in these events.

Our main findings showed that coffee will lose suitability in countries like Indonesia, Tanzania, Southern Mexico and regions in Brazil and Bolivia. In contrast, Colombia, Perú, Honduras and Uganda are expected to remain suitable for production. As for cocoa, we see a widespread shift in agro-climatic zones where comprehensive adaptation is the dominant impact category. While the regions would stay suitable, changes in climatic hazards will require a substantial overhaul of local farming practices to adapt to climate change - a phenomenon particularly evident in Colombia, Venezuela, Perú and Central Africa. Meanwhile, Ecuador, Côte d'Ivoire, and Ghana stood out for maintaining higher future suitability compared to other regions.

Keywords: Agroclimatic indices, climate change, cocoa, coffee, random forest

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Long-term monitoring of tropical oil palm ecosystem fluxes: A comparative study of two ENSO events in Jambi, Indonesia

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The conversion of tropical landscapes into monoculture plantations like oil palm (*Elaeis guineensis*) has fundamentally altered regional carbon and water cycle dynamics. Understanding how oil palm plantations respond to the El Niño-Southern Oscillation (ENSO) is critical for predicting their long-term sustainability. This study presents a comparative assessment of the biophysical and biogeochemical responses of a mature oil palm plantation (FLUXNET site ID-JOP) in the lowlands of Sumatra, Indonesia, from 2014 until 2025. To evaluate ecosystem-scale carbon and water dynamics, high frequency (10 Hz) eddy covariance measurements were obtained from a 22 m tower using a Metek USA-1 sonic anemometer and a LI-7500A open-path infrared gas analyser.

A data processing chain to ensure high-quality meteorological and eddy covariance flux data has been developed. Further for data continuity, meteorological and flux variables have been gap-filled by using a XGBoost machine learning approach and integrating ERA5-Land climate reanalysis data; any remaining long gaps were subsequently filled using a Random Forest model. We quantified Net Ecosystem Exchange, Gross Primary Productivity, Ecosystem Respiration and ecosystem functional properties including Evaporative fraction, Water-use efficiency, and surface conductance. To identify drivers and their contributions, XGBoost machine learning models in combination with SHapley Additive exPlanations (SHAP) analyses were applied.

Previous studies indicate that the 2015 peak was uniquely characterised by a bimodal driver distribution, an initial phase of radiation-driven uptake was superseded by a severe radiative deficit caused by aerosol-induced smoke haze originating from wildfires during the ENSO drought. In contrast, we hypothesise that the less severe 2023-24 event will exhibit a unimodal distribution, where NEE is primarily regulated by thermodynamic constraints. During such El Niño phases, atmospheric vapour pressure deficits typically increase, inducing a reduction in canopy stomatal conductance and other ecophysiological functions to balance carbon gain against water consumption. By comparing the 2015 and 2023 El Niño events, this research characterises how ENSO intensity regulate carbon sequestration.

Keywords: Carbon fluxes, eddy covariance, enso variability, Indonesia, land–atmosphere interactions, tropical agroecosystems

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Climate risk assessment of coastal rice farming in eastern India

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Odisha, located on the eastern coast of India, is among the most climate vulnerable states, where nearly 80 per cent of the geographical area is exposed to natural hazards and about 40 per cent of the population is affected by floods, cyclones and drought. Among the affected, the worst off are the rice farmers, since their livelihoods are closely linked with vulnerable ecosystems and unpredictable weather, making every season a struggle for survival and recovery. Considering these realities, the present study aims to assess the climate risk faced by rice farmers in the flood and cyclone prone districts of Puri and Ganjam by calculating the Climate Risk IndexFlood (CRIF) and evaluating its robustness through sensitivity analysis. Following the Intergovernmental Panel on Climate Change (IPCC) framework, the CRIF integrates three dimensions of risk, i.e. hazard, vulnerability, and exposure, where vulnerability includes sensitivity and adaptive capacity. Based on this framework, 13 major components and 68 indicators were identified, and primary data was collected from 256 rice farmers using a semi-structured interview schedule. The CRIF, standardised from 0 (no risk) to 1 (high risk), showed that although Puri and Ganjam recorded similar values for hazard (0.59 and 0.563) and exposure (0.471 and 0.453), they differed in sensitivity and adaptive capacity, with Puri having higher sensitivity (0.466) and lower risk to adaptive capacity (0.377), while Ganjam showed lower sensitivity (0.341) and higher risk to adaptive capacity (0.441). The major components indicate that farmers in Puri are more vulnerable due to poor drainage, saline intrusion, and prolonged water logging, whereas in Ganjam, frequent flash floods and higher dependence on erratic rainfall are critical concerns. The leave-one-out sensitivity analysis validated the robustness of the CRIF and showed that water and natural disaster impacts significantly affected overall risk. Overall, the study shows that CRIF captures farmers' realities and provides a pathway for targeted interventions such as improving water management in Puri and strengthening rainfed farming resilience in Ganjam to enhance livelihoods in Odisha's climate vulnerable landscape. The CRIF proposed in this study is replicable in other coastal and flood prone regions with suitable refinement of indicators.

Keywords: Climate change, climate risk index, hazard, sensitivity, vulnerability

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Spatial distribution pattern of *Pavetta crassipes* under global change and its implications for conserving savannah

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Among the most significant challenges to biodiversity worldwide is climate change. It has a considerable impact on ecosystem transformation and species distribution patterns. An understanding of the interactions between climate change, human pressures, and the spatial distribution of species is required to implement effective biodiversity conservation strategies. This study analyses the current and future distribution of *Pavetta crassipes* K. Schum. (Rubiaceae), a tropical species that is currently well-represented in Benin and provides important ecosystem services. The analysis is based on species distribution modelling (SDM) and combines presence data from field surveys and the Global Biodiversity Information Facility (GBIF) database with bioclimatic, edaphic, and anthropogenic variables. We estimated potential distributions using the MaxEnt algorithm under current and future climatic conditions (SSP2–4.5 and SSP5–8.5 scenarios up to 2050). The results suggest that the distribution of P. crassipes is associated with climatic gradients, particularly temperature during the warmest quarter (Bio10), as well as with soil characteristics, land use, and human interactions. While ecological niches show significant overlap between the Sudanian, Sudanian-Guinean, and Guinean zones, future projections suggest redistribution and fragmentation of suitable habitats. Notably, the Guinean subgroup is expected to contract significantly. Nevertheless, some areas, particularly those within protected areas and the mountain ranges of northern Benin, could retain favourable environmental suitability. These results underscore the necessity of adopting differentiated conservation strategies that integrate strengthened *in situ* conservation, targeted *ex situ* conservation actions, and the planning of functional ecological corridors to ensure the persistence of *P. crassipes* in Benin in the face of global changes.

Keywords: And ecological zoning, climate resilience, ecological compatibility, global change

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Impacts of climate change on cropping systems in sub-Saharan Africa: Knowledge gaps and research priorities

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Background: Crop productivity in sub-Saharan Africa (SSA) must increase to sustain food security and farmer livelihoods. However, climate change is likely to make this more difficult by intensifying drought and heat stress through rising temperatures greater rainfall variability, and more frequent extreme events, many cropping systems in SSA operate under nutrient-limited conditions, which are often insufficiently considered in impact assessments. Here, we review the current empirical evidence on climate change impacts in key annual arable food- crop systems in SSA. We examine the climate drivers studied, the performance dimensions assessed, and the adequacy of existing approaches for supporting future climate impact assessments.

Methods: A systematic literature was conducted using a structured search in Web of Science and Scopus, complemented by reference tracking. From 1,204 records initially identified, we conducted title and abstract screening, and the full-text screening based on defined inclusion and exclusion criteria. Of these, 182 studies were finally included in the evidence synthesis.

Results: Research on climate impacts under nutrient-limited conditions is largely concentrated outside SSA, and more than 90 % of the studies focus primarily on single climate stressor. Within SSA, research has predominantly focused on drought and water stress and nitrogen limitation, with most studies conducted on maize under field experimental conditions. Most studies assessed crop production, particularly yield and physiology, whereas environmental outcomes, biodiversity, soil processes, and broader system responses

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were rarely considered. In SSA, important food security crops and elevated CO_2 remain understudied. Globally, relatively only 40 studies examine how climatic interactions with nutrient limitation beyond nitrogen.
Implication and outlook: These patterns suggest that current evidence is too narrow to support robust climate impact assessment across SSA cropping systems. Progress will require more coordinated studies in SSA that test climate stress together with nutrient limitations and management options. Future assessments should move towards multi-criteria assessment of cropping system performance. Further model improvement will depend on SSA-based evidence from both targeted experiments and on-farm monitoring. Combining process-based models with machine learning could help integrate diverse field data, identify key stress interactions, and improve model calibration and scaling to support future sustainable intensification strategies in SSA.

Keywords: Climate stress, cropping systems, nutrient limitation, sustainable intensification

The role of anthropogenic climate change in shaping food security: An explicit assessment of 16 West African countries

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Climate change poses a significant threat to food security, particularly through its impacts on agricultural productivity and on livelihoods. Food security is a combination of multiple factors including socio-economic dynamics affecting food access and consumption. Several studies quantify the impacts of climate change on yields, disentangling the effects on other dimensions of food security remains unexplored.

We develop a spatially explicit framework for West Africa to evaluate the impacts of hu-man-induced climate change on food security at the grid-cell level. This framework inte-grates crop model simulations with socioeconomic data. Crop yields for key staple crops - maize, sorghum, and peanut are generated using the APSIMx model under two scenarios: one that includes human-induced emissions (factual) and another that excludes them (counterfactual). To assess food security, we adopt the FAO framework, focusing on three core pillars: availability, stability, and access and utilisation. Food availability is measured through per capita calorie supply derived from simulated crop production. Stability is eval-uated by analysing interannual variability in yields and the probability of crop failure. Food access is represented using spatially detailed indicators of household income and food af-fordability, capturing the economic capacity of populations to obtain food.

Preliminary results show significant anthropogenic climate impacts on crop yields across the region. While elevated atmospheric CO_2 enhanced yields for certain crops through CO_2 fertilisation, these gains only partially offset the adverse impacts associated with increasing temperatures and rainfall variability. Moreover, the magnitude and direction of these effects are spatially heterogeneous and crop-specific. Importantly, the potential benefits from CO_2 fertilisation are frequently counterbalanced by increased interannual yield variability, a higher incidence of unfavourable growing conditions, and rising food demand driven by population growth. As a result, localised improvements in food availability do not necessarily translate into gains in overall food

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security. This decoupling is particularly evident in areas with structural socioeconomic constraints, underscoring the multidimensional nature of food security.
This study provides a novel framework for analysing food security in impact attribution studies without reducing food security to agricultural production, and quantifies the historical burden of anthropogenic climate impacts on nutrition-relevant food availability in vulnerable regions.

Keywords: Attribution, climate change, food security, West Africa

Blue and green water resources: Projected changes under climate change in the Upper Nile basin, Ethiopia

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Future climate change is a critical issue for the Nile River Basin; however, its impact on water resources has been insufficiently studied despite the basin's substantial water potential. This study evaluated the impact of climate change on blue and green water in the Upper Nile, focusing on the Kessie watershed (~65,000 km^2) in Ethiopia, using the Soil and Water Assessment Tool (SWAT+). Multisite model calibration and validation were performed using streamflow data from four gauging stations (the main outlet and three subbasin stations). The quality-managed and homogenised meteorological climate data were used to set up the model. The study used a statistically downscaled best-fitted ensemble of Global Circulation Models (GCMs) from the Coupled Model Intercomparison Project Phase 6 to simulate future blue and green water. The simulations were performed at the three time periods: 2030s (2015 to 2044), 2060s (2045 to 2074), and 2090s (2075 to 2100) under the Shared Socioeconomic Pathways (SSP) (SSP1–2.6, SSP2–4.5, and SSP4–8.5), using simulations based on observed climate data (1986–2014) as a reference to evaluate changes. The SWAT+ demonstrated sufficient-to-excellent performance at all gauging stations. For instance, at the main outlet, the model showed good performance with R^2 = 0.74 (0.74), NSE = 0.71 (0.70), KGE = 0.81 (0.80), and PBIAS = -12.7 (-11.9) for calibration (validation). Both blue and green water components are projected to increase in all future periods. By the end of the 21st century, water yield is expected to increase by 17.6 %, 38 %, and 65 % under SSP1–2.6, SSP2–4.5, and SSP4–8.5, respectively. Green water flow is projected to increase by 8.6 %, 13.5 %, and 17 %, while green water storage may increase by 14 %, 20 %, and 66 %. Increased water yield indicates potential for irrigation and hydropower development in the basin. However, increased water availability may also heighten the risk of flooding and soil erosion, underscoring the need for watershed management and climate adaptation measures.

Keywords: Blue and green waters, climate change, SSP scenarios, SWAT+ editor, SWAT+ Toolbox

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Drivers of cocoa yield variability in on-farm trials across major cocoa-producing countries in West Africa

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In recent years, concern about the effects of climate change on cocoa production has increased. This concern intensified following the significant decline in cocoa productivity reported during the 2023/2024 season, particularly in Côte d'Ivoire and Ghana. This yield decline has largely been attributed to shifts in climatic conditions, including rising temperatures, erratic rainfall patterns, and increased exposure to El Niño events. Previous studies have shown that cocoa is highly sensitive to climate variability and change, including higher temperatures, irregular rainfall distribution, increased frequency of extreme climatic events (e.g., El Niño), and elevated atmospheric CO_2 levels. However, management practices have also been identified as major determinants of on-farm cocoa yields. In this study, we aim to identify the factors associated with cocoa yield variation and assess their potential role in explaining recent yield declines. We analyse data from more than 300 on-farm trials established in 2020 across four major cocoa-producing countries in West and Central Africa: Ghana, Nigeria, Cameroon, and Côte d'Ivoire. We evaluate the effects of management and climate using a hypothesis-driven approach based on cocoa phenology to derive climatic covariates, with harvest date used as a reference point. Detailed data on management practices and fertiliser application were collected throughout the evaluation period (September 2020- September 2025). The objectives of this study are: (i) to identify the main management and climatic factors associated with cocoa yield variation across time and space; (ii) to evaluate the predictive power of these factors in explaining yield variability and yield decline; and (iii) to assess the role of fertiliser application under the observed climatic conditions.

Keywords: Climate change, cocoa yield variability, fertiliser application, management practices, on-farm trials, yield decline

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Effects of long-term reduced tillage on greenhouse gas emissions, soil C and N dynamics and crop-weed responses under ambient and reduced rainfall

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Reduced tillage (RT) is widely promoted to enhance soil organic carbon sequestration, yet its long-term effects on greenhouse gas (GHG) emissions and crop performance remain uncertain under climate change. We used the long-term Garte-Süd field experiment, established in 1970 in Göttingen, Germany, to compare RT with conventional tillage (CT) on a silt loam Luvisol. In 2023, rainout shelters (2 m × 2 m) were installed to exclude 50 % of rainfall. Crop yield, soil CO_2 and N_2O emissions, soil mineral nitrogen (N), microbial biomass carbon (MBC), and dissolved organic carbon (DOC) were quantified under RT and CT at two soil depths (0–10 cm and 10–30 cm). These variables were measured from March to August 2025 under Faba bean, and from October 2025 onward under Winter wheat. Our results showed that rainfall exclusion did not significantly affect cumulative CO_2 and N_2O fluxes, likely because high soil water retention buffered the moderate water deficit. Instead, gas fluxes were mainly regulated by soil temperature, water-filled pore space, and mineral N, with emission peaks following management events. RT did not affect soil CO_2 efflux but tended to increase N_2O emissions. RT also decreased soil mineral N availability, particularly NO_3-, while reduced rainfall further constrained N dynamics and accelerated leaf senescence, with limited effects on plant growth. However, RT showed slightly higher chlorophyll than CT under reduced rainfall, suggesting improved buffering of soil water and nutrient availability. RT was associated with greater labile C availability in the topsoil (0–10 cm), as indicated by the highest MBC and relatively high DOC, suggesting enhanced microbial activity and substrate turnover in topsoil. In 2025, RT did not significantly affect Faba bean yield or yield components, but it consistently increased weed biomass and weed proportion, suggesting a potential shift in crop-weed competition with implications for crop productivity and nutrient use efficiency over time. Overall, long-term RT reshaped topsoil C and N dynamics more strongly than reduced rainfall, while the main agronomic trade-off was increased weed pressure rather than yield loss. These findings highlighted the need to combine conservation tillage with integrated weed management under variable rainfall conditions.

Keywords: Greenhouse gas emissions, long-term reduced tillage, rainfall exclusion, soil carbon and nitrogen cycling

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Phenology and soil moisture dynamics under conservation practices in rainfed sub-humid maize systems

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Drought stress driven by intra-seasonal rainfall variability and rising evaporative demand limits maize productivity in rainfed sub-humid systems of sub-Saharan Africa. This study evaluated the effects of Conservation Soil Water Management Practices (CSWMPs) such as straw mulch, half-moon pits, and permanent planting basins on seasonal, phenological, and depth-wise soil moisture dynamics over three maize growing seasons. Volumetric soil moisture (θnow) was monitored at 0 – 40 cm depth using FDR probes and linked to soil water storage, deficit to field capacity (Dr), available water, and soil physical properties.

Soil moisture increased from planting to vegetative stages, peaked during tasseling to silking (up to 0.43 $m^3\,m^{-3}$), and declined towards maturity. The CSWMPs consistently maintained significantly higher soil moisture than the control ($p \leq 0.05$), with half-moon pits showing the greatest retention during critical growth stages. Enhanced moisture was observed within the root-active zone (10 – 30 cm) and sustained in deeper layers (30 – 40 cm), improving buffering against dry spells. Mixed-effects modeling revealed crop growth stage ($\chi^2 = 50.65 – 86.23$, $p < 0.001$) and soil water storage ($p < 0.001$) as key determinants of θnow, while Dr alone was not significant but interacted strongly with phenology ($p < 0.001$). Bulk density and saturated hydraulic conductivity significantly influenced soil moisture ($p < 0.001$), whereas static thresholds (field capacity, permanent wilting point) were less explanatory.

Overall, the CSWMPs improved infiltration, reduced evaporative losses, and enhanced soil structural functioning, thereby increasing phenology-specific water availability. These results demonstrate that conservation-oriented soil water management strengthens maize resilience and stabilizes yields under increasing climatic variability.

Keywords: Climate-resilient agriculture, hydraulic properties, maize phenology, soil moisture dynamics, soil water management

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Attributing climate change impacts on wheat yields in northern India during the heatwave year 2022

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Extreme weather events are an increasingly important driver of crop yield losses worldwide. Wheat - central to India's food and nutrition security - is highly sensitive to terminal heat stress. In 2022, an early-onset heatwave affected wheat cultivation in its terminal growing phases in northern parts of India, leading to a substantial yield decrease, followed by an imposed export ban on wheat due to domestic food security concerns.
Attribution science is an emerging field that establishes a causal link between climate change and its consequences. While there is robust evidence that anthropogenic climate change has amplified weather extremes, few studies have explicitly attributed observed extreme event related crop losses to anthropogenic climate change. This lack of impact attribution studies limits the evidence base for risk management, adaptation planning, and climate policy.
This study investigates the impact of anthropogenic climate change on wheat yields during the heatwave in northern India in 2022 for the two major wheat-producing states, Punjab and Haryana. We apply a probabilistic climate impact attribution approach and compare simulated yield distributions under a factual (world with climate change), counterfactual (world without climate change) and future climate scenarios. We use downscaled and bias-adjusted CMIP6-based climate data from five climate models. Simulated yields are generated with a crop model ensemble (APSIMx, DSSAT and InfoCrop), allowing for a robust analysis and accounting for crop model uncertainty.
Preliminary results show that climate change did not significantly influence the probability of a low-yield event such as the 2022 yield event, because elevated CO_2 in the factual scenario compensates for the detrimental effects of increased heat stress. In future scenarios, however, increasing heat stress is expected to outweigh potential CO_2 fertilisation benefits, leading to an increased probability of low wheat yields in both the near and far future.
This study advances climate impact attribution by providing a probabilistic, model-based assessment of how anthropogenic climate change influences crop yield risks. By demonstrating that rising heat stress is likely to increase the probability of low wheat yields in the future, this study provides critical evidence to inform climate-resilient agricultural policy and adaptation planning.

Keywords: Apsim, climate impact attribution, heat, india, terminal heat stress, wheat

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Exploring the impacts of climate change on food security and household income: A CGE model approach

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Climate change poses an increasing threat to the commercialisation of agriculture, food security, and rural livelihoods in Afghanistan, where horticultural crops such as grapes, apples, and potatoes play a key role in income generation and food consumption. This study uses an integrated econometric-stochastic-CGE modelling framework to investigate the impact of climate variability and extreme events on crop productivity and commercialisation, and to examine the implications for household income and food security. The analysis follows a three-step approach. First, climate–yield relationships are estimated using panel data at the agroecological zone (AEZ) level, incorporating the non-linear effects of temperature and precipitation, as well as indicators of heatwaves and frost events, and time trend. Second, these relationships are embedded in a stochastic Monte Carlo simulation to generate crop- and region-specific yield distributions under adverse, average, and favourable climate scenarios, producing climate-induced productivity shocks. Third, these shocks are integrated into a computable general equilibrium (CGE) model calibrated to Afghanistan's social accounting matrix to assess the impacts on agricultural commercialisation, food prices, household income, and consumption across the entire economy. Climate variables are obtained from the ERA5-Land dataset (1974–2024), and extreme indicators are constructed using AEZ-specific percentile thresholds. Provincial yield and cultivated area series are reconstructed from national data and limited provincial observations using backcasting, spatial borrowing, normalisation, and smoothing. The regression results revealed AEZ level heterogeneity in crop responses to climate variables, while Monte Carlo simulations indicated yield losses exceeding 20 percent in highly vulnerable regions under adverse climate conditions. Overall, the findings showed that the impacts of climate change on food security and household income depended critically on agroecological conditions, crop composition, and commercialisation pathways. By integrating AEZ-specific econometric estimation, uncertainty-based scenario construction, and CGE modelling, the study provided a coherent empirical bridge from climate variability to distributional and economy-wide outcomes, underscoring that uniform national policy responses masked substantial subnational vulnerability and that climate-resilient agricultural and market strategies were essential for safeguarding food security and rural livelihoods in Afghanistan.

Keywords: Afghanistan, CGE model, climate change, crop commercialisation, food security, household income, Monte Carlo simulation

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Impacts of climate-induced water scarcity on rice production among smallholder farmers in the Northern Region, Ghana

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Climate change has intensified water scarcity threatening rice production and food security in Northern Ghana. Despite the gradual increase in rainfall trends over short rainy seasons, the region is concurrently experiencing recurrent drought conditions and drastic reductions in water bodies, suggesting climate-induced hydrological imbalance. This paradox has raised concerns about the vulnerability of smallholder farmers and sustainability of rice farming in the region. This study assessed the impacts of climate-induced water scarcity on rice production among smallholder farmers in the Northern Region, Ghana using the mixed-method approach. Primary data were collected from 420 rice farmers using semi-structured questionnaire, while secondary data were obtained from reputable sources. Data were analysed using geospatial analysis, descriptive and inferential statistics. The trends analysis showed increasing rainfall suggesting a disconnect between rainfall pattern and effective water availability. Additionally, minimum and maximum temperatures, and minimum relative humidity indicated upwards trends, while maximum relative humidity showed decreasing trend over the period (1990–2022). Spatio-temporal dynamics of land-use/land-cover changes between 2014 and 2024 showed significant expansion in settlement (63.62 %) and cropland (19.23 %), while a decline in vegetation (−25.06 %), water bodies (−33.56 %), and open-land (−5.29 %), demonstrating rapid landscape changes over this period. The result showed that rainfall, minimum and maximum temperatures significantly influenced rice yields over the period (1990-2022). The cross-sectional results indicated that adaptation practices such as improved seed, irrigation practices, and soil moisture conservation, significantly influenced rice yields. The results showed that institutional weakness (19.8 %), water stresses (14.3 %), financial challenges (13.5 %), and climate vulnerability (12 %) accounted for 60 % of the total variance of the farmers' challenges. The study developed two models including Farmer Vulnerability Tree

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(FVT) and Integrated Farmer Vulnerability (IFV) Models for further studies. In conclusion, the study reveals a climate-agriculture paradox, where increasing rainfall does not translate into adequate water availability leading to recurring water scarcity. Climatic factors have a significant influence on the rice yield, underscoring the need for effective adaptation practices. The study recommends the use of FVT and IFV models for future studies, alongside strengthened regional stakeholder-led interventions including capacity building in water-energy-food nexus, and strengthening irrigation systems for sustainable rice production.

Keywords: Ghana, land-use/land-cover changes, multidimensional challenges, rice production, vulnerability, water scarcity

Analysing the combined drought index using geospatial technology in the Tigray region, northern Ethiopia

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Drought continues to be a significant environmental challenge in Ethiopia's Tigray Region, posing serious threats to agricultural productivity, food security, and the livelihoods of local communities. This study develops and applies a Combined Drought Index (CDI) by merging various satellite data sources, such as vegetation, temperature, precipitation, soil moisture, and hydrological indices on the Google Earth Engine (GEE platform). This study analysed CDI for a period of 25 years (2000–2024) to examine spatial and temporal drought dynamics. The findings show that drought is a frequent hazard, with over 50 % of the Region consistently affected across the years studied. Moderate drought was the most prevalent category, affecting between 26 % and 55 % of the study area for each year. Severe droughts were particularly intense in 2004, 2009, 2010, 2012, and 2013, affecting more than 30 % of the land. Although extreme droughts occurred less often, they caused considerable damage, especially in 2008 and 2009. Moreover, the study validated the findings against the EM-DAT disaster records, which supported the accuracy of the CDI-based assessments. The analysis of crop yields showed a strong correlation with the CDI, especially for teff (MAE = 0.67; RMSE = 0.81) and barley (MAE = 0.74; RMSE = 0.97), highlighting their resilience to water stress. Conversely, maize and sorghum had higher prediction errors (MAE = 1.25 and 1.16), pointing to their vulnerability to variability in rainfall. Additionally, regression models indicated a strong correlation between the CDI and rainfall data from 12 sampled stations (R^2 = 0.72–0.78; r = 0.91–0.95), reinforcing the reliability of the CDI as a comprehensive drought indicator. In summary, these findings emphasise the potential of the CDI to improve early warning systems, guide adaptive agricultural strategies, and inform policy decisions. It is essential to promote resilient crops such as teff and barley in cropping seasons, invest in irrigation development, and work on drought-tolerant varieties to mitigate climate risks and enhance food security in Tigray and similar semi-arid Regions.

Keywords: CDI, climate variability, drought, food security, remote sensing

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Modelling the impact of climatic variability and heat stress on olive productivity in Lattakia, Syria

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This study provides a comprehensive econometric analysis of the relationship between climatic variability and olive productivity (*Olea europaea*) in Lattakia Governorate, Syria, spanning more than two decades (2002–2024). Utilizing high-resolution climatic data from the NASA POWER platform integrated with local agricultural records, the research employs the Newey-West estimator. This methodology was specifically chosen to ensure statistical robustness by effectively addressing issues of autocorrelation and heteroskedasticity inherent in long-term time-series agricultural data.

The empirical results confirm that alternate bearing (the biological on-off cycle) remains the primary and most significant determinant of annual productivity fluctuations. From a climatic perspective, the model reveals a statistically significant negative impact of spring rainfall on olive yields. This phenomenon is scientifically attributed to excessive moisture levels during the critical flowering and fruit-setting stages, which physically interferes with wind pollination and creates a highly conducive environment for fungal pathogens, most notably Olive Peacock Spot (*Spilocaea oleagina*).

Furthermore, regarding qualitative indicators of production, the analysis identified a distinct negative correlation between autumn rainfall and oil percentage. The findings suggest that late-season precipitation leads to a dilution effect, where increased fruit water content occurs at the expense of oil concentration, complicating the extraction process. Crucially, the study detected a significant long-term upward trend in May maximum temperatures, rising by 0.09 °C per year. This warming trend signals escalating future risks associated with heat stress during the sensitive reproductive phase.

The study recommends establishing integrated early warning systems for spring humidity management and enhancing phytosanitary strategies against fungal diseases. Additionally, it advocates for optimising harvest timing to adapt to shifting autumn precipitation patterns, ensuring both oil quality and the long-term sustainability of olive production in the Mediterranean coastal region.

Keywords: Alternate bearing, climate variability, Lattakia, Newey-West Model, oil content, *Olea europaea*, spring heat stress

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Behavioural heterogeneity, inequality, and household resilience to shocks: Evidence from Vietnam

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Growing evidence suggests that observed heterogeneity in shock responses cannot be explained by income and asset positions alone. Behavioural preferences and socially embedded perceptions of relative status systematically mediate households' risk-taking, investment decisions, and recovery trajectories, with important implications for the transmission and persistence of shocks. This paper examines how risk preferences and perceived relative well-being interact with initial wealth and ethnic status to shape household resilience to idiosyncratic and covariate shocks in rural Vietnam.

This study draws on three waves of the Vietnam sub-sample of the Thailand–Vietnam Socio-Economic Panel (TVSEP). The panel structure allows for the identification of welfare dynamics surrounding shock events while controlling for time-invariant unobserved heterogeneity, following established approaches in applied vulnerability research.

Household fixed-effects models are employed to estimate the causal impact of shocks on welfare outcomes, allowing for heterogeneous effects across behavioural traits and ethnic groups. To capture complex non-linearities and interaction effects that are difficult to model parametrically, an Artificial Neural Network (ANN) is used to map initial household conditions to long-term resilience outcomes, such as recovery to pre-shock consumption levels. Explainability techniques (SHAP values) are applied to extract interpretable evidence on thresholds, complementarities, and risk amplification mechanisms, in line with recent applications of machine learning in applied economics. The findings provide evidence that behavioural heterogeneity materially conditions shock transmission and persistence at the household level, particularly among ethnic minority households, reinforcing concerns about inequality dynamics. It suggests that uniform social protection instruments may be less effective in environments characterised by strong behavioural and structural heterogeneity. These insights underscore the importance of early, targeted, and behaviourally informed policy interventions to prevent temporary shocks from translating into persistent welfare losses, with direct relevance for central banks and policy institutions concerned with financial resilience, inequality, and the effectiveness of stabilisation frameworks.

Keywords: ANN, behavioural vulnerability, poverty persistence

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Climate variability and cocoa vulnerability in West Africa: Projection and reality

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Africa is among the most affected continents by climate variability and change. Cocoa is an important agricultural export in West Africa (Cameroon, Côte d'Ivoire, Ghana, Liberia, Nigeria, and Sierra Leone). Cocoa production systems in Africa are particularly rain-fed systems and are highly vulnerable to climate variability, with significant implications for crop yields, food security, and livelihoods. This study assesses climate suitability projections against observed climate variability, evaluates their impact on sustainable cocoa production in West Africa from 2014 to 2023, and identifies potential adaptation strategies. The study combines a systematic review of climate variability projections with quantitative analysis of 10-year secondary data (2014–2023) from FAOSTAT (cocoa yield and production), WorldClim2 (precipitation and temperature), and Global Forest Watch (tree cover loss). The secondary data were analysed in R using regression models, trend and anomaly analyses, and a climate vulnerability index, and the results were interpreted alongside evidence from literature.

Results confirm pronounced climate variability across Cameroon, Côte d'Ivoire, Ghana, Liberia, Nigeria, and Sierra Leone, with rainfall anomaly indices indicating unstable precipitation patterns and rising temperatures. Ricardian regression analysis identifies temperature and precipitation as significant determinants of cocoa yield, reinforcing the sensitivity of cocoa systems to climatic conditions. Observed temperature increases, with dry-season values already reaching 35–36 °C, confirming earlier projections of further warming (1.7–2.1 °C by 2050) and suggest that heat stress is becoming an immediate constraint. While total rainfall remains within optimal ranges (1,200–2,500 mm), increasing variability and evapotranspiration are intensifying moisture stress, particularly in transition zones. The Climate Vulnerability Index (CVI) reveals clear spatial differences, with Sierra Leone being consistently more

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vulnerable.
Addressing these challenges requires transitioning to sustainable, diversified production systems to boost resilience and prevent forest encroachment, supported by well-resourced extension services that provide climate information and farmer training. Targeted financial mechanisms and incentives are also needed to promote climate-smart practices and compliance with sustainability standards across the cocoa value chain.

Keywords: Climate, cocoa, productivity, suitability, sustainability

Plant growth rate and photosynthetic capacity of selected Nigerian indigenous and underutilised leaf vegetables under drought- and heat-stress conditions

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Abiotic stresses represent the most limiting conditions for horticultural productivity and plant exploitation worldwide. Important factors among those are water, temperature, and light. In this study water and temperature stress conditions were imposed on three species of Nigerian indigenous leaf vegetables (*Amaranthus cruentus* L.; *Amaranthus hybridus* L. and *Celosia argentea* L.) to evaluate their effects on the plants growth rate and photosynthetic capacity. Plants were raised from seeds in pots at the climate-controlled greenhouse of Justus-Liebig-University, Giessen, Germany. Both heat and drought stress experiments were conducted in two growth chambers, one control (day/night temperatures of 27/20 °C respectively) and one with raised temperature (35/30 °C day/night temperatures respectively). Both chambers also had drought stressed plants and control. The conditions were maintained for 4 weeks. Plant growth indices and photosynthetic capacity of the plants under stress conditions and controls were measured every other day for four weeks using Li_600 and Licor_6800.

Plant growth indices showed that plant height (cm) across the species evaluated was not significantly affected by both the heat and water stresses. However, *Celosia aregentia* was shorter in both controlled and the stressed plants compared to other species. Number of leaves across the species was not also significantly affected by both heat and water stresses. However, *Celosia aregentia* had higher number of leaves in both controlled and the stressed plants compared to other species. The shoot fresh weight (g) was significantly reduced by both heat- and water- stress conditions across the plant species. *Amaranthus hybridus* had highest weight in the control while *Amaranthus cruentus* had highest weight in the heat stressed plants. Stomatal conductance of the water stressed plants was lower compared to control, while it was higher for the heat stressed plants. Stomatal conductance for *Celosia aregentia* under both stresses was higher compared with other species. Net photosynthetic rate was higher in control and lower in heat stressed plants except for *Celosia aregentia*. photosystem II efficiency (PhiPS2) of the species was not significantly affected by both stress conditions. Response of the plants to the stress conditions was species dependent.

Keywords: Climate change, growth rate, heat stress, indigenous vegetables, photosynthesis

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Biogeophysical and biogeochemical feedbacks of West African land use change: A systematic review

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Land use change plays a major role in shaping climate dynamics, particularly in West Africa, where environmental and socioeconomic changes are occurring rapidly. Although research on this topic has expanded in recent years, there remains a lack of targeted synthesis on land use–climate interactions that can directly inform Sustainable Land Management (SLM) strategies and decision-making. This study presents a systematic review of 74 peer-reviewed articles published in English and French between 2010 and 2025, following the ROSES (RepOrting standards for Systematic Evidence Syntheses) protocol. Only studies explicitly addressing land use–climate interactions are considered.

The review examines commonly used approaches for analysing these interactions, synthesizes existing evidence, and identifies key research gaps. Implications for SLM are inferred from the collective findings to support policy and practice. The literature is largely dominated by biogeophysical processes and climate extremes, while biogeochemical aspects remain less explored (18 % of studies).

The findings indicate a clear shift toward landscapes increasingly shaped by human activity. On average, built-up areas have expanded by about 155 %, while cropland has increased by around 40 %, especially at the expense of natural vegetation. Overall, land cover dynamics influence surface temperatures, with a mean coefficient of determination (R^2) of approximately 0.5, as well as precipitation patterns, with values reaching up to 0.8, particularly when linked to vegetation changes. Extreme events, such as floods, are often more associated with poor land management than with change in climate alone. Business-as-usual scenarios project a significant decline in the region's carbon storage capacity. However, restoring natural vegetation under SLM presents important trade-offs, balancing climate regulation benefits against

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land competition and the effect of large-scale atmospheric processes. The review highlights several key gaps for future research.
In addition to the limited attention given to future projections (26 % of studies), there is a scarcity of long-term ground-based data, persistent scale mismatches, and insufficient integration of socioeconomic factors. Most studies adopt one-way approaches, with fewer than 14 % explicitly addressing two-way feedback mechanisms between land use and climate.

Keywords: Climate, interactions, sustainable land management, West Africa

From climate projections to action: A risk assessment framework for resilient economic zones in Africa

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Climate change is intensifying risks to economic zones across sub-Saharan Africa, where rapid urbanisation, resource pressures, and climate variability intersect. This study presents a standardised climate risk assessment framework developed within the NatuReS II programme to support decision-making in selected economic zones in Zambia, South Africa, Tanzania, and Ethiopia. The approach combines climate modelling, contextual analysis, and risk synthesis to generate comparable, policy-relevant insights across diverse settings.

Daily temperature and precipitation projections from multiple CMIP6 global climate models were analysed using a multi-model ensemble approach to capture uncertainty and improve robustness. Data were processed into continuous time series and evaluated against a 30-year historical baseline (1985–2014), following World Meteorological Organisation standards. A set of indicators was derived to assess key hazards, including extreme precipitation, heatwaves, and drought conditions. These indicators were selected for their relevance to infrastructure, water systems, and economic activities within the study areas.

To translate climate hazards into actionable insights, the analysis integrates exposure and vulnerability through a structured hazard–exposure–vulnerability framework. This includes a desk-based assessment of hydrological conditions, socio-economic factors, and environmental characteristics specific to each economic zone. The resulting risk profiles identify key sectoral pathways through which climate impacts may materialize, such as disruptions to water supply, industrial productivity, and urban services.

Across all case studies, results indicate a consistent trend toward rising temperatures, increasing frequency of extreme heat events, and greater variability in precipitation, with implications for both flood and drought risk. While the magnitude and nature of impacts vary by location, common vulnerabilities emerge, particularly related to water security, infrastructure limitations, and rapid, often unplanned urban expansion.

The framework provides a transferable and scalable tool for climate risk assessment at sub-national level. By linking global climate projections with local context, it supports stakeholders in identifying priority risks and informing adaptation planning in economically critical regions.

Keywords: Adaptation planning, climate risk assessment, CMIP6, economic zones, extreme weather, multi-model ensemble, sub-Saharan Africa, urban resilience, vulnerability, water security

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Impact of climate change on paddy yield in rainfed agriculture system

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Climate change poses several risks to agriculture in India, which is vital to food security and the livelihoods of more than half of India's people. Odisha, a coastal rice-producing state in eastern India with high climate fluctuation and considerable physiographic diversity consisting of coastal plains, central plateaus, hilly areas and western undulating uplands, is heavily reliant on the monsoon. Bridging the research gap, the study provides the relative importance of moisture persistence, temperature extremes and their spatiotemporal interconnections with paddy productivity at subdistrict scales in Odisha.

The climate-yield connections for paddy across Odisha, India is quantified using annual block level yields (1995–2023) together with rainfall and temperature indices. Rainfall and temperature indices were calculated from daily India Meteorological Department (IMD) gridded data based on regular IMD operating thresholds and ETCCDI definitions. De-trended and standardised yield series were used to extract climate-driven variability. Climate impacts were assessed through lag diagnostics, two-way fixed-effects panel regression, non-linear threshold modelling, and rolling-window estimation. Spatial risk was summarised by a Composite Climate Vulnerability Index (CCVI).

The results suggest that, despite long-term high yield growth, paddy production has been highly sensitive to climate variability and extremes. The climate-driven fluctuations remain substantial, with detrended anomalies frequently exceeding $\pm$50 %. Drought-year yield losses are strongly spatially structured, exceeding 9–10 % in interior plateau and undulating zones but limited to 2–4 % in coastal plains, reflecting contrasts in irrigation access and soil-moisture buffering. CCVI results identify persistent vulnerability hotspots in western and interior tableland zones, whereas coastal regions remain comparatively buffered. This work demonstrates that there is a high degree of regional variability in vulnerability, suggesting that state-wide uniform approaches to adaptation are unlikely to be beneficial. Instead, adaptation should be regionalised in terms of combinations of climate exposure-yield sensitivity. These findings highlight the necessity for region-specific climate-smart adaptation measures in rainfed agricultural systems to achieve climate resilient agriculture.

Keywords: Agricultural vulnerability, climate vulnerability index, rice

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Influence of power dynamics on multi-level governance of climate adaptation in the water sector of Khuzestan, Iran

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The impacts of climate change transcend political and territorial boundaries, requiring coordinated responses across global, regional, and local scales. This transboundary nature necessitates a shift from traditional, top-down governance toward Multi-Level Governance (MLG) – a system where decision-making authority is distributed among diverse actors, including state institutions, private entities, and civil society. This shift is essential for addressing the intricate socioeconomic challenges posed by climate-induced water scarcity. Although actor plurality promises enhanced learning and accountability, it functions as a double-edged sword. Overlapping responsibilities, fragmented mandates, and conflicting institutional priorities often trigger coordination dilemmas that disrupt essential adaptation processes. The decisive factor in this context is power dynamics: whether institutional interactions gravitate toward an elite-centric arrangement (concentrating power within a small minority) or a pluralistic one (fostering equitable influence) determines the success or failure of climate-responsive policies. However, prevalent literature often conceptualises the state as a monolithic entity, neglecting intense intra-governmental contestation and the ways power asymmetries impact lower-level actors – a challenge acute in the Global South. This analytical blind spot marginalises local stakeholders, allowing institutional elites to maintain disproportionate control over critical decisions. To unpack these complexities, this study focuses on the water sector in Khuzestan Province, Iran, a region facing severe climate stresses. The research adopts a mixed-methods approach. We utilise stakeholder analysis to classify organisations based on their material (e.g., funding, infrastructure) and ideational (e.g., knowledge, policy framing) power resources. This is complemented by semi-structured interviews and Social Network Analysis (SNA) to map interaction patterns and uncover the gap between official structures and the real flow of power. The findings demonstrate that agricultural water governance in Khuzestan reproduces a pervasive form of hidden centralisation. Despite an outward appearance of participation, these structures constrain local agency. Consequently, this study proposes a strategic framework for redesigning governance structures to recalibrate power dynamics, advocating for more inclusive policies essential for the transition toward climate-resilient agro-ecosystems.

Keywords: Climate change adaptation, power dynamics, social network analysis

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Assessing key drivers in shaping farmers' decision towards crop species diversity across Indian districts and agroecological zones

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India, an agrarian country, is highly vulnerable to climate variability, particularly fluctuations in temperature and precipitation. Agrobiodiversity, especially higher crop species diversity (CSD), is considered a potential adaptation strategy that enhances the resilience of the agricultural system against climatic stress. Although several studies have examined climatic variables separately, very limited empirical studies have quantified CSD in relation to climate variability, at both national and sub-national scales in India. This study addresses this gap by analysing the spatiotemporal pattern of CSD across 625 districts grouped into 20 agroecological zones over 23 years (1997–2019), evaluating the impacts of heatwaves, rainfall deficit and irrigation intensity on farmers' crop diversification decisions. CSD was quantified using the Shannon index; heatwaves and rainfall deficit were measured as total heat spell days and standardised rainfall anomaly, respectively. Irrigation was measured as irrigation intensity, a key management variable representing farmers' adaptation capacity. Trend analysis was performed using the MMK test and Sen's slope, while Pearson correlation and the dynamic panel system GMM identified the dominant drivers. Results revealed that CSD exhibits a slow yet significant increase, alongside a strong increase in irrigation intensity ($+1.081\,\text{year}^{-1}$), heatwave days ($+0.220\,\text{days year}^{-1}$), and rainfall deficit ($+0.020\,\text{year}^{-1}$). About 24 % of districts showed a significant increase in CSD, mainly in Southern Peninsular India (agroecological zones - AEZs 3, 6, 7, 8), whereas 23 % showed a significant decline, mostly in the western and southeastern regions (AEZs 11, 12, 18). Heatwave exhibited the strongest negative relationship with CSD, whereas irrigation showed a positive association. Nearly 42 % districts were identified as vulnerable to heatwaves, particularly the western region (AEZ 2 and 4). System GMM further revealed that lagged CSD ($\text{CSD}\,t^{-1}$) positively influenced current CSD. Lagged heatwave reduced CSD, whereas lagged irrigation positively supported CSD, highlighting that

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current crop choices are strongly shaped by past climatic exposure and management conditions. The findings establish heatwaves as the strongest climatic constraint, rainfall deficit as a region-specific stress factor, and irrigation as the most effective adaptation mechanism, highlighting the need for region-specific adaptation policies to build climate-resilient agricultural systems.

Keywords: Generalised method of moments (GMM), heatwaves, irrigation intensity, modified Mann-Kendall (MMK) test, rainfall deficit, shannon index

APSIM-based optimisation of maize-soybean intercropping in Malawi: Calibration, simulation, and sensitivity analysis

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Maize-soybean intercropping is a key strategy for sustainable intensification and food security in sub-Saharan Africa, yet optimising management under variable climates remains challenging. This study applied the Agricultural Production Systems Simulator (APSIM) to calibrate the model, simulate planting windows and nitrogen management, and conduct sensitivity analysis to evaluate system performance and identify key drivers of maize–soybean intercropping in Malawi.

APSIM was calibrated and validated using observed data and subsequently applied to long-term simulations (2005–2024). The model reproduced treatment variability with high accuracy for maize ($R^2 \leq 0.82$; Nash–Sutcliffe Efficiency (NSE) ≤ 0.77) and strong agreement for soybean ($R^2 \leq 0.92$). Simulation results indicated that optimal productivity occurred when crops were sown between mid-December and mid-January, with maize yields of 5.5–9 t ha^{-1} and soybean yields of 0.7–1.2 t ha^{-1}. Simulated nitrogen responses showed that 50–75 kg N ha^{-1} optimised maize productivity and agronomic efficiency, with yields plateauing beyond 100 kg N ha^{-1}, indicating limited responsiveness to higher fertiliser inputs and suggesting potential economic advantages of moderate application rates. Soybean relied largely on biological nitrogen fixation. The simulated trends were consistent with observed data, with early and medium planting resulting in significantly higher yields than late planting.

Sensitivity analysis using the Morris method (μ^* and δ) identified plant population, rainfall, and sowing date as main drivers of yield variability, while strip configuration had minor effects. Soil fertility variables showed low direct influence but strong interactions, and runoff (used as a proxy for soil structural effects linked to tillage and rooting conditions) exerted a stronger influence than other soil-related factors.

Overall, APSIM effectively simulated maize-soybean intercropping systems and highlighted how management choices shape system resilience to rainfall variability and seasonal drought risk for smallholder farmers in Malawi. Importantly, the simulated optimal planting window broadly aligns with current farmer sowing practices in some regions but also suggests that a proportion of farmers planting earlier or later than this window could potentially gain yield benefits by adjusting planting timing and plant population management.

Keywords: APSIM modelling, maize-soybean intercropping, nitrogen management, planting windows, sensitivity analysis, smallholder systems

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A context-sensitive adaptive framework for managing sowing delays in rice–wheat systems

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Timely sowing is a critical determinant of productivity in rice–wheat systems (RWS) across the eastern Indo-Gangetic Plains (EIGP) of India. Planting delays and climate extremes act as a foundational production constraint. Despite the extensive reach of multi-channel advisories to the farmers, most of the existing advisories remain static and based on blanket advisory frameworks. Consequently, they fail to reflect the complex interplay of monsoon variability, resource constraints, and management options that influence real-world farming decisions. We developed a pilot study to send optimum planting date advisory through a mobile app (AgDay). The framework of this dynamic advisory system was created using the integration of ground data, geospatial and crop simulation model. We tested it with 190 farmers in 2023–24 by sending advisories on the optimum planting dates and establishing field trials to ascertain yield gain and found an approximately 1.4 t/ha system level yield gain. The shift from static to dynamic decision support enabled selected farmers to optimise system productivity. Furthermore, keeping our findings as a baseline, we intend to explore the complexity of determining where, why, and what can be possible to modify planting dates that has impeded progress. The current study intends to address a context-sensitive, integrated decision-support framework that identifies climate adaptive intervention pathways to enhance the rice-wheat productivity. A diagnostic research through remotely sensed data, ground level information and scenario-driven analytics will be carried out to understand the farm-level barriers in the region. By integrating binding constraints such as weather variability, agro-management practices and resource limitations, we seek to create a framework to minimise losses and enhance system resilience. This enhanced platform will serve as a theory of change for climate-adaptive agricultural advisory systems in monsoon-dependent regions.

Keywords: Climate-adaptive advisory, Indo-Gangetic plains, remote sensing, rice-wheat systems, simulation model, system yield

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Nature based solutions for climate resilient food systems: Lessons from the eastern and southern Africa

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Food systems in Eastern and Southern Africa face escalating risks from climate change, land degradation, biodiversity loss, and social inequities. These pressures disproportionately affect women and vulnerable communities who depend on healthy landscapes for food security and livelihoods. To address these challenges, the Nature Positive Food Systems for Climate Change Adaptation (Nature+) Program implemented a holistic framework combining gender responsive nature-based solutions (NbS), climate resilient livelihoods, inclusive governance, and community driven learning across Ethiopia, Kenya, and the transboundary Chimanimani landscape of Zimbabwe and Mozambique. By 2025, MEL data showed adoption of NbS by over 52,000 farmers (58 % women), improved land management across more than 30,000 hectares, and growing of 17.9 million predominantly indigenous trees. Over three years, Nature+ supported integrated implementation of Soil and Water Conservation (SWC), Conservation Agriculture Plus (CA+), Assisted/ Farmer Managed Natural Regeneration (ANR/FMNR), and rangeland restoration across ten landscapes. SWC engaged 29,437 individuals, with women comprising 62 % of participants. Practices of terraces, bunds, check dams, zai pits, farm ponds, swales, and gabions reduced erosion, enhanced water retention, and improved soil fertility across cultivated and communal lands. CA+, practised by 36,340 individuals, promoted minimum soil disturbance, permanent soil cover, and crop diversification. Farmers reported improved soil moisture retention, more stable yields, and strengthened resilience to climate variability. Gender responsive adaptations increased participation by women and youth through Village Savings and Loan Associations and Farmer Field Schools. ANR/FMNR was adopted by 26,864 individuals (61 % women), restoring vegetation cover and ecosystem services through protection of natural regeneration, enrichment planting, agroforestry, and grass reseeding. Rangeland restoration reached 10,608 individuals, improving pasture availability and livestock productivity through controlled grazing and community-based management. Biophysical monitoring using a University of Manitoba designed protocol shows measurable ecological gains. Composite soil health scores were higher under NbS than business as usual, with CA+ sites averaging 3.4/5 versus 2.8, and FMNR sites 2.6/5 versus 1.9. Biodiversity assessments showed increased beneficial insect abundance and higher composite biodiversity scores under NbS. These results demonstrate that integrated, gender responsive NbS can simultaneously regenerate soil, conserve water, and restore biodiversity, offering a credible pathway toward resilient and inclusive food systems.

Keywords: Business as usual, climate resilient livelihoods, composite soil health score

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Adoption of climate-resilient rice farming practices in Battambang, Cambodia: Challenges, perceptions, and stakeholder roles

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Cambodia is among the countries most vulnerable to climate change. Rising temperatures, erratic rainfall, and more frequent floods and droughts are expected to negatively affect agriculture, livelihoods, and economic stability nationwide. These hazards cause substantial yield losses and threaten household incomes, particularly for smallholders farmers with limited or no access to irrigation. Climate-resilient agriculture aims to strengthen smallholders' ability to adapt through cost-effective and diversified systems that help secure production. Farmers' decisions are shaped by financial resources, knowledge, social structures, and trust within the village. This study assesses rainfed and irrigated rice farming systems in southern Battambang Province, focusing on adoption of climate-resilient practices, stakeholder influence on farmers' decision-making, and crop diversification.

The findings based on a participative qualitative-quantitative survey with 50 farmers reveal clear differences between the rainfed (RA) and the irrigated area (IA). RA farmers depend almost entirely on seasonal rainfall and typically cultivate one crop per year, whereas most IA farmers produce two or occasionally three crops when plots are close to irrigation canals. Access to water remains highly unequal within the IA.

Eleven climate-resilient practices were examined. Only three are widely known and used: incorporation of rice straw, rainwater conservation, and weather forecasts. Reduced tillage, coordinated cropping calendars, and early warning systems remain largely unknown. A clear gap between awareness and implementation exists for climate-stress-tolerant varieties, cover crops, machine sowing of rice, rice-fish-duck systems, and alternate wetting and drying. Cash-crop diversification is minimal and rice-centered, whereas home gardens for household consumption are more diversified, especially in the RA. Farming families usually keep a few cows, chickens and sometimes ducks

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or grasshoppers. Diversification potential for fodder and cash crops is limited, whereas ponds in the RA offer considerable potential for household consumption and local markets.
Social interactions within the community and with local authorities strongly influence access to information. Projects and farmer training are more common in the IA, leaving RA farmers with limited institutional support.
Overall, the adoption potential follows farmers' perceived constraints. Targeted strategies are needed to reduce information gaps, improve enabling conditions, strengthen trust within communities and ensure accessibility and affordability of such practices.

Keywords: Adoption, Battambang province, Cambodia, climate-resilient, climate-smart, perception, rice-farming

Salinity stress enhances secondary metabolite production in *Fagonia indica*: Insights for climate-resilient medicinal plant resources in dryland ecosystems

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Climate change and land degradation are accelerating soil salinisation in many arid and semi-arid regions, posing significant challenges for plant productivity and biodiversity in dryland agro-ecosystems. Understanding how stress-adapted plant species respond to saline conditions can provide insights into plant resilience while supporting sustainable utilisation of valuable plant bioresources. *Fagonia indica*, a medicinal plant naturally distributed in dry and saline environments, is known for its diverse pharmacologically active compounds; however, the production of these metabolites often varies depending on environmental conditions. This study investigated the effects of salinity stress on biomass production, antioxidant activity, and secondary metabolite accumulation in *F. indica* using controlled culture systems. Callus cultures were exposed to sodium chloride (NaCl) and sodium carbonate (Na_2CO_3) at concentrations of 1, 10, 50, 100, 250, and 500 mM over a 21-day elicitation period. NaCl at 250 mM significantly enhanced biomass production (54.8 g L^{-1}), total phenolic content (7.56 $\pm$ 0.144 μg mg^{-1}), and total flavonoid content (2.24 $\pm$ 0.059 μg mg^{-1}). Antioxidant activity was also highest under this treatment, with FRAP and ABTS values of 371.22 $\pm$ 9.52 and 422.79 $\pm$ 12.44 μmol TEAC mg^{-1} DW, respectively. HPLC analysis revealed increased accumulation of key metabolites including caffeic acid, nahagenin, and betulinic acid. In contrast, moderate Na_2CO_3 treatments showed notable anti-inflammatory activity through inhibition of COX^{-1} and LOX enzymes. These results demonstrate that salinity stress can stimulate the biosynthesis of valuable bioactive compounds in *F. indica*. Such findings contribute to understanding plant biochemical responses to environmental stress and highlight the potential of controlled production systems for sustainable metabolite production from climate-resilient medicinal plant species adapted to dryland ecosystems.

Keywords: Climate change adaptation, dryland ecosystems, medicinal plants, salinity stress, secondary metabolites

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Integrating *azolla*, pruning, and ratoon systems within circular agricultural bioeconomy for sustainable, climate-adaptive rice farming

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Circular agricultural bioeconomy is increasingly recognised as a strategic framework for enhancing soil and food security in sustainable, climate-resilient rice production systems. By optimising biological resource use and nutrient recycling, it sustains productivity while minimising environmental impacts. However, rice production remains constrained by soil degradation, inefficient resource utilisation, and rising greenhouse gas emissions under climate change. These challenges underscore the need for low-emission, regenerative practices that maintain soil functions, improve resource-use efficiency, and stabilise productivity under variable climatic conditions. This study evaluates the integration of *Azolla*, strategic canopy pruning, and ratoon rice systems within a circular agricultural bioeconomy framework to strengthen soil and food security while improving productivity and reducing environmental impacts. The study was conducted using a Climate Field Farmers School (CFS)-based approach in Pangandaran, Indonesia, promoting participatory learning and accelerating farmer adoption of sustainable innovations. *Azolla*, an aquatic fern symbiotically associated with *Anabaena* cyanobacteria, functions as green manure, biofertiliser, and a carbon sequestration agent. It enhances nutrient cycling, supports biological nitrogen fixation, and increases soil carbon accumulation. Field observations indicate that *Azolla* incorporation supplies 40–60 kg N ha^{-1}, reduces synthetic nitrogen fertiliser use by 25–40 %, and increases soil organic carbon by 10–20 %, contributing to yield gains of 10–15 %. Strategic canopy pruning improves plant architecture and light interception, increasing effective tiller formation by 15–25 %. The ratoon rice system enables regrowth after harvest, producing 30–60 % of the main crop yield with 20–40 % lower inputs. Collectively, these practices enhance carbon sequestration by 15–25 %, improve fertiliser-use efficiency by 20–30 %, and increase annual rice productivity by 20–40 %. This integrated system supports low-emission, climate-resilient rice production while strengthening long-term soil and food security

Keywords: Biofertiliser, carbon capture, circular agriculture, green manure, net-zero farming (NFZ), soil ameliorants

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Climate resilience through sustainable rangeland management catalysed by effective early warning: Cross-border region within IGAD

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Karamoja Cluster (Kenya–Uganda cross-border area, extending to Ethiopia and South Sudan) is a hotspot of climate-induced hazards including droughts, rangeland degradation and resource conflicts affecting pastoral and agro-pastoral communities. The BMZ-funded SCIDA III project (Strengthening IGAD's Capacity to Increase Drought Resilience in the Horn of Africa) implemented by GIZ strengthens IGAD's regional role through transhumance development plans and cross-border resilience measures. This contribution demonstrates how Earth Observation (EO) technologies are applied to support sustainable rangeland management (Thematic Area 1), climate-change adaptation and mitigation (Thematic Area 2), and technology/data/knowledge systems (Thematic Area 6). Using multi-sensor satellite data (vegetation indices, soil moisture, land-cover change) from the East Africa Drought Watch platform, combined with participatory ground-truthing and indigenous knowledge, the project characterised and mapped transboundary rangelands, identified grazing capacities, and quantified degradation hotspots.

A tailored multi-hazard early warning system was co-developed for the Karamoja Cluster, integrating EO-derived drought risk profiles, seasonal forecasts, and community indicators into actionable cross-border bulletins. These tools inform timely livestock mobility decisions, early destocking alerts and nature-based restoration planning under the Transhumance Development Plan. Cognizant that most early warning systems usually do not reach the intended beneficiaries in hard to reach areas and in the appropriate medium(localised language), SCIDA III has supported in ensuring in ensuring the effectiveness of early warning system is implemented within the Karamoja cluster through a multi-layered information management system called Husika.

Results show improved rangeland monitoring accuracy (>85 % agreement with field data), earlier drought detection (up to 4–6 weeks lead time), and enhanced cross-border coordination among IGAD member states. Women and youth pastoralists reported higher preparedness and reduced livestock losses during the 2023–2025 dry seasons.

The SCIDA III approach proves that EO-driven, participatory systems, can transform vulnerability into resilience in dryland agro-ecosystems. Scalable lessons for other IGAD clusters and tropical rangelands are discussed.

Keywords: Drought resilience, earth observation, IGAD, Karamoja cluster, multi-hazard early warning, rangeland management, remote sensing, transhumance

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Climate information services and extension systems: Access, constraints, impact, and future outlook for rural cocoa farmers in Ghana

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Climate change and variability have increasingly exposed Ghana's cocoa sector to significant vulnerabilities, resulting in declining yields, reduced export revenues, and threatened farmer livelihoods. One critical but underexplored role of extension agents under the Cocoa Health and Extension Division (CHED) of the Ghana Cocoa Board is the dissemination of timely and accurate Climate Information Services (CIS) to help farmers mitigate climate-related risks.

This study examined cocoa farmers' access to and use of CIS, types of CIS accessed and utilised, dissemination pathways, barriers to reliance on CIS, and its overall impact on farm yield. It also assessed the capacity and challenges of extension agents in delivering CIS. Data were collected from 320 cocoa farmers and 15 extension agents. A Multivariate Probit (MVP) model was employed to analyse the determinants of the types of CIS accessed and used, while Ordinary Least Squares (OLS) regression was used to estimate the effects of extension access and CIS on cocoa yield.

The results indicate that 84.1 % of farmers accessed CIS, 70.3 % used it, and 55.3 % relied on traditional or indigenous knowledge for production decisions. Knowledge-use patterns show that 26.8 % relied solely on traditional knowledge, 41.9 % relied exclusively on CIS, 28.5 % used both CIS and traditional knowledge, while 2.8 % relied on neither source. Multiple response analysis revealed that daily (67.2%; 57.8 %) and weekly (61.5%; 48.7 %) weather forecasts are the most commonly accessed and used CIS types, predominantly disseminated through fellow farmers (68.7 %) and extension agents (65.6 %). Although extension agents demonstrate adequate capacity to deliver CIS, several institutional and logistical constraints hinder effective dissemination.

The OLS results show that extension access and the use of CIS for production were positive and significant determinants of cocoa yield, whereas access alone to CIS has a negative effect, suggesting that access alone does not guarantee improved outcomes without proper utilisation. The MVP results further reveal that demographic/socioeconomic, farm-level, and institutional factors significantly influence both access to and use of various CIS types.

The study recommends that the Ghana Cocoa Board strengthen support for extension agents to improve CIS delivery, productivity, and farmer livelihoods.

Keywords: Climate information services, cocoa farmers, cocoa yield, extension services, multivariate probit model

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Can experiential learning enhance perceived behavioural control for climate adaptation? Experimental evidence from rural Namibia

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As the frequency and severity of climate-related disasters escalate globally, the urgency to adapt to climate change has never been more pressing, particularly for vulnerable communities that are highly dependent on multifunctional agro-ecosystems in the Global South. In Namibia's Zambezi region, projected impacts include higher average temperatures alongside declining precipitation, intensifying heatwaves and aridity while also increasing the likelihood of extreme rainfall events. In such sparsely populated rural land-use systems, large-scale public adaptation can be costly and unevenly distributed, making community-based and individual efforts critical to filling gaps in public provision. These locally driven approaches are often more responsive to the specific needs, knowledge, and priorities of affected populations. However, individual and community responses depend on a range of behavioural and contextual factors, including how people perceive climate risks, their confidence in their ability to act, prevailing social norms, and the costs they associate with adaptation. Influencing such behavioural factors remains a challenge.

In the work presented here, we explore whether an experiential learning game intervention as a structured activities that let participants "learn by doing" through a cycle of direct experience, guided reflection, and active experimentation can enhance perceived behavioural control for climate adaptation. In 26 rural communities in Namibia's Zambezi region, participants played a game simulating resource trade-offs between current and future generations, followed by facilitated discussions on long-term adaptation strategies. Using between-subject comparisons of participants interviewed before, immediately after, and eight months following the intervention, we find that the intervention significantly increased self-efficacy and demand for climate-related information in the short run. While concern for future generations was already high, the intervention broadened participants' normative focus

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to include both current and future generations. At eight-month follow-up, initial gains in self-efficacy had faded, though information-seeking and perceived adaptation costs had risen. Community-level documentation reveals that some further worked on their adaptation prototypes they developed during the workshop, though many faced organisational and technical barriers. Our findings demonstrate that brief experiential interventions can shift key cognitive and motivational drivers of adaptation, particularly among marginalised groups, but sustaining these effects requires ongoing support and clear pathways to action.

Keywords: Behavioural control, climate adaptation, experiential learning, future visioning, Namibia

Factors influencing adaptation practices among smallholder farmers in multi-hazard regions: Evidence from Bali, Indonesia

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The increasing frequency and severity of natural hazards, particularly climate-induced disasters, put growing pressure on agricultural systems, especially in disaster-prone regions such as Indonesia. Repeated and overlapping shocks are affecting smallholder farmers, challenging their ability to sustain their livelihoods and recover. Extensive research has demonstrated that protective motivation can influence farmers' adaptation practices; however, existing studies focus on single hazards or isolated event contexts. This study examines farmers' adaptation practices in Bali, an Indonesian island characterized by multi-hazard conditions. A quantitative survey was conducted among 367 farming households across three districts between June and August 2025. For analysis, the study adopted a typology-first approach using Latent Class Analysis, and the resulting classes were further analysed using Multinomial Logistic Regression.

The class analysis resulted in three adoption categories: (i) No adoption strategy (81.52 %), (ii) On-farm disaster risk reduction (DRR) and seed strategy (13.75 %), and (iii) Off-farm and water strategy (4.73 %). The multinomial logit results indicate that farmers' adaptation behavior is highly dynamic and offer a more complex understanding than a simple adopter-versus-non-adopter classification. In particular, multi-hazard experience is strongly associated with the adoption of on-farm disaster risk reduction practices and seed-saving strategies. Consistent with previous studies, household income is positively associated with both active adaptation strategies, suggesting that greater economic capacity facilitates farmers' ability to respond to disaster risk. Education, farming experience, and farm size also appear to increase the likelihood of adopting on-farm DRR-oriented practices. In the context of motivation to protect livelihoods, the results show that coping appraisal significantly increases the likelihood of not adopting on-farm practices, suggesting that social support functions more as an informal coping mechanism after shocks, and doesn't necessarily translate into the adoption of more proactive on-farm DRR measures.

The findings highlight the need for greater focus and support for farm resilience against geophysical and climate-related extreme weather events.

Keywords: Adaptation practises, climate change, disaster, disaster risk reduction, Indonesia, multi-hazard

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Who adapts and how? Household-level inequalities in coping and adaptation within WEF-nexus in drought-prone Namibia

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Households of smallholder farmers in semi-arid and arid regions across sub-Saharan Africa experience and cope with climate stress differently. Differences in access to resources impact responsive strategies implemented. Recurring droughts and climate variability experienced in Namibia influence smallholder households' daily access to water, energy and food. How they respond varies across households and communities. Although there is growing attention to climate-responsive development, there is limited empirical evidence demonstrating how access to different forms of resources such as water, energy and food shape households' responses to effects of long dry spells, especially droughts. This comparative study investigates variations in coping and adaptation among smallholder households in Hardap (arid) and Oshikoto (semi-arid) regions of Namibia. Through a combination of the Sustainable Livelihoods Framework with WEF-nexus lenses, the study draws on mixed-methods. Household survey data were collected from 216 households across rural and peri-urban communities. Indicators of water, energy and food access were used to construct a Water Access Index, Energy Access Composite Index and the Household Dietary Diversity Score as proxies for food access. These data were analysed alongside livelihood capital indicators. Findings show that socio-economics influence household adaptation capacity. In Hardap urban, households face compounded access challenges despite proximity to infrastructure and formal support systems. Contrary, rural households demonstrated flexibility, implementing diversified livelihood strategies that were not dependent on rainfall but on stronger social networks. Further, the study showed that each household's access to WEF resources shaped types and effectiveness of coping responses. Access to these resources influenced the way households made decisions regarding livestock management, crop choices and when to depend on external support such as the government and church-led drought relief programmes. Households with stronger financial and social capital had the ability to anticipate and adjust to climate

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stress. Households with fewer resources seemed to rely on short-term coping strategies which weakened longer-term resilience. In highlighting different ways households access WEF to survive under drought conditions, the study points to the importance of targeted, community-specific interventions that consider household-level dynamics. This strengthens the need for evidence-based decision-making in designing households and community support for climate-adaptated agro-ecosystems in developing countries.

Keywords: Arid, coping and adaptation, semi-arid

Effects of irrigation scheduling on soil moisture and water use efficiency in quinoa

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Efficient irrigation management is critical for sustainable crop production in water-scarce regions. While drip irrigation systems improve water application efficiency, irrigation performance largely depends on decision-making regarding the timing and quantity of water application. This study evaluates the effects of different irrigation scheduling strategies on soil moisture dynamics, crop yield, and water use efficiency of quinoa (*Chenopodium quinoa* Willd.) under field conditions in northeast Morocco.

A field experiment was conducted using a resolvable row-column design with six irrigation strategies, i.e. sensor-based irrigation, model-based irrigation (FAO Cropwat), farmers' practice-based irrigation, sensor-based irrigation combined with artificial intelligence using weather forecast data, and two deficit irrigation treatments. All plots were drip-irrigated, and treatments were applied from the end of flowering onwards. Soil moisture was continuously monitored using Dragino LSE01 sensors at multiple depths and positions, complemented by periodic soil moisture profile measurements using a PR^2 Profile Probe. Weather data were collected on-site to characterise climatic conditions and to estimate crop water demand.

Preliminary results show that irrigation strategies had a highly significant effect on total irrigation quantities ($p < 0.001$), with farmer-based and model-based approaches applying the largest quantities, deficit irrigation treatments the smallest, and sensor- and AI-based strategies resulting in intermediate levels. Treatment effects on average soil moisture in 20 cm depth within the rows were smaller but still significant ($p = 0.008$). The highest soil moisture levels were observed under farmer-based and model-based irrigation, whereas deficit irrigation resulted in the lowest values. However, most treatments showed overlapping soil moisture ranges, and only the difference between deficit irrigation and farmer-based irrigation was statistically significant ($p = 0.0169$).

These findings suggest that while irrigation strategies strongly influence water application, their impact on soil moisture in the main root zone is more moderate, highlighting the potential of sensor- and AI-based irrigation to reduce water use without substantially reducing soil moisture levels. Additional results, including crop yield, biomass components and water use efficiency, will be presented.

Keywords: Artificial intelligence, drip irrigation, irrigation scheduling, quinoa, soil moisture, water use efficiency

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Determinants of livestock management adaptation to perceived climate change among agro-pastoralists of the Koh-e-Suleiman range, Pakistan

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Agro-pastoral households in Pakistan's Koh-e-Suleiman range face intensifying climate pressures, yet the socioeconomic, ecological, and socio-cultural determinants of their livestock adaptation choices remain largely undocumented. This study investigates what drives the adoption of six adaptive livestock management strategies, namely destocking, transhumance, supplementary feed purchasing, feed stockpiling, hired herder use, and prolonged grazing among 198 Baloch tribal households. The survey was conducted in Dera Ghazi Khan and Rajanpur districts from October 2023 to February 2024. Respondents were from three tribes, namely Buzdar (n = 107), Lighari (n = 47), and Gourchani (n = 44). Adaptation choices were modelled using a binary logistic regression for each strategy and a Poisson regression for the total adaptation count. The predictors were of socioeconomic (herd size, income), ecological (water stress, grazing access), sociocultural (tribe, herder arrangements), and perceptual (composite climate-perception accuracy) nature and were tested in sequential blocks. Gourchani households owned the largest herds (mean = 128 head) compared to Lighari (77) and Buzdar (72) ($p < 0.001$), reported the highest median livestock income (1750 USD versus 1430 USD for Buzdar and 1140 USD for Lighari; $p < 0.002$), and occupied the most water-stressed zones, experiencing on average 2.6 months of annual drinking-water shortage. These structural differences were mirrored in the adaptive strategies, with 66 % of Gourchani practicing transhumance versus 38 % Lighari and 25 % Buzdar ($p < 0.001$). In contrast, Buzdar preferentially stockpiled feed (52 % versus 17 % and 16 % among Lighari and Gourchani; $p < 0.001$), revealing a clear storage-for-mobility substitution. While the counts of total adaptations differed significantly between tribes ($p = 0.005$), composite climate perception accuracy was similar among tribes ($p = 0.792$), implying that behavioural differences in terms of adaptation practices cannot be attributed to dissimilar climate awareness. These findings indicate that resource endowments and tribal affiliation, rather than differences in climate awareness, shape adaptation choices among Baloch agro-pastoralists. The results provide a preliminary evidence base to inform context-specific management advice to livestock keepers faced with climate change effects in Pakistan's semi-arid mountain regions.

Keywords: Adaptation determinants, agro-pastoralism, Baloch pastoralists, climate adaptation, Koh-e-Suleiman range, Pakistan

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Perception, personality and behavioural pathways to agricultural transformation under climate risk

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Climate smart agriculture (CSA) is promoted as a pathway to strengthen resilience and market participation among smallholder farmers, yet the behavioural foundations of adoption remain insufficiently understood. This study investigates how personality traits shape CSA adoption typologies and how these typologies relate to commercialisation and accumulation of crop and livestock within households in Morocco's Marrakesh–Safi region. We achieve this by using survey data from cereal producing households, we employ a multinomial control function approach with personality traits as instruments, complemented by causal mediation analysis. Our results show that personality traits are distal determinants of CSA typology choice, with openness and agreeableness reducing behavioural adoption and extraversion increasing institutional adoption. Behavioural CSA adoption showed a strong and consistent direct effects on household crop-related outcomes, including sales ratios, crop Household Commercialisation Index (HCI), and land allocation. Institutional adoption plays a smaller and more specification sensitive role. In livestock systems, behavioural adoption remains central, but experiential factor, especially concern about climate risks, significantly mediate commercialisation and accumulation decisions. Robustness checks using fractional logit and beta regressions confirm the stability of these findings. Some policy implications include the need for domain specific interventions. Notably, crop policies should strengthen direct behavioural adoption pathways, while livestock policies must integrate risk perception and associated experiential dimensions. Our results also holds implications for targetted interventions and communication strategies for highly exposed and climate vulnerable communities. More broadly, climate adaptation strategies should move beyond uniform interventions, designing targeted, context sensitive approaches that enhance resilience and market engagement among smallholder farmers in climate vulnerable regions.

Keywords: Behavioural adoption, big five traits, climate-smart agriculture, crop commercialisation and livestock accumulation, livelihood outcomes

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Community capitals as enabling conditions for climate adaptation of rural livelihoods in northern of Guatemala

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Northern Guatemala is home to the Lachuá ecoregion, a karst landscape characterised by high precipitation and extensive evergreen and semi-evergreen tropical forests, recognised as a Ramsar Site. This region is inhabited by Q'eqchi' Indigenous communities whose livelihoods are increasingly affected by climate change, within a context of limited information on their socioecological vulnerability.The objective of this study was to develop climate adaptation strategies through the characterisation of livelihoods and the assessment of their socioecological vulnerability.

A mixed participatory approach was applied in three communities, combining workshops (n=9) and semi-structured surveys (n=7). Using the "Uniendo Saberes" (CATIE) methodology, livelihoods were analysed alongside their vulnerability based on exposure, sensitivity, and adaptive capacity, incorporating community capitals as key dimensions. A comparative matrix was also used to prioritise adaptation measures.

The results indicate that drought and increasing temperatures are the main climate threats. Subsistence-based staple crop systems show higher exposure, with delays of up to two months in maize production cycles. In contrast, commercial crops such as cardamom and cocoa exhibit phenological changes, reduced yields, and increased pest incidence. Vulnerability varies among communities and is associated with differences in built, financial, and political capital, with financial capital emerging as the main constraint to adaptation.

Priority measures include agroforestry systems, water harvesting, drought-tolerant crop varieties, watershed restoration. This study provides relevant inputs for climate adaptation planning in rural territories by highlighting that higher levels of financial, physical, and institutional capital are associated with greater adaptive capacity and lower relative vulnerability, as they facilitate access to resources, infrastructure, and decision-making processes. Conversely, deficits in these capitals, combined with constraints in human and social capital, contribute to increased vulnerability, particularly in subsistence-based livelihoods. These patterns influence access to resources and adaptation opportunities, underscoring the need for more inclusive and context-specific adaptation strategies.

Keywords: Climate change adaptation, community capitals, livelihoods, vulnerability

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Embedding climate services in coffee smallholder realities: A broadened conceptual framework for effective interventions

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Climate change is a lived reality for smallholder coffee farmers around the globe. Many farmers already react through farm and household level everyday adaptation; meanwhile coffee value chain actors often push for climate adaptation projects that focus on ensuring consistent quality and supply of coffee. Thus, in the context of price-volatile coffee markets and unequal value chain relationships, climate resilience needs to be thought more broadly to avoid risking maladaptation.

Building on a targeted engagement with literature on smallholder-decision-making, the socio-political dimensions of climate resilience, and (coffee) climate adaptation governance, we developed a framework through an iterative process that combined insights from the literature with reflections from practice-based experiences in global coffee climate adaptation projects. Core dimensions of climate adaptation in smallholder contexts were identified and integrated into an analytical lens that captures how farm-level decision-making, everyday adaptation practices, and externally driven adaptation initiatives interact. To illustrate its explanatory power, the framework is applied to a set of illustrative cases of perceived "paradoxes" encountered when trying to advance climate resilience in coffee farming contexts.

The three core elements of the framework - coffee, climate change, and the general household - help refocus interventions toward supporting holistic resilience and economic development at the household level. The attention paid to the different time scales relevant to each of these elements then also stresses the longitudinal importance, unfolding as overlapping farm-level management timescales, climate change expressing itself through multiple stressors over time, and the time dimension of the yearly and generational cycles related to the farming household. Our framework advances the understanding of climate adaptation in smallholder coffee farming contexts. It allows to discuss adaptation beyond the main cash crop, coffee in this case, and therefore takes a farmer - rather than company focused - point of view, putting the local livelihoods at the center of any intervention and thereby contributing to the literature around transformational, in the understanding as development-orientated, adaptation with high relevance for both coffee production- and development-orientated actors. Lastly, the integration of conceptual reflection with adaptation-orientated climate services is of high relevance to smallholder-focused adaptation processes.

Keywords: Climate adaptation, climate information services, household, maladaptation

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Certification, climate risk, and farmer vulnerability: Evidence from coffee systems in Rwanda

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Agricultural certification schemes are widely promoted as tools to enhance sustainability and improve farmers' ability to cope with climate-related risks. However, evidence on whether certification reduces farmers' vulnerability to shocks remains limited. This study examines the relationship between certification, climatic conditions, farm practices, and shock outcomes among coffee farmers in Rwanda. Using detailed household survey data combined with historical weather indicators, we analyse the pathways linking exogenous climate conditions, certification, farm practices, and shock outcomes. We first show that certification is not systematically correlated with climatic risk, supporting its treatment as conditionally exogenous. We then estimate a sequence of models capturing shock occurrence, severity, coping and mitigation responses. Across all specifications, higher temperatures are consistently associated with greater shock incidence, intensity, severity, and adaptive responses, highlighting the central role of climatic stress. Importantly, these outcomes are self-reported by farmers, yet their strong alignment with objective temperature data provides external validation of perceived climate impacts. In contrast, certification status does not significantly affect any dimension of vulnerability or response behaviour. While certified farmers are more likely to adopt certain agronomic practices, these do not translate into measurable reductions in shock or severity. The role of farm practices is more nuanced. Resistant coffee varieties do not show a statistically significant association with shock outcomes in this specification, suggesting that their protective effect may be limited once other factors are controlled for. Some other practices, such as pruning, are more strongly associated with mitigation responses, suggesting reactive rather than preventive adaptation. Overall, the findings suggest that while certification may influence farmer behaviour, it does not safeguard farmers against climatic risks. This points to a gap between promoted practices and effective risk-reduction under real-world conditions.

Keywords: Climate change, coffee, Rwanda, voluntary sustainability standard (VSS)

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Comparative adaptive responses of improved and indigenous lowland rice to water management under Nigeria's derived-savannah

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Lowland rice production in tropical regions is increasingly constrained by water scarcity and climate variability, creating an urgent need for water saving while not compromising yield. Alternate wetting and drying (AWD) irrigation is a promising option, but lowland rice varietal differences in adaptation under Nigeria's derived-Savannah lack under AWD during the vegetative growth stage. This study evaluated the adaptive responses of three improved lowland rice varieties (Africa Rice Centre) (ARICA 3, NERICA® L-19 and WITA 4) and one indigenous landrace (Ofada) under AWD and continuous flooding, focusing on morpho-physiological traits, biomass accumulation, yield performance, and water-use efficiency. A controlled environment pot-experiment was conducted using hydromorphic inland valley soil with a 4 (varieties) × 2 (water regimes) factorial arrangement with three replicates in a Completely Randomised Design under continuous flooding, providing 5 cm depth from transplanting to maturity. AWD pots were irrigated every 5 days during the vegetative growth stage. Data were collected across five developmental stages, including leaf and root biomass, growth rates, yield components, and water-use efficiency (water applied/grain yield). Mixed-effect models and multivariate clustering were used to identify variety-specific responses. AWD reduced water use by 28%-34 % compared to continuous flooding. Grain yield was maintained in ARICA 3 and NERICA® L-19 under AWD, whereas Ofada recorded an 18 % yield reduction. At reproductive stages under AWD, the improved varieties maintained higher leaf chlorophyll (12–15 % higher over landrace) and greater root volume (~22 % higher) than Ofada,

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indicating stronger adaptation. ARICA 3 exhibited the most stable relative growth rate across water regimes (CV = 8.2 %) whereas Ofada had the greatest variability (CV = 24.7 %). Multiple-index evaluation identified NERICA® L-19 as the most resilient variety, with water productivity 31 % higher than Ofada. The greatest differences were between tillering and flowering growth stages, highlighting this period as the crucial window for water-management. NERICA® L-19 and ARICA 3 exhibit better adaptation to AWD with sustain productivity while conserving water in Nigeria's derived-Savannah lowlands. Prioritizing these varieties in AWD extension packages, include root-traits screening into breeding programmes, and targeting water management during tillering to flowering transition offers climate resilience and supports more sustainable lowland rice systems.

Keywords: Alternate wetting and drying (AWD), biomass accumulation, climate resilience, climate variability, lowland-rice varietal adaptation, tillering to flowering transition, water scarcity, water-use efficiency (WUE)

Birds over benches, middle over rich: Rethinking who pays for climate-resilient blue-green infrastructure and why

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Rapid urbanisation in tropical regions is intensifying heat island effects, flooding and biodiversity loss, driving global interest in blue-green infrastructure (BGI) as a multi-functional, climate-resilient asset. BGI is vanishing fast across the Global South, where densification and encroachment outpace restoration. Investment decisions remain constrained by limited evidence on how residents value BGI attributes, how preferences vary across socioeconomic groups, and whether they attend to all attributes, a behavioural feature that biases valuation. This study jointly models heterogeneous citizen preferences, attribute non-attendance (ANA) and socioeconomic drivers of BGI demand to inform behaviourally grounded prioritisation of climate-resilient investments.

A discrete choice experiment (DCE) surveyed 354 residents (42 % women) in 2025 in Coimbatore, India, a growing tropical city. Each evaluated paired BGI scenarios with four attributes (bird diversity, lake cleanliness, picnic facilities, trails) alongside a recurring annual contribution, yielding 2,478 panel choice observations. Preferences were estimated using a mixed logit model (random parameters, panel structure), with ANA analysis adjusting for ignored attributes.

Only 9.6 % of choices were for the status quo, indicating strong latent BGI demand. Bird diversity was the most valued attribute, generating the largest mean Willingness to Pay (WTP) and most consistent attention, the only attribute earning both. Lake cleanliness had a null mean but the largest dispersion and highest ANA, revealing polarised preferences. Trails added modest WTP, picnic facilities none. Socioeconomic status shaped BGI demand asymmetrically – higher income and younger age strongly increased support, whereas asset wealth had a significantly negative coefficient. This aligns

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with Kotchen's (2006) public-private substitution mechanism, where private environmental amenities crowd out demand for collectively provided green goods, a defining feature of green-space inequity in urbanising contexts. Mid-asset households are the strongest BGI constituency, with bird-diversity preference following an inverted-U across asset levels and the awareness premium concentrated among the asset-rich, signalling latent capacity-to-pay mobilisable through targeted information. ANA correction raised WTP for attended attributes.
Findings inform climate-resilient urban planning: bird-diverse, multifunctional BGI delivers the largest welfare gains; divergent income and asset effects require socioeconomically differentiated rather than uniform provision, and behavioural-economic diagnostics in stated-preference research are essential to avoid misvaluation of urban environmental goods.

Keywords: Bird habitat, climate resilience, Global South, nature-based solutions, urban biodiversity

Supporting community-based climate change adaptation by a low-cost microclimate observation network in the northern Ecuadorian Andes

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The Northern Ecuadorian Andes (NEA), a critical global biodiversity hotspot, faces acute socio-ecological risks resulting from intensive land use and climate change. In 2024, a severe drought facilitated the spread of fires in urban and rural areas around Quito. Only a few months later, the same region experienced intense precipitation events that caused flooding of infrastructure and soil erosion, e.g., by landslides. However, the imprint of these extremes varied strongly from valley to valley, reflecting sharp contrast in topography and land use. Country-wide syntheses revealed that past extreme events left contradicting signals in the high-elevation transition zone between the Pacific and the Amazon slopes where the Metropolitan District of Quito with 2 Mio. inhabitants is located.

To support local climate-change adaptation, we need a better understanding of the sensitivity of local landscapes to climatic extremes, especially to what extent the presence and condition of forest vegetation can buffer local microclimate compared to more open land uses. The sparse coverage of weather stations and the limited spatio-temporal resolution of gridded weather and climate observations such as from the Climate Hazards Group Infrared Precipitation with Stations (CHIRPS), complicate community efforts to integrate climate data in land-use adaptation planning.

In 2024, we therefore established a first network of around 25 low-cost soil moisture and temperature sensors (TOMST TMS) in different land-use types between c. 2000 and 4000 m a.s.l. north and east of Quito, designed for long-term community use. We will present first results from the transition from the dry to the wet season in 2025 across land-use types in comparison to existing weather data and a new weather station in the upper Rio Piganta catchment. Using simple plot-scale metrics of vegetation structure derived from mobile laser scanning (MLS), we will test the effect of vegetation for buffering the microclimate. Overall, we aim to provide a first assessment of the sensitivity of local landscapes and land-use systems in the valleys near Quito and to discuss to what extent these easy-to-handle observational data can support local communities and decision makers in integrating climate and microclimate information into land-use planning.

Keywords: Andes mountains, climate change adaptation, community work, droughts, Ecuador, forest fires, land use change, microclimate, soil moisture, vegetation structure

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Land tenure insecurity and the adoption of sustainable practices in rice production systems in Ghana

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Current rice production systems in Ghana are significantly vulnerable to unpredictable extreme weather events. To combat drought-related losses, many farms have increased their use of irrigation. However, measures aimed at enhancing soil fertility, such as integrated fertility management, which could improve resilience to water stress, are often underrepresented. These investments in soil fertility are long-term and require continuous action. Farmers in Ghana often face land tenure insecurity, cited as a barrier to limited adoption rates. This master's thesis aims to analyse the hypothesis that perceived land tenure insecurity hinders farmers' willingness to invest in climate-smart fertility-enhancing practices. The investigation is based on Protection Motivation Theory (PMT) as an analytical framework to ascertain how perceptions of climate-related threats, maladaptive rewards, and coping appraisals related to soil fertility-enhancing practices form farmers' intention to adopt such practices. We enrich the model by incorporating perceived land tenure insecurity and exploring its role in defining threats and coping appraisals. We employ a quantitative survey, sampling randomly from the population of rice farmers in Ghana. Data analysis uses logistic regression. Pre-survey expert discussions with agronomists and local extension services were already undertaken; the survey is currently in its pilot phase. The expected findings may inform how insecure land tenure can influence farmers' willingness to adopt sustainable practices. We expect that insecure land tenure poses a threat to the current system, but also a maladaptive reward for farmers to adopt soil fertility-enhancing measures. The study contributes to the adoption of technology literature by an explicit examination of the role land tenure insecurity can play. It will further provide evidence-based policy recommendations necessary to strengthen land tenure systems and to facilitate the adoption of practices that enhance the climate resilience of rice production systems in Ghana.

Keywords: Ghana, land tenure, protection motivation theory, sustainable rice farming

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Contextualising the marginal returns of regenerative agriculture on maize performance under climate change in Nigeria

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This study addresses the growing challenge of climate variability, including droughts and erratic rainfall, which threaten maize production and smallholder livelihoods in Nigeria. Despite the increasing promotion of regenerative agriculture (RA) as a sustainable alternative, its marginal returns and heterogeneous impacts on maize performance remain insufficiently understood, particularly under extreme climate conditions. The objective of the study is to examine the marginal effects of RA on maize yield, yield variability, and yield distribution, while accounting for both observed and unobserved farmer heterogeneity. A multistage sampling technique was used to collect cross-sectional data from maize farmers in Southwest Nigeria. Analytical methods include Seemingly Unrelated Regression (SUR) to assess determinants of RA adoption and a Marginal Treatment Effect (MTE) framework to evaluate impact heterogeneity, complemented by robustness checks. Results show that RA adoption significantly improves maize yield and reduces yield variability among adopters, indicating enhanced resilience. However, the average treatment effects remain modest, and benefits are not uniformly distributed. The MTE results reveal that farmers with lower unobserved resistance (e.g., higher adaptability or innovation capacity) derive greater benefits, while those with higher resistance experience limited or even negative returns. Additionally, RA increases yield skewness, suggesting a higher probability of achieving exceptional yields. Key drivers of adoption include land ownership, access to financial services, extension services, and climate change perception, whereas labour intensity and limited awareness constrain uptake. The study concludes that RA holds promise for improving productivity and resilience in climate-stressed maize systems, but its effectiveness is context-specific. It recommends targeted policies that strengthen extension systems, improve land tenure security, and promote farmer awareness to ensure inclusive and scalable adoption of regenerative practices.

Keywords: Climate change, maize yield, marginal treatment effect, Nigeria, regenerative agriculture

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Four decades of nature-based solutions at landscape levels in semi-arid region of northern Ethiopia: Practices and impacts

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Land degradation and rainfall variability remain global challenges. In recent years there is a growing attention on nature-based solutions (NbS) to address effects of climate change. The northern Ethiopia, focus of this study, has been known for land degradation, droughts, food insecurity, and even famine (1984/85). In 2021–2022 the region was also affected by armed-conflict which resulted in one of the worst humanitarian crises. The region has been implementing integrated landscape management (ILM), small-scale water harvesting (SSWH) (e.g. check-dams, ponds, river/flood diversions, etc), dams, and groundwater development at scale for over four decades. We have been documenting and monitoring the performances and impacts of the implemented interventions for 30 years (1995–2025) in five representative watersheds. The study involved: (i) inventory of the implemented interventions, (ii) hydrological monitoring: groundwater levels in wells, suspended sediment concentration in streams/rivers, and discharges of streams/rivers and springs, (iii) assessments of effects on livelihoods, and (iv) assessments of emerging challenges. Our study revealed that though different efforts have been made since the 1970s, the implementations have varied over the years (scale, types, approaches, and impacts)- broadly categorised into five phases: Phase I (1970–1985) - soil and water conservations (SWC) mainly at farm levels; Phase II (1985–1995) - catchment level SWC with some SSWH; Phase III (1995–2010) – ILM, SSWH, dams, groundwater development, and promotion of small-scale irrigation at scale; Phase IV (2010–2020) - upscaling ILM, SSWH, dams, groundwater development, and livelihood diversification; and Phase V (2021–2025) – demand (by local community) and private-sector driven water resources development and agricultural intensification. The earlier phases (Phase I and II) were associated with limited success while the later phases (especially phases III and IV) were more successful as more focus was given to integrated approaches - resulting in: enhanced water availability; improved groundwater quality; reduced erosion and sediment delivery to streams/rivers; and enhanced livelihoods. The implementation of complementary and NbS interventions at landscape levels over the years have not only enhanced water availability, livelihoods and environmental management but also buffered effects of worst crises (droughts and armed-conflicts) in such semi-arid area; a lesson for promoting resilience at landscape levels.

Keywords: Climate change, groundwater recharge, landscape restoration, nature-based solutions, water management

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The role of climate smart agriculture practices on productivity, adaptation, and mitigation in Ethiopia: Systematic review approach

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Agriculture is the foundation of the economy in Ethiopia, which has greatly contributed to the national income and employment. Climate change poses a major threat to agricultural productivity, food security, and sustainability in Ethiopia, where agriculture is predominantly rain-fed. This study systematically reviews the role of Climate Smart Agriculture (CSA) practices in improving productivity, enhancing climate adaptation, and mitigating greenhouse gas (GHG) emissions. Using the Preferred Reporting Items for Systematic Reviews and Meta Analysis (PRISMA) framework, 1,029 studies were identified, of which 52 met the inclusion criteria for analysis. The review shows that CSA practices such as conservation agriculture, integrated soil fertility management, agroforestry, crop diversification, and small-scale irrigation are widely adopted across different agro ecological zones. Education, access to credit, extension services, farm size, and climate information are the key determinants of CSA practice adoption. Empirical evidence consistently identified that CSA practices improve crop productivity, technical efficiency, and farmers' livelihoods while reducing production risks associated with climate variability. Moreover, CSA contribute to climate change mitigation by enhancing soil carbon sequestration and reducing greenhouse gas emissions particularly through agroforestry, conservation agriculture, and improved soil management practices. These reviews confirm the "triple-win" role of CSA in enhancing productivity, adaptation, and mitigation. However, gaps remain in integrated assessments of the three CSA pillars, the role of social capital in adoption processes and long-term environmental impacts. The study concludes that scaling up CSA practices, supported by climate information services, strong institutional frameworks, and financial access, is essential for promoting sustainable and climate resilient agricultural development in Ethiopia.

Keywords: Agricultural productivity, climate smart agriculture, Ethiopia, greenhouse gas emissions, sustainability

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Building climate resilience in semi-arid Zimbabwe through agroecology: Pathways for smallholder farmers in Muzarabani district

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Semi-arid landscapes across southern Africa are increasingly defined by climatic uncertainty, and few places reflect this reality more starkly than Muzarabani District in northern Zimbabwe. Recurrent droughts, shifting rainfall regimes, and rising temperatures continue to erode the viability of conventional rain-fed agriculture, placing smallholder livelihoods under sustained pressure. This study examines agroecology not merely as a set of farming techniques, but as a locally grounded pathway for resilience-building under conditions of climatic stress. The research draws on a multi-layered field design combining household-level data (n = 240), community dialogues, and on-farm observations conducted between 2022 and 2025 across three wards. Rather than isolating single interventions, the study evaluates bundled agroecological practices, including conservation tillage, diversified cropping systems anchored in small grains, water harvesting structures, agroforestry, and the revitalisation of indigenous seed networks.

Findings indicate that households adopting integrated agroecological systems experienced marked improvements in yield stability during drought years, alongside measurable gains in soil condition and reduced dependence on external inputs. More significantly, the results point to less tangible – but equally critical – outcomes: strengthened local knowledge systems, enhanced cooperation among farmers, and increased confidence in managing climatic risk. The study in additionargues that use of local resources is the key stone to climate change adaptation. The paper argues that agroecology's strength lies in its ability to align ecological processes with social realities, making it particularly suited to fragile environments such as Muzarabani. It concludes that scaling resilience in semi-arid regions will depend not only on technical interventions, but on approaches that restore agency, rebuild ecological integrity, and embed adaptation within local knowledge systems.

Keywords: Agroecology, climate adaptation, climate resilience, food security, indigenous knowledge, semi-arid regions, smallholder farmers, sustainable agriculture, Zimbabwe

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Spatiotemporal analysis of climate variability and smallholder adaptation: Evidence from Chewaka resettlement site, southwest Ethiopia

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Understanding spatiotemporal trends of climate variables and farmers' responses is essential for designing effective adaptation strategies. This study examined the spatial and temporal trends and variability of rainfall and temperature across different elevation zones and time periods (1980–2022) in the Chewaka resettlement site, Oromia Regional State, Western Ethiopia. It also assessed farmers' perceptions of climate variability and their adaptation strategies. Historical climate data from CHIRPS-v2 and CHIRTS-ERA5 were analysed using the Mann-Kendall trend test, Sen's slope, coefficient of variation (CV), standard anomalies, and spatial mapping techniques to quantify patterns of change. A structured household survey was conducted to collect data on farmers' perceptions and adaptation responses and analysed using descriptive statistics. Results show a significant increasing trend in mean annual rainfall ($p < 0.001$), increasing by 5.34 mm per year with 9.37 % interannual variability. Seasonal rainfall analysis indicates significant increases during Bega and Belg seasons ($p < 0.05$) with high variability, while changes in Kiremt rainfall were not statistically significant. Spatial analysis revealed highly significant differences in rainfall distribution across elevation zones ($\chi^2 = 117.87$, $p < 0.001$). Both minimum and maximum temperatures showed significant increasing trends ($p < 0.001$), rising by 0.029°C and 0.025°C per year, respectively. The strongest increase in maximum temperature occurred during Belg (0.037°C yr^{-1}), followed by Bega (0.017°C yr^{-1}) and Kiremt (0.016°C yr^{-1}). Tmin also exhibited a consistent upward trend across seasons. Farmers demonstrated strong awareness of climate variability, with 81.6 % reporting rising temperatures and changing rainfall patterns, 79.1 % noting reduced dry-season water availability, 80.7 % observing increased rainfall amounts, and 65.1 % reporting longer dry spells. Common adaptation strategies included crop diversification, soil and water conservation, intercropping, crop rotation, and adjusting planting dates. These strategies are largely low-cost and land-based. The study highlights the value of integrating gridded climate datasets with local knowledge for understanding climate dynamics in data-scarce regions. Findings provide a basis for designing climate-resilient agricultural interventions and sustainable livelihood policies, particularly for vulnerable lowland agroecologies facing population pressure and resource stress.

Keywords: Climate change, rainfall, resettlement, temperature, trend

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Impact of environment and crop management on the variance of maize (*Zea mays* L.) yield in different agroecological zones in Kenya

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Addressing the limited understanding of how environmental factors and crop management affect maize (*Zea mays* L.) grain yields across agroecological zones (AEZs) is essential in improving decision making and climate change adaptation planning in sub-Saharan Africa (SSA). This study evaluated how environmental (seasonal climate factors, soil type) and crop management practices (irrigation, planting dates) affected rainfed and irrigated maize yields in semi-arid, sub-humid and humid agroecological zones (AEZs) in Kenya and identified critical thresholds that demarcated the transition between yield gains and losses. We conducted field experiments in Maktau, Kishenyi and Kabete over four growing seasons (2024–2025), covering both long (LR) and short (SR) rains, applying full irrigation in LR2024 and SR2024 and growth-stage based deficit irrigation in LR2025 and SR2025. AquaCrop was calibrated and validated with the observed data and used to simulate four other early and delayed planting (local planting date $\pm$15 and $\pm$30 days) and corresponding rainfed alongside full and deficit irrigation strategies. We employed XGBoost models to estimate yield responses to seasonal environmental and crop management factors and utilized SHAP (Shapley Additive Explanations) values to quantify the relative importance and influence of each predictor across the AEZs. Across the three AEZs, SHAP-derived yield responses to seasonal irrigation, seasonal rainfall and seasonal mean maximum temperature followed patterns consistent with their respective moisture regimes. In semi-arid Maktau, yield gains were associated with seasonal irrigation above 585 mm and yields declined at seasonal rainfall below ~110mm, while temperature effects were weak and inconsistent across the 29–31°C range. In sub-humid Kishenyi, the yield gains corresponded to seasonal irrigation above 547 mm and seasonal rainfall above ~270–315 mm range, with temperature contributions turning negative above ~24°C. In humid Kabete, yield gains strengthened sharply beyond seasonal irrigation of ~495 mm, seasonal rainfall above ~600 mm, and temperature followed a clear inverted-U pattern, with yield gains between ~23–25°C and losses outside this range. Early planting (local

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planting date −15 and −30 days) consistently produced positive yield contributions across all AEZs, while delayed planting (local planting date +30 days) produced increasingly negative yield contributions. This study highlights the complex AEZ-specific interplay between environmental, crop management and maize yield. The thresholds identified and interaction effects enables transition from broad interventions to targeted AEZs aligned strategies, that improve yield and enhance climate resilience in maize cropping systems.

Keywords: AquaCrop, irrigation, planting dates, sub-Saharan Africa, XGBoost model

Diagnosing agricultural water risk and climate vulnerability in the tropics: A transcontinental comparative assessment of Amazonian and Mozambican watersheds

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Climate-induced water scarcity is rapidly becoming the most binding constraint on rainfed tropical agriculture. The World Resources Institute estimates that twenty-five countries – home to one quarter of the global population – already face extremely high baseline water stress, a figure projected to escalate under CMIP6 trajectories. In agricultural hubs of the Global South, the convergence of declining freshwater availability, intensifying climate variability and Virtual Water Scarcity Risk (VWSR) along agri-food supply chains threatens food sovereignty, rural livelihoods and downstream economic resilience. Yet comparative diagnostics that translate sub-basin hydro-climatic indicators into actionable vulnerability assessments remain scarce, particularly across tropical geographies that are simultaneously climate-sensitive and structurally underserved. This study deploys the WRI Aqueduct Water Risk Atlas 4.0 a peer-reviewed, open-source framework underpinned by the PCR-GLOBWB 2 hydrological model and CMIP6 climate forcings – to diagnose current and projected hydro-climatic risks across two structurally analogous yet geographically distant agricultural frontiers: the municipalities of Belterra, Mojuí dos Campos and Santarém in the Brazilian Amazon (Tapajós sub-basin) and the districts of Boane, Moamba and Namaacha in southern Mozambique (Umbelúzi catchment). A comparative methodology was applied at monthly and annual scales, integrating sector-specific weighting schemes to evaluate quantitative indicators (baseline water stress, interannual and seasonal variability, drought risk), qualitative indicators (untreated wastewater, coastal eutrophication) and ecological vulnerability under business-as-usual, optimistic and pessimistic scenarios for 2030 and 2050. Results converge transcontinentally: quantitative water-stress indicators dominate the composite risk profile, accounting for approximately 70 % of the overall weighting relative to qualitative and ecological dimensions. Consequently, water scarcity already imposes severe, binding constraints on rainfed agricultural systems in both watersheds. Climate projections further indicate thermal increases of 1.0–2.6 °C by mid-century, expected to compress wet-season duration, amplify interannual variability and significantly compromise long-term water availability for staple and commodity production. These convergent findings across the Amazon and southern Africa underscore a shared tropical vulnerability profile and highlight the urgency of embedding Aqueduct-based diagnostics into the design of multi-functional, climate-resilient agro-ecosystems a strategic priority for safeguarding agri-food systems and rural livelihoods across the Global South.

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Enhancing rice farmers adaptation to climate change through combined use of drought-tolerant rice varieties and water-saving technologies in Mali

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Rice is a major staple food for over half of the population in Mali. However, climate change poses significant challenges to rice cultivation in the country due to increasing water scarcity and heat stress and add to the constraints of soil fertility depletion and labour scarcity faced by farmers. Adaptation strategies are urgently needed to reverse the trend in increasing food insecurity. The objective of this study was to identify appropriate management strategies to increase rice yield, labour and water productivities and nutrient use efficiency. On-farm experiments were conducted at two sites (Selingue and Mbewani) during two consecutive seasons (2023 and 2024) and included three water management practices (continuous flooding: CF; alternate wetting and drying: AWD; and farmers' practices: FP) and four rice varieties (ARICA3, GAMBIACA, KAFACI 1 and Sutura) in a split plot design.
Water management and variety had significant effects on rice yield, labour and water productivities and nutrient use efficiency. Compared to FP and CF, AWD resulted in the highest labour productivity (99.9 kg day^{-1}) and water productivity (1 kg m^{-3}), nitrogen use efficiency (88 kg kg^{-1}). AWD increased farmers' yields by 16 % and the net benefits by 26.2 % compared to FP (yields of 9.6 t ha^{-1} and 8.3 t ha^{-1} and net benefits of 1758.5 and 1393.9 USD ha^{-1} respectively). Sutura increased the yields by 62 % and the net benefits by 144 % (1497.4–1716.3 USD ha^{-1}) compared to Gambiaka (yields of 9.4 and 5.8 t.ha^{-1} and the net benefits of 1716.3 and 704.3 USD ha^{-1}). The interactions between water management and varieties were significant with the highest yield and net benefit recorded under AWD combined with Sutura and FP. AWD and Sutura rice could be recommended to the smallholder farmers to increase water and labour productivities, nitrogen use efficiency, rice yield and farmers' income in irrigated systems in Mali.

Keywords: Benefit, income, nutrient, water scarcity, yield

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Hybridizing global carbon finance onto domestic forest governance: Evidence from Vietnam's emission reductions payment program

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Result-based forest carbon finance is increasingly promoted as a forest conservation and climate mitigation instrument in agroecosystems. Its effectiveness depends not only on formal design, but on how global carbon finance requirements are translated into domestic institutions and forest governance. This study examines Vietnam's Emission Reductions Payment Program (ERP) as a case of global-to-domestic institutional translation. It asks how ERP interacted with Vietnam's pre-existing forest governance architecture and what forms of institutional compatibility and divergence emerged through its implementation process. The study adopts a qualitative method combining policy and government document analysis with triangulation of interview evidence from eight key informants at the central level. Rather than considering ERP as a stand-alone intervention, the analysis examines how it interacted with pre-existing institutional arrangements, including Payment for Forest Environmental Services (PFES) fiscal-delivery system, national and provincial forest funds, forest tenure arrangements, and earlier Reducing Emissions from Deforestation and Forest Degradation (REDD+) and Measurement, Reporting, and Verification (MRV) infrastructures. The findings show that ERP's initial implementation leveraged on extant institutional arrangements: PFES and forest fund structures provided an administrative backbone that enabled emission reduction transfer and pay-outs without creating a fully parallel system. However, the compatibility was partial and mainly administrative. Considerable translation work was required to operationalize global requirements of ERP in domestic procedures, reporting, safeguards, and benefit-sharing implementation. The main bottleneck emerged not at the point of initial transfer, but in downstream fund use at subnational level, particularly among state organisational forest owners. Here, legally compliant cash flow was constrained by management plan requirements, approval procedures, and mismatches between forestry implementation cycles and annual financial controls. These tensions shaped how authority and accountability were operationalized within hybrid governance arrangements, and charted complex pathways for benefit-sharing among local actors. The study shows that forest carbon finance is not simply a technical payment mechanism, but a process of institutional reuse, translation and partial integration into domestic governance. In this sense, Vietnam offers lessons for climate-resilient, multifunctional forest landscapes in the Global South, where institutional fit may enable implementation in the short term, but leaves unresolved questions of governance sustainability.

Keywords: Benefit-sharing, forest carbon finance, institutional translation

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Examining climate mitigation and community benefits of community-based forestry: A systematic review

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Community-based forestry has become a widely adopted approach to improve forest governance, involving local communities in forest management through diverse schemes and institutional arrangements. Numerous countries also include this initiative as a climate mitigation strategy. However, despite its broad implementation, a clear understanding of how effectively it reduces greenhouse gas (GHG) emissions and delivers benefits to local communities across different ecosystems remains limited. This study conducts a systematic literature review on how much community-based forestry contributes to climate mitigation, based on empirical studies. Following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework, 185 papers were selected and analysed. Findings show that studies on community-based forestry and climate change mitigation are heavily concentrated in Asia and Africa, with uneven coverage across countries. In terms of ecosystem type, studies focus on terrestrial ecosystems, while wetlands receive considerably less attention. Regarding climate mitigation pathways, carbon stock enhancement and avoiding deforestation emerge as the most examined pathways. Evidence suggests that these actions lead to GHG emission reductions/removals. However, the quantification of climate mitigation potential largely depends on indirect estimation methods and tends to focus on the site scale, with few studies providing estimates expressed in CO_2 units. By implementing climate mitigation actions, local communities receive multiple ecosystem service benefits, including monetary gains. However, income derived specifically from carbon revenue remains limited. In addition, greater attention is needed to develop clear criteria for benefit-sharing mechanism to ensure transparency and equitable distribution of carbon revenue within local communities. This review offers insights to improve the quantification of climate mitigation potential at broader scales, expand the evidence beyond existing studies, and strengthen institutional capacity and funding access. These findings can support future studies and contribute to the development of climate policy frameworks that enhance and sustain community-based forestry practices, helping countries meet their national climate targets.

Keywords: Carbon revenue, climate mitigation, community benefit, community forestry, systematic review

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Land-use change emissions from cocoa in Côte d'Ivoire: Food systems' contributions to national GHG budgets and potential EUDR noncompliance

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Agricultural food systems account for one-third of global anthropogenic greenhouse gas (GHG) emissions, but the share of commodity supply-chains in national GHG inventories is poorly understood, especially in tropical producing countries where most of the emissions are driven by land-use change. In the world's leading cocoa producer, Côte d'Ivoire, the cocoa food system has grown rapidly recently, but its emissions profile and geographical distribution have rarely been quantified accurately.

This study fills that gap. We quantify GHG emissions from the cocoa food system in Côte d'Ivoire between 2010 and 2020, determine which cocoa-producing regions are the most carbon-intensive, and assess what these emissions trends mean for compliance with the EU Deforestation Regulation (EUDR), a policy that prohibits the importation of commodities associated with post-2020 deforestation into the European Union. We address three questions: what extent cocoa production contributes to climate change through land-use change; which cocoa-producing regions are most vulnerable to potential exclusion under the EUDR; and what recent cocoa-driven deforestation patterns suggest about the potential effectiveness of the EUDR.

We use high-resolution satellite imagery, above-ground biomass, and estimates of below-ground biomass, and soil organic carbon to calculate that the cocoa food system produced average emissions of 25.7 tCO□e/ha/year between 2010 and 2020, accounting for about 22.56 % of the entire AFOLU sector, which represents 65.19 % of Côte d'Ivoire's total net GHG emissions. Emissions were highest in the west and south-central regions, where 38 % of Tropical Moist Forest cover lost was converted to cocoa, with Haut-Sassandra (70.3 %), Cavally (52.4 %) and Gôh (50.4 %) having the highest conversion rates. Total emissions were highest in Cavally, San-Pédro, Haut-Sassandra, Tonkpi, and Lôh-Djiboua, while emissions per hectare converted were highest in San-Pédro, Tonkpi, Sud-Comoé, Grands-Ponts, and the Autonomous District of Abidjan.

If this trajectory continues, much of Ivorian cocoa will be potentially excluded from the EU market, one of its major destinations, causing impacts on export earnings and carbon finance. This study provides quantitative evidence to identify high-risk landscapes and support supply-chain due diligence under EUDR requirements.

Keywords: Cocoa, deforestation, EUDR, food systems, land-use, supply-chain

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Agroforestry in the voluntary carbon market: Global patterns and implications for climate mitigation

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The voluntary carbon market (VCM) plays a growing role in mobilising private finance for climate mitigation and carbon removal projects. Beyond carbon sequestration for global climate mitigation, nature-based carbon projects provide multifunctional benefits and are currently still more cost-effective and scalable compared to technology-based carbon projects. This study focuses on agroforestry carbon projects due to their potential to combine food production and carbon sequestration while also potentially enhancing biodiversity and livelihood benefits. However, the contribution of agroforestry projects within the VCM remains poorly understood. This study draws on data from registries of major standards in the VCM to identify and analyses the global distribution and characteristics of agroforestry carbon projects. Results identified a total of 241 project, where 87.6 % of the identified projects are located in Sub-Saharan Africa, South Asia, and Latin America. Only 27.8 % of the projects have issued carbon credits while the rest are still in the pipeline, meaning that there is a high future issuance potential of carbon credits from agroforestry. The highest contribution of credits came from high-value wood agroforestry, followed by coffee, cacao, and fast-growing multipurpose wood and industrial crops. Agroforestry projects in the VCM are associated with multiple Sustainable Development Goals and reflect the potential of aligning climate mitigation efforts with sustainable development objectives. Overall, the findings demonstrate the growing role of agroforestry in the VCM while highlighting the challenges related to transparency, outcome monitoring, and benefit sharing mechanisms involving multiple actors.

Keywords: Agroforestry, carbon credits, climate mitigation, voluntary carbon market

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Carbon markets and food system climate change mitigation: Evidence from the clean development mechanism

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While carbon market mechanisms like the Clean Development Mechanism (CDM) offer a promising pathway to measurable mitigation outcomes, their contribution to food system emissions has not yet been systematically studied. The study applied a quantitative, retrospective analysis using the CDM pipeline dataset, covering projects from 2002 to 2023. A stepwise filtering approach reduced 12,896 projects to 483 food system–related projects related to Article 6, followed by classification across food system stages, project types, and regions. GHG emission reductions were analysed using annual values reported by the projects and modeled with a Gamma-based GLM, while SDG co-benefits were identified through keyword-based text analysis of project documents. Our results show that CDM projects contributed approximately 606,555 ktCO□e in emission reductions across the food system. Food waste management related projects alone account for 562,951 ktCO□e of total mitigation, while production (17,929 ktCO□e), consumption (16,457 ktCO□e), processing (4,759 ktCO□e), preproduction (786 ktCO□e) and projects contributing to more than one food system stage remain marginal. Similarly, mitigation outcomes are dominated by a narrow set of technologies, with landfill gas (66 %), methane avoidance (17.3 %), and biomass energy (13.6 %) accounting for over 96.9 % of total reductions. Regionally, the Americas (49.8 %) and Asia (41.7 %) together contribute more than 90 % of total emission reductions, while Africa accounts for only 8.1 %, highlighting persistent structural inequalities in carbon market participation. Regression results indicate that mitigation performance is primarily driven by project type and duration rather than food system stage or geography. Projects using high-performing technologies and longer implementation periods consistently achieve greater emission reductions. Beyond mitigation, the contribution to sustainable development is uneven. SDG6 (clean water and sanitation) and SDG7 (affordable and clean energy) account for 39.3 % and 22.8 % of project co-benefits, respectively, while 19.5 % of projects report no SDG contribution. Although CDM has demonstrated its ability to mobilise mitigation at scale, it falls short of enabling a balanced, system-wide transformation. These findings highlight the need for more inclusive, flexible, and context-sensitive carbon market mechanisms under Article 6 to unlock the full mitigation potential of food systems.

Keywords: Carbon markets and clean development mechanism, climate finance, food system, greenhouse gas emissions

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Current knowledge and research gaps for manure management in sub-Saharan Africa

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Livestock production in sub-Saharan Africa (SSA) is expanding rapidly to meet the growing demand for animal-sourced foods. This growth generates increasing volumes of livestock manure, which represents both a critical resource for sustaining soil fertility and a significant environmental challenge. When poorly managed, manure contributes to greenhouse gas emissions, nutrient losses, and risks to human and animal health. This presentation synthesizes current knowledge on manure management practices across mixed crop-livestock and extensive pastoral systems in SSA. We evaluate the magnitude and dynamics of nutrient losses and emissions of methane (CH_4), nitrous oxide (N_2O), and ammonia (NH_3) along the entire management chain, from housing and collection to storage and field application. To address these challenges, we assess the viability of context-specific mitigation strategies, including improved collection infrastructure, co-composting with biochar or black soldier fly larvae, anaerobic digestion, and land application. Our review reveals substantial empirical data gaps, particularly the critical lack of whole-chain mass balance assessments and baseline field data on NH_3 emissions under SSA conditions. Furthermore, optimising manure management extends beyond agronomy and climate mitigation; it intimately intersects with public health challenges, including zoonotic pathogen transmission and the environmental spread of antimicrobial resistance. Importantly, the successful adoption of improved practices relies on overcoming socio-economic barriers, particularly regarding labour demands, gender equity, and social inclusion. Ultimately, advancing sustainable manure management in SSA requires coordinated multi-site empirical research, refined whole-farm modelling tailored to smallholder and pastoral realities, and coherent policy frameworks. Addressing these interconnected dimensions is essential to optimise nutrient use efficiency and increase productivity while mitigating environmental and health trade-offs.

Keywords: Ammonia, circularity, methane, nitrous oxide, pastoralism

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Regenerative integrated aerohydroculture within a circular agricultural bioeconomy for flood- and climate-resilient, low-emission paddy systems

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Regenerative agriculture within a circular bioeconomy is increasingly recognised as a strategic pathway to achieve low-emission and climate-resilient rice systems, particularly in flood prone environments. The systems optimise biological resources, enhance nutrient cycling and strengthen ecosystem resilience to sustain long-term productivity. This study aims to evaluate the effectiveness of Regenerative Integrated Circular Aerohydroculture (RICA) in improving soil health, nutrient-use efficiency, carbon sequestration and productivity in flood prone and climate resilient paddy systems. The study was conducted from November 2025 to February 2026 in Pangandaran using a farmer-led participatory approach, with farmers actively involved in experimental design, monitoring and documentation. RICA integrates crop production, livestock and green bioinputs, including *Azolla*, biochar-based organic bioameliorant briquettes (BOB) and green liquid *Azolla* biofertiliser (GLAB), utilising locally available biomass such as rice straw, banana stems, maize stalks and livestock waste to enhance nutrient cycling and soil organic matter. Treatments included *Azolla* (500 g m^{-}2), BOB (1 t ha^{-1}), and GLAB (40 L ha^{-1}, foliar application), combined with the integration of 500 Nile tilapia fingerlings and 100 Mojosari ducks to support nutrient cycling and natural fertilisation. Result showed significant increases in soil microbial biodiversity, with total bacteria reaching 3.5×10^8 CFU g^{-1}, fungi 4×10^4 CFU g^{-1}, nitrogen-fixing bacteria 5×10^6 CFU g^{-1}, and phosphate-solubilising bacteria 5.8×10^8 CFU g^{-1}. *Azolla* contributed 45.73 kg N ha^{-1}, while carbon sequestration reached 712.12 kg C ha^{-1} (2.61 t CO_2-eq ha^{-1} per cycle). Agronomic performance improved, including higher 1000-grain weight, productive tillers, filled grain percentage and rice yields of 6–7 t ha^{-1}. The system also produced 87 kg of Nile tilapia per cycle, indicating enhanced productivity and income diversification. RICA strengthens circular agricultural bioeconomy practices by improving biodiversity, nutrient circularity, carbon sequestration and system resilience, offering a scalable strategy for low-emission, flood and climate resilient rice farming systems.

Keywords: Carbon stock, economy circular, farmer led-research, integrated rice–fish–duck farming

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Which countries and income groups are responsible for the environmental footprints of global food trade?

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Understanding the environmental implications of global food trade is essential for effective climate change mitigation and equitable resource governance. Agricultural production not only deploys resources at the point of origin but also embeds virtual flows of water, land, greenhouse gas emissions (GHG), and biomass in traded commodities, flows that are ultimately driven by the consumption decisions of importing countries. Attributing these environmental costs to final consumers, rather than producers alone, is central to a fair accounting of global sustainability responsibilities. Building on a multi-regional input-output framework (FABIO), we compile a comprehensive dataset of virtual water, land, GHG, and biomass flows covering 192 countries, 125 crop sectors, and the period 1990–2022. A novel crop-specific GHG emission factor panel, interpolated from benchmark datasets and scaled by country-level production intensity, enables temporally resolved accounting of agricultural emissions embedded in trade for the first time at this resolution. Aggregating results by income group reveals stark structural asymmetries. Virtual flows across all four resources have expanded dramatically since 1990, with middle-income countries, many located in the Global South, driving the growth in agricultural exports. High-income countries (HICs), despite being relatively resource-rich, consistently run environmental deficits, as they are net importers of virtual water, land, and GHG-intensive production. This dynamic implies that the ecological burden of feeding wealthy nations is increasingly borne by countries with lower adaptive capacity and often more fragile ecosystems. These findings have direct implications for climate adaptation and mitigation policy. Consumption-based environmental accounting exposes the hidden transfer of environmental pressure from high-income consumers to lower-income producers, undermining the sustainability of agricultural systems in the Global South. We argue that trade-linked environmental accountability must be incorporated into both national climate strategies and international sustainability frameworks if multifunctional, resilient food systems are to be achieved globally.

Keywords: Environmental accountability, responsibility, virtual resources

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Potential of selected soil and water conservation practices to reduce greenhouse gas intensity in sub-humid agro-ecozones of Kenya

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Food insecurity and global warming are major challenges for agricultural production. Soil and water conservation practices (SWCPs) can improve crop yields through hydrothermal regulation and are widely applied as a common practice among smallholder farmers. However, their impacts on net global warming potential (GWP) and greenhouse gas intensity (GHGI) are not well understood. We implemented mulching and tied ridges with the following treatments: mulch-conventional (MCONV), mulch-integrated (MINT), mulch-organic (MORG), tied ridge-conventional (TRCONV), tied ridge- integrated (TRINT), tied ridge-organic (TRORG), and the control in randomised incomplete block design to evaluate the effects of SWCPs on GWP and GHGI. We employed static, vented chamber techniques for greenhouse gas sampling. We used mixed linear model fitted with lmer function during data analysis. Net GWP ($p < 0.001$) and GHGI ($p < 0.001$) significantly varied by treatment. We observed high CH_4 uptake under TRORG (-247 %, $p = 0.02$) compared to the control. There were significantly higher CO_2 and N_2O emissions under MORG and TRORG compared to control. We observed increased CO_2 emissions by +54 % and +65 %, and N_2O emissions by +217 % and +238 % under MORG and TRORG respectively compared to control ($p < 0.05$). Compared to the control, net GWP was higher under MINT (+118 %) and TRINT (+115 %), while it was significantly lower under TRORG (−32 %). We observed high GHGI sinks under TRORG (−86 %), and MRORG (−74 %). Although CO_2 and N_2O emissions increased under organic-based treatments, enhanced CH_4 uptake and yield effects resulted in reduced net GWP and strong GHGI sinks, particularly under TRORG. These findings suggest that integrating tied ridges with organic inputs increases GHGI sinks without compromising crop yields.

Keywords: Climate- smart agriculture, greenhouse gas intensity, greenhouse gas mitigation, sub-Saharan Africa

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Contribution of milk production to total greenhouse gas emissions in Bangladesh

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The objective of this study was to quantify the contribution of milk production to total greenhouse gas (GHG) emissions in Bangladesh. This study applied the Typical Farm Approach (TFA) of the International Farm Comparison Network (IFCN), which is calibrated through the Integrated Dairy Research Network (IDRN) methodology and data. Data from 1930 dairy farms with a major focus on dairy herd structure, feeds and feeding management, milk yield, factors of production (land, labour, capital) and allocation of farm resources between dairy and beef were analysed for regional profiling, and a panel study was performed to construct and validate the typical farms. Two typical farms, BD-2 (Bangladesh 2 cow farm, a household farm that is also called a small farm) and BD-14 (Bangladesh 14 cow farm, a family farm that is also called a large farm), representing 2 and 14 cows, respectively, were selected, and the total GHG emissions expressed as CO_2e were estimated. A system boundary considering both off-farm and on-farm activities where milk is considered until the farmgate delivery (Partial Life Cycle Assessment) was established, and estimation of the GHG was performed via both Tier 1 and Tier 2 approaches according to the Intergovernmental Panel for Climate Change (IPCC). In addition, GHG emissions are corrected for beef production, as dairy farms in Bangladesh consist of dairy but also some beef cattle. Utilizing the total milk production data, total national GHG emissions was 44.57 million ton (using IDRN milk production data) and 62.58 million tons $CO_2e\ year^{-1}$ (using DLS milk production data). On the basis of the total number of dairy farms, a total of 58.7 million ton of CO_2e was estimated. The variations on total GHG emission were mainly attributed due to the differences of the milk production which implies that the IFCN approach is a good tool for farm simulation for GHG emission at national level but needs a reliable database. These results are expected to contribute to policy decisions to identify measures for reducing greenhouse gas emissions at the farm level.

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The limits of carbon market integrity: Governance tensions in land-based carbon credits

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Carbon markets have gained significant relevance as mechanisms for climate finance, with high-integrity credit supply projected to drive demand to 7.9 $GtCO_2e$ by 2030. Yet integrity frameworks remain predominantly focused on carbon accounting methodologies, overlooking the governance tensions that fundamentally shape whether land-based carbon projects deliver legitimate climate outcomes. This research examines how governance tensions at the local level shape what integrity means in land-based carbon credits, using the Paraguayan Chaco as a case study. We explore this question through a relational lens, understanding carbon market integrity not as a technical attribute of accounting methodologies but as something that emerges through relationships between diverse actors, farmers, indigenous communities, government agencies, project developers and the ways these actors relate to nature and each other. From this perspective, integrity is continuously constituted through negotiations over what counts as legitimate land use, whose knowledge matters, and how governance tensions open or close pathways for transformation. The Paraguayan Chaco, represents 62 % of Paraguay´s territory and is one of South America´s most significant carbon sinks. Paraguay recently established a national carbon market regulatory framework, creating a unique opportunity to examine how governance structures interact with perceived territorial tensions before market expansion intensifies them. To ground the relational framework empirically, we conducted Rich Picture Modelling (RPM) workshops in Asunción in May 2025 with 34 participants from 32 organisations across seven sectors, complemented by 44 in-person interviews across four Paraguayan localities. RPM is a transdisciplinary visual methodology that makes visible the values, principles, and material practices through which diverse actors understand governance arrangements, dynamics that formal policy processes routinely render invisible. The analysis revealed four critical governance tensions undermining integrity: formal property rights systems that structurally exclude indigenous communities from project participation; fragmented multi-agency authority creating incoherent regulatory environments; temporal mismatches between multi-decade carbon commitments and short electoral government cycles; and certification frameworks that impose compliance relationships rather than enabling contextually appropriate solutions. This research suggests that recognising these tensions can help navigate and strengthen this carbon market system that delivers on its integrity promise.

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A web-based greenhouse gas calculator to empower climate-aware young farmers toward low-emission agriculture in Indonesia

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According to IPCC 6th Assessment Report, the agriculture sector contributes 22% of the total greenhouse gases (GHG) emissions. To mitigate the emissions from this sector, it is importance to imposed capacity building for the farmers. This study aimed to evaluate the implementation of a web-based GHG calculator as a decision-support tool for enhancing climate awareness among young farmers. The web-based GHG calculator is a user-friendly tool designed to enhance emission accounting and promote climate awareness among young farmers, thereby supporting the transition toward low-emission agricultural practices. The project "Rural Youth Climate Action Movement for Cool Farming (RYCAM)" has been developed with funding support from IKI international to develop a practical web-based GHG calculator tailored to smallholder agriculture in Indonesia context. This tool was based on the GHG Protocol methodology, covering Scope 1 and Scope 2 emissions, and applied a combination of Tier 1 IPCC emission factors and Tier 2 national emission factors. It featured a user-friendly interface to ensure accessibility for young farmers and integrated a basic profit-and-loss analysis to assess the economic feasibility of climate-friendly practices. The tool was implemented in the Young Cool Farmer Challenge (YCFC) program involving five groups of young farmers engaged in diverse crop and livestock enterprises. Participants recorded daily farming activities, calculated monthly emissions, and compiled cumulative emissions over one production cycle. The result shows the GHG calculator enabled systematic emission quantification across farming systems. During the 4-month YCFC program, total emissions per group ranged from 87.91 to 376.14 kg CO_2-eq for crop and livestock production. Crop-based activities contributed approximately 87.91 to 126.96 kg CO_2-eq, while livestock systems accounted for 217.47 to 376.14 kg CO_2-eq. Major emission sources from crop production (horticulture) included chemical fertilizer, fuel, and electricity, while emissions from livestock production mainly originated from feed production and manure management. The use of the tool also enhanced farmers' awareness of emission hotspots and encouraged the initial adoption of mitigation practices such as circular bioeconomy approaches, climate-resilient farming, and regenerative agriculture.

Keywords: Calculator, climate change, greenhouse gasses, low-emission agriculture, young farmers

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Cattle, energy, and emissions: Dynamics of sustainability in Latin America

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Increasing demand for animal-source products has positioned cattle ranching as a strategic driver of rural development in Latin America. However, the environmental footprint associated with its expansion, particularly greenhouse gas emissions, poses a critical sustainability challenge. In this context, improving energy-use efficiency emerges as a key lever for reducing the sector's environmental impact while sustaining productivity growth. This study investigates the dynamic relationships between cattle production, agricultural energy intensity, and environmental degradation – measured as cattle-related CO_2-eq emissions – across 12 Latin American countries over the period 2000–2018. Using Vector Autoregressive (VAR) and Panel VAR (PVAR) models, the analysis explores causal linkages among these variables and evaluates the extent to which energy efficiency can mitigate emissions. The empirical framework integrates sector-specific data on the gross value of cattle production, agricultural energy intensity, and emissions, capturing both regional trends and cross-country heterogeneity. The results reveal a clear unidirectional causal chain: increases in cattle production precede changes in agricultural energy intensity, which in turn drive CO_2-eq emissions. Additionally, cattle production directly influences emissions, reinforcing its role as the primary driver of environmental pressure in the sector. Impulse–response functions show that production shocks initially increase both energy use and emissions; however, over time, improvements in energy efficiency contribute to a gradual reduction in emissions, indicating partial decoupling between productivity and environmental impact. Descriptive and correlation analyses support these findings, showing a strong positive relationship between cattle production and emissions and a negative association between energy intensity and emissions. Forecasting results suggest that continued growth in cattle production may be accompanied by declining energy intensity and a modest stabilisation or reduction in emissions. However, efficiency gains alone may not fully offset the environmental effects of expanding production without broader systemic change. These findings highlight the importance of technological and management innovations in reconciling productivity and environmental objectives. Climate-smart agriculture practices, such as silvopastoral systems, improved forages, and renewable energy use, emerge as effective strategies for enhancing resource efficiency and reducing emission intensity. Scaling such interventions requires integrated policies combining technical assistance, financial incentives, and inclusive governance to accelerate sustainable intensification.

Keywords: Cattle production, climate-smart agriculture, energy efficiency, greenhouse gas emissions, panel VAR (PVAR), sustainable intensification

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Agricultural carbon sequestration and supply chain resilience: Evidence from large language models and multimodal data

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Against the backdrop of intensifying climate change, more frequent extreme weather events, and rising volatility in agricultural product markets, enhancing the resilience of agricultural supply chains has become a critical issue for safeguarding food security, farmers' livelihoods, and the green transition. In response, this paper integrates large language models, multimodal remote sensing data, and causal machine learning methods to identify the effects of agricultural carbon sequestration on supply chain resilience and the mechanisms through which these effects operate. Specifically, the paper employs large language models to conduct semantic parsing and knowledge extraction from policy documents, corporate ESG disclosures, and local government work reports, thereby identifying key variables such as the intensity of low-carbon governance, the degree of supply chain coordination, characteristics of risk exposure, and institutional response capacity. Combined with remote sensing and geospatial information, the study measures regional agricultural carbon sequestration potential, land-use change, and ecosystem stability, and on this basis constructs an indicator system for agricultural supply chain resilience. In terms of identification strategy, the paper applies double machine learning and heterogeneous treatment effect methods to estimate the average and distributional effects of agricultural carbon sequestration on supply chain resilience, while also using complex network analysis to reveal the mechanisms through which risk shocks propagate and are mitigated among supply chain actors.With respect to the underlying mechanisms, this paper focuses on examining whether agricultural carbon sequestration enhances production resilience through the diffusion of green technologies, the optimisation of resource allocation, and improvements in ecological stability; whether it improves contractual relationships and information transparency through low-carbon certification, green preferences, and digital governance, thereby strengthening circulation resilience and organisational resilience; and whether it alleviates financing constraints, reinforces benefit-sharing arrangements, and enhances overall recovery capacity and adaptability through ecological compensation, carbon incentives, and local policy responses. From the perspectives of multimodal data integration and causal identification, this paper extends the research frontier on the economic consequences of agricultural carbon sequestration and provides empirical evidence for the development of multifunctional agricultural ecosystems.

Keywords: Agricultural carbon sequestration, climate shocks, double machine learning, multimodal data fusion, supply chain resilience

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The role of climate information in enhancing household food security in rural northern Ghana

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Climate variability continues to undermine agricultural productivity and household food security in the global south, where smallholder agriculture is predominantly rainfed. Particularly, agriculture in Ghana is highly vulnerable to climate variability, with erratic rainfall, prolonged dry spells, and rising temperatures posing persistent threats to crop production and household food security. Climate Information Services (CIS), including seasonal forecasts, rainfall advisories, and weather warnings, have emerged as critical tools for helping farmers anticipate climate conditions and make informed decisions. Access to timely and reliable climate information is therefore increasingly recognised as an essential component of climate smart agriculture and rural resilience. Despite growing investments in CIS dissemination, there is limited empirical evidence to identify factors shaping household access to climate information, and the pathways through which such information affects yield, food consumption, and food access. Using cross-sectional survey data from 2,934 farm households in rural northern Ghana, the probit model was estimated to identify determinants of households' CIS access, and the mediation framework was applied to trace direct and indirect effects of CIS on food security via yield. Food security was measured using the food consumption score and the household food insecurity access scale. The study reveals that male-headed households, extension access, larger households, literacy, ownership of phones and radios, higher asset levels, and perceptions of increased temperature and reduced rainfall significantly increase the probability of accessing CIS. Regional dummies reveal substantial spatial inequalities, with households in the Northeast and Upper West significantly less likely to access CIS. The mediation estimate reveals that CIS significantly increases FCS by approximately 21 % and reduces HFIAS by about 10 %. Therefore, the study concludes that CIS is an effective resilience-building tool that improves both farm productivity and household food security. It recommends expanding extension services, mobile-based CIS delivery, and prioritising underserved locations to maximise the benefits of climate information for vulnerable farming households.

Keywords: Causal mediation analysis, socioeconomic factors

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Mapping lived urban food environments: Revealing social-spatial disparities and public health implications

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Food environments are the interface between people and the food system, playing a central role in shaping diet and nutrition outcomes. Centring lived experiences of food environments is critical for understanding how policies operate in practice and identifying entry points for effective interventions. However, such research remains limited and predominantly qualitative. This study examines how lived experiences of urban food environments shape food purchasing and consumption behaviours across socioeconomic (SES) groups using a quantitative Public Participation Geographic Information System (PPGIS) approach. Between February and June 2025, a total of 501 adults were recruited through face-to-face interviews using stratified random spatial sampling in Kuala Lumpur, Malaysia. Participants geocoded home locations and food outlets they visited monthly, and completed a structured questionnaire assessing sociodemographic characteristics, food outlet usage, food insecurity, and dietary diversity. Participants were classified into higher and lower SES groups using two-step cluster analysis. Results revealed a transition in food outlet usage, with increased reliance on modern retail and food-service outlets, reflecting greater dependence on food-away-from-home, particularly among higher SES individuals. Higher SES individuals had significantly higher dietary diversity scores than lower SES individuals ($p = 0.006$), though average travel distances to food outlets did not differ significantly. Spatial analysis showed that both SES groups demonstrated high mobility in sourcing food, engaging with diverse food outlets beyond their residential neighbourhoods. However, pronounced socio-spatial disparities in outlet utilisation were observed, with certain areas predominantly utilised by specific SES groups, suggesting that socioeconomic factors such as purchasing power may outweigh spatial proximity in urban contexts. This study advances food environment research by applying a novel PPGIS approach that integrates spatial and non-spatial data to link "where", "who", and "what", providing nuanced, context-specific insights into how individuals navigate complex urban food environments. The findings highlight critical public health implications, emphasising the need for targeted, equity-focused interventions to improve both physical and financial access to healthy foods, particularly for lower SES populations.

Keywords: Activity space, dietary behaviours, food environment, lived experience, participatory mapping, socioeconomic inequalities, urbanisation

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Bridging policy design and implementation gaps in school feeding programmes: Experimental evidence from Benin

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Globally, School Feeding Programmes (SFP) are increasingly recognised as strategic entry points to improve child nutrition, educational outcomes, and sustainable food systems. In Benin, national policies promote diversified diets and local procurement within a food systems framework, yet their effective implementation at school level remains limited.

This study examines the policy–implementation gap in SFP and evaluates whether an integrated, participatory intervention can translate policy intent into measurable outcomes. A mixed-methods, end-to-end approach was applied across diverse schools' geography combining dietary assessment using Dietary Diversity Score (DDS) (n = 1,050), anthropometry, menu observations, school food environment assessment, and stakeholder analysis. Findings informed a Randomised Controlled Trial (RCT) targeting key bottlenecks across demand, supply, and enabling environments.

Baseline results revealed structural constraints within school food systems. Meals showed low DD(mean DDS: 5.8$\pm$5.4/14), with fewer than 22 % of children consuming fruits and vegetables daily. Food environments lacked diversity in 75 % of schools, and local procurement remained limited, reflecting weak integration of value chains. Undernutrition persisted (stunting 13 %, wasting 15 %, underweight 13 %), with DD significantly associated with nutritional status.

The intervention combined complementary actions across multiple leverage points. Nutrition education sessions were delivered to all school actors to improve knowledge and behaviours. School gardens were established to increase direct access to fresh commodities, while local producers received technical and organisational capacity strengthening to enhance production, aggregation, and supply to schools. In parallel, WASH infrastructure and prac-

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tices were improved to strengthen the overall school food environment. This integrated design simultaneously addressed demand-side behaviours, supply-side constraints, and enabling conditions. Intervention fidelity was monitored throughout implementation to ensure consistency across study sites. The RCT demonstrated significant improvements in children's dietary practices, particularly fruit consumption, alongside increased availability of nutrient-dense foods in schools. High engagement of teachers, communities and local producers enhanced implementation fidelity and sustainability, including spontaneous replication of school gardens and more consistent supply, These findings provide robust experimental evidence that integrated, food systems-based interventions can effectively reduce the policy–implementation gap. Scaling such approaches requires strengthened governance, local value chains, and multisectoral coordination to improve nutrition outcomes and support resilient food systems.

Keywords: Benin, dietary diversity, food environment, food systems, local procurement, randomised controlled trial, school feeding programmes

Who wants to eat more vegetables? Determinants of consumption and aspiration in Ghana

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In both high-income and low- and middle-income countries, low vegetable consumption is a key feature of poor diet quality and a central focus of nutrition interventions. However, it is often unclear whether those who underconsume vegetables actually want to change their diets. Using primary data from 846 households across the urban-rural continuum in Ghana, this paper examines the relationship between actual vegetable consumption and the aspiration to consume more, as well as the food environment-related, socioeconomic, and motivational factors that drive both. Descriptive results show that aspiration for higher vegetable consumption is widespread, with over 60 % of households wanting to consume more. At the same time, consumption is significantly and positively associated with aspiration, indicating that households with the lowest consumption are also the least likely to want to increase it.

To identify key determinants of both consumption and aspiration, we use seemingly unrelated regressions (SUR), as well as interaction and multinomial logit models to assess how these determinants differ across households with different levels of consumption and aspiration.

Vegetable-related nutritional knowledge and positive beliefs emerge as consistent positive predictors across outcomes, while food environment determinants have varied relationships with consumption and aspiration, highlighting important trade-offs. For example, hours spent in paid work are positively associated with consumption but negatively associated with aspiration, suggesting a distinct role for the opportunity cost of time.

Our findings point to both opportunities and constraints. While households with lower consumption are less likely to want to consume more vegetables, several observed factors can be leveraged to boost and sustain demand across household types. Promoting vegetable-related nutrition knowledge and positive health beliefs offers a particularly promising pathway for strengthening both consumption and aspiration.

Keywords: Dietary aspirations, food demand, nutrition knowledge, vegetable consumption

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The impact of interactive voice response message reminders on health and nutrition outcomes in northern Ghana

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In 2022, 1801 households receiving Livelihood Empowerment Against Poverty (LEAP) cash transfer with children under 10 years in Northern Ghana were randomly selected to receive WASH and/or nutrition or placebo messages through interactive voice response (IVR). The experiment presents the opportunity to analyse the impact of digital communication (i.e., interactive voice response (IVR) reminders) on safe water behaviours, health and nutrition outcomes in Northern Ghana. Data analysis techniques employed include intention-to-treat (ITT) and analysis of covariance (ANCOVA). After seven months of receiving the digital messages, the results showed positive impact on safe water behaviours (including treatment of water to make it safer for consumption), cleanliness of the dwelling, and self-reported health status). Interestingly, the study found improvement in weight for height and body mass for age z-scores of children under 10 years. The study found considerable heterogeneity based on receipts of specific messages. A qualitative analysis also revealed that the health and nutrition messages are effectively communicated to the respondents via the IVR. Based on the accounts of the respondents, there are observable changes in health and nutrition outcomes among treatment households which were attributed to the IVR messages. Additionally, a quantitative survey conducted in November/December 2024 (i.e., about one and half years after the dissemination of the messages) shows that most of the positive impacts on WASH behaviour, child health and nutrition outcomes have waned. In conclusion, the results imply that digital communication could be cost effective "social marketing" strategy in enhancing WASH behaviour change, environmental quality and nutrition outcomes of poor households in developing countries where access to digital services and infrastructure remains low. Based on the limited success in using traditional approaches including in-person communication in achieving WASH behaviour changes, the results highlight the importance of using digital technologies in addressing major public challenges such as low nutrition outcomes in developing countries.

Keywords: Digital communication, environmental quality, interactive voice response, Northern Ghana, nutrition, randomised experiment, reminders

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From tradition to transition: A multidimensional analysis of household dietary sustainability in Uganda

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Sustainable diets are increasingly central to global food systems research, yet evidence from low- and middle-income countries remains limited. This study assesses changes in the sustainability of Ugandan household diets from 2005 to 2020. The study constructed a Sustainable Diet Index (SDI) that encompasses healthfulness (measured as food variety score), environmental impact (measured as carbon dioxide emissions equivalent), cultural appropriateness (measured as the ratio of expenditure on ultra-processed foods to total food expenditure), and economic affordability (measured as the ratio of expenditure on food to total household expenditure). Using nationally representative time-series data and structural equation modelling, the study found that diets generally became more diverse over time. The increased diversity of household diets was driven by increased consumption of plant-based foods, while intake of animal-sourced foods remained low. In addition, economic affordability showed mixed patterns, generally worsening in Eastern and Northern Uganda, while showing no particular pattern in Western Uganda compared to the Central region. Higher carbon dioxide equivalent emissions decreased in the northern and eastern regions but increased in the western region compared to the central region. Although healthfulness improved, overall dietary sustainability declined slightly due to reduced affordability and rising consumption of ultra-processed foods. Households headed by more educated or urban residents had more diverse diets and lower shares of food expenditure, but also higher spending on ultra-processed foods. These findings highlight that urbanisation and education both enhance and challenge dietary sustainability. Policies that promote access to nutritious, affordable, and culturally appropriate foods, alongside education on sustainable eating and monitoring of dietary transitions, are essential for advancing sustainable food systems in Uganda.

Keywords: Dietary trends, food affordability, household food consumption, sustainable diet index, sustainable food systems, Uganda

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Does nutrition information increase consumer acceptance of black rice? Evidence from a cluster randomised controlled trial

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Black rice (*Oryza sativa*) is a nutrient-dense crop rich in anthocyanins and essential micronutrients, with potential to contribute to improved diets. However, its acceptance among consumers in Sub-Saharan Africa remains largely unexplored. The National Cereals Research Program of Uganda's National Agricultural Research Organisation (NARO) is working to introduce it to address the challenge of malnutrition in the country. This study investigates the role of nutrition information and sensory attributes in shaping consumer acceptance of black rice in Uganda, using an extended Theory of Planned Behaviour (TPB) framework. In particular, nutrition information represents an information-based cognitive stimulus that may shape consumers' perceptions of health benefits while sensory attributes capture experiential evaluations derived from direct product tasting. Integrating these elements within the TPB framework allows for a more comprehensive understanding of how cognitive, experiential, and socio-psychological factors jointly influence consumer responses to unfamiliar foods. Data were collected from 765 respondents through a cluster randomised controlled trial (cRCT), and analysed using an ordered logit generalised structural equation model (GSEM). The results indicate that provision of nutrition information significantly increases consumer acceptance. Among sensory attributes, aroma has a positive effect on acceptance, whereas shape and taste are negatively associated with it. Behavioural factors, including perceived benefits and perceived behavioural control, positively influence acceptance, while food-related disgust reduces it. Results suggest that a combination of targeted information, sensory optimisation, and trust-building measures is likely to support broader consumer acceptance and integration of black rice into local diets. Our study provides much-needed evidence to guide early-stage consumer preference insights to the on-going breeding process of black rice at NARO. Additionally, the study contributes to the literature on consumer food choice by providing empirical evidence on the determinants of acceptance of a novel, nutrient-rich staple in an emerging market context.

Keywords: Black rice, consumer acceptance, nutrition information, sensory attributes

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Understanding smallholder readiness for nutritious food systems in Kenya: A domain-sensitive assessment

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Smallholder farmers are central to supplying nutritious foods in low- and middle-income countries, yet their participation is often constrained by limited market access, inadequate post-harvest infrastructure, and fragmented institutional support. These constraints contribute to post-harvest losses, reduced income, and limited availability of nutritious foods. Despite these, most assessments approaches remain narrowly focused on production, overlooking the broader set of capacities required for effective participation. This study develops and applies a domain-sensitive framework to assess smallholder readiness for nutritious food systems in rural Kenya. Baseline data were collected from 172 fruit and vegetable farmers in Kilome Subcounty, Makueni County, Kenya. Readiness was assessed across six domains: production capacity, market engagement, post-harvest handling and storage, labour practices, institutional embeddedness, and strategic orientation. Composite indices were constructed using a hierarchical aggregation approach. A comprehensive measurement validation framework was applied to evaluate the reliability and robustness of the indices. Measurement validation confirms that the indices provide a reliable basis for assessing smallholder readiness, with stronger internal consistency in market-related constructs. Readiness is uneven across domains. Production capacity is moderate, driven by strong land tenure but constrained by irrigation and input limitations. Market engagement is modest, indicating shallow integration despite participation. Post-harvest handling and storage are critically low and represent the main bottleneck. Institutional embeddedness is also weak, with limited access to finance, infrastructure, and support, despite relatively high training levels. Overall, the results reveal a fragmented readiness profile, where strengths in one domain do not translate into broader system readiness. These results demonstrate that constraints to nutritious food systems extend beyond production and reflect broader structural and institutional gaps. The proposed framework offers a practical tool for diagnosing multidimensional readiness and identifying priority areas for intervention. Strengthening post-harvest systems, market linkages and institutional support will be essential for enabling smallholder participation in nutrition-responsive food systems and rural livelihoods.

Keywords: Institutional support, market engagement, multidimensional framework

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Displacement, food insecurity, and loss of traditional ecological knowledge among the Batwa of southwestern Uganda

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The Batwa, an indigenous and marginalised minority community residing in Southwestern Uganda, were displaced following the implementation of the Ugandan government's 1990 biodiversity conservation policy. This displacement led to profound disruptions in their traditional food systems, livelihoods, and cultural continuity. Their removal without compensation or resettlement has resulted in persistent landlessness, livelihood precarity, and the erosion of traditional food systems. This study provides one of the first mixed-methods analyses linking the socio-economic conditions, food security status, and declining intergenerational transmission of traditional ecological knowledge among Batwa households in Kisoro and Rubanda Districts. Using a mixed-methods design, we conducted four key informant interviews (KIIs) and administered surveys to Batwa households (N = 67; 28 men and 39 women), employing the World Food Programme's Food Consumption Score (FCS). Results reveal that 75 % of the Batwa households rely primarily on casual labour, while only 16 % reported owning land. Food insecurity is severe: 59.7 % fall within poor or borderline Food Consumption Score categories, reflecting low dietary diversity and dependence on purchased food or labour exchange.

Traditional knowledge loss is pronounced: 85 % of individuals no longer consume forest foods, and 60 % no longer pass this knowledge on to youth. These findings demonstrate that displacement, restricted forest access, and structural marginalisation have simultaneously undermined food security and cultural continuity. These patterns, observed among the Batwa, reflect broader challenges faced by Indigenous communities worldwide under exclusionary, conservation-driven displacement. Integrated, culturally grounded interventions, especially securing land access and revitalising Indigenous food knowledge, are essential for equitable development outcomes and long-term food system resilience for the Batwa.

Keywords: Food security, forced displacement, indigenous food systems, land rights, traditional ecological knowledge, Uganda

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The potential of participatory approaches in school-based prevention of non-communicable diseases in Mexico

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The global rise of non-communicable diseases (NCDs) represents a major global health challenge of the 21st century. To promote more sustainable healthy diets to achieve the UN Sustainable Development Goals, novel strategies are required. Given the important role adolescents play in advancing public health nutrition, schools are a key setting to implement health-related interventions for NCD prevention. Mexico as an upper-middle-income country is a prominent example of a country facing a high double burden of malnutrition, with persisting undernutrition and a growing number of diseases related to overnutrition. At the same time many innovative efforts have already been undertaken to improve food environments and health literacy among young people. However, interventions are often policies and programs, traditionally designed using a top-down approach, in contrast to a bottom-up approach. This paper examines how participatory and co-design approaches can inform the design of more meaningful and context-specific interventions for multifaceted health challenges. This represents a way to empower youth to take action on their own well-being and to increase awareness of the importance of healthy lifestyle choices from a young age. The literature review includes 23 papers from different countries around the world facing the topic of school-based participatory NCD prevention, by analysing possible design methods and assessing feasibility and effectiveness where available. Comparing the different approaches will serve to evaluate the transferability and research gaps of school-based participatory approaches in NCD prevention. These findings provide insights to inform similar design processes in future interventions in Mexico, following the objective of motivating healthy lifestyle and nutrition habits as well as adapting the surrounding food environments to facilitate and sustain these changes in future generations.

Keywords: Adolescents, bottom-up approach, children, co-design, Mexico, non-communicable diseases, participatory research, public health nutrition, school food environment, school-based

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School meal programme models and food environments in semi-arid region, Kilifi county, Kenya

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School meal programmes are crucial for improving food and nutrition security and contributing to Sustainable Development Goals, particularly SDGs 2, 3, 4, and 5. In climate-vulnerable, Arid and Semi-Arid Lands (ASALs), aligning these programmes with planetary-friendly dietary principles defined as nutritionally adequate, diverse, plant-rich diets with low environmental impact drawn from locally available foods is both urgent and understudied.

This exploratory cross-sectional study, conducted between May and July 2025 in Kilifi County, Kenya, aimed to: (i) identify and compare existing school meal programme models; (ii) characterise school food environments, and (iii) assess the extent to which current practices align with planet-friendly school meal standards.

Using purposive and random sampling, 48 public primary schools were selected across four sub-counties. Data was collected via structured questionnaire administered to headteachers and teachers responsible for school meal programmes. Descriptive statistics was employed to summarise programme characteristics and comparative analysis to identify patterns across models and school food environments.

Four models of school meal programmes were identified: government-funded (all schools at Early Childhood Development Education level), donor-supported (29 %), parent-led (4 %), and garden-based (10 %). Across all models, meals were predominantly blended sorghum, millet maize porridge (100 %), maize, rice and beans. Findings reflect centralised procurement systems and dependence on rainfall-sensitive staple crops. Dietary diversity was generally low, with vegetables seldom included (10 %) and fruits largely absent. Garden-based programmes improved access to indigenous vegetables such as amaranth, cowpeas, and black nightshade, though production volumes remained insufficient for school wide consumption. School food environments were characterised by vendors offering predominantly energy-dense, nutrient-poor foods including confectionery items, doughnuts, fried pota-

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toes and cassava, with fruits (mangoes and bananas) available only inconsistently. There was no difference among schools in the foods sold around school premises (within 100 metres). All schools relied on firewood for cooking, contrary to clean energy policy directives.
These exploratory findings reveal school meal programmes in Kilifi County's ASALs fall substantially short of planet-friendly standards. Strengthening school food policies, diversifying procurement systems, and scaling nutrition-sensitive, climate-resilient strategies are critical priorities for ASALs school meal programmes. To understand which integrated strategies work best locally, longitudinal and interventional research is needed.

Keywords: Dietary diversity, food environment, Kenya, planet-friendly, school meal programmes, semi-arid region

Roots of resilience: Exploring the impact of agroforestry on food security in western Rwanda

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The world is challenged to meet the food demand of a growing population, especially in developing countries. Consequently, food insecurity remains a reality for 757 million people. Sub-Saharan Africa remains amongst the most food insecure regions in the world, with 20.4 % of the population showing prevalence of undernourishment. In this region, rising population pressure has forced farmers to shorten fallow periods or practice continuous cropping, even on hillslopes, accelerating erosion, depleting soil organic matter, and causing nutrient loss without adequate replenishment.

While interventions often focus on raising agricultural productivity, the role of landscape diversity remains underexplored. Agroforestry, defined as the integration of trees into farming systems, is proposed as a low-input, sustainable solution to enhance food production and ecosystem resilience. However, empirical evidence on its mechanisms and impacts on household food security is limited, especially regarding diverse pathways of influence and the role of tree species composition.

This study investigates how agroforestry affects food security among smallholder farmers in Western Rwanda, using cross-sectional data from 598 households across four districts. We analyse four key pathways: (1) direct consumption, (2) agroecological, (3) income, and (4) energy provision. Unlike previous research, we explicitly consider the diversity of tree species to assess its role in mediating these pathways.

Preliminary findings suggest that agroforestry contributes to food security through multiple, interconnected channels. Direct consumption of tree-based foods and income from tree products emerge as significant predictors of improved household nutrition, while agroecological and energy pathways show context-dependent effects. Notably, tree species diversity enhances ecosystem services, supporting both crop production and dietary diversity.

These results underscore the importance of tailored agroforestry interventions that account for local ecological and socio-economic contexts.

Keywords: Agroforestry systems, ecosystem services, food security, rural development, smallholder livelihoods

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A systematic review of nutrition-sensitive agriculture research in Ethiopia: Implications for food systems transformation

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Malnutrition remains a persistent public health challenge in Ethiopia despite the country's strong agricultural base and multiple policy efforts aimed at improving food and nutrition security. Nutrition-sensitive agriculture (NSA) has emerged as a key strategy to address this challenge by leveraging agriculture to improve dietary quality and nutritional outcomes through multiple pathways. This study systematically reviews NSA research conducted in Ethiopia between 2010 and 2025 to synthesize evidence, identify thematic trends, and highlight research and policy gaps. A systematic review guided by PRISMA protocols was conducted, yielding 62 eligible peer-reviewed studies. The analysis was framed using the agriculture–nutrition pathways, including food production, income generation, women's empowerment, and enabling environment. The findings reveal that the majority of studies (over 90 %) focus predominantly on the food production pathway, particularly livestock-based interventions such as poultry and dairy, which have shown positive effects on dietary diversity, child growth, and micronutrient intake. Integrated interventions combining agricultural production with nutrition education and behaviour change communication demonstrated stronger and more consistent improvements in nutrition outcomes. However, the review also identifies critical gaps. Research is geographically concentrated in highland regions, with limited representation from pastoral and lowland areas. Methodologically, most studies are cross-sectional, with relatively few experimental or longitudinal designs providing causal evidence. Additionally, pathways related to income, women's empowerment, and enabling environments remain underexplored. Only small proportions of the studies explicitly align with national policies or generate actionable policy-relevant evidence. The study underscores the need for more integrated, multi-sectoral NSA interventions and context-specific research that addresses diverse agro-ecological settings. Strengthening the link between research, policy, and practice is essential to scale up effective NSA strategies and accelerate progress toward improved nutrition outcomes in Ethiopia.

Keywords: Agriculture–nutrition pathways, dietary diversity, Ethiopia, nutrition-sensitive agriculture

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Decision making in institutional food systems: Insights from university canteens on plant based menus and sustainability

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Transforming food systems is an integral part of efforts to address climate change, public health, and animal welfare. Current diets rely heavily on animal based products, thereby contributing substantially to greenhouse gas emissions and land use change. They are also closely associated with diet related non communicable diseases and animal welfare concerns. For this reason, shifts toward more plant based diets are increasingly seen as an important strategy for reducing environmental and animal welfare impacts, while improving dietary quality.

Existing research has largely focused on agricultural production or individual consumer behaviour. Less attention has been paid to the institutional decision makers who shape everyday food environments and determine what food is actually offered. This study fills this gap in the literature by focusing on German university catering, an influential but under researched part of institutional food systems. Operated by 57 Studierendenwerke, university catering in Germany comprises 893 dining halls and cafeterias nationwide and reaches millions of consumers each year.

Using Q-methodology, this study takes a systematic exploratory approach to examine how decision makers in university catering prioritise and balance decisions about whether and to what extent to offer more plant based meals. We collect primary data through a structured Q sorting exercise administered to catering managers and equivalent decision makers across Germany. The analysis identifies shared decision making viewpoints, illustrating how sustainability and nutrition objectives are weighed against cost pressures, operational feasibility, and concerns about student's sense of autonomy.

The study makes three contributions. First, it provides empirical insight into an under researched area of institutional food governance. Second, it helps explain why sustainability ambitions are unevenly translated into practice by highlighting the role of economic and organisational constraints. Third, the findings offer policy relevant insights for designing support mechanisms that enable institutional caterers to contribute more effectively to sustainable and nutrition sensitive food system transformations. Although grounded in the German context, the results are relevant for institutional food systems in other regions, including low and middle income countries where collective food provision plays an important role in shaping diets.

Keywords: Decision-making, large-scale caterers, plant-based diet, q-methodology, sustainability

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Ultra-processed food consumption in Cambodia in a changing food environment

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Cambodia is currently undergoing a nutrition transition characterised by a shift from traditional diets toward energy-dense, processed foods and increasing rates of non-communicable diseases (NCDs) while undernutrition and micronutrient deficiencies persist. This study examines how changes in the food environment influence food purchasing behaviour, dietary intake, and food perceptions.

Data were collected in 2021 as part of the Multisectoral Food and Nutrition Security project in the rural provinces of Kampot and Kampong Thom and in the capital, Phnom Penh. A mixed-methods design was applied. Quantitative data were collected through a household survey with 1036 caregivers of children aged 6–59 months, assessing caregivers' and children's food consumption, perceptions of food groups, and the influence of socioeconomic factors and media use on dietary patterns. The global dietary recommendation (GDR) score was used to assess food quality, a higher score indicating better adherence to healthy dietary guidelines. A food environment assessment captured vendor type and products traded. Qualitative data were obtained through 15 focus group discussions and seven expert interviews.

Children living in rural areas had a significantly higher mean GDR score than urban children (10.0 ± 1.8 vs. 9.5 ± 1.9, $p < 0.001$). No significant correlation was found between household income and children's diet quality. In contrast, caregivers' educational level affected children's GDR scores, with higher scores among children of caregivers who had sought nutrition information. Food groups classified as healthy were largely perceived as such across all locations, whereas perceptions of unhealthy foods varied: "ultra-processed packaged salty snacks" were perceived as "healthy" or "somewhat healthy" by 21.9 % of caregivers in urban areas and 30.3 % in rural areas. Regular exposure to food advertising was associated with a more accurate perception of unhealthy food groups, yet also with higher consumption.

Lower GDR scores observed in urban areas suggest a potential shift toward less diverse, less balanced diets as urbanisation continues. The findings highlight the importance of nutrition education in promoting healthy dietary practices, preserving dietary diversity, and preventing NCDs. Special attention should be given to young children to protect and support healthy dietary development in the context of a rapidly changing food environment.

Keywords: Cambodia, dietary diversity, food environment, non-communicable diseases, nutrition transition, ultra-processed food, urbanisation

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Regenerative agriculture and dietary outcomes among smallholder farmers in Kenya

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Regenerative agriculture (RA) is increasingly promoted as a pathway to enhance smallholder livelihoods, strengthen resilience, and improve food systems in sub-Saharan Africa. However, empirical evidence on how RA adoption translates into household nutrition outcomes, and through which pathways, remains limited. In this study, we examine the association between RA implementation and dietary outcomes among smallholder farmers in Kenya.

We use data from 949 households across two contrasting agroecological contexts and apply a sequential mixed-methods approach combining descriptive analysis, multivariable regression models, and qualitative insights from 14 focus group discussions and 33 interviews. We measure dietary outcomes using household dietary diversity (HDDS 12 and HDDS 9) and food consumption scores (FCS).

Results show that RA implementation is positively associated with improved dietary diversity and food consumption quality. Both peer-trained and NGO-trained implementers exhibit significantly higher dietary diversity relative to non-adopters, with consistent effects across different model specifications. We further find that direct (NGO-trained) implementation is associated with higher food consumption scores. In contrast, no significant differences are observed in food expenditure, indicating that improvements are not driven by increased purchasing power.

Post-estimation tests show no statistically significant differences between peer-led and NGO-led implementation pathways across all dietary outcomes. This suggests that nutrition benefits are not dependent on the modality of knowledge transfer. Instead, improvements appear to operate primarily through production-based pathways, particularly increased on-farm diversity and reduced reliance on market purchases.

We find that RA contributes to improved food security primarily through self-provisioning rather than income-mediated channels. and that these benefits do not depend on the modality of knowledge transfer These findings highlight the potential for scalable and cost-effective dissemination strategies that leverage farmer-to-farmer learning and locally embedded knowledge systems in smallholder contexts in the Global South and beyond.

Keywords: Agroecology, dietary diversity, food security, food systems, knowledge transfer, livelihoods, nutrition-sensitive agriculture

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The evolution of rice and bean consumption in Brazil

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The consumption of rice and beans represents the cornerstone of food security and culinary heritage in Brazil. Despite their traditional importance, household survey data have highlighted a marked reduction in domestic acquisition, influenced by profound socioeconomic shifts. This research sought to estimate the Apparent Per Capita Consumption (APCC) of these staples between 1961 and 2025. By utilising a metric that considers total food market availability – incorporating production, stocks, seeds, and foreign trade – this study provides a more systemic view of national consumption patterns than surveys limited to household acquisition. The results reveal contrasting historical trajectories for both commodities. Rice consumption reached its zenith in the 1990s, with an annual average of 47.01 kg per inhabitant, before entering a steady decline to 33.74 kg in the 2020s. Conversely, beans have undergone a continuous structural decline across the sixty-year period, dropping from 22.69 kg in the 1960s to just 12.90 kg in the 2020s. This represents a substantial reduction of approximately 43 % over six decades. Several factors drive this nutritional transition. Rapid urbanisation and modern lifestyles have constrained the time available for traditional home cooking, particularly for beans, which require longer cooking times. The discrepancy between the APCC and household data suggests that a significant portion of rice and bean intake now occurs through processed foods or meals eaten away from home. Additionally, the study identifies a concerning trend in food sovereignty: bean exports increase while domestic consumption declines. Without intervention, this decline may deepen as these staples lose prominence in school meal programmes. The study concludes that targeted public policies are essential to maintaining healthy eating habits, preserving culinary traditions, and safeguarding the nutritional security of future generations.

Keywords: Apparent consumption, food security, food supply, supply

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Coping strategies and resilience for improving food security & dietary quality in rural Zambia

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The 2023/24 El Niño driven drought had devastating impacts on Zambia's agriculture, triggering widespread crop failures, livestock deaths and a sharp rise in poverty. While households quickly adopted a range of coping strategies to mitigate food insecurity, resilience remains vital for long term stability.

In partnership with GIZ under the Food and Nutrition Security, Enhanced Resilience (FANSER) project, this study examined rural household coping strategies and perceived resilience during unusual weather events in Zambia's Eastern Province and Luapula, the latter less affected by drought. This included the influence of FANSER interventions on strengthening resilience during extreme weather events.

A mixed methods design was employed. In 2024, GIZ staff surveyed 1,009 households (401 FANSER participants and 608 non participants) on 15 predefined coping strategies. In 2025, 19 focus group discussions (FGDs) with women, men and adolescents, alongside seven household observations, provided richer contextual narratives.

The survey revealed that 79.2 % of Eastern Province households and 3.6 % of Luapula households reported experiencing the drought. Considering all types of shocks, coping intensity varied: Eastern households applied 1 coping strategy (treatment) versus 1.2 (control), while Luapula households applied 0.5 (treatment) and 0.4 (control) on average. Consumption based coping dominated: In Eastern households, 11.9 % of treatment and 18.2 % of control groups reported reduced diet quality; 18.9 % of treatment versus 27.3 % of control reported reduced food quantity or skipped meals. In Luapula, 20.2 % of treatment and 22.8 % of control reported reduced diet quality, and 19.1 % of treatment versus 23.8 % of control reported reduced quantity or skipped meals.

FGDs highlighted severe crop failures and soaring poverty levels. Beyond skipping meals and cutting food quantity, respondents cited borrowing money, selling productive assets, prostitution, child marriage, early pregnancy, and

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adolescents' turn to substance abuse. However, respondents highlighted adaptive practices that bolster resilience, such as cultivating home gardens or planting early maturing crop varieties. These qualitative accounts paint a more alarming picture than the quantitative data alone, underscoring the limitations of the survey in capturing the full spectrum of hardship. While less treatment households had to apply coping strategies, future interventions need to focus even more on climate resilience and adaptive coping strategies.

Keywords: Climate change, coping, dietary diversity, drought, food security, nutrition, resilience, rural, Zambia

Organic products consumer characteristics and preferences in Uganda

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This study investigates the demographic and socio-economic characteristics of organic food consumers, as well as their perceptions, preferences, and purchasing behaviour in Kampala. Against the backdrop of rising global concerns over food safety, health outcomes, and environmental sustainability, the study provides empirical evidence from a developing country context where organic markets remain underexplored. A cross-sectional research design was employed, integrating quantitative and qualitative approaches. Primary data were collected from 150 consumers using structured questionnaires, complemented by descriptive statistics, cross-tabulations, and regression analysis to identify key determinants of organic food consumption.

The findings reveal that organic consumers are predominantly female, married, and highly educated, with consumption largely concentrated among individuals aged 36–69 years. Awareness of health benefits is widespread, with over 90 % of respondents associating organic products with improved health, absence of synthetic chemicals, and natural production systems. However, only a minority recognise formal organic certification, indicating a significant trust and information gap within the market. Consumer preferences are strongly skewed toward fresh produce, particularly fruits and vegetables, although demand for animal products and traditional staples is also notable.

Econometric results indicate that awareness of health benefits and education level are significant positive determinants of organic food purchasing, while access to market information exhibits an unexpected negative effect, suggesting deeper structural constraints such as limited availability and certification credibility. Age and price perceptions also influence purchasing decisions, though to a lesser extent.

The study concludes that organic food consumption in Uganda is driven primarily by health consciousness and socio-economic status, but constrained by institutional weaknesses and market inefficiencies. Policy interventions should prioritise consumer education, strengthen certification and regulatory systems, and improve market access to enhance trust and expand the organic sector.

Keywords: Characteristics, consumers, organic products, preferences

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Women's time allocation and dietary outcomes: Evidence from smallholder livestock production systems in rural Kenya

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Food and nutrition insecurity (FNiS) remains a persistent challenge in Bungoma County, Kenya, where 19 % of the population was classified as acute food insecure in beginning of 2026. This challenge has a distinct gender dimension, with women often experiencing higher levels of vulnerability. Existing evidence points to strong linkages between women's empowerment and food and nutrition security (FNS). Yet, the persistent disproportionate burden of care and domestic work is often an invisible constraint on women's ability to improve individual and household nutritional outcomes. This research, conducted within the "Scaling Innovations for reduced and redistributed (I4RR) women's unpaid care work in smallholder livestock feed provision" project in rural Bungoma County, investigates how the reduction and redistribution of women's unpaid care work, e. g. through childcare facilities, can contribute to improved FNS, while identifying social and structural constrains on women's empowerment. Quantitative data was collected from 133 female project participants, combining the Women's Empowerment in Livestock Index (WELI)'s Time-Allocation module with Household Dietary Diversity Score (HDDS), Household Food Insecurity Access Scale Score (HFIASS), a negative score for food insecurity, and individual Dietary Diversity Score (IDDS). Eight FGDs with 77 participants provided qualitative insights into perceived changes in work distribution, decision-making and intra-household dynamics. On household level, quantitative results show significant associations between women´s time allocation and HFIASS, but not HDDS. Regarding intra-household food allocation, quantitative findings show improved individual dietary outcomes when women´s time is reallocated, positive effects on a more equal distribution of food. Qualitative findings supplement these results, indicating reduced workloads and improved diets of the household members. Increased control over own income and greater decision-making power over household food allocation were reported as key mechanisms for improved dietary outcomes. Simultaneously, the main responsibility for care work and housework continues to lie with women. Persistent gender norms and insufficient childcare facilities remain critical barriers. These results indicate that reducing and redistributing unpaid care work improves FNS by freeing time for non-care activities beyond purely economic gains, while requiring shifts in gender norms and supportive environments that enable women's empowerment.

Keywords: Care work, dietary diversity, food insecurity, women's empowerment

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Resilience capacity and food security in post-conflict northern Ethiopia: Baseline evidence from Tigray and Afar

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Rural households in northern Ethiopia face chronic exposure to climate and market shocks, compounded by the 2020–22 civil war that displaced many and depleted their assets. This study draws on baseline household survey data under the Regreening Africa II programme collected in 2025 to examine the household level capacities that buffer against shocks and food insecurity. We also assess whether these capacities differ between households in rain fed highlands and pastoral lowlands.

The survey covered 1,008 rural households across five woredas in Tigray (n = 908) and one woreda in Afar (n = 100). We build indices of absorptive, adaptive and transformative resilience capacity from the survey items and estimate how each interacts with shock exposure in predicting the Food Insecurity Experience Scale (FIES) and a Household Dietary Diversity Score (HDDS), with kebele fixed effects and kebele-clustered standard errors.

Our result shows that households in Afar report three times as many shocks and hold ten times more livestock per household than Tigray households, yet food-security outcomes are similar in the two regions. We find that resilience capacity reduces the shock cost but does not eliminate food insecurity. Splitting shocks into covariate events (those that affect many households at once) and idiosyncratic ones (affecting individual households) clarifies the mechanism: absorptive capacity lowers the FIES cost of a covariate shock but not of an idiosyncratic one. Communities can pool idiosyncratic risk; covariate risk must be absorbed at the household level.

The implication of our findings is that programmes operating in similar settings should priorities investments in absorptive capacity, particularly savings, informal safety nets, and psycho-social agency. A follow-up survey with a cluster-randomised design will support causal identification of the programme at endline, including both average and heterogeneous treatment effects.

Keywords: Afar, agroforestry, cluster randomisation, factor analysis, food security, northern Ethiopia, pastoral systems, resilience capacity, Tigray

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Crop-residue burning and women's anemia outcomes: Evidence from agricultural smoke exposure in northern India

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Post-monsoon crop-residue burning is a primary driver of seasonal particulate pollution across the Indo-Gangetic Plain in India, yet its causal health consequences for rural women remain poorly documented. While existing literature links ambient PM2.5 to anemia and respiratory outcomes, causal evidence from rural settings and agricultural pollution sources is scarce. This study examines whether wind-transported agricultural smoke worsens hemoglobin status and increases anemia risk among rural women, using individual health data from the Indian National Family Health Survey (NFHS-5) combined with satellite-derived fire activity, wind fields, and gridded pollution data.

The estimation sample comprises 47,783 women interviewed during the October–December burning season across eight Indo-Gangetic Plain states and 68 districts. Identification exploits plausibly exogenous day-to-day variation in wind direction and speed to construct wind-weighted smoke exposure indices over 60-day and 90-day trailing windows. Models include district and interview year-month fixed effects, absorbing confounding seasonal and geographic variation alongside controls for weather and household characteristics. PM2.5 is examined as a mechanism check rather than the primary estimand, since agricultural smoke carries a complex pollutant mixture and instrumenting for PM2.5 alone would require an exclusion restriction that is difficult to defend in this setting.

In the main 90-day reduced-form specification, a one-standard-deviation increase in wind-weighted smoke exposure reduces altitude-adjusted hemoglobin by 0.028 g/dL ($p < 0.001$) and raises anemia probability by 0.72 percentage points ($p < 0.001$). The smoke index strongly predicts ambient PM2.5 concentrations over the same window, supporting a pollution-transport pathway. Results are robust to alternative window lengths, exposure radii of 75, 100, and 150 kilometres, functional form, and a range of placebo and falsification tests including future-exposure placebos, randomisation-based falsification, and predetermined covariate balance checks.

These findings provide causally identified evidence that crop-residue burning imposes measurable health costs on rural women across the Indo-Gangetic Plain, with direct implications for agricultural residue management, environmental regulation, and rural public health policy across India.

Keywords: Agricultural smoke, anemia, causal identification, crop-residue burning, hemoglobin, India, Indo-Gangetic Plain, $pm^2.5$, rural women, wind-weighted exposure

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Food environments and dietary change in urban Africa and South-East Asia

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Undernutrition, micronutrient deficiencies, and obesity are becoming increasingly prevalent in low- and middle-income countries (LMICs), especially in deprived urban communities. Despite the growing awareness that the food environment influences dietary habits and nutrition-related health outcomes, robust comparative evidence from these communities remains limited. The FETE (Food Environments in Transitioning Economies) project aims to close this knowledge gap. The project is composed of research organisations in Ghana, Malaysia, South Africa, and Tanzania and is coordinated by the Thünen Institute in Germany. The project applies a harmonised, interdisciplinary approach to analyse the development of the food supply over the past 40 years, food policies and actors promoting healthy diets, and the structure of urban food outlets and the characteristics of residents influencing accessibility, affordability, convenience, and desirability on a local scale.

The results for the four countries reveal that economic growth, as reflected by rising GDP per capita over the past 40 years, has been associated with increases in food supply, particularly in fats and proteins. Animal protein supply has grown faster than plant protein supply. Malaysia and South Africa have higher supplies, while Tanzania and Ghana have lower but changing levels, reflecting different stages of economic development and the nutrition transition. Fiscal and regulatory policies, which directly affect food affordability and accessibility, are mostly concentrated in general VAT systems, targeted sugar-sweetened beverage taxes, and nutrition-sensitive food taxes or subsidies. The external urban food environment is marked by significant differences in the spatial distribution of food outlets. In Malaysia, formal retail dominates, while in Ghana, informal systems prevail. Tanzania has a

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mixed system, and in South Africa, the distribution is highly centralised. Although 52.8 % of survey participants had adequate dietary diversity (highest in Malaysia at 72.1 % and lowest in Ghana at 41.7 %), more than half (63.2 %) were overweight or obese. Three-quarters indicated eating out. Personal food environment vulnerability profiles differed across countries. Vulnerability to accessibility was highest in South Africa and lowest in Tanzania. Vulnerability to affordability was most pronounced in Tanzania and Ghana. Vulnerability to convenience was highest in Tanzania and Malaysia.

Keywords: Africa, food environments, food policies, food supply, South-East Asia

Could dietary diversity be a proxy indicator for 2–5 years old children nutrients adequacy? The case of selected woredas, Sidama region, Ethiopia

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Micronutrient deficiencies remain a critical challenge in child health, especially in rural Ethiopia, where poor dietary diversity contributes to inadequate intake of essential nutrients, leading to stunting, wasting, and poor development. As full dietary assessments are costly and time-consuming, this study aimed to investigate whether dietary diversity could serve as a simple proxy for nutrient adequacy among children aged 2–5 years in selected woredas of the Sidama Region. A community-based cross-sectional study was conducted in Hula, Dale, and Loka Abaya woredas, involving 415 children aged 2–5 years selected using multi-stage sampling. Data were collected using a 24-hour dietary recall and analysed with SPSS v25 and NutriSurvey 2007, calculating Nutrient Adequacy Ratio (NAR), Mean Adequacy Ratio (MAR), and dietary diversity scores (DDS), along with sensitivity, specificity, and predictive values to assess dietary diversity's effectiveness. Results showed that children's diets were dominated by grains, roots, and tubers (96.1 %), with minimal intake of legumes, dairy, and eggs, and no consumption of flesh foods; the mean MAR was 49.3 %, with significant deficiencies in vitamins D, B9, B12, calcium, and zinc, and a moderate positive correlation was found between dietary diversity and nutrient adequacy ($p < 0.05$), with sensitivity improving at higher intake thresholds, though specificity remained low. The findings suggest that while dietary diversity is moderately associated with nutrient adequacy, it cannot fully capture micronutrient sufficiency alone due to its low specificity, especially in contexts with monotonous diets and small portion sizes. Therefore, dietary diversity can be used as a proxy indicator for nutrient adequacy among 2–5-year-old children but should be complemented with strategies to promote the intake of nutrient-rich foods, including focused nutrition interventions and education to improve the consumption of dairy, legumes, eggs, and vitamin A-rich foods in the Sidama Region.

Keywords: Dietary diversity, mean adequacy ratio, micronutrients, nutrient adequacy

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Multisector drivers of healthy diet costs and gender disparities in Africa

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Structural inefficiencies in food systems and socioeconomic inequalities increasingly constraint affordability of nutritionally adequate diets across many African countries. This study examines the multisectoral factors of the real cost of healthy diets (CoHD) and the gender-related effects in shaping diet affordability across selected African countries. Using cross-country panel data covering 2017–2024 from Food System Dashboard and Food Prices for Nutrition, the analysis integrates the indicators from market performance, infrastructure, food system performance, agricultural productivity, socioeconomic, governance, and environmental conditions. Specifically, the study examines how supply chain infrastructure, retail market development, food price volatility, remittance, gender inequality, food supply variability, food policy, and agricultural value-added influence the cost of healthy diets. A log linear panel regression is employed to estimate the fixed effects and random effects models, allowing for unobserved heterogeneity and temporal dynamics. The results indicate that food supply instability, growth in retail of ultra-processed foods, and food price volatility, significantly increases the cost of healthy diets, while agricultural value addition and improved supply chain infrastructure moderate diet costs. Personal remittance shows a mixed association with diet affordability, suggesting their impact in household dietary consumption smoothing. Gender inequality is a major structural driver associated with higher diet costs, indicating that social disparities worsen nutrition access and performance. The findings highlight the importance of nutrition-sensitive and gender transformative strategies within the food system that cuts across multifunctional factors whose influence trickle down to higher cost of healthy diet. These insights contribute to the broader view of food system transformation and nutrition strengthening policies in the Global South.

Keywords: Cost of healthy diet (CoHD), food price volatility, food systems, gender inequality, nutrition affordability

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Women's participation in the rice value chain and household dietary diversity: Empirical evidence from eastern Uganda

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Rural women's engagement in local food systems plays a critical role in sustaining household welfare, especially in developing countries like Uganda. The study explored the underlying factors influencing women's participation in activities related to rice production, processing, and marketing. In addition, the research assessed the dietary diversity status of rice farming households in Eastern Uganda and investigated the association between women's participation in the rice value chain and household dietary diversity. A cross-sectional survey was conducted using a pre-tested structured questionnaire that collected quantitative data from 137 female rice farmers selected with cluster and stratified random sampling methods. Econometric analysis employed the Heckman two-stage model with Seemingly Unrelated Regression (SUR) and Ordinary Least Squares (OLS). The results indicate that while women dominated rice production and processing activities, behavioural selection bias observed in market participation was mainly influenced by household labour availability, saving behaviour, and marital status. Regarding value chain participation intensity, on average, women spent more time on manual rice processing (7.6 hours per day) and production (5.5 hours per day) activities, compared to marketing (1.1 hours per day). Household structure, asset ownership, mobility, and autonomy factors significantly influenced the time allocated to the respective value chain stages. Household dietary outcomes showed that rice farming families consumed moderately diverse diets that were predominantly composed of low-cost starch-based foods primarily produced on the farm. Women's participation in rice marketing was positively linked to higher dietary diversity scores. This study underscores the influence of women's participation in smallholder commercial value chains on household food and nutrition security. Despite women's profound contribution to household welfare, the study highlights the underlying constraints to women's equitable value chain participation. Given the laborious nature of work women undertake, it is essential to allocate affordable labor-saving rice technologies to rural women. Strengthening collective access mechanisms may enhance women's access and utilisation of stage-specific technologies. This would improve value chain performance and contribute to better nutrition outcomes among rural rice farming households in Eastern Uganda.

Keywords: Dietary diversity, Heckman two-stage model, ordinary least squares, Participation, rice value chain, rural women, seemingly unrelated regression, Uganda

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Association of food environment and hypertension risk factors in Dar es Salaam, Tanzania

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Hypertension is rising rapidly in sub-Saharan Africa, driven by urbanisation, dietary transitions, and increasingly obesogenic food environments. In Tanzania, evidence linking the urban food environment to hypertension risk remains limited despite the growing burden of diet-related non-communicable diseases (DRNCDs). This study investigated the association between the urban food environment and hypertension risk factors among adults in low-income settings in Dar es Salaam.

A cross-sectional study was conducted among 341 adults across four wards in Ilala Municipal Council. Sociodemographic characteristics, food outlet exposure, and food security indicators were collected using geocoded Maptionnaire surveys. Anthropometric measurements included weight (digital SECA scale), height (SECA stadiometer), and waist and hip circumferences (non-elastic SECA tape). Body mass index (BMI) and waist–hip ratio were derived using WHO-standardised protocols. Blood pressure was measured following WHO STEPS guidelines using an automated monitor. Descriptive statistics summarised socio-demographic characteristics. Continuous variables such as age and BMI were presented as means and standard deviations. Chi-square tests and multivariable logistic regression were used to identify predictors of hypertension.

Females comprised 70 % of participants, and 50 % were aged 35–59 years. About 52 % of households were low-income earners. Approximately 87 % of participants were exposed to both healthy and unhealthy food outlets, and 60 % reported consuming ready-to-eat foods outside the home. The prevalence of hypertension was 49.6 %. Overall, 59 % of participants were overweight or obese, and 60 % had abdominal obesity. Hypertension was significantly associated with increasing age (AOR = 1.1; 95 % CI: 1.0–1.1) and higher BMI (AOR = 2.3; 95 % CI: 1.4–3.7).

Adults in low-income urban settings of Dar es Salaam have a high burden of hypertension, associated with excess body weight and increasing age. These findings highlight the need to prioritise routine blood pressure screening and weight management programmes at the primary healthcare level, alongside promoting healthier urban food environments to reduce hypertension risk.

Keywords: Abdominal obesity, hypertension, non-communicable diseases, urban food environment

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Layered food security: the public distribution system and indigenous food system practices in nagaland, India

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This paper examines how Indigenous food systems interact with state-led food transfers to shape food systems in Nagaland, India. While public food programmes are often evaluated in terms of access and delivery, less is known about how they integrate with existing subsistence-based provisioning systems in Indigenous contexts. Drawing on primary data from 416 households across rural and urban areas, this study focuses on rice consumption to analyse how households maintain food security across seasons and how different food sources interact.

The paper highlights two main findings. First, Naga households exhibit strong food system resilience, maintaining stable rice consumption across harvest and lean seasons. This stability reflects the continued importance of Indigenous provisioning strategies, particularly long-term grain storage, which enables households to smooth consumption despite seasonal fluctuations in production and market access. Rather than relying on a single source, households draw on a diversified portfolio of food channels, including own production, storage, markets, kinship-based transfers, and state-led transfers distribution.

Second, the analysis shows that access to subsidised food through the Public Distribution System (PDS) reshapes sourcing behaviour without displacing traditional systems. PDS grain partially substitutes for market purchases and reduces reliance on informal transfers, especially in urban areas, while complementing rather than replacing stored grain from subsistence production. This indicates that public transfers are incorporated into existing food systems, forming a layered structure in which multiple sources jointly support food security.

These findings contribute to broader debates on multifunctional agro-food systems by demonstrating how state-led interventions can reinforce, rather than undermine, Indigenous food systems. In this context, resilience emerges not from any single source of food, but from the interaction between public provisioning, markets, and culturally embedded storage practices. Strengthening such complementarities is critical for designing food policies that support sustainable and resilient food systems in the Global South.

Keywords: Consumption smoothing, dietary resilience, food security, food systems, indigenous food systems, Public Distribution System (PDS)

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The impact of economic and environmental shocks on household food security and sustainability in Afghanistan

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Household food security in Afghanistan remains highly fragile due to economic instability, environmental shocks, and persistent structural vulnerabilities affecting rural livelihoods. While existing studies often examine economic or environmental shocks separately, limited evidence exists on their combined effects across multiple dimensions of food security, particularly coping capacity, dietary quality, and hunger severity. This study investigates the joint impact of economic and environmental shocks on households' food security, focusing on coping stress (rCSI), food consumption score (FCS), dietary diversity (HDDS), and household hunger outcomes (HHS) in rural Afghanistan. Using survey data from 2,143 rural households, the analysis employs Ordinary Least Squares (OLS), Poisson, and Ordered Logit models to assess how exposure to high food prices, low crop prices, droughts, floods, and other shocks influences food security outcomes. The findings reveal that most households experience moderate to severe food insecurity. Both economic shocks (e.g., high food prices, low crop prices) and environmental shocks (e.g., droughts, floods) significantly increase coping stress (rCSI), reduce dietary diversity (HDDS), and intensify hunger (HHS). In contrast, exposure to cold temperatures and hail is associated with lower coping stress and hunger, alongside modest improvements in food consumption (FCS), indicating context-specific effects. Socioeconomic factors, particularly higher income and secondary education, consistently enhance resilience, although higher education shows mixed effects, including reduced dietary diversity in some cases. These findings highlight the urgent need for integrated policy interventions, including income stabilisation, education investment, climate-smart agriculture, and social protection measures, to strengthen resilience and improve access to adequate and nutritious food in Afghanistan.

Keywords: Climate change, climate shocks, economic shocks, household resilience, livelihood adaptation, vulnerability

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Understanding the right to adequate food through children's voices: A qualitative study with street-connected children in Ethiopia

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The right to adequate food is a fundamental human right; however, it remains largely unmet for street-connected children, who represent one of the most marginalised and vulnerable population groups in urban settings. Despite increasing global attention to food systems transformation and nutrition, limited research has explored how this right is experienced, negotiated, and often denied in the everyday lives of children living and working on the streets, particularly in rapidly urbanizing contexts in the Global South.

This study examines the lived experiences of street-connected children in Addis Ababa, Ethiopia, with a particular focus on their access to and perceptions of adequate food. A qualitative research design was employed, combining focus group discussions, in-depth interviews, and visual participatory methods. As part of the visual action research component, children were actively engaged in drawing activities, through which they illustrated and explained their food experiences and daily realities. This approach enabled a deeper, more child-centered understanding and created space for children to express complex experiences that may not easily emerge through conventional verbal methods alone.

The data were analysed using qualitative content analysis, allowing for the identification of key themes related to food access, agency, coping strategies, and structural constraints. The findings reveal a complex interplay between children's agency and systemic barriers, including poverty, social exclusion, precarious livelihoods, and limited institutional support, all of which shape their ability to realise their right to adequate food.

By centering children's voices and experiences, this study contributes to ongoing debates on inclusive food systems and rights-based approaches to food security. It highlights the urgent need for context-sensitive, participatory, and rights-based interventions that address both immediate needs and the broader structural inequalities affecting vulnerable population groups.

Keywords: Food access, inclusive food system, qualitative study, right to adequate food, street-connected children, vulnerable population groups

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A global systematic review of the water–energy–food (WEF) nexus in advancing sustainable and resilient agrifood systems

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Transforming agrifood systems to achieve sustainability and resilience under conditions of climate change and resource scarcity remains a critical global challenge. Sustainability and resilience are increasingly recognised as essential for ensuring long-term food security, system stability, and the capacity to absorb and adapt to shocks such as climate change–induced extremes (e.g., droughts and floods), geopolitical disruptions, energy crises, and global pandemics such as COVID-19. A sustainable and resilient agrifood system maintains food production and access while balancing environmental integrity, economic viability, social equity, and governance dimensions.

This study presents a systematic literature review conducted using the PRISMA protocol of 62 peer-reviewed studies assessing the application of the Water–Energy–Food (WEF) nexus in agrifood systems, compared to the thousands of existing WEF nexus publications globally. The findings reveal that while sustainability is assessed in all studies, only 6.5 % explicitly incorporate resilience, indicating a major gap in addressing system adaptability. Key determinants of sustainability and resilience are consistently underrepresented. Food productivity dominates (82.3 %), while food access (8.1 %) and food losses (4.8 %) are minimally considered. Similarly, water availability is assessed in 71 % of studies compared to only 21 % for water quality and 17.7 % for water access. In the energy sector, demand dominates (56.5 %), whereas energy access is included in just 14.5 % of cases.

These patterns reveal a strong bias toward biophysical and efficiency-oriented metrics, with limited integration of social equity, governance, and access dimensions that are critical for system sustainability and resilience. Methodologically, System Dynamics Modelling (SDM) is applied in only 23 % of studies despite its capacity to capture feedbacks and adaptive behaviour. Spatially, research is concentrated at provincial and basin scales (63 %), while local-scale studies account for only 14.5 %, creating a critical scale mismatch. Furthermore, only 30 % of studies include stakeholder participation, limiting inclusive governance.

This study highlights critical gaps in WEF nexus applications and exposes methodological, spatial, and conceptual biases that must be addressed to enable the transition toward sustainable and resilient agrifood systems.

Keywords: Agrifood systems, PRISMA protocol, resilience, SARAs, sustainability, water-energy-food nexus

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Inclusive food systems and livelihoods

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Towards regenerative, inclusive food systems in Eastern Africa: A multi-level approach

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A widespread paradigm of current food system development hinges on the short-term, linear exploitation of natural resources, aiming at high cash crop yields. This Green Revolution style of farming usually does not account for vulnerable groups and nature. This is also true for places in Eastern Africa where environmental and social degradation is being observed. Instead of trying to repair with similar means which have created the apparent impasse, we suggest a transformative approach to shift the direction of agri-food systems. Regenerative thinking and acting offers a comprehensive, long-term, place and landscape-based development approach. Its aim is to continuously foster and balance biophysical and social capitals, potential and opportunities. We conceptualise and test a development approach with an international team, spanning doers, thinkers and enablers from Ethiopia, Kenya, Uganda and The Netherlands. Concrete action takes place on the ground. This is why we facilitate multi-stakeholder interactions in selected locations. Understanding the locations and their manifold stakeholder groups that depend on the environment is the crucial entry point. We develop workshops with such groups to verbalize and elaborate on their visions, needs and offers. In a stepwise procedure, the groups diverge and converge, coming to a joint understanding of actions that are desirable, feasible and benefiting local groups with different degrees of vulnerability, power holders and nature. While these local initiatives are developed from within, they are also seeking inspiration from outside and aim to generate positive spillover effects. Regional food system innovation platforms, equally set up as multi-stakeholder groups, play roles as brokers, inspirers and policy influencers. The platforms' ultimate aims are to improve the enabling environment for fair and just agri-food systems to flourish, and to initiate and support transformation. Monitoring, evaluation and learning are embedded at all levels since this individual and collaborative development process is a way of life that tries to remain valid under changing conditions, thus, requiring critical reflection and adaptation. We are looking forward to presenting our state of the art and discussing prospects, traps and new ideas with the audience.

Keywords: Food system transition, inclusivity, multi-stakeholder partnership, regenerative development, theory of change

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Sustainability hot spot analysis: A review of methods and case studies from Senegal and Kenya

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The identification of sustainability hotspots along food value chains is a key step in designing interventions for sustainable food systems. However, existing sustainability assessment approaches are often fragmented, with limited integration of stakeholder perspectives and weak links between hotspot identification, solution development, and feasibility assessment. This paper reviews and advances methodological approaches for Sustainability Hot Spot Analysis (SHSA), framing it within a life cycle perspective that captures sustainability impacts across all stages of value chains, with a particular focus on producers. The paper synthesizes core methodological components proposing an extension that integrates four elements: (i) identification of hotspots across the full life cycle of value chains, spanning social, economic, and environmental dimensions, (ii) structured sustainability assessment using context-specific indicators, (iii) co-development of solution pathways with stakeholders, and (iv) evaluation of the feasibility of these solutions, particularly at the producer level. The framework follows a stepwise approach, including scoping, life cycle mapping, hotspot identification, participatory assessment, prioritisation, and solution appraisal. Its applicability is illustrated through field testing in Senegal (tomato, mango, and onion value chains in coastal areas) and in Kenya (amaranth and mango value chains in Kilifi County). Empirical applications demonstrate how the integration of life cycle thinking with participatory methods enables the identification of sustainability constraints faced by producers and supports the development of context-specific responses. The results indicate that even though sustainability hotspots frequently emerge at the production stage, they remain closely linked to dynamics along the the value chain. These hotspots often span multiple sustainability dimensions and are interdependent, requiring integrated and context-sensitive positioning. The inclusion of feasibility assessment, encompassing economic viability, social acceptance, and institutional conditions proves essential for translating analytical findings into actionable strategies. The approach aligns with agroecological principles and contributes to identifying

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leverage points for transformative change in food systems. Overall, this ex-post method review contributes a practical and adaptable SHSA framework that links life cycle–based sustainability assessment with participatory solution design and feasibility evaluation. By focusing on producers while retaining a value chain perspective, it provides a pathway for researchers and practitioners seeking to support context-specific and implementation-oriented improvements in food systems.

Keywords: Agroecology, food value chains, participatory methods, sustainability hot spot analysis

The hidden costs of food systems in Colombia and Peru

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Agri-food systems (AFS) in Colombia and Peru generate substantial economic value but also produce significant environmental and social externalities that remain unpriced and largely invisible to policymakers and market actors. Using the Global Impact Database (GID) and the True Cost Accounting (TCA) framework, this study quantifies the hidden costs embedded across 19 AFS sectors, with a focus on seven major crop sectors. As one of the first cross-country applications of GID data in Latin America, the analysis offers a harmonised and comprehensive assessment of the true costs of food production, processing, and distribution. Our findings indicate that externalities amount to 12 percent of AFS output in Colombia and 13 percent in Peru, revealing a substantial burden not captured by conventional economic indicators. Environmental externalities dominate in both countries, driven primarily by land occupation, climate change impacts, air pollution, and scarce water use. Social externalities, most notably underpayment, child labour, and gender wage disparities, are smaller in aggregate but become markedly more significant within crop sectors, where labour intensity and informality characterise production systems. Livestock, dairy, and bovine meat consistently emerge as the most externality intensive sectors, whereas cereals, rice, sugarcane, oilseeds, and fruits and vegetables exhibit comparatively lower externality shares. A value-chain decomposition shows that most externalities originate at the production stage, though upstream and downstream costs vary by category. These insights highlight clear leverage points for targeted policy and investment – reducing environmental pressures in livestock systems, improving labour conditions in crop sectors, and integrating TCA metrics into national planning and sustainability strategies. Making these hidden costs visible is essential for advancing more sustainable, equitable, and resilient food systems in Colombia and Peru.

Keywords: Agrifood systems, Colombia, environmental impacts, externalities, Peru, social impacts, true cost accounting, value chains

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Livelihoods, and equity in neglected livestock species production: Evidence from Ogun and Oyo states, Nigeria

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Food systems in sub-Saharan Africa face pressure from rapid population growth, and conventional livestock systems are increasingly unable to meet rising demand for animal-sourced protein in alignment with Sustainable Development principles. Despite this, locally utilised, adapted and nutritionally valuable livestock species by rural communities - termed "neglected livestock species (NLS)" remain marginalised by policy and research. These species may offer important but underutilised alternatives, and while widely produced across the region, operate within fragmented and underexplored informal value chains. Applying value chain analysis with a One Health framework, the study examined producer profiles, husbandry practices and value chain dynamics for selected NLS species – rabbits (*Oryctolagus cuniculus*), Helmeted guinea fowl (*Numida meleagris*), and grasscutter (*Thryonomys swinderianus*) in Ogun and Oyo States, Southwest Nigeria. A mixed-methods approach was employed, combining household surveys (n=134), focus group discussions including resource mapping and matrix scoring (n=63), and stakeholder interviews (n=4).

Findings show that production was predominantly small-scale, with women representing majority (55 %) of producers and Guinea fowl was the most common species (54 %) produced. Activities concentrated at the production stage, with limited value addition and strong reliance on informal processing and marketing. Feed was sourced from wild and local markets, and animal husbandry, including disease management, was largely self-directed. Processing was minimal, as producers preferred selling live animals. Marketing relied on social media, personal networks and community markets. Further, we noted that majority of producers engaged with these livestock species owing to a range of advantageous characteristics, such as their ability to adapt to varying conditions, and minimal input demands. Producers cited income

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generation and improvement of household meat and egg consumption as primary production motivations. Key production constraints included limited financial support, feed scarcity and pest infestation, while land, water and local market access were generally perceived as adequate.
In conclusion and despite the constraints, the production of NLS in southwest Nigeria demonstrates meaningful livelihood and food security potential to advance nutrition-sensitive food systems and rural income equity in Nigeria. Improving these systems through targeted research, policy support and value chain development could enhance their role in sustainable, resilient and fair food systems.

Keywords: Food security, neglected livestock species, rural livelihoods, smallholder livestock systems, southwest Nigeria, value chain

Beyond income: Cost-saving livelihoods and women's empowerment in black soldier fly farming, evidence from Zambia

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Women are the main contributors to agricultural production in Zambia, yet persistent gender inequalities limit their access to resources, decision-making, and income opportunities. Black soldier fly (BSF) farming has emerged as a sustainable innovation to address the persistent high prices for animal feed and fertilisers, but its benefits for women's empowerment remain underexplored. This study, therefore, examines the potential of small-scale BSF farming for women's empowerment in Zambia through Kabeer's lenses (resources, agency, achievements). Data were collected through semi-structured interviews during on-site visits at all five existing BSF farms with owners and farm workers (in total, n=7), and with six key informants involved in BSF farming in Lusaka and Central Province. Thematic analysis revealed three themes shaping women's empowerment in BSF farming: (i) access to BSF resources, (ii) socio-cultural and gender constraints, both identified as constraining, and (iii) economic viability and livelihood improvements, as a supporting theme. Findings indicate that from the economic perspective, BSF farming mainly supports women through cost savings on animal feed and fertiliser, rather than through stable income from the sale of BSFL-derived feed. While women gained access to skills, community recognition, and decision-making, their empowerment was constrained by inadequate training, limited access to capital and equipment, weak market access, and restrictive gender norms. These constraints challenge policies that treat economic engagement alone as sufficient for empowerment. Overall, BSF farming offers conditional opportunities for women's empowerment. To reach the full potential, it requires coordinated institutional support, improved access to training and capital, and efforts to address gender barriers within the BSF value chain.

Keywords: Agricultural value chains, circular agriculture, gender equality, rural livelihoods, smallholder farming, sub-Saharan Africa

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Livelihood dynamics and child nutrition in East African drylands: Evidence from a panel survey in the Karamoja border region of Kenya and Uganda

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Livelihoods in parts of the East African drylands are shifting from pastoralism towards a more sedentary, mixed and non-farm portfolio. Implications of these dynamics for child nutrition remain under researched in these high-burden settings. The aim of the study was to assess livelihood strategy dynamics and their implications for child nutrition in the Karamoja border region of Kenya and Uganda.

The study used data from a baseline and a follow-up survey, covering 861 households and children aged 6–59 months (n=673 at baseline and n=575 at follow-up) across four study areas in Kenya and Uganda. Principal component analysis followed by k-means cluster analysis was used to identify household livelihood strategies. Anthropometric data from the two surveys on weight and height/length was utilised to determine the nutritional status of the children. Four livelihood strategies were identified; 1) market-oriented pastoralism, 2) diversified agro-pastoralism, 3) small-scale pastoralism and 4) non-agricultural. These differed by location and socioeconomic position and were associated with child nutrition status. Market-oriented pastoralism and diversified agro-pastoralism had significantly higher proportions of children who were neither wasted, underweight, nor stunted.

Livelihoods in the study area are diversified, dynamic and shaped by agro-ecological conditions and seasonality. There were significant transition and retention into the most socioeconomically disadvantaged and less nutritionally remunerative livelihoods, confirming that households in the low socioeconomic position may be trapped in low return livelihoods with limited chances of moving out. Effective development interventions should be targeted to support the unique needs of each livelihood group.

Keywords: Agro-pastoralism, child nutrition, livelihood strategies, principal component analysis, socioeconomic position

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When conflict meets the farm: Youth disengagement and system collapse in Myanmar

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Myanmar faces a severe hunger crisis, with around 15 million people projected to experience food insecurity (World Food Programme, 2025). Declining youth participation in agriculture is reducing the farm workforce and threatening food production. We examine systemic drivers and constraints shaping youth engagement in farming in Depayin Township, Sagaing Region, Myanmar, using a systems-thinking approach combining the Iceberg Model and causal loop diagramming (CLD) to identify structural and mental-model factors and feedback dynamics linking conflict, market disruption, profitability, and outmigration. Data were collected through 53 semi-structured interviews with farmers, complemented by literature and secondary sources, including international and government reports and news articles. A CLD was developed from these data and validated through four focus group discussions with 20 stakeholders, including local authorities, policymakers, NGO staff, truck drivers, farmers, business owners, and a women-only group of farmers and entrepreneurs. Results show that the farming system persists through a fragile balancing dynamic despite declining profitability. Small farms remain operational through remittances from family abroad, reflecting youth outmigration and loss of on-farm labour. Larger farms sustain marginal profits through economies of scale, though profitability remains constrained. However, conflict-driven reinforcing dynamics are accelerating system decline. Airstrikes have disrupted markets by displacing wholesalers, forcing farmers to rely on brokers offering low farm-gate prices. Heightened insecurity discourages storage and long-term planning, leading to rapid sales and reduced returns. Vegetable production is particularly vulnerable due to high transport costs, taxation, confiscation risks, and spoilage. Tomato production, a major Depayin crop, is approaching collapse within this reinforcing dynamic, as many farmers have stopped cultivating tomatoes and shifted toward rice production, where broker networks still function. Across both

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farm types, most young people express a desire to leave farming due to insecurity, low profitability, and uncertain futures. Leverage points identified include improving transport safety and reducing transport-related taxation. Critically, efforts to eliminate airstrikes against civilian and economic targets are essential, as ongoing conflict is a key driver of market collapse, livelihood insecurity, and youth exit from agriculture. By making these dynamics visible, this study provides a replicable framework for identifying intervention points in other conflict-affected agricultural systems.

Keywords: Agriculture, causal loop diagram, conflict-affected farming systems, food insecurity, Myanmar, rural livelihoods, systems thinking, youth engagement

From food safety to climate resilience: CamGAP-certified vegetable value chains in Battambang, Cambodia

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Vegetable value chains in Cambodia remain largely informal, with smallholder farmers facing unstable prices, limited bargaining power, weak quality differentiation, and increasing concerns over food safety. CamGAP certification offers a pathway to improve vegetable production by promoting safer farming practices, strengthening consumer trust, and creating opportunities for more sustainable and resilient value chains. However, its practical contribution to smallholder value-chain upgrading remains underexplored.
This study examines the role of CamGAP certification in supporting sustainable and climate-resilient vegetable value chains in Battambang Province, Cambodia. A qualitative value-chain approach was applied, using interviews with vegetable farmers, traders, and relevant value-chain actors. Total of 12 interviews across the value chain were collected during August and September 2025. The analysis focused on production practices, certification experiences, market access, price incentives, and constraints to wider adoption.
The findings show that CamGAP certification improves the reputation and marketability of vegetables by signaling safer production and better product quality. Certified farmers reported stronger buyer confidence and price premiums compared with non-certified products. However, adoption remains limited by high certification costs, complex procedures, limited technical knowledge, weak farmer awareness, and difficulties in maintaining compliance with standards. Market incentives are also inconsistent, reducing farmers' motivation to pursue or renew certification.
The study suggests that CamGAP can contribute to sustainable and climate-resilient vegetable value chains when certification is supported by practical training, cooperative coordination, quality control, traceability systems, and reliable buyer demand. Strengthening these support mechanisms can help move smallholder vegetable production from informal market participation toward safer, more coordinated, and more resilient agri-food systems.

Keywords: Agricultural certificate, good agricultural practices, quality standards, small-holder market access, sustainable farming

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Determinants of women's willingness to pay for beekeeping kits in rural Kalimantan

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Oil palm expansion has fundamentally reshaped rural livelihoods across Indonesia. As oil palm replaced more diversified farming systems, women lost agricultural roles they previously held and were pushed into unpaid domestic work or low-paid informal activities. Targeted interventions can help address this through productive assets that enable women to generate independent income, yet little is known about what drives women's demand for such assets.

Beekeeping is one promising option. Indonesia hosts more than 40 native stingless bee species well suited to oil palm landscapes, and the activity fits naturally into women's daily lives without requiring additional land or competing with other livelihood activities. It also supports pollination services and creates incentives to protect remaining forest areas. Despite this potential, beekeeping remains a minor livelihood activity in Indonesia and a formal market for beekeeping kits has yet to develop. Understanding how much women are willing to pay (WTP), which factors shape this willingness, and whether stated willingness reflects actual payment behaviour are therefore essential for effective intervention design.

This study examines the determinants of women's WTP for beekeeping starter kits among 300 women in Kapuas Hulu, West Kalimantan, an oil palm dominated district with strong traditions of wild honey harvesting. In 2024, a double-bounded dichotomous choice experiment with randomised real and hypothetical payment conditions was used to elicit women's WTP. A machine learning and interval regression framework then identifies the factors most strongly shaping WTP under both conditions.

Women's WTP is primarily associated with the number of income-generating household members, perceived forest productivity on oil palm land, and substantial household income from off-farm activities. Women in the real payment condition reported WTP approximately 64 percent lower than in the hypothetical condition, revealing substantial hypothetical bias.

These findings are directly relevant for designing gender responsive livelihood programmes in oil palm landscapes. Targeting should account for household income diversification and forest resource perceptions. The gap between stated and actual WTP suggests that hypothetical demand estimates may overstate uptake of productive asset interventions, a concern relevant to agricultural development across the Global South.

Keywords: Dichotomous choice experiment, gender inequality, women empowerment

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Policy coherence for nutrition-sensitive agri-food systems in Ethiopia: Implications for research and evidence-informed practice

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Ethiopia's policy landscape has increasingly emphasised nutrition-sensitive agriculture (NSA) as part of broader agro-food system transformation. This study examines how NSA has evolved within national policy frameworks, assesses coherence across agriculture-related strategies, and evaluates the role of research evidence and enabling conditions in supporting nutrition-sensitive agro-food systems.

The study applies a qualitative longitudinal policy analysis combined with objective-level coherence assessment, enabling environment evaluation, and citation-based evidence mapping. Four analytical pillars are examined: (i) evolution of NSA policy framing, (ii) coherence of selected agriculture strategies with the National Agro-Food System Strategy (NAFSS), (iii) enabling environments for NSA pathways, research, and agroecological diversity, and (iv) use of research evidence in policy formulation. Data were drawn from official Government of Ethiopia policies and strategies and systematically analysed using thematic and comparative approaches.

Findings show a clear progression from sector-linked nutrition interventions under the National Nutrition Programmes (NNP I and II), through the National Nutrition-Sensitive Agriculture Strategy, to the systems-oriented NAFSS, where nutrition is embedded as an emergent food system outcome. Policy coherence across agriculture strategies is generally medium to high, particularly for food availability, value chains, resilience, and institutional capacity. However, explicit attention to dietary quality, food environments, and consumption-side nutrition outcomes remains uneven. The analysis also reveals growing reliance on national data, Ethiopia-based research, and global evidence, alongside persistent gaps in dedicated financing for nutrition-sensitive and food system research. Context-specific initiatives, notably the Enset Development Flagship Program, demonstrate strong alignment across nutrition, resilience, and inclusion pathways.

Ethiopia has established a strong foundation for nutrition-sensitive agro-food system transformation. Strengthening nutrition accountability, enhancing research financing, institutionalizing evidence-to-policy linkages, and better leveraging agroecological diversity are critical to translating policy ambition into measurable nutrition gains.

Keywords: Agrifood systems, dietary diversity, Ethiopia, nutrition-sensitive agriculture, policy coherence

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Socio-economic conditions and livelihood systems of settled Bedouin households in north and east Lebanon

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Settled Bedouin households in Lebanon face multiple livelihood and economic pressures, yet evidence on their current living conditions remains limited. This cross-sectional study examined the socio-demographic profile, education, livelihood systems, and economic conditions of 361 settled Bedouin households (2,152 household members) in the North (Akkar) and East (Baalbeck-Bekaa) regions of Lebanon. R software was used to generate descriptive statistics, bivariate tests, and multivariable logistic regression models to assess regional differences and household factors associated with livestock rearing and crop farming.

The results revealed marked regional disparities. Households in the North were significantly smaller (mean = 4.96, SD = 1.9) than in the East (mean = 7.03, SD = 3.4) and showed higher educational attainment and literacy outcomes, while the prevalence of stateless Bedouins was higher in the East. Regional differences were also evident in the employment sector, whereby employment was strongly gendered, with men more likely to be employed than women. Livestock rearing was limited to 79 households across the sample and did not differ significantly by region. Yet, important regional differences emerged in herd structure, feed sources, and land tenure. Older household heads were more likely to engage in livestock rearing than younger ones. Crop farming was more common in the North than in the East (16.9 % vs 8.7 %). Land tenure also differed regionally: crop farmers in the East depended almost entirely on rented land, whereas crop farmers in the North cultivated a mix of owned and rented land. The likelihood of crop farming increased with household age and medium education level and household size.

Economic vulnerability was pronounced across the study population. Household-level income was generally low, with 49 % of households reporting less than USD 300 per month. Debt was also highly prevalent, affecting nearly four in five households. Among households engaged in livestock keeping and/or crop farming, agriculture remained the primary source of income despite widespread income diversification. Overall, the findings show that settled Bedouin households in Lebanon face severe socioeconomic challenges, reflected in low educational attainment, constrained livelihood opportunities, low household incomes, and widespread indebtedness, highlighting clear regional differences in education, livelihoods, and access to land.

Keywords: Bedouins, crop farming, livestock rearing, socioeconomic vulnerability

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Socioeconomic and medicinal dimensions of indigenous knowledge and livelihood resilience on selected native tree species in northern Ghana

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Indigenous knowledge (IK) systems underpin multifunctional agroecosystems that sustain livelihoods, enhance climate adaptation, and support primary healthcare in the savannah landscapes of Northern Ghana. This study uses a mixed-method design to evaluate the socioeconomic and ethnomedicinal services of six native tree species of priority (*Adansonia digitata*, *Parkia biglobosa*, Lannea acida, *Sclerocarya birrea*, *Bombax costatum* and *Ziziphus mauritiana*) in 15 communities. Structured questionnaires, focus group discussions and participatory ranking were used to collect data with 198 respondents, and this was analysed using Relative Importance Index (RII), Spearman rank correlation, Chi-square tests and thematic coding. Findings indicate that more than 90 % of households rely on native tree species to obtain food, income and healthcare, and *Parkia biglobosa* and *Adansonia digitata* have been found to be key species because of their multi-purpose nature and high market value. Ethnomedicinal use was noted in 85 % of the respondents and was mostly applied to gastrointestinal, respiratory, musculoskeletal and dermatological conditions. The most used plant parts were the bark (41.4 %) and leaves (37.9 %) with most of the preparation being done by decoction. Statistically, there were significant positive correlations between the perceived medicinal efficacy and species availability (rho = 0.588, $p = 0.001$), and the trade importance (rho = 0.660, $p = 0.001$), and medicinal value was strongly correlated with utilisation pressure (rho = 0.560, $p = 0.001$), which indicated a clear livelihood–conservation trade-off. Although IK is widespread, there is still a lack of sustainable management practices, and overharvesting and poor regeneration of high-value species are the most common perception. A main policy implication is to prioritise native tree species incorporation in national climate adaptation and agroforestry policies via community-based domestication and controlled harvesting systems which allow conservation and livelihood gains to be sustained. This is essential in the development of climate resilient, multifunctional agroecosystems in especially drylands of West Africa.

Keywords: Climate adaptation, ethnomedicine, food security, savannah ecosystems

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Systemic innovation for sustainable agri-food systems: A comparative mapping of international organisations

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Innovation is widely presented as a key lever for transforming agri-food systems amid climate change, biodiversity loss, and food insecurity. Yet the term is often used inconsistently, frequently reduced to technological solutions. This paper examines how major international organisations frame innovation for agri-food systems transformation and its implications for multi-functional, climate-resilient agro-ecosystems that enhance nutrition, resilience, and livelihoods across all world regions. The analysis draws on a comparative mapping from the Leibniz Lab Systemic Sustainability (LL SYSTAIN), covering 27 recent reports by FAO, CGIAR, IFAD, IPBES, IPCC, OECD, UNEP, UNDP, UNFSS, WHO, WFP, World Bank, and World Ocean Assessment. It compares innovation definitions, systems thinking application, emphasised types and clusters, and links to sustainability goals and pathways.

Results reveal broad convergence: organisations share a systemic view of transformation needs and innovation systems. Innovations are not just seen as isolated technical fixes, but as multi-dimensional processes embedded in complex socio-ecological systems, involving technological, social, financial, governance, and policy changes. Key clusters identified include dietary shifts, alternative foods and feeds, cross-sector policy coherence, financial tools, precision and digital agri- and aquaculture, diversified production systems, and circularity. However, production-oriented and technological innovations are often more visible than social, behavioural or policy innovation, whileDemand-side change, including diets and food environments, also receives less attention than would be needed for food system transformation. Also, blue foods remain underrepresented, despite their importance for food and nutrition security and their connection to land-based systems.

This Innovation Mapping provides a structured basis for understanding how international organisations understand and frame innovations for agri-food system transformation, where they converge and where gaps remain. It contributes to current debates on how food systems can be transformed beyond isolated technical fixes and toward systemic sustainability. This is crucial for our future as sustainable agri-food systems are linked to international goals on food security, climate, biodiversity, health, livelihoods, equity and economic development.

Keywords: Agri-food systems, climate resilience, food systems transformation, innovation mapping, international organisations, systemic innovation, systemic sustainability, systems thinking, transformation pathways

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Restoring landscapes, reshaping livelihoods: Labour allocation, decision-making, and well-being in forest landscape restoration across western Rwanda

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Restoring degraded landscapes is widely promoted as a pathway to improving environmental conditions and rural livelihoods, yet its implications for household well-being and labour division remain insufficiently understood. In Rwanda's western region, where land degradation is closely linked to population pressure and agriculture-dominated livelihoods, the government has implemented large-scale restoration policies including agroforestry, terracing, and woodlot establishment, often within forest landscape restoration programs. These interventions shape rural livelihood strategies across on-farm, off-farm, and non-farm activities, with important implications for household economic opportunities.

We use cross-sectional survey data from about 600 households in four districts (Nyabihu, Rubavu, Rutsiro, and Ngororero), including over 1,000 respondents. Using correlation analysis, random forest models, and regression analysis, we examine how restoration activities and livelihood strategies relate to household labour distribution, decision-making and multidimensional well-being, including involvement in both own-farm and village-level restoration.

Preliminary findings suggest that restoration-related activities such as on-farm terracing, and own woodlots, as well as off-farm work are associated with higher workloads, with women and younger members bearing a disproportionate share. We find that greater decision-making power in expenditure and institutional trust for women are associated with lower working hours, suggesting that intra-household agency may help moderate labour burdens. Livelihood activities are largely complementary rather than substitutive, with households combining multiple strategies. Restoration programme participation is also associated with higher labour burdens, particularly for women.

In terms of well-being, our study suggests higher reported income in households engaged in own-farm agroforestry, terracing, and off-farm employment, indicating potential economic gains from more diversified and restoration-related livelihoods. However, life satisfaction is more closely associated with

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broader livelihood diversification than with specific restoration practices, suggesting that well-being depends more on overall livelihood portfolios than on individual restoration activities.
Our findings highlight how restoration interacts with livelihood portfolios, labour allocation, and well-being across households. Overall, the study situates forest landscape restoration within the broader theme of forests, trees, and human well-being in smallholder systems, emphasising that restoration policies must be assessed not only for ecological outcomes but also consider implications for labour, agency, livelihoods, and well-being.

Keywords: Decision-making, forest landscape restoration, gender, labour allocation, rural livelihoods, Rwanda, wellbeing

Translocality and smallholder farm sustainability: A case study of rural households in Arochukwu, southeast Nigeria

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Smallholder farmers in sub-Saharan Africa face increasing challenges that influence sustainable agricultural development. Among the problems eliciting policy debate in rural areas in the southeast region Nigeria, labour migration is a problem. This study contributes to the policy discussion, by assessing how translocality influences the economic, social, and environmental sustainability of smallholder households in Arochukwu, the southeast region. The study used a mixed method to analyse data from 241 migrant households in the area of origin, and 50 migrants in the area of destination. The Sustainability Assessment of Farming and the Environment (SAFE) theoretical framework was employed to develop indicators for economic, social, and environmental dimensions of sustainability. Data Envelopment Analysis (DEA) was used to generate a sustainability index, while extended beta regression was used to analyse the influence of translocality on farm sustainability of the rural households. The qualitative results reinforce the problem of shortages to the workforce due to migration, which also influences the amount of land cultivated. The livelihood of the people in the region is also influenced by migration, as well as exchange of food, goods, and money. Empirical evidence suggests a divergent and significant relationship between translocality and farm sustainability, with translocality positively influencing social sustainability, and negatively influencing environmental sustainability. The results also revealed that farm size positively influences the economic sustainability of smallholder farmers in the area. Notably, extension service was also a significant determinant of both social and environmental sustainability, underscoring the potential of translocality, as a tool for dissemination of sustainable agricultural practices, to enhance farm sustainability, rural livelihoods, and agricultural development in the region.

Keywords: Farm sustainability, smallholder farmers, translocality

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Water use, livelihoods, and sustainability: Analysing blue water footprints in smallholder vegetable production in northern Ghana

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Water use is central to sustaining livelihoods; however, increasing pressures from climate change, population growth, and governance challenges threaten freshwater availability and long-term sustainability. In rural and peri-urban communities of the Global South, water insecurity undermines food security, income generation, and social equity, highlighting the need for integrated approaches linking water, energy, and food systems with livelihood perspectives. Despite methodological advances, gaps remain in harmonizing social sustainability indicators and integrating behavioural dimensions into water use research. This literature synthesis addresses these gaps by examining empirical and conceptual evidence on the interconnections between water use, livelihoods, and sustainability, focusing on identifying frameworks, methodological contributions, and spatial scales to inform policy and practice. A systematic review approach, guided by PRISMA principles, was employed to identify and synthesize relevant studies published between January 2015 and March 2026. Literature was retrieved from major academic databases, including PubMed, Web of Science, MEDLINE, EMBASE, Google Scholar, JSTOR, and Semantic Scholar. Inclusion criteria emphasized methodological rigor, empirical evidence, and relevance to water use, livelihoods, and sustainability. Narrative synthesis was used to integrate findings thematically, given study design heterogeneity. The review employed several analytical tools to structure and interpret findings. Automation tools assisted in duplicate removal and preliminary screening, while manual cross-checking ensured reliability. Frameworks such as the Analytical Hierarchy Process (AHP) and TOPSIS were used as reference points to evaluate study robustness. Hydro-economic models and composite indices provided comparative benchmarks for assessing how studies linked water management strategies with livelihood outcomes. Narrative synthesis was organized thematically, guided by these methodological lenses, allowing structured comparison across heterogeneous study designs. AHP and TOPSIS informed how trade-offs between efficiency, equity, and sustainability were interpreted, while hydro-economic models highlighted integration of biophysical and socioeconomic dimensions. Livelihood sustainability indices guided thematic coding of social assets and resilience factors. The review highlights the importance of integrated natural resource management for sustainable livelihoods – promoting environmental livelihood security, equity, and resilience in global change – and reveals how methodological innovations strengthen evidence synthesis to inform policy-relevant insights.

Keywords: Environmental livelihood security, governance and equity, WEF nexus

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Colliding ecologies and forced adaptation: Tenure insecurity and farmer livelihoods in Ghana's artisanal mining frontiers

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Across sub-Saharan Africa, artisanal and small-scale mining (ASM), a low-tech, labour-intensive form of mineral extraction, is rapidly reshaping rural agrarian economies, where farming has historically been a major livelihood activity. In Ghana, the expansion of ASM into agricultural areas has intensified competition for land, labour, and water, a scenario we describe as colliding ecology. This phenomenon has generated new forms of livelihood uncertainty for farming households. While existing studies document the impacts of mining and farmers' coping strategies, they often treat farmers' responses as voluntary adaptations and overlook the role of tenure insecurity in shaping differentiated outcomes. Using a mixed-methods approach and drawing on field data from 195 participants, this paper examines how tenure insecurity and expanding ASM reshape access to land and power, influence how tenant farmers respond in their everyday lives, and affect their livelihoods. The findings show that tenant farmers face a deterioration in their livelihood options due to the increasing activities of ASM operators, resulting from insecure access to land, poor compensation, and uneven power structures. Consequently, they are compelled to resort to short-term and often precarious strategies that stabilise consumption in the short run but jeopardise future welfare, including food security, income, and assets. The findings further reveal that coping strategies are less expressions of choice than outcomes of structural constraints. The paper stresses the need for policy action to mitigate insecurity and to acknowledge the different contexts in which farmers adapt to the extractive change. It contributes to debates on agrarian change, sustainable livelihoods, and resource governance in the Global South.

Keywords: Artisanal and small-scale mining (ASM), colliding ecology, forced adaptation, tenant farmers, tenure insecurity

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Perceptions of women in agri-food supply chains under climate change

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Women's roles in agri-food supply chains are essential as they sustain livelihoods, enhance productivity and drive innovation forward. However, women face challenges due to gender-specific norms and their needs are often overlooked. Strengthening women's empowerment in agri-food supply chains is essential for building resilience to climate change.

Workshops with female farmers were conducted in Tanzania, the Dominican Republic, Thailand and Nepal. Additionally, 21 qualitative interviews were conducted with company actors, eight of whom were women. Qualitative data collection and content analysis were guided by the Community Capital Framework and the Proximity Framework to identify indicators that support women's future visions across the production and processing side.

All interviewed women express strong self-efficacy and view themselves as pioneers of innovation. One of the female farmers interviewed describes her motivation: "The production of goods and things – that's what fulfils me. It pushes me forward.". In Nepal in particular, female farmers actively participate in workshops and share their innovations to adapt to climate change within their communities. Female company actors in companies also expressed strong motivation to implement adaptation measures to climate change.

Nevertheless, all interviewed women face challenges due to gender specific norms. Female farmers in particular, highlighted traditional caregiving roles. They shoulder a heavy dual workload across household and farm responsibilities. Moreover, their access to resources especially land remains limited and is predominantly held by men. One of the female farmer interviewed describes her situation: "So, if the husband is present, he represents her. When he can't attend meetings, they send the wife who can come, but ultimately, they [men] handle everything."

Climate change compounds these constraints with increasing droughts, irregular rainfall and floods. Therefore, access to irrigation systems and rainwater storage is needed to secure water availability. Overall, company actors view climate change as a pressing future issue and plan to invest in their supply chains; however, most lack a stronger gender lens.

For the future, supporting women's leadership, as well as fostering access to financial and non-financial resources will enhance their resilience to climate change across agri-food supply chains for both companies and farmers.

Keywords: Agri-food supply chain, climate change, female farmers, women

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Migration from farm families: Determinants and its impact on the rural livelihoods in Bangladesh

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Migration is one of the important livelihood strategies particularly in rural Bangladesh for poor farm households to diversify their income for their survival. Internal migration particularly rural - urban migration are most predominant in the country whereas international migration is also significant from the farm familes to the overseas. The study area was covered three Upazilas –namely Karimganj, Tarail, and Nikli of Kishoreganj district in Bangladesh. A total of 246 respondents were purposively chosen, including 81 farm households with one or more internal migrants, 80 farm households with one or more international migrants and 85 farm households without any kind of migrants. Data were collected through face-to-face interviews using a structured questionnaire. The study employ a mixed – methods approach combining structured surveys for quantitative data with qualitative methods like focus group discussions and key informant interview. The data were analysed by using both descriptive statistics and econometric models. The multinomial logistic regression model was used to analyse the determinants of internal and international migration at the farm household level. The results shows that household head's age, households head education and household size significantly- positively influenced internal migration decisions in the study areas. In case if international migration, along with demographic characteristics, households wealth status (own cultivable land and household asset) have significant positive influence on their migration decision. Our study findings reveal that farm households with either internal or international migrant member have achieved significant improvement in their different livelihood aspects (food, housing, sanitation, child education, health). On the contrary, farm households without any migrant member have shown limited improvement in different livelihood aspects compared to the households with migrant member. The study recommends addressing the proper policy issues for balanced regional development of the country so that migration decision always should not be a necessity. The findings also highlight the need for proper institutions for migration issues of the country to accrue the positive benefits of migration as well as to create a more supportive economic environment for migrant households for productive investment of their remittances.

Keywords: Bangladesh, farm families, internal, international, livelihoods, migration

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Kumbu yams: Nutrition dense, underutilised staples for equitable, climate smart food systems and rural livelihoods

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Growing food and nutrition insecurity in Africa is closely linked to narrow, cereal dominated systems that marginalise indigenous staples and constrain health oriented diversification. Kumbu yams (Nyake, Mwende, Jaseh), a wild Dioscorea complex from the Mount Cameroon Region, are positioned here against the reference staple *D. rotundata* to evaluate their potential as next generation "super staples" for climate smart, nutrition sensitive food systems. Semi structured questionnaires administered to 583 respondents across 41 villages ($\alpha = 0.05$) showed that Kumbu is either a "wild yam in process of domestication" or "in process of extinction": only 38.4 % of households still cultivate it, 69.3 % report severe seed scarcity, 30.7 % prefer other yams, and 68.1 % cannot distinguish cultivars, indicating rapid erosion of indigenous knowledge and genetic resources Building on this diagnostic, Morphological and molecular characterisation resolved Nyake, Mwende and Jaseh as three distinct candidate *Dioscorea* species, >99 % similar at genus level and closely allied to wild African yams (*D. praehensilis* / *D. abyssinica*), suggesting shared evolutionary origins and high likelihood of new species to science. Agronomic trials established sett propagation, combined with beneficial microbes and poultry manure, as a practical low input package, raising yields up to 37,075 $\pm$ 2,392 kg ha^{-1} versus 9,569 $\pm$ 549 kg ha^{-1} under minisett, while simultaneously reducing tannins and phytates by up to 84 % and increasing ascorbic acid. Comparative nutritional profiling demonstrates that all three Kumbu cultivars deliver more than double the metabolisable energy of *D. rotundata* on a dry weight basis, with substantially higher protein, useful fat, ash (mineral proxy) and exceptionally elevated vitamin C (1,716–2,412 mg 100 g^{-1}), other vitamins alongside safe dietary levels of tannins, phytates and oxalates. Thus, while *D. rotundata* remains a conservative bulk energy staple, Kumbu clearly emerges as a high value, nutrient dense, health promoting yam complex ideally suited for nutrition sensitive agriculture, value added product development and equitable rural income generation. We argue that strategic valorisation of Kumbu – through seed system support, on farm conservation, breeding to fine tune oxalate/alkaloid profiles and integration into extension programmes – could reposition this wild yam as "Africa's next super staple" within tropical food system.

Keywords: Indigenous staples, kumbu yam, nutrition sensitive food systems, rural livelihood, underutilised crops

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Nutritional, pasting, and sensory attributes of some Ghanaian cereals-, root-, tuber-, and plantain-based complementary blends as influenced by spontaneous fermentation

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Despite the potential of spontaneous fermentation (SF) to enhance food quality, there is a gap in understanding its impact on the nutritional, rheological, functional, and sensory properties of Ghanaian cereal-, root-, tuber-, and plantain-based complementary blends. This study investigated the influence of SF on these qualities in these blends formulated from selected cereals, roots, tubers, and plantain. Complementary blends were formulated using unfermented or fermented cereals (maize, sorghum, millet), sweetpotato, cassava, and plantain. Nutritional, antinutrients, pasting, and functional properties were determined using standard protocols. Gruels from formulations underwent consumer acceptability tests with 210 untrained panellists. Sensory attributes, including appearance, aroma, taste, mouthfeel, and overall acceptance, were evaluated using a 9-point hedonic scale (1 = extremely dislike to 9 = extremely like). SF did not significantly alter crude protein content ($p = 0.182$), though slight increases were observed. SF significantly decreased ($p < 0.01$) crude fibre content across all blends, except for millet- and sorghum-based blends. The calorific value did not differ much after SF, except for the millet-based blend, which showed a 3.2 % decline. A slight increase in iron was observed in starchy roots, tubers, and plantain-based formulations after SF. However, SF led to a 43.6 % decrease ($p < 0.001$) in the sorghum mix. Zinc levels increased 20.4 % in the cassava-based, 57.7 % in sweetpotato-based, 113.0 % in plantain-based, 21.9 % in sorghum, and 13.6 % in millet blends after SF. Phytate levels were reduced by 26.1 %, 40.0 %, and 27.9 % in maize, millet, and sorghum mixes, respectively. The phytate/minerals molar ratios declined significantly with SF across the blends. Although the sweetpotato-based blends showed no aflatoxin contamination, the aflatoxin levels in millet and sorghum mixes declined by 1.5- and 1.03-fold, respectively, following SF. The setback, peak, trough, and final viscosities increased substan-

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tially ($p < 0.001$) in all blends following SF, except cassava- and plantain-based blends. Unfermented gruels generally received higher median scores in consumer acceptance than fermented products, with cereal-based gruels scoring higher than the cassava- and plantain-based gruels. SF improved key nutritional (phytate reduction, slight protein increase) and functional attributes of the blends, highlighting its value for local complementary foods.

Keywords: Cassava, cereal, complementary blend, phytate, spontaneous fermentation, sweetpotato

Participatory modelling of the water-energy-food nexus: A case study of a cassava processing hub in Oyo state, Nigeria

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Cassava production plays a crucial role in providing food and income for smallholder farmers, and raw materials for agro-processors in Nigeria. A cassava processing hub serves as a shared facility for agro-processors to aggregate and process cassava, using common infrastructure to ensure processing efficiency, increase market access, and improve their livelihoods. However, interlinked pressures on water, energy, waste management, and local environmental systems are increasingly constraining their expansion. This study examines the dynamics that impact the sustainable growth of a cassava processing hub in Oyo State, Nigeria. The processors collectively manage approximately 6–9 tons of cassava per processing cycle, reflecting a small- to medium-scale processing operation. The hub is established on a shared land area of 4,180.64m^2, enabling access to pay-as-you-use equipment and infrastructure that would otherwise be too costly for smaller-scale processors. Hence, a participatory system dynamics modelling approach was employed using qualitative insights from Focus Group Discussions (FGDs) with cassava processors. These insights were used to develop a System Dynamics Model (SDM) in Stella Architect, by applying the Limits to Growth system archetype, represented through Causal Loop Diagrams (CLDs). The CLDs illustrate how initial expansion in processing capacity is constrained by resource dependencies and negative environmental feedback. The SDM reveals how feedback loops, time delays, and non-linear relationships link water use, energy demand, processing capacity, and waste discharge. Results indicate that while processors pursue expansion through a reinforcing production loop, this growth is systematically constrained by five balancing loops: environmental impact (B1), water resource dependency (B2), energy resource dependency (B3), waste management limitations (B4), and escalating operational costs (B5). By explicitly identifying these structural constraints and their interactions, the study advances system-level understanding of sustainability challenges in cassava processing hubs. The study concludes that unlocking resilient, inclusive, and sustainable growth requires coordinated interventions, including communal wastewater infrastructure, resource-efficient technologies, strengthened governance among processors, and improved access to training and knowledge through a combination of processors' collective efforts and support from Oyo State government extension services and development agencies. These insights position participatory system dynamics modelling as a practical decision-support tool for guiding sustainable agro-processing development.

Keywords: Cassava, limits to growth, participatory modelling, wastewater

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Understanding meat consumption patterns and use of naturally occurring food additives (NOFA) in urban Rwanda

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Rwanda has the highest population density in Africa and is expanding its poultry sector as a food security strategy; however, this sector remains underdeveloped, with critical food safety infrastructure largely absent, increasing the risk of microbial contamination. Food preparation practices, including cooking culture, storage methods, and ingredient choices, directly influence pathogen presence, survival, and transmission. Although antimicrobial properties of certain herbs and spices have been confirmed, evidence on their systematic use in low-resource settings is lacking. To examine the socio-cultural, economic, and behavioural factors influencing meat consumption and handling in Rwandan communities, and to identify the use of naturally occurring food additives (NOFA), including herbs, spices, and natural sanitisation, as well as their perceived efficacy and potential for adoption in food safety interventions. A qualitative research design was employed. A total of six focus group discussions (FGDs) with 48 participants from diverse demographic and socioeconomic backgrounds in urban Rwanda were held. Thematic analysis was conducted using a coding process, performed both manually and using NVivo software, to identify key patterns, themes, and sub-themes. Five major themes emerged: A widespread use of natural substances (garlic, lemon, ginger, vinegar) with perceived antimicrobial and preservation roles; prevalent use of commercial condiments ('maggi', soy sauce, 'masala' blends); a culturally embedded multi-stage cooking sequence serving implicit food safety functions; and beef as the dominant meat consumed primarily twice weekly, with cultural variation by occasion. Significant food safety concerns were reported, including retail hygiene deficiencies, lack of cold chain during transport, and, in some areas, absence of poultry abattoirs with limited regulatory inspections. Urban Rwandan households demonstrate meat preparation practices that integrate natural and commercial additives while maintaining inherent food safety functions. Significant food safety gaps exist. These findings provide a novel qualitative evidence base to inform culturally appropriate food safety interventions, NOFA-based antimicrobial strategies, and public health policy in Rwanda. This research is among the first systematic social science studies on meat consumption and traditional food safety practices in Rwanda, providing foundational evidence to support evidence-based food safety regulation, nutrition programmes, and NOFA-focused public health interventions in sub-Saharan Africa.

Keywords: Antimicrobial herbs, focus groups, food safety, traditional spices

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Process optimisation for enhanced yield and quality of West African soft cheese: Effects of temperature control and coagulant concentration

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West African soft cheese (WASC) remains an essential source of nutrition and a critical livelihood asset in Western Africa. In cheesemaking, processing temperature, coagulant type, and coagulant concentration are key determinants of product yield and quality. However, there is limited empirical evidence on how these factors influence the yield and quality of WASC. First, the effect of temperature was studied, followed by the effects of type and amount of coagulant. Two independent replicates of WASC were produced at three processing temperatures (60°C, 80°C, and 100°C) using 30 g of crushed Calotropis procera (CP) leaves as coagulant per litre of raw cow milk. Analysis of variance was performed at 5 % significance level to assess factor effects. Increasing the processing temperature from 60°C to 100°C reduced coagulation time (41.0 min to 4.2 min), cheese yield (54.1 % to 30.2 %), and magnesium and calcium contents ($p < .05$). WASC yield did not differ significantly between 60°C and 80°C. Using the optimal temperature (60°C) for WASC processing, coagulant type (CP leaves vs. stems) levels of 10 g L^{-1}, 20 g L^{-1}, 30 g L^{-1}, and 40 g L^{-1} were tested. The coagulant type and concentration significantly affected most of the measured parameters, both independently and interactively. On average, the CP leaves resulted in longer coagulation times, higher WASC yields, and lower whey volumes than the stems. Increased coagulant concentration significantly improved WASC yield from 33.6 % to 49.7 % while reducing the coagulation time from 38.5 min to 28.3 min. For interaction effects, using 30 g L^{-1} of CP leaves produced the highest WASC yield (52.6 %), whereas using 10 g L^{-1} of leaves resulted in the lowest yield (32.9 %). The leaf-coagulated WASC (notably at 40 g L^{-1}) appeared slightly green and had higher protein, iron and zinc (at 30 g L^{-1}) contents than the stem-coagulated WASC.
In conclusion, optimal WASC yield and better nutritional quality can be achieved at moderate processing temperatures (60–80°C) and coagulant concentrations not exceeding 30 g/L. Processors should maintain these conditions for increased yield and nutritional and sensory quality. Further research should assess whether yield gains translate into income improvements and evaluate market acceptance and storage stability as coagulant levels increase.

Keywords: Cheese yield, coagulant concentration, colour and nutritional traits, optimisation, temperature control

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Consumers' preference for beef quality attributes and modern market system: Evidence from Nigeria

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The dominance of traditional, unregulated food markets and the lack of a credible mechanism to signal food quality in many low- and middle-income countries continue to undermine consumers' dietary quality. Although modern market systems – such as supermarkets - are gradually emerging and have the potential to enhance food quality signaling, empirical evidence suggests that consumers in SSA often exhibit a strong preference for traditional market outlets, motivated by perceptions of superior taste, freshness, and familiarity. Focusing on the case of beef safety, this study employs a discrete choice experiment (DCE) to analyse how 209 urban Nigerian consumers make trade-offs between market outlet types (supermarkets, modern abattoirs, traditional slaughterhouses, and open markets) and beef quality attributes (meat colour, fat content, and production system). A split-sample design is used to examine differences in preferences between scenarios with and without certification labeling, and mixed logit models are estimated to account for preference heterogeneity. The results indicate that in the absence of a certification label, consumers are indifferent between modern abattoirs and traditional slaughterhouses, but express a strong aversion to supermarkets. Furthermore, consumers prefer low-fat beef and are indifferent to meat colour when meat is unlabeled. However, introducing a certification label significantly shifts consumer preferences toward light-red, lean beef and, surprisingly, beef from traditional slaughterhouses. These findings yield two key implications. First, consumers need to be better informed about the implications of traditional market systems for their health and how modern retail infrastructure can improve their dietary quality. Second, food safety certification labels alter consumers' heuristics to infer quality from observable product and market attributes.

Keywords: Beef attributes, certification verification, discrete choice experiment, food safety, market transformation system

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Relating phenotypic traits, aroma and untargeted metabolomes of boiled sweet potato from Uganda

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Boiled sweet potato (SP) produced from nine sweet potato varieties harvested in Iganga and Buyende districts of Uganda were freeze-dried and milled into flour. The texture of boiled sweet potato was analysed by a standard texture profile analysis (TPA) procedure. Trained panellists rated boiled SP for twenty-two sensory attributes on ordinal intensity scales ranging from 0 (lowest) to 10 (highest). Microstructure, dry matter (DM), pasting properties, total pectin, swelling power, and solubility were determined in the raw and cooked states. Aroma composition was obtained by dynamic headspace – GCMS analysis and untargeted metabolomes were analysed by LCMS analysis. Results show that instrumental hardness was associated with sensory hardness and mealiness, dry matter, swelling power, solubility, and paste viscosities (peak, trough, final), most evidently with genotype UGP202000232–12 of notable SP-like aroma and chalky appearance. Instrumental cohesiveness was associated with the genotype D20 which sensorially exhibited pumpkin-like aroma and odour and intense orange colour. Instrumental resilience and springiness was associated with a purple-fleshed genotype that was sensorially fibrous and had good recovery after deformation. Instrumental chewiness was associated with the genotype UGP202000296–42 which had high DM, sensory bitterness and hardness, and paste breakdown. Tanzania, NAROSPOT 7, UGP202000302–12, and UGP202000161–16 were sensorially moist and smooth. Pectin has no correlations with other phenotypic traits. Scanning electron microscopy (SEM) showed that only UGP202000302–12 and UGP202000232–12 retained intact cells after cooking, with others having a continuous matrix indicative of cell-wall disruption and starch release. Boiled SP released 41 untargeted aromatic compounds including Ethanol, Toluene, Hexanal, m-xylene, Heptanal, D-Limonene, Eucalyptol, Octanal, Furfural, Benzaldehyde, Linalol, Isopropyl myristate, Phenol and trans-Geranylgeraniol.

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Untargeted analysis of the SP panel indicates changes in metabolome composition after cooking, linked to the phenotypic classification based on texture parameters.
SP metabolome was strongly correlated with textural hardness, gumminess and flour solubility particularly after cooking. Strong correlations were observed between the metabolome of both raw SP and, particularly, cooked SP flour and textural hardness, gumminess and flour solubility. Over 150 chemical features were identified as robust differentiators for these textural parameters. These were putatively characterised as phenylpropanoids, monosaccharides and nitrogen-containing compounds.

Keywords: Aroma, boiled sweet potato, sensory, texture, untargeted metabolomics

Sustainable transformation of the West African soft cheese value chain via milk substitution and whey valorisation

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West African soft cheese (WASC) is predominantly produced by Fulani women through traditional practices, generating a meaningful source of household income. Despite its nutritional, economic and cultural significance, the WASC value chain faces recurring challenges. Seasonal fluctuations in cow milk supply drive up production costs and retail prices during the dry season, pushing some processors toward adulteration, which compromises quality, fuels food fraud, and erodes consumer trust. Additionally, whey, a nutrient-dense by-product of WASC production, remains largely wasted throughout the value chain.

This study investigated the potential of partially substituting cow milk with soya-based drink (referred to as soya milk) at rates of 0, 5, 10, 15, and 20 % in WASC production, and the incorporation of whey as an ingredient in Tuo zaafi (TZ), a cereal-based staple widely consumed in Ghana. Cheese yield was assessed across six independent replicates, and its sensory evaluation involved 30 semi-trained panellists in a non-replicated full cross-over design, where each panellist assessed all products once using a Check-All-That-Apply (CATA) questionnaire with 23 descriptors. Nutritional evaluation of whey-based TZ was conducted in two independent replicates. ANOVA was used for comparisons, while Cochran Q test, correspondence analysis, and penalty-lift analysis were applied for CATA data.

Results showed that soya milk can replace up to 20 % of cow milk in WASC production without compromising sensory properties or consumer acceptability, though yield was significantly reduced compared to the control (23.2 % vs. 27.8%; $p < 0.001$). As for TZ, partially replacing water with whey utilisation at up to 40 % in TZ preparation significantly improved its nutritional profile, with notable increases in protein (+42 %), calcium (+149 %), magnesium (+33 %), and iron (+311 %) ($p < 0.001$).

These findings highlight the potential of these solutions to strengthen the WASC value chain by improving supply stability and reducing waste. Future research should examine consumer acceptance of whey-enriched TZ. WASC incorporated with soya milk should be clearly labelled to prevent food fraud, allergic risks to protect consumers. The economic implications should also be studied for both processors and consumers, particularly during the dry season when cow milk is scarce, and WASC retail prices rise.

Keywords: by-product utilisation, dairy value chain, milk, Wagashi

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Levels of selected physicochemical indices in some tap-water commonly accessed by residents in Wukari, Nigeria

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Water is required daily by humans and water quality is measured by several factors, including physicochemical parameters. This study evaluated the levels of selected physicochemical indices of water quality in selected tap water commonly accessed by residents in Wukari metropolis, Nigeria. Methodology: The water samples were collected from some boreholes located at different parts of Wukari metropolis: Central Mosque Wukari, FUW Teaching Hospital, Veterinary Hospital Wukari, New Site Area and Elim-Top Suites. A total of ten (10) water samples (two from each source) were tested. The selection of the locations for the water collection was of local importance because many residents of Wukari, Nigeria consume water from the selected locations. They were analysed for the selected physicochemical indices.
Iron, copper and lead were not detected to be present in all the selected tap water. Nitrate was only present in tap water collected at Central Mosque Wukari and Elim-Top Suites. Nitrite, fluoride, cyanuric acid and chlorine dioxide were not present in all the tap water samples. Carbonate was higher in the tap water collected at Central Mosque Wukari and FUW Teaching Hospital than in others. Total hardness was higher in the tap water collected at Central Mosque Wukari, followed by FUW Teaching Hospital. The level of total alkalinity was higher in tap water collected at Central Mosque Wukari. The pH values of the samples ranged from 7.20 to 8.20. The TDS values of all the tap water samples ranged from 112.00 to 261.50 mg/L. All the tap water samples were colourless, odourless and tasteless.
This study is significant because it has provided the results and showed how safe the selected tap water are for consumption, which is important to the consumers and general public. This study showed that all the tap water samples analysed are safe for drinking.

Keywords: Acceptability, contamination, physicochemical indices, water quality

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Dietary relevance and potential of Kenyan grown quinoa for food applications

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Despite the growing interest in quinoa cultivation in Kenya, limited information exists on the nutritional quality and functional performance of quinoa grown under Kenyan conditions. To bridge this information gap, this study assessed the nutritional composition, *in vitro*-protein digestibility, phytochemical content and functional properties of six quinoa genotypes grown in Kenya to determine genotype-dependent variations, dietary relevance and their suitability in local food applications. Proximate composition showed significant variations with crude protein ranging from 15.0 to 23.12 %, fibre from 1.58 to 2.60 %, and carbohydrate from 58.6 to 65.91 %. Mineral analysis indicated high concentrations of potassium (2,337.5 – 12,750 mg kg^{-1}), magnesium (2,107.5 – 2,467.5 mg kg^{-1}) and phosphorus (3,877.5 – 4,430 mg kg^{-1}). Phytic acid and saponin were more abundant than total phenolic compounds. Phytate levels showed significant inhibitory effects on Fe, Ca, and Zn bioavailability, while saponin levels exceeded the upper limit for direct human consumption. *In vitro* protein digestibility ranged from 70.0 to 79.8 %. In functional properties, the genotypes showed good water -and oil holding capacities (WHC, OHC) exceeding 100 %, swelling capacity (SC) ranged from 70.14 to 88.67 %, emulsification capacity from 45.33 to 56.56 %, foaming capacity from 15.0 to 32.41 % and foaming stability from 28.91 to 46.66 %. Crude protein correlated positively with WHC (r =0.85), OHC (r =0.83) and protein water solubility (r=0.90).Carbohydrate had negative correlations with WHC (r =−0.68), OAC (r =−0.66) and SC (r=−0.61). The six quinoa genotypes showed adequate nutritional quality and functional performance, which can be further improved through processing, for developing diverse quinoa-based products targeting specific nutritional and functional requirements.

Keywords: Bioavailability, digestibility, food, nutrients, products, quinoa

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Phenotypic association of textural, sensory, physicochemical, and untargeted aroma of boiled yam in Nigeria

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This study aimed to elucidate the relationships among the textural and physicochemical properties of boiled yam (BY) and to identify untargeted aroma features associated with BY quality. Twelve yam varieties harvested in Nigeria were freeze-dried, milled, and analysed using standard protocols. Texture was assessed through a penetration test, while nineteen trained panelists evaluated five 'champion' genotypes for two key sensory attributes of boiled yam: *yammy* and *earthy/woody* aroma. Dry matter (DM) content and colour parameters were measured in both raw and cooked samples. Aroma profiles were obtained using dynamic headspace GC–MS.

Dry matter content showed a significant correlation with penetration parameters associated with hardness. Principal component analysis (PCA), explaining 71.3 % of total variation, revealed that hardness was primarily associated with several *Dioscorea rotundata* genotypes, including Igangan, Meccakusa, TDr21002085, TDr1830024, and TDr1741006. In contrast, *D. alata* genotypes (Akuabata, Va yam, Ewura), the *D. rotundata* genotype Sharp Sharp, and the *D. dumentorum* genotype Esuru were more strongly linked to the fracturing/crumbling characteristics. Colour attributes also varied among genotypes: yellowness (b*) aligned with Igangan and TDr21002085, brownness (a*) with Sharp Sharp and TDa1665001, and lightness (L*) with Akuabata.

Sensory evaluation associated the *D. rotundata* genotypes Meccakusa and Favourite with the highest yammy aroma, whereas the *D. alata* genotype Akuabata had the least yammy aroma. More than 162 aroma compounds were detected, of which 43 were validated using the NIST20 spectral library and considered relevant to boiled yam quality. Some of these include furfural, ethyl acetate, pentanal, 2-pentylfuran, cyclohexanone, benzaldehyde, trans-2-nonenal, acetophenone, acetamide, phenol, and toluene.

Overall, the findings highlight the importance of integrating textural, physicochemical, sensory, and aroma data to better understand the quality attributes and underlying diversity of yam genotypes.

Keywords: Fracturing, hardness, penetration, sensory, untargeted aroma

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From soil to diet: Linking soil micronutrient to hidden hunger in northern Ghana

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Hidden hunger, also known as micronutrient deficiency, impacts the entire globe. About half the population of preschool-aged children and two-thirds of women of reproductive age are affected by at least one micronutrient deficiency. In Ghana, the situation is worse in the rural areas of the Northern region, where up to 40 % of the children are reportedly stunted. In terms of human nutrition, micronutrients are not limited to mineral elements like Fe, Mn, Cu, Zn and Mo, but also include vitamins. It is, however, notable that soil micronutrients influence vitamin synthesis by plants. As such, soil micronutrients have both direct and indirect effects on human nutrition. Indeed, a major cause of micronutrient malnutrition/hidden hunger in humans is the inadequate micronutrient availability in soils, which is the primary source of the essential micronutrients. Besides mitigating hidden hunger, adequate supply of soil micronutrients also improves crop output and farmers' wellbeing. Consequently, if the soil is fertile, the plants will absorb all nutrients in adequate amounts. The animals and humans that feed on those plants will, in turns, get an adequate amount of the nutrients from the food (plants and animals) they consume. Soil micronutrients are generally variable across Northern Ghana, with corresponding impacts on rate of plant absorption and concentration in food. Plant-available iron (Fe) and manganese (Mn) are high across the region. Fe and Mn malnutrition would expectedly be low in the region, especially if crops with efficient absorption and assimilation capacity are grown and consumed. Molybdenum (Mo) is low across the region, so Mo malnutrition may be endemic. Copper (Cu) is moderate, while Zinc (Zn) ranges from low to moderate. This is an indicator of low to moderate Cu and Zn malnutrition in the region. Therefore, to effectively improve crop productivity and mitigate hidden hunger in Northern Ghana, efficient and sustainable Mo, Zn and Cu fertilisation is essential.

Keywords: Hidden hunger, linking soil to diet, malnutrition, micronutrient deficiency, stunting

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Utilisation of agri-food by-products within the water-energy-food nexus in sub-Saharan Africa

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Food processing in most African countries is semi-mechanised resulting into generation of abundant agri-food by-products that are frequently underutilised, discarded as waste, burnt or dumped. Examples include pomace, husk, bran, spent grain, oilseed cakes, which retain valuable bioactive compounds such as phenolic compounds, organic matter, minerals, fibres, proteins, functional lipids, and natural pigments. With the increasing awareness of environmental sustainability, resource and food scarcity, agri-food by-products are increasingly being viewed not as waste but as valuable resources for sustainable utilisation. Despite these advances, most of the research on agri-food by-products utilisation have been explored from isolated perspectives such as renewable energy production, soil fertility improvement, wastewater treatment and food or feed development with limited consideration of how these applications interact across interconnected resources systems. As a result, opportunities to maximize resource efficiency, reduce trade-offs and create synergies among water, energy and food systems (WEF nexus) are often overlooked. Therefore, a systematic review was carried out to collect evidence on the multifunctional contributions of agri-food by-products across the Water-Energy-Food (WEF) nexus. A search was conducted in three main data bases, PubMed, Science direct and Scopus as well as in Google Scholar for studies published between 2022 and 2026. The review followed PRISMA 2020 guidelines and 39 eligible studies met the inclusion criteria and were included in the review. The synthesis indicated that the most generated by-products are cereal brans/husks, roots and tuber peels, fruit peels/kernels, oil-seed residues, and brewery extracts that are utilised in bioenergy/ biofuel production, waste water treatment, food ingredients and biofertiliser production. Therefore, instead of focusing on isolated benefits, this review provides a comprehensive synthesis on agri-food by-products utilisation into an integrated Water-Energy-Food (WEF) nexus that reveals patterns synergies and opportunities for sustainable resources management and circular bioeconomy strategies. This is because the Water-Energy-Food (WEF) nexus provides an integrated framework that recognise that water, energy and food systems are highly interdependent, such that decision in one sector influence resources availability, efficiency and sustainability in the other.

Keywords: Agri-food by products, circular economy, functional food ingredients, gender equity, smallholders, sub-Saharan Africa

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From grain to greater nutrition: Solid-state fermentation with *Aspergillus oryzae* enhances nutrient bioavailability and digestibility of cereals – A research contribution conducted within the SoLFOOD project

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Solid-state fermentation (SSF) using filamentous fungi represents a versatile, sustainable approach for producing nutrient-dense, minimally processed whole foods. By colonizing solid substrates such as cereals, filamentous fungi can improve protein quality, enhance nutrient bioavailability, and reduce anti-nutritional factors through their enzymatic activities. *Aspergillus oryzae* (Koji mold) is a well-established filamentous fungus that has been used for centuries in the production of fermented foods and is classified "Generally Recognized as Safe" (GRAS). Within the SoLFOOD project, which aims to reduce food losses associated with mycotoxin contamination among Kenyan smallholder farmers, SFF was investigated as a low-cost and locally applicable strategy for producing safe and nutrient-rich food products. To assess the feasibility of household-scale fermentation, freeze-dried *A. oryzae* (MRI389) was inoculated onto pre-steamed cereal substrates (maize, rice, and wheat) and incubated at temperatures representative of local environmental conditions (20, 30 and 40 °C). Fungal growth was monitored by ergosterol analysis after 3, 5, 7, 10, 12, and 14 days of fermentation. Nutritional assessments were conducted after 7 and 14 days and included the determination of phytate content, proximate nutrient composition, and *in vitro* digestibility. Preliminary results demonstrated successful colonisation of all cereal substrates by *A. oryzae*. Fermentation resulted in improved *in vitro* digestibility and reduced phytate concentrations compared with unfermented controls. These changes indicate enhanced nutrient accessibility and underscore the potential of SFF as a simple, low-technology intervention for improving the nutritional quality of staple cereals in resource-limited settings. Although SFF has demonstrated considerable potential for improving the nutritional quality and functionality of food products, most studies have been conducted under controlled laboratory conditions that are difficult to reproduce in resource-limited settings. Therefore, this study evaluated the performance of *A. oryzae* under simplified fermentation conditions designed to reflect those encountered in rural households. The results indicate that SFF using *A. oryzae* represents a promising and cost-effective strategy for enhancing the nutritional value of staple foods, supporting circular food systems, reducing post-harvest losses, and contributing to food security in resource-constrained environments.

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Coeliac disease and the future of traditional gluten-rich foods: Evidence from four EU countries

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The rise of gluten-related disorders such as Coeliac Disease (CD) and Gluten Intolerance (GI) across Europe challenges the continued consumption of traditional gluten-rich foods. While the existence of Coeliac disease is becoming more widely recognised, there is still a significant lack of thorough research that explores the complex relationship between gluten intolerance and consumer behaviour in the context of traditional and regional food consumption within the European Union. This study aimed at analysing data on consumer attitudes on gluten-free products in Belgium, France, Spain, and Cyprus while identifying trends in traditional food consumption. Using the purposive sampling approach and a cross-national survey of 2,005 respondents aged from 18 to 84 years and above, and other key predictors such as sex, reason for purchasing gluten-free products, and ranking of traditional or regional foods, the study explored the cultural value of gluten-rich foods and provided strategies for individuals with Coeliac disease to enjoy them. This study identified various measures, such as ingredient substitutions, processing techniques and cultural modifications, to enable people with coeliac disease participate safely in traditional culinary practices. This was achieved through an in-depth analysis of existing literature, dietary guidelines and available gluten-free alternatives. Consumer trends explained that while most participants purchased gluten-free products in the stores, others made them at home, others stopped eating regular gluten foods due to unavailability, high prices, and low quality, and others consumed gluten foods occasionally despite dietary preferences. In addition, the research evaluated the feasibility and efficacy of several approaches to promote the integration of people with coeliac disease into traditional dietary practices. Overall, this study provided an insightful assessment and practical recommendations for promoting dietary inclusion and improving the quality of life of people with coeliac disease.

Keywords: Coeliac disease, gluten-free alternatives, traditional food

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Antimicrobial resistance patterns in *Escherichia coli*, *Salmonella* spp., and *Enterobacter* spp. from broiler meat in Mzimba, Malawi

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Antibiotic resistance (ABR) in poultry production poses a growing threat to global food safety and public health, particularly in developing countries where inappropriate antibiotic use is prevalent. This study links the prevalence of antibiotic resistance in broiler meat to the Water-Energy-Food (WEF) Nexus framework, highlighting interconnected links across sectors. Excessive antibiotic use in poultry production generates resistant pathogens that contaminate water resources through runoff, wastewater, and poor waste management in informal markets. This causes treatment failures and production losses, increasing compensatory energy demand for feed production, water treatment, and health care, creating inefficiency, and trade-offs across the nexus. The study assessed the prevalence of antibiotic resistance of *E. coli, Salmonella*, and *Enterobacter* species in broiler poultry meat sold in informal markets in Mzimba District, Malawi. A cross-sectional study was conducted between March and May 2025. A stratified sampling technique was used to select 100 chicken meat samples from informal markets across the district. Descriptive statistics and inferential statistics were performed using R version. *E. coli* (69 %) and *Enterobacter* (12 %) species were the most frequently isolated pathogens. The highest prevalence of antibiotic resistance was observed in *E. coli* against three commonly used antibiotics, ampicillin (91.3 %), meropenem (82.6 %), and tetracycline (71%). *Enterobacter* spp. showed similar results. MAR values were considerably high, ranging from 0.1 to 0.75. Ninety-seven percent of the isolates had MAR of over 0.2. Twenty-eight isolates (29%) had extreme MAR of 0.5 or higher. Informal markets in Mzimba were the most significant predictors of the MAR index ($p = 6.096e^{-05}$, $\eta^2 = 0.372$). High levels of MAR revealed are concerning. They reflect a high-risk of antibiotic treatment failure in animal and human infections, threatening food security and resilience. Combating MDR requires coordinated, multisectoral approaches through a One Health program to address ABR through a WEF Nexus approach, via coordinated intervention, surveillance, educating farmers and veterinarians regarding antibiotic use, improved waste and water management, and a supportive policy framework to safeguard food safety, protect water, and promote sustainable energy-efficient food systems in Malawi and similar environments.

Keywords: Antibiotic resistance, antimicrobial use, awareness, chicken meat, informal markets, Malawi, MAR index, Mzimba, WEF nexus

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Postharvest fruit losses and management in fresh jamun (*Syzigium cumini*) berry supply chains and domestic market efficiency in Pakistan

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Jamun (*Syzygium cumini*), commonly known as java plum, is a tropical to subtropical fruit tree that remains underutilised in Pakistan, where it is primarily grown as boundary or shelterbelt planting with limited commercial orchards. Despite its high nutritional and medicinal value and potential for processing, the fresh jamun industry faces significant postharvest challenges, including substantial physical and weight losses due to improper handling, high perishability, short shelf life, and disease incidence.To address these issues, a comprehensive research study funded under the HEC NRPU programme was conducted over three years. In Year I, postharvest losses were quantified across the supply chain, varietal quality was assessed, and preliminary interventions were introduced. Year II focused on managing quality deterioration through pre- and postharvest applications of ripening-delaying treatments, particularly citric acid (CA), and on developing value-added products such as pulp leather and jam, which were evaluated for nutritional and sensory attributes. In Year III, market and consumer studies were conducted, alongside investigations into postharvest diseases, including pathogen identification and validation of quality management practices. Results indicated strong consumer acceptance of jamun and high market potential for processed products, with preferences for medium-sized, affordable packaging. Postharvest treatments with 2 mM citric acid significantly reduced weight loss, preserved total soluble solids, delayed acidity decline, and maintained ascorbic acid content. Combined pre- and postharvest applications were most effective in sustaining quality and regulating juice pH. Overall, the study demonstrates the commercial viability of jamun products and the effectiveness of citric acid treatments in reducing postharvest losses and enhancing shelf life.

Keywords: Fruit quality, horticulture, local market, pomology

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Assessment of camel milk handling practices and bacterial loads along the value chain in Borana and East Shewa, Ethiopia

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Camel milk plays a vital role in the livelihood and food security of pastoral and agro-pastoral communities in Ethiopia, especially in Borana and East Shewa zones. However, poor milk handling practice compromises the quality and safety of milk along the value chain. A cross sectional study was conducted to investigate hygienic milking, milk handling practices and microbial quality along the value chain in Borana and East Shewa. Milk handling practices were assessed through semi-structured interviews and through observation involving 48 camel milk producers, 20 collectors, 10 retailers, 10 cafeterias, 4 cooperatives, 20 consumers and 12 experts. A total of 752 milk, hand swab and container swab samples were collected from both zones during the wet and dry seasons, and subjected to aerobic plate and coliform count. Results showed that while most producers never washed their hands (73 %) or cleaned the udder (95.8 %) before milking, post-milking hand washing was common (91 %). In contrast, vessel hygiene practices were considerably better as nearly all producers washed (97.9 %) and smoked (95.8 %) their milk containers daily. All of the retailers (100 %) and 60 % of the collectors washed their hands with water and soap while handling milk. Nearly all of the value chain actors keep milk at room temperature until consumption. Regarding the awareness of food safety risks along the milk value chain, experts demonstrated the highest awareness of zoonotic diseases (83.3 %), whereas boiling of milk especially for vulnerable population groups is not a common practice, particularly among producers and consumers. In both zones and seasons, the mean aerobic plate (7.47 log CFU ml^{-1}) and coliform (7.13 log CFU ml^{-1}) counts surpassed the EU standard for raw milk other species. Bacterial contamination peaks at the retailer level, whereas relatively lower values recorded at the cafeterias and cooperative level. The overall mean aerobic plate counts slightly increased in the wet season as compared to the dry season, while coliform counts slightly decreased in the wet season. Given the prevailing poor hygiene and limited food safety awareness, milk is exposed to contamination risks that require interventions in training and handling practices to enhance food safety.

Keywords: Camel milk, Ethiopia, microbial quality, milk handling, milk hygiene, value chain

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Energy-efficient drying of African walnut (*Tetracarpidium conophorum*): Implications for the water–energy–food nexus and climate-resilient agro-processing

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African walnut (*Tetracarpidium conophorum*) is a perennial, oil-rich indigenous nut widely distributed in the humid forest zones of West and Central Africa, particularly in Nigeria, where it grows naturally in wild and semi-managed forest systems. It is commonly consumed boiled as a snack and used in traditional diets due to its high nutritional and functional value and its role as a locally consumed food. The nut contains approximately 30–35 % lipid content, 20–25 % crude protein, and is rich in essential minerals such as potassium, magnesium, and iron, making it an important contributor to household nutrition and emerging local agro-processing value chains. Despite its nutritional importance, commercialisation remains limited due to its high moisture content, rapid spoilage, and lack of optimised postharvest processing systems.

Drying is a key preservation method, but it is energy-intensive and often inefficient in smallholder processing systems. Within the Water–Energy–Food (WEF) Nexus, improving drying efficiency offers a pathway to reduce postharvest losses, lower energy demand, and enhance food availability while maintaining resource sustainability.

This study evaluates the drying kinetics, effective moisture diffusivity, and energy efficiency of African walnut using cabinet and oven drying systems at 50, 65, and 80 °C, with and without shells. Energy efficiency refers to the amount of electrical energy required per kilogram of water removed, while effective moisture diffusivity describes the internal moisture migration rate within the nut structure under thermal gradients. Results showed that increasing temperature significantly reduced drying time and increased diffusivity from 6.23×10^{-8} to 4.72×10^{-7} $m^2\,s^{-1}$, with oven drying at 80 °C achieving the lowest specific energy consumption (0.11 $kWh\,kg^{-1}$ water removed). While higher temperatures improved drying efficiency, they may also accelerate degradation of heat-sensitive nutrients such as vitamins and unsaturated fatty acids, highlighting a trade-off between process efficiency and nutritional quality.

From a WEF Nexus perspective, improved drying technologies can extend shelf life, enable storage, and support value addition such as kernel processing and small-scale oil extraction. This improvement in efficiency will strengthen emerging local market opportunities and enhance livelihood opportunities in rural West Africa.

Keywords: African walnut, agro-processing, drying kinetics, energy efficiency, moisture diffusivity, Nigeria, water–energy–food nexus

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Institutions, finance, and productivity in agricultural value chains

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Multi-output production and technical efficiency in maintained NTFP systems: Evidence from the Brazilian Cerrado

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Rural development and biodiversity loss remain central challenges in developing regions, where forest-dependent communities depend on natural resources as a primary livelihood strategy. With over 3.5 billion people worldwide relying on Non-Timber Forest Products (NTFPs), with more than half in rural settings, these products play a critical role in supporting vulnerable communities. Sustainable NTFP management practices are widely promoted to protect biodiversity and support forest communities. However, it remains unclear whether these practices come at the cost of productive efficiency. If efficiency losses occur, farmers may be incentivized to specialise, transitioning from diversified maintained systems toward more intensive cultivated production and undermining biodiversity. This is particularly relevant in maintained NTFP systems, an intermediate management stage characterised by diversified multi-output production and low specialisation, which remain relatively understudied compared to single-product or advanced cultivated systems.

This research examines technical efficiency in multi-output NTFP production under maintained management, and assesses whether the adoption of sustainable management practices supports biodiversity and influences productive efficiency. Using data from 173 smallholder farmers in the Brazilian Cerrado and a stochastic frontier analysis, we estimate technical efficiency for multi-output NTFP production. Labor emerged as the only significant binding input, suggesting that improving labour efficiency, rather than expanding land area, is key to productivity gains. High technical inefficiency (mean TE ≈ 0.24) and decreasing returns to scale point to substantial room for output gains without additional inputs, but inherent limits to simple scaling up. Notably, technical inefficiency decreases with NTFP diversity, suggesting diversified production systems may simultaneously support both conservation and productivity objectives. Finally, sustainable practice adoption restructures NTFP production from a land-extensive toward a labor-intensive system, with high adopters showing significantly higher labour elasticity despite

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lower efficiency scores. Findings have potential relevance for other forest-dependent communities that rely on diversified NTFP production systems, with important implications for agricultural extension programmes and agri-environmental policies. Agricultural extension services should support farmers in maintaining and expanding species diversity and prioritise labour efficiency over land-extensive strategies. By examining multi-output NTFP production, this study contributes to a better understanding of how forest-based livelihoods can support both sustainable production and biodiversity conservation.

Keywords: Agroforestry, efficiency determinants, rural development, smallholder farmer, species diversity

Does cluster farming work? Productivity gains and institutional dynamics among smallholders in South Punjab, Pakistan

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Farming in Pakistan's smallholder sector has never been easy, but the pressures have intensified. Landholdings are shrinking, markets remain inefficient and exploitative, and institutional support is, at best, uneven. Against this backdrop, cluster farming has attracted considerable attention as a practical organisational arrangement in many regions through which smallholders can pool resources, bargain collectively, access better inputs, and grow high-value crops particularly vegetables that would otherwise be beyond their individual reach. The idea is compelling, yet despite growing policy interest, rigorous empirical evidence on whether cluster farming works and under what institutional conditions, remains limited, especially for South Punjab.

The present study investigates the productivity and income effects of cluster farming among smallholders in South Punjab, Pakistan, with a focus on vegetable and chili clusters by employing a mixed-methods explanatory sequential design. Quantitative data were collected from 400 smallholder farmers, from both cluster members and non-member controls across the study area using stratified random sampling and employing the Yamane formula Date and were analysed through Propensity Score Matching (PSM) and Difference-in-Differences (DiD) estimation. These were complemented by semi-structured interviews with 30 key informants, including extension agents, cooperative leaders, and local officials, with findings interpreted through thematic analysis.

The results suggest that cluster membership does make a measurable difference. Farmers within clusters reported higher crop yields, improved net farm income, and better input-use efficiency. They also showed greater independence from commission agents and stronger connections to formal markets. Qualitative findings reveal that governance weaknesses, limited financial inclusion, and poor extension coordination constitute the primary institutional constraints to cluster scalability and sustainability. This study contributes context-specific evidence to the agricultural innovation systems literature and offers policy recommendations for strengthening institutional support to scale cluster-based farming interventions for smallholder livelihoods and food security in South Punjab.

Keywords: Difference-in-differences, institutional dynamics, propensity score matching, smallholder productivity, vegetables

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The role of governance and institutions in participation and upgrading in global agrifood value chains

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Global agrifood value chains (GAVCs) have expanded rapidly in recent decades, reshaping agricultural production and transforming food systems by linking producers, processors and consumers across borders. Despite this expansion, the gains from this expansion remain unevenly distributed. While some countries have moved into higher value-added activities, others remain concentrated in low-value production. Understanding the factors that drive both participation and upgrading in these value chains is critical. This paper examines how governance and institutions quality shape countries' integration into GAVCs and their position within these chains. Although existing literature demonstrates that institutions influence trade flows and agricultural performance, systematic cross-country evidence on their role in value chain participation and upgrading remains limited.

Using cross country panel data combining measures of agrifood value chain participation with indicators of institutional quality, this study examines how governance affects a countries' participation and upgrading in GAVCs. GAVC is derived from the UNCTAD-EORA multi-region input-output database, capturing forward and backward linkages for 137 countries over the period 2000–2020. Governance quality is proxied by the World Governance Indicators. Upgrading is measured as the relative participation of countries in higher value-added downstream segments of the agrifood sector compared to primary agricultural production. The empirical analysis applies panel fixed effects models to estimate the relationship between governance, participation and upgrading.

The results show that higher governance quality is positively associated with participation in global agrifood value chains and plays a significant role in enabling upgrading. Countries with stronger institutions are more likely to engage in higher value-added segments, whereas weak governance constrains both integration and upgrading, reinforcing dependence on low-value activities. By distinguishing between participation and upgrading, this paper provides cross country evidence on governance shapes both the extent and nature of integration into global agrifood value chains. The findings offer important policy insights for institutional reforms aimed at promoting more inclusive and value-enhancing participation in global agrifood markets.

Keywords: Global agrifood value chains, governance, institutional quality, participation

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Financing climate-smart agriculture: Evidence from individual and VSLA-mediated cash transfers in Madagascar

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Adoption of Climate-Smart Agriculture (CSA) remains limited among smallholder farmers in sub-Saharan Africa, constraining agricultural productivity and resilience to climate shocks. While liquidity constraints are often cited as a key barrier, less is known about how the institutional form of financial support shapes farming decisions. We examine this question using a multi-participant experimental game involving 378 farmers in south-eastern Madagascar, with data from a parallel cluster-randomised controlled trial (RCT). The study compares the effects of cash transfers delivered directly to individuals with transfers channelled through Village Savings and Loan Associations (VSLAs), a widely used rural financial institution in sub-Saharan Africa. We find that individual cash transfers significantly increase adoption of CSA practices (+2.8 percentage points) relative to the baseline. VSLA transfers increase adoption only among participants who actively borrow within the group (+4.6 percentage points), suggesting that group-based finance affects agricultural decisions through the actual use of credit rather than membership alone. The two transfer modalities also generate distinct behavioural patterns in financial decision-making. Individual transfers reduce reliance on VSLA borrowing and lead to higher but more dispersed earnings, reflecting greater autonomy in investment choices. In contrast, VSLA transfers increase borrowing intensity while producing more stable and more equal earnings outcomes, consistent with returns depending jointly on individual loan performance and the evolution of the group savings fund. Patterns observed in the experimental game are consistent with those from the parallel RCT, supporting the external validity of the behavioural approach in capturing farmers' responses to liquidity interventions. Overall, the findings show that supporting Climate-Smart Agriculture requires not only financial resources, but also effective design in how financial support is delivered in rural settings: direct transfers are more effective at relaxing investment constraints broadly, while group-based transfers are more conditional on participants' ability to access and use credit, and may be better suited to contexts where equity and income smoothing are central policy objectives.

Keywords: Agricultural decision-making, cash transfers, climate-smart agriculture, experimental games, Madagascar, randomised controlled trial, rural finance, village savings and loan associations

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How transaction costs affect gross margins in informal vegetable value chains in northern Tanzania

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Transaction costs, including negotiation efforts, risk management, and payment collection, are widely acknowledged in theory but rarely quantified empirically, particularly in informal markets. This study investigates how transaction costs influence profitability in the tomato and African eggplant value chains in Northern Tanzania. Drawing on Transaction Cost Economics, we collected primary survey data from 305 value chain actors operating in informal markets, monetized transaction costs, and evaluated their impact on the gross margin for the different value chain actors. Results show that wholesale traders and brokers invest more time in negotiating a deal and face higher risks (proxied by the likelihood of failed transactions). In both value chains, conventional gross margins were substantially higher for farmers than for midstream actors, with considerable variation across actor types. However, these raw figures do not yet reflect the costs each actor bears to complete a transaction. Once transaction costs were incorporated, margins for brokers and wholesalers declined sharply, in some cases by more than half, while retailers were less affected. Farmers' margins also declined after adjustment, though they remained substantially higher than those of midstream actors. These adjustments indicate that transaction costs are economically impactful and affect the distribution of returns across actors in informal value chains. Gross margin estimates alone therefore substantially overstate the effective profitability of intermediary actors, as they fail to capture costs associated with coordination, uncertainty, and failed transactions. Farmers' margins, by contrast, remained comparatively high after adjustment, indicating that the burden of transaction costs concentrates among midstream actors. These findings challenge the prevailing assumption that brokers and wholesale traders capture disproportionately high returns for minimal value added. Recognizing and quantifying transaction costs is therefore essential to inform policies aimed at improving efficiency and equitable value distribution in food value chains in low- and middle-income countries

Keywords: Margin, Tanzania, tomato, transaction costs, value chain, vegetable

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Towards multi-functional agro-ecosystems: Multi-actor collaboration as a driver of demand for agricultural technologies

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The present study investigates how government, agricultural technology firms, development / international organisations and market actors stimulate and create demand for digital and smart agricultural technologies in Ghana to enhance productivity, economic inclusion as well as climate-resilient agricultural transformation and improved productivity. With an interpretivist / qualitative design, the study analysed semi-structured interviews with 55 stakeholders or actors across government institutions, agri-tech firms, development organisations, buyers and processors of agricultural products. The findings show that demand for technologies is not simply generated by technology availability but it is actively co-created through coordinated interventions that lower financial, informational and institutional barriers. Key mechanisms include input subsidies, flexible credit and payment schemes, extension and advisory services, participatory co-creation, digital platforms, pilot demonstrations, strategic partnerships and market-based incentives. Agricultural technology firms emerged as important technology demand shapers. This happens through need-based innovation, trust-building, flexible service models and value-oriented communication. Development organisations strengthen adoption by aligning interventions with national strategies, supporting capacity building and facilitating value-chain linkages. Market actors further create for agricultural technologies by ensuring quality standards, buyer-led guidance and preferential access to organised markets. The study makes three contributions to literature and theory. First, it shifts attention from supply-side explanations of technology diffusion to a multi-actor demand-creation perspective. Second, it extends the Technology Acceptance Model and Innovation Diffusion Theory by showing how ecosystem-level interventions shape perceived usefulness, compatibility and behavioural intentions. Third, it shows that multi-actor collaboration drives sustainable agricultural technologies in developing economies like Ghana through the interplay of policy, entrepreneurship, development support and market coordination. The study provides a practical framework for fostering inclusive, resilient as well as a climate-smart agricultural innovation systems in Ghana.

Keywords: Agricultural technologies, climate-resilient agriculture, demand creation, Ghana, innovation ecosystems, multi-actor collaboration

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Governance challenges of school meals programmes as a tool for family farming development: A study case from three Brazilian municipalities

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Public food procurement has emerged as a strategic instrument for food system transformation, with school meal programmes its largest global expression. Brazil's school feeding programme (PNAE) is a reference for its scale and universality, and since 2009 for linking nutritional quality, origin and production methods within its procurement criteria. While PNAE's effects on dietary quality and farm income are well documented, fewer studies address the governance processes mediating its performance at the municipal level, particularly under low institutional capacity. This paper examines these challenges in three small, low-income, semi-arid municipalities of the Brazilian Cerrado combining semi-structured interviews, farm economics data and the Process Net-Map tool with farmer-suppliers, public officers (agriculture, education, social action, general management), local council members and third-sector representatives. Preliminary findings reveal a marked gap between formal compliance and effective implementation. On the supply side, farmers struggled to deliver contracted volumes due to limited logistics infrastructure, the absence of staggered production planning, production losses to pests and climate events, and quality criteria insufficiently specified at contracting. On the demand side, menus were poorly adapted to local productive capacities, purchase schedules failed to support farm-level planning, payments were systematically delayed, and orders were frequently redirected to large lower-cost suppliers to generate budget savings. Although contracting involved coordinated planning between education and agriculture departments with farmers and cooperatives participation, execution was subject to recurrent deviations and weak oversight, with local management councils captured by government actors and limited scrutiny of failures originating in procurement processes. PNAE provides meaningful income for participating farmers, but its territorial reach is limited by the scale of school procurement. Consolidating it with other public food procurement (hospitals, administrative centers, institutional events) could broaden participation, yet volume alone is insufficient: tenders fall short of fully covering the budgeted procurement volume, revealing a binding supply-side constraint. Expanding procurement must be paired with locally tailored policies to strengthen productive capacity – credit, technical assistance, water access and logistics – since national instruments are too fragmented for low-capacity territories. To catalyse its potential, the PNAE must be better articulated with local actors who can support local productive capacities expansion and strengthen oversight bodies.

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Beyond compliance: Food security and governance in South Africa's table grape sector

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The wellbeing and fairness along global agri-food value chains is frequently conceptualised as an outcome of employment and compliance with standards. However, this assumption obscures structural and governance-related drivers of food insecurity among agricultural workers. This paper critically examines food security among seasonal farmworkers in South Africa's export-oriented table grape sector, situating the analysis within debates on global value chain governance and private regulation. The study combines an exploratory survey, focus group discussions, participatory Net-Map analysis, and semi-structured interviews with multiple actors (farmworkers, producers, auditors, and industry representatives). This multi-method approach enables a triangulated analysis of lived experiences, institutional arrangements, and actor-specific perceptions of influence and accountability.

Empirically, the findings demonstrate that food insecurity is not primarily driven by availability constraints, but by unstable and insufficient access linked to income volatility, seasonal employment, and asymmetric power relations within the actors in the value chain. While the private standards, regulatory frameworks and governance arrangements emphasise formal compliance, particularly regarding wages and labour conditions, they tend to overlook the temporal and structural dimensions of food access possibilities of farm workers.Building on this critique, the Food Security Standard (FSS) is examined as a potential outcome-oriented governance instrument that explicitly integrates food security dimensions into certification frameworks. Beyond its empirical contribution, the paper engages with broader debates on outcome-oriented sustainability governance by highlighting the gap between formal compliance and experienced well-being. It argues that addressing food insecurity within agri-food value chains requires moving beyond audit-based indicators toward governance approaches that account for temporal income dynamics, labour precarity, and the distribution of power across actors. The study shows that sustainability standards can only contribute to improved food security outcomes when they move beyond static compliance metrics to address income volatility across seasons, reduce workers' reliance on debt-based coping strategies, and incorporate mechanisms that account for power asymmetries between buyers, producers, and labour. By reframing food security as a governance-dependent outcome shaped by power relations and institutional design, the paper contributes to advancing critical perspectives on sustainability standards and highlights the limitations of existing regulatory approaches in addressing worker well-being in global agri-food systems.

Keywords: Global value chains, income volatility, labour precarity, power relations, seasonal farmworkers, sustainability standards

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Enabling access to climate-smart irrigation technologies: Institutional feasibility of collective finance in Mount Kenya

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In Kenya, climate-smart irrigation technologies (CSIT) are widely promoted as key instruments for poverty reduction, climate change adaptation, and agricultural transformation, featuring prominently in national strategies such as Vision 2030, the Big4 Agenda, the Agricultural Sector Transformation and Growth Strategy. In the northern region of Mount Kenya, stakeholders increasingly promote rooftop rainwater harvesting, drip irrigation, and solar-powered irrigation systems (SPIS) as part of a Water–Energy–Food Nexus approach to enhance water-use efficiency, off-grid energy access, and food security. Despite this strong policy emphasis, uptake among smallholder farmers remains limited, largely due to financial constraints and restricted access to formal credit.

Barriers such as lack of collateral, high transaction costs, income uncertainty, and information asymmetries continue to hinder engagement with conventional financial services. In this context, Agricultural Group Guarantee Loans (AGGLs) are emerging in many african countires as an alternative mechanisms that leverage collective guarantees and shared responsibility to facilitate access to credit. However, their effectiveness depends not only on financial design but also on underlying social and institutional conditions.

This study assesses the institutional feasibility of AGGL-type financing arrangements for CSIT adoption among smallholder farmers in the Timau catchment (Upper Ewaso Ng'iro Basin). It conceptualises AGGLs as collective financial mechanisms operating under shared risk, whose viability depends on factors such as trust among participants, group homogeneity, coordination capacity, prior experience with collective organisations, and perceptions of investment risk. Drawing on institutional economics and collective action theory, the study examines how these conditions shape farmers' willingness to participate in group-based financing.

Empirical data are collected through a structured household survey of 150 farmers, stratified across 32 Community Water Projects to capture variation in organisational and irrigation contexts. By shifting the focus from financial availability to institutional viability, this study contributes to debates on rural finance and irrigation development, offering insights into the conditions under which group-based lending can support scalable access to climate-smart irrigation technologies.

Keywords: Agricultural group guarantee loans, climate-smart irrigation, collective action, farmers organisations, rural finance, solar powered irrigation systems

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How do microcredit interventions impact agricultural risk management strategies among smallholder farmers? Review of African evidence

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In recent years, microcredit has emerged as a key tool for financial inclusion, poverty reduction, and women's empowerment among smallholder farmers in Africa. The purpose of this study is to consolidate existing evidence and provide a clearer understanding of the role of microcredit in helping farmers withstand risks related to climate change, market information, and production uncertainties. Using a comprehensive Systematic Literature Review (SLR) to synthesize existing studies on microcredit in Africa, the study identified 518 articles from the major databases of Scopus and Web of Science, out of which 35 met the inclusion criteria and were analysed in detail. By careful consideration of quantitative and qualitative evidence published between the years of 2010 and 2025, the findings clearly show that access to microcredit has enabled smallholder farmers to adopt various risk management strategies like investment in better inputs, the use of informal insurance mechanisms, and crop diversification, among others. However, the review also highlights notable ongoing challenges facing farmers, like loan repayment uncertainties, financial literacy, and persistent unequal access to credit, especially the cultural barriers facing women in business and particularly poor farmers. The originality of this study primarily lies in consolidating the scattered articles into one comprehensive review, taking into account the balanced view of both the benefits and the limitations of Microcredit. The study review ultimately highlights the microcredit dual role in fostering economic participation and addressing social inequalities by offering a critical roadmap for inclusive, sustainable, and gender-based financial ideas for policymakers, practitioners, and researchers in designing more inclusive financial solutions for smallholder farmers.

Keywords: Africa, agricultural risk management, microcredit, smallholder farmers, systematic literature review.

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Environmental governance in the Paraguayan humid Chaco and Pantanal: State and indigenous narratives on grassland and savannah conservation, 2000–2025

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The Paraguayan Humid Chaco and the Pantanal are ecologically significant regions that are facing escalating threats due to agricultural expansion, livestock ranching, and infrastructure development. Despite their biodiversity value and the presence of active indigenous and community-based territorial claims, grassland and savannah ecosystems in these areas remain understudied compared to forest-centric conservation research. Drawing on political ecology, this article examines how indigenous and community-based organisations articulate narratives of conservation and territoriality and how state policy discourses have shaped grassland and savannah conservation in Paraguay from 2000 to 2025. Rooted in post-war land dispossession and consolidated through decades of elite capture of state institutions, Paraguay's highly concentrated land ownership and agro-industrial expansion have systematically undermined indigenous and campesino territorial rights and community-based land management. Using Blaser's ontology of environmental politics and notions of territory and territoriality from Latin American studies, the research analyses how these two sets of discourses challenge, complement, or exclude one another within broader environmental governance dynamics. Methodologically, the study employs narrative analysis as its primary interpretative approach and uses content analysis to identify thematic patterns across primary and secondary sources. These sources include declarations and reports from indigenous and community-based organisations, as well as state policy documents. These sources are triangulated with NGO reports and national and local news coverage. Results suggest that the conservation-versus-production dichotomy oversimplifies a complex field of competing worldviews, interests, and power relations, and that dominant conservation approaches commonly fail to incorporate indigenous territorial rights. The findings contribute to understanding how conservation is politically constructed and negotiated across state, indigenous, and agro-industrial actors in one of South America's most dynamic socio-ecological frontiers.

Keywords: indigenous territorial rights, narrative analysis, political ecology

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Group-based aquaculture systems in Ghana: A collective action assessment

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As climate change and declining capture fisheries place increasing pressure on food systems, aquaculture is emerging as a key pathway for building resilient and multifunctional agro-ecosystems in Ghana. Fish accounts for about 60 % of animal protein consumption, yet declining domestic capture fisheries have driven fish imports exceeding $200 million annually. This widening gap highlights the potential of aquaculture particularly among smallholders and youth to strengthen food security, livelihoods, and climate resilience. In response, the Government of Ghana introduced the Aquaculture for Food and Jobs (AFJ) programme in 2018 to promote sustainable aquaculture and employment, especially for youth and women. Building on this initiative, group-based aquaculture has been implemented in small reservoirs, ponds, and lakes across multiple regions of Ghana. However, evidence on how these collective action arrangements influence performance and sustainability remains limited. This study unpacks lessons from different experiences of youth group-based aquaculture in 14 communities, which are either supported by government or development partners. Using Elinor Ostrom's collective action design principles, it analyses the institutional, social, and economic factors shaping their performance and sustainability. Our findings show that even though technical capacity building, institutional support and initial capital support are essential, social dynamics such as group cohesion, group composition and enterprise development trainings are very critical for the long-term viability of these projects. In community-managed reservoirs, local legitimacy and acceptance by traditional and community leaders are also decisive. Across cases, key constraints include theft, flooding, high feed costs, and weak market linkages. The study highlights the need for context-specific institutional arrangements that integrate both technical and social dimensions, stronger private sector engagement, and innovative financing and risk management mechanisms, including insurance. More importantly, it demonstrates that the success of aquaculture systems and their contribution to climate-resilient, multifunctional agro-ecosystems depends not only on technology and inputs, but fundamentally on effective collective governance and social organisation.

Keywords: Aquaculture, collective action, food security, institutional governance, youth groups

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The numbers we want to see: Reporting bias in community mangrove restoration in Indonesia

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Community-based mangrove restoration has expanded rapidly as a response to coastal degradation and climate-related vulnerability. Yet many restoration programmes continue to rely heavily on self-reported indicators such as planting performance and seedling survival, despite limited independent verification. This raises an important question: do reported outcomes accurately reflect what happens in the field? The accuracy of self-reported restoration outcomes, particularly planting rates and survival estimates, remains critically underexamined.

This study examines reporting bias among members of mangrove community groups involved in restoration activities in Indonesia. Using survey data from 600 respondents across several coastal villages, we applied a list experiment to elicit honest responses on sensitive behaviours that may be concealed under direct questioning, particularly failure to plant distributed seedlings and overstatement of survival rates. The analysis is complemented by a measure of social desirability bias and regression models exploring how sociodemographic factors, resource access, and programme participation relate to the tendency to misreport outcomes.

Preliminary findings reveal a substantial gap between direct responses and indirect estimates. For both behaviours examined, prevalence under the list experiment is considerably higher than under conventional survey questions, in some cases approaching twice the directly reported level. This suggests that inaccurate reporting is not simply random measurement error, but may reflect social expectations, accountability pressures, and weak monitoring systems.

The study provides new quantitative evidence of the prevalence of coastal restoration actions, contributing to conservation of social science. Beyond its empirical contribution, the study offers actionable insights for programme policymakers. More broadly, it highlights the need to complement ecological monitoring with survey approaches that better capture sensitive behaviour. Strengthening restoration accountability may therefore require not only improved technical verification, but also closer attention to the incentives that shape how success is reported.

Keywords: Environmental governance, Indonesia, list experiment, mangrove restoration, monitoring accountability, reporting bias

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Farmer centered multi stakeholder platforms for agroecological innovations and markets: Insights from Burkina Faso and Senegal

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Local multi-stakeholder platforms (MSPs) are regaining interest among development actors as mechanisms to stimulate collaboration towards fostering local innovation, and supporting agroecological markets. Yet their outcomes remain mixed, particularly in terms of addressing farmers' vital interests. This article examines the factors influencing MSP performance with the aim of strengthening their farmer-centeredness in the production and marketing of agroecological products. The study is part of the Proli-SAM project ("Strengthening local multi-stakeholder platforms for local innovation and sustainable agroecological markets in the Sahel"), being implemented in Burkina Faso and Senegal. Data were collected between June and August 2025 through 20 interviews with farmer innovators, three focus groups involving about twenty actors from research and extension services, and national multi-stakeholder workshops in each country. The analysis focused on MSP structures and functioning, members' knowledge and practices related to participatory innovation development (PID), and forms of support for agroecological production and markets, using qualitative methods. Results indicate that MSPs connect networks of farmer innovators with diverse support organisations, while private sector actors and digital marketing start-ups remain largely absent. In Burkina Faso, MSPs are organised at the municipal level, whereas in Senegal they operate at the higher departmental level, which limits the regularity of meetings. Most members have experience with PID, particularly in identifying and documenting local innovations and conducting farmer-led experiments on agricultural water management. Approximately one hundred agroecological innovations have been catalogued, of which about twenty have undergone PID processes for testing or improvement. Farmer innovators reported strengthened capacities and increased confidence through peer exchanges, dissemination of their innovations, and ad-

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vocacy campaigns broadcast on local radio. However, identification of agroecological market innovations and facilitation of products marketing remains limited. These findings suggest that to enhance MSP effectiveness and sustainability, it is necessary to strengthen their territorial anchoring, broaden participation to include private actors from down-stream stages of value chains, and better integrate marketing dimensions. Farmer centeredness of MSPs, linking local technical innovation with marketing opportunities, appears to be a key condition for supporting agroecological transition in the Sahel.

Keywords: Agroecological innovations, local multi stakeholder platforms, markets, participatory innovation development approach, Sahel

Market structure and vendor performance of Slow Food Earth Markets in Kenya

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Slow Food is an international organisation promoting socially and environmentally sustainable food systems. Its Earth Markets initiative, launched in 2004, aims to connect small-scale producers with consumers through short supply chains while fostering local economies and food culture. Despite their global expansion, empirical evidence on market structure and vendor outcomes remains limited. This study investigates the operational performance of seven Earth Markets in Kenya (Embu, Gilgil, Kagio, Molo, Murang'a, Nakuru, and Njoro) using a dataset of 150 market observations collected across multiple markets and trading days between 2023 and 2025. We assessed product diversity, category distribution, presence of indigenous and Ark of Taste-listed heritage foods, vendor income ranges, and self-reported satisfaction. The analysis shows a concentration in vegetables and fruits, with comparatively lower representation of categories such as dairy, grains and legumes, poultry and meat, root tubers, and honey. A share of the traded vegetables and fruits are indigenous or locally adapted species and heritage varieties recognised by the Ark of Taste, reflecting a meaningful connection to local food traditions. Most vendors specialise in a single product category, a pattern that may reflect both market efficiency and individual expertise, while also indicating potential for gradual portfolio expansion over time. Despite this focused product structure, vendor satisfaction levels are consistently high, and an average sell-through rate of 88 % suggests sufficient demand for available products. Daily revenues are largely concentrated in the 1,000–4,000 KES (approx. 7–30 Euro) range across all markets, indicating relatively modest but stable income levels. However, the results also reveal a partial alignment between Earth Market principles and on-the-ground realities. Building on this foundation, there is an opportunity to further enhance the visibility and diversity of agroecological products to strengthen contributions to food biodiversity and system transformation. The study highlights the need for standardised performance indicators and longitudinal monitoring to better evaluate the long-term impact of Earth Markets on smallholder livelihoods, dietary diversity, and agroecological resilience in Kenya.

Keywords: Agroecology, Ark of Taste, Earth Markets, farmers' markets, food biodiversity, indigenous foods, Kenya, local markets, slow food, smallholder livelihoods, sustainable food systems, vendor performance

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Integrating maize-based feed and dairy value chains for structural transformation in Cameroon's agro-industrial clusters

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Cameroon's ambitions for food security and import substitution, as outlined in the National Development Strategy 2020–2030, rely heavily on the competitiveness of the maize and dairy sectors. Despite an annual maize production exceeding two million tons and a significant cattle population, both value chains underperform and remain poorly integrated; an issue which the territorial cluster model aimed to address. This study investigated the structural constraints hindering this integration and examined how existing policy frameworks could bridge the gap between the two value chains.
The analysis employed a value chain approach involving field visits in the West (maize-based feed hub) and Adamawa (dairy hub), and interviewed about 100 stakeholders, including farmers, feed producers, dairy value chain actors, relevant ministry officials and sector experts. A review was also made on production and importation data, feed milling capacity utilisation, actor relationships, infrastructure gaps, governance systems, and territorial agro-industrial cluster performance as an integration mechanism. Findings reveal that maize and dairy are structurally intertwined yet policy-fragmented and managed by separate ministries, resulting in weak institutional integration across the two value chains. Feed costs account for up to 70 % of livestock production costs; yet inefficiencies in the maize sector, such as post-harvest losses, aflatoxin risks, and seasonal price volatility, undermine the reliability of feed supply, constraining effective integration with dairy production. Consequently, feed milling and dairy processing plants operate far below capacity, reflecting weak transmission between the two systems. Despite spatial complementarities, weak logistics and the absence of contractual aggregation limit physical and commercial linkages, preventing the emergence of a functional feed-dairy corridor. Although the territorial cluster model aims to address these gaps, its success is limited by incomplete financing and weak private-sector anchoring.
To escape the current challenges, Cameroon must transition from fragmented interventions to well-managed, integrated, cluster-based systems. Priorities include investing in shared infrastructure (drying facilities, quality labs, and cold-chain logistics) and strengthening governance through functional farmer organisations. Policy should focus on improving the integration between these value chains to improve the circular bio-economy, reduce dairy imports and foster inclusive rural growth.

Keywords: Agri-food policy, circular bio-economy, food security, post-harvest losses, structural constraints, value chain integration

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Predicting informal food vendor distributions in Kuala Lumpur using maxent: A spatial modelling approach for urban food environment research

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Informal food vendors are a prominent feature of urban food environments in the Global South, shaping food accessibility and availability. Amidst rapid urbanisation and development, informal food vending continues to thrive due to high consumer demand for its accessible, affordable and convenient food offerings. Food environment research often utilises Geographic Information Systems (GIS) to examine the geography and spatial distribution of food outlets to understand its associations with population health. However, informal food vendors are systematically underrepresented in spatial food environment datasets due to their fluid and mobile operations which are challenging to document. Yet, excluding the informal food vendors and their spatial distribution create an incomplete or inaccurate picture of the overall food environment, potentially leading to flawed decision making to improve food environments and ultimately population health. To address these gaps in current data and knowledge systems, this study aimed to introduce a methodological framework which applies MaxEnt, a machine learning based species distribution model to predict informal food vendor distribution in Kuala Lumpur. To ensure a robust data system, occurrence data was collected across both high and low population density areas to minimise sampling bias and spatial clustering. A spatially explicit probability surface of informal food vendor distribution in Kuala Lumpur was modelled based on key environmental, socio-economic, and built environment predictors. The MaxEnt model showed strong discriminatory performance, assessed using the area under the receiver operating characteristic curve (AUC = 0.705) in distinguishing vendor presence from background conditions. Proximity to formal food outlets, population density, proximity to train stations and land use land cover (integrating remote sensing data to capture urban land use change) were the strongest contributors to predict vendor suitability. These findings demonstrate that applying digital modelling tools such as MaxEnt can generate spatially explicit suitability maps for informal food vending, providing a scalable and replicable approach to support urban food environment assessment and guide data driven decision making in Global South cities.

Keywords: Food environment, Global South, informal food vendors, maximum entropy modelling, spatial analyses, spatial modelling

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Beyond price stabilisation: Liquidity explains farmer behaviour under evolving soybean market regulation in Tanzania

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Farmers cultivating soybean in Tanzania is increasing amid volatile markets. Scattered production increases transaction costs and price disparities within and across seasons. Informal traders link farmers to buyers, yet also contribute to price volatility. Since 2018, the government has regulated soybean through a warehouse receipt system (WRS) and auctions to stabilise prices. Procured soybean must go through the Agricultural Marketing Cooperative Societies (AMCOS). Membership is not required, yet most farmers rely on traders who then sell through AMCOS, raising the question of whether this reflects preference, necessity, or limited AMCOS access. This study explains farmer economic behaviour amid evolving market regulation in the Ruvuma region. We used a mixed-effects logistic regression to model farmer-reported annual cultivation decisions from 2018 to 2025, collected through a cross-sectional survey, and triangulated findings with stakeholder interviews.

Results reveal strong persistence: 28 % of farmers cultivated soybean consistently, 31 % did not cultivate in any year, and the remainder grew the crop irregularly. Consistent growers were most prevalent among AMCOS members, less so among non-members, and least in villages without AMCOS, suggesting distinct membership and access effects. Interviews revealed that soybean, harvested before maize, serves as an early cash source to finance maize harvest and urgent household needs. Farmers received significantly lower prices from traders than from AMCOS. However, AMCOS delay payment, as auctions proceed only once sufficient volume is procured, leading most farmers, including AMCOS members, to rely on traders for quick cash. Under the regulation, traders face a dilemma: either delay procurement until the first auction price is announced or buy early at low, speculative prices to reduce risk. Both strategies compound farmers' liquidity constraints, cutting off early cash access through both channels simultaneously. Further, since regulations compel traders to operate through AMCOS, villages without one offer traders little incentive to engage, which may explain why cultivation is lowest in these areas. Expanding AMCOS presence in underserved villages and allowing traders to procure more flexibly would improve market access and support soybean cultivation. Announcing auction prices earlier, closer to the harvest period, would increase price transparency between farmers and traders and reduce speculation-driven price volatility.

Keywords: Cooperatives, informal traders, mixed-effects logistic regression, smallholder farmers, warehouse receipt system

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Reconciling trade and sustainability: The EU-Mercosur trade agreement as a driver for multi-functional agro-ecosystems in South America

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Agriculture remains central to global land-use change, requiring a delicate balance between productivity and planetary health. In the context of the EU-Mercosur trade agreement, signed in January 2026, this research assesses the opportunities and challenges for transitioning towards climate-resilient agricultural systems in Brazil, Argentina, Paraguay, and Uruguay. As agricultural products constitute 42.7 % of Mercosur's exports to the EU, the agreement represents an opportunity to align trade with sustainability standards demanded by European markets and to comply with European regulations. The analysis focuses on sustainable intensification and the capacity to meet stringent European regulations, particularly as the EU Deforestation Regulation (EUDR). Central to this transition are integrated systems, specifically the Integrated Crop-Livestock-Forestry system, and no-till farming, which currently covers 33 million hectares in Brazil. These multi-functional systems enhance soil fertility and water management while diversifying rural incomes and reducing climate risks. Furthermore, the research evaluates the ABC+ plan for low-carbon agriculture as a framework for providing auditable metrics on carbon sequestration and animal welfare. Findings indicate that while integrated systems provide a robust pathway for intensification without frontier expansion and high costs of compliance, and traceability remains. These regulatory burdens risk excluding small-scale producers from sustainable value chains. However, the agreement fosters institutional confidence through harmonised sanitary protocols and digital georeferencing tools. In conclusion, the EU-Mercosur partnership can promote multifunctional landscapes if supported by technological, market and social innovations and inclusive governance. By treating trees, crops, and livestock as interconnected components within the One Health framework, Mercosur countries can safeguard ecosystem functions while ensuring food security and new market opportunities. The success of this initiative depends on the equitable distribution of resources and the effective integration of sustainability data across regions.

Keywords: Integrated crop-livestock-forestry systems, low-carbon agriculture, no-till farming, regulatory compliance, traceability

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Navigating risks through organisational innovations: The potential of contract farming for smallholders' in Punjab, Pakistan

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Small-scale agriculture is a major source of livelihoods in large parts of Pakistan with more than 60 % of farmers cultivating less than two ha of land, a large share of them in Punjab, Pakistan's agricultural heartland. While impact from climate change, increasing water scarcity, and soil degradation put small-scale production systems under pressure, economic stressors have an exceptionally high relevance for smallholders often lacking market access, depending on middlemen, and competing with bigger producers or agricultural corporations.

Therefore, production arrangements are needed that specifically counterbalance such unfavourable conditions smallholders operate in. Besides cooperatives, such arrangements also include, for instance, contractual approaches. While cooperatives have rather failed in Pakistan mostly due to dependency on government credits, lacking self-sustenance, and internal power dynamics, contractual approaches mostly involve medium- or large-scale agricultural producers in Pakistan, usually excluding smallholders.

Against this backdrop, we analyse the potential of contract farming arrangements in Punjab/Pakistan in terms of value-chain relations and economic effects for involved small-scale farmers as well as effects on their production systems.

Based on empirical data from selected districts in Punjab, we explore circumstances under which different types of smallholders can partake in contract farming as well as contract farming strategies and contractual conditions that are needed for smallholders to improve market access, enhance competitiveness, reduce economic risks, while still adhering to sustainable production practices, and eventually improve their livelihoods. Our empirical data comprise qualitative interviews with contract- and non-contract farmers engaged in various cultivation systems as well as with contracting companies and experts.

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Regarding suitability, value-chain integration, and economic effects, preliminary results indicate that smallholder participation in contract farming can be successful under specific conditions and potentially improves bargaining power and reduces vulnerability to market fluctuations. These initial results also suggest a tension between economic viability and sustainable production practices.
We therefore draw the following tentative conclusions: contractual arrangements should account for scale-specific needs, should be tailored to smallholders' realities, and must navigate trade-offs between sustainability and competitiveness. Moreover, the entailed risks for smallholders need to be sufficiently addressed in order not to defeat the purpose of reducing smallholders' economic risks.

Keywords: Contract farming, organisational innovations, risk reduction strategies, smallholders

Does sustainable intensification pay for small-scale producers? An analysis of earnings from sub-Saharan Africa

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Sustainable intensification (SI) practices are widely promoted as win-win-win approaches for fostering agricultural productivity growth while reducing the environmental and health consequences of conventional agriculture. Yet their ability to improve the economic wellbeing of small-scale producers has not been empirically tested in a multi-country context. Using nationally representative plot and household level data from seven countries in sub-Saharan Africa, we measure the returns to family labour, returns to land, and changes in labour inputs associated with the application of four SI practices: cereal legume intercropping, organic fertiliser, soil and water conservation, and agroforestry. Using an OLS model with a battery of demographic, farm-specific and spatial control variables, and a variety of robustness checks, we show that only cereal-legume intercropping consistently generates positive returns to family labour. The adoption of the other three practices are shown to generate negative returns to family labour, due to a combination of increased labour inputs and/or reductions in returns to land. The results further show important regional heterogeneities between east and west Africa, with SI practice being more profitable for adopters in west Africa. We find limited evidence suggesting that adopting SI practices as bundles or increased adoption duration changes the overall findings. Similarly, our results show that SI practices generate few additional returns to family labour in the context of extreme precipitation or drought. Taken together, our results suggest that there is a significant risk that the public goods generated by SI practices can come with significant private costs to the small-scale producers who adopt them. While widespread adoption of SI practices is essential to support a transition toward a more sustainable agrifood system, achieving this will require technical solutions to reduce their labour burden and productivity and policy solutions that effectively compensate producers for the public goods through their private efforts.

Keywords: Africa, climate change, profitability, returns to labour, returns to land, sustainable intensification

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Digital credit governance in Kenya: Is the borrower a silenced subject?

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Kenya's launch of M-PESA in 2007 marked a global milestone in digital financial innovation, extending financial services to millions of previously unbanked citizens. The rapid growth of digital credit platforms followed, offering easy access to loans disbursed through mobile phones based on algorithmic assessments by lenders. However, this expansion has produced troubling outcomes. Over-indebtedness, high default rates, and predatory lending practices have emerged as serious governance challenges disproportionately affecting low-income borrowers. The regulatory framework governing digital credit remains weak, particularly on matters of consumer protection. Primary actors, including the Central Bank of Kenya and lending institutions, have not meaningfully involved low-income borrowers in governance decisions that affect their financial lives. True participation extends beyond mere access to financial services. This study argues that information asymmetry is a key driver of financial exclusion in low- and middle-income countries. When lenders and borrowers lack equal access to information, the poor struggle to make sound financial decisions. Existing research on digital credit governance relies on top-down models that treat borrowers as data points rather than as people with legitimate knowledge drawn from lived experience. These models overlook the voices and agency of the very communities they claim to serve. This paper proposes Participatory Communication theory, rooted in the work of Freire (1970) and elaborated by Servaes (1999), as an alternative analytical framework that centres borrower participation in governance processes. The paper pursues three objectives: explaining how participatory communication theory shapes development communication research, examining digital credit governance through this framework, and identifying the theory's strengths and limitations in addressing consumer protection challenges in Kenya's digital lending landscape.

Keywords: Communication, development, digital, exclusion, financial, Kenya, participatory

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Who bears the climate burden? Resource governance, inequality, and the political economy of environmental risk

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Climate change is often discussed in the language of temperatures, emissions, and adaptation strategies, yet its consequences are ultimately borne by people, unevenly, unjustly, and often silently. Despite a growing body of political economy literature on natural resources, insufficient attention has been paid to who bears the everyday costs of environmental degradation and climate risk. This study addresses that gap by asking a deceptively simple but urgent question: who bears the climate burden in Rivers State, Nigeria?

Rivers State is one of Nigeria's most resource-rich regions and yet one of its most environmentally fragile. Decades of oil extraction have left deep ecological scars, polluted rivers, degraded farmlands, disappearing mangroves, and poisoned livelihoods.

This study approaches environmental change as a profoundly political and moral issue, shaped by power relations embedded in resource governance systems. It argues that climate vulnerability in Rivers State is not accidental, but socially produced through institutional arrangements that privilege extraction.

Three questions guide the analysis: How do resource governance arrangements in Rivers State shape the distribution of environmental and climate-related risks? In what ways do social hierarchies – particularly gender roles, occupational dependence on natural ecosystems, and rural–urban divides – mediate vulnerability to environmental change? And how do power relations between the state, oil companies, and local communities determine whose lives are protected, whose voices are heard, and whose suffering is normalised?

Methodologically, the study adopts a qualitative, community-centred approach, focusing on selected oil-producing and riverine communities in Rivers State. Through in-depth interviews with women, youth, fisherfolk, farmers, and informal workers, as well as focus group discussions and conversations with community leaders, activists, and local officials, the research foregrounds lived experiences and local knowledge. Qualitative analysis of environmental policies and corporate practices further reveals the distance between formal governance promises and everyday realities.

Ultimately, the study argues that responding meaningfully to environmental change requires confronting the unequal distribution of power and risk and recognising that climate justice begins with asking who bears the burden, and why.

Keywords: Climate justice, environmental inequality, Nigeria, political economy, resource governance

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Rainfall shocks, labour migration, and the climate adaptation deficit: Remittances as a missed opportunity in small holder maize systems in southwest Nigeria

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Climate change poses escalating threats to smallholder agricultural systems across sub-Saharan Africa, intensifying the frequency and severity of rainfall variability, pest pressure, input price shocks, and soil degradation. In this context, migration, already a widespread livelihood strategy in rural Nigeria operates simultaneously as a climate vulnerability amplifier (depleting agricultural labour) and a potential adaptation resource (generating remittance income). This paper examines the intersection of migration, remittances, and climate adaptive capacity among maize farming households in Saki East Local Government Area, Oyo State, Nigeria, using primary survey data from 180 farming households.

The study finds that while 63.33 % of households receive remittances averaging ₦96,452 per season, approximately 95 % of these transfers are consumed rather than invested in climate-adaptive farm practices. Multiple linear regression analysis reveals that remittance receipt does not significantly predict farm-level investment ($\beta = 0.002$, $p = 0.936$), while access to extension services ($\beta = 0.098$, $p = 0.002$) the primary institutional channel for climate-smart technology diffusion emerges as the strongest investment driver. The analysis documents a critical climate adaptation deficit: farm insurance uptake is near-zero, irrigation investment is minimal, and post-harvest storage infrastructure is largely absent across the sampled households. These gaps leave smallholder maize systems highly exposed to climate-induced shocks with no financial buffer.

The paper argues that remittances represent a latent climate adaptation resource that structural and institutional barriers prevent from being mobilised productively. It proposes a climate-adaptive remittance investment framework, integrating weather-indexed micro-insurance, remittance-backed adaptive input credit, and climate-focused extension advisory to close the adaptation deficit in Nigeria's smallholder maize systems. These findings contribute empirical evidence from the Global South to Tropentag 2026's thematic focus on climate change impacts, adaptation strategies, and data-driven approaches to agro-ecosystem resilience.

Keywords: Agricultural resilience, weather-indexed insurance

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Circular food systems as a policy pathway for climate-resilient agro-ecosystems in eastern and southern Africa

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Climate resilience in African agri-food systems is frequently framed through improved production practices, yet the institutional conditions required to close resource loops and sustain multifunctional agro-ecosystems remain underdeveloped. This paper examines how circular food systems are being enabled, constrained, and governed in Tanzania, Mozambique, and Zimbabwe across diverse agro-ecological and institutional settings. It draws on comparative analysis of national policy and regulatory frameworks, country case evidence, and findings from structured multi-stakeholder policy dialogues involving government, research organisations, producers, private sector actors, and civil society.

The results show that circularity is already present in practice through composting, nutrient recycling, use of crop and livestock residues, water reuse, biomass-based energy, and waste-to-value enterprise activity. However, these practices remain weakly embedded in mainstream policy implementation. Across the three countries, the principal constraints are institutional rather than technical. Circular initiatives are limited by fragmented mandates, sectoral policy design, weak incentives for resource recovery, poor coordination between agricultural and municipal systems, and inadequate recognition of informal and small-scale circular enterprises within planning and investment frameworks. While existing agricultural, environmental, and local government policies contain relevant provisions, they operate in isolation and rarely provide an integrated basis for scaling circular practices.

The paper argues that circular food systems should be treated as a governance framework for reorganising relationships among production, consumption, waste, land, water, and local markets. Where policy alignment is stronger, circularity contributes to improved soil health, more efficient resource use, diversified rural incomes, and reduced exposure to climate and market shocks. Advancing climate-resilient agro-ecosystems therefore requires more than technical innovation. It requires policy architectures that integrate circularity into agricultural transformation strategies, territorial planning, and public investment systems. The paper concludes by proposing a policy framework centred on cross-sector coordination, locally grounded enterprise development, and stronger science-policy interfaces to support the transition from fragmented pilots to system-level implementation.

Keywords: Agro-ecosystem governance, circular food systems, climate resilience, policy integration, resource recovery

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Preferential trade, economic growth and poverty reduction in sub-Saharan Africa

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The number of preferential trade agreements has more than doubled over the past decades. This has been enabled by the protracted Doha Round of negotiations, rising regional integration, and global production networks. Sub-Saharan Africa (SSA) has received a considerable number of preferential trade agreements, among them the African Growth and Opportunity Act (AGOA) from the United State of America and the Everything But Arms from the European Union. Despite these preferential trade agreements, SSA continues to be the world's region with the lowest share of international trade flow and the highest level of poverty. However, most studies on the effect of preferential trade agreements in SSA tend to focus on trade flow with less emphasis on economic growth and poverty reduction. This study assessed the effects of agricultural trade flow on economic growth and poverty reduction in SSA with a specific focus on the African Growth and Opportunity Act. The analysis made use of data on poverty rate, inflation, agricultural trade flow, GDP per capita, remittance flow, inequalities, and investment rate for the period 2000–2022 for twenty-two SSA countries. The data were sourced from the World Development Indicators and the World Integrated Trade Solution. The study employed a dynamic panel generalised method of moment and a fixed effect panel model. The findings revealed that agricultural trade flow has a positive and significant effect on economic growth and a negative and non-significant effect on poverty rates in SSA. Moreover, the analysis shows that remittance flows have a positive and significant effect on economic growth and a negative effect on poverty rate in SSA. The findings of this study recommend trade facilitation with SSA as an engine for economic growth and poverty reduction. This study provides important insights on how trade can promote economic growth and poverty reduction in SSA.

Keywords: Agricultural trade flow, dynamic panel generalised method, economic growth, fixed panel model, poverty reduction, preferential trade, sub-Saharan Africa

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Lessons from and for the AU-EU food and nutrition security and sustainable agriculture (FNSSA) roadmap

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The African Union–European Union Food and Nutrition Security and Sustainable Agriculture (FNSSA) Roadmap 2016–2026 has guided a decade of cooperation in research and innovation on agrifood systems, nutrition and sustainable agriculture. As the roadmap comes to an end, this paper reflects on key lessons and identifies priorities for the next phase (2027–2036). The analysis draws on documents from African and European institutions, selected peer-reviewed literature, and project reports funded under AU, EU and joint AU–EU programmes. Agrifood systems are shaped by interacting societal, economic and environmental pressures. Climate change is the dominant cross-cutting factor, linked to biodiversity loss, resource degradation, demographic growth, urbanisation, changing diets, and market and geopolitical instability. Although African and European agrifood systems face similar pressures, they differ in their starting points as well as in regional needs and demands. Programme implementation and governance represent a distinct set of constraints related to how cooperation is organised and delivered. Responsibilities are dispersed across AU, EU and national levels, coordination between institutions and funding streams is weak, and programming cycles are poorly aligned. Administrative complexity, limited follow-up and low interoperability of results reduce the effectiveness and visibility of investments. Research-driven instruments dominate, while coordination, stakeholder engagement and support mechanisms remain comparatively underdeveloped within the partnership architecture. Capacity and participation highlight who is able to engage in cooperation, under what conditions, and whose knowledge is recognised. Structural gaps in research infrastructure, co-funding, grant management and training limit participation, particularly in parts of Africa. Women, youth and holders of local and place-based knowledge remain underrepresented, affecting both the quality of collaboration and the relevance of outcomes. Translating research into impact remains difficult. Knowledge exchange is often short-term and project-based, data systems are poorly connected, and links between research, policy and practice are weak. Regulatory fragmentation, limited investment, weak advisory systems and lack of support beyond project lifetimes constrain scaling and uptake. Based on these findings, the paper outlines directions for a future FNSSA Roadmap that strengthen coordination, address capacity gaps, broaden participation, and guide digitalisation in ways that are inclusive, secure, interoperable and supportive of long-term resilience.

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Market price dominance in contract breach: A double lasso approach using experimental data from Ecuador

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Contract farming is considered a means by which farmers and buyers in developing countries can, among other advantages, reduce price and market uncertainty and supply high value products to the export market. Nevertheless, contract breach is a pervasive problem that threatens the sustainability of the scheme. Both actors can face opportunism from their partner: producers can divert on the contract and deliver their produce to other buyers, or buyers can delay their payment, capturing additional value from producers. We used a framed field experiment and a structured survey of 180 small broccoli farmers in the highlands of Ecuador to explore the factors influencing contract adoption and breach. In the experiment, where each farmer played 12 repetitions, the farmer who previously decided to engage in a fixed-price agreement, could decide to fulfil it or to sell the broccoli in the spot market where prices vary greatly. We further explored the effect of possible buyer´s opportunism on the probability of farmer´s breach. For this, we used a double LASSO-Heckman approach that applies L1 regularisation to both, the selection equation (contract acceptance) and the outcome equation (contract breach). The results show that market price dominates contract breach decisions, while other variables considered significant in standard models prove redundant. Selection bias is also significant and automatically considered through LASSO selection. Thus, farmers that enter a contract have specific characteristics that differentiate them from the rest of the population, and their decision to breach is mainly dominated by short-term profits. This reflects rational behaviour under incomplete enforcement. Interestingly, the probability of buyer´s opportunism doesn´t seem to increase the probability of farmer´s default. The implications of the results translate into the need for a better contract design under volatile market prices. Future research could focus on exploring the effectiveness of including price stabilisation mechanisms (e.g. floating price or a bonus) in the agreement, to avoid breach and make contracts more stable.

Keywords: Contract breach, field experiments, small farmers, vertical coordination

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Is it possible to price nature? Looking from the perspective of ecosystem economics and biodiversity

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In recent decades, the debate on environmental conservation has been marked by discursive disputes: nature as a common good; and nature as a commodity, endowed with economic value. On the second front, there is the term "Natural Capital," consolidated by Robert Costanza (2008), denoting the extension of the economic notion of capital to environmental goods and services. In this context, the study "The Economics of Ecosystems and Biodiversity" (TEEB) emerges as a symbol of this economistic paradigm, considering that its objective is to make visible the economic benefits of biodiversity, as well as the costs of its loss through monetary quantification. In this dynamic of monetising to preserve, it starts from the premise that many products are used free of charge because they are public, but are lost because they are free, highlighting the economic invisibility of the services provided by ecosystems. Nevertheless, monetarily quantifying losses requires defining what is being measured and what parameters are being used for comparison – something made difficult by the fact that biodiversity is dynamic and multidimensional. Consequently, there is no consensus on methodologies, since, according to Joe Bull (2013), biodiversity offsets are based on the exact quantification of losses and gains (something that requires complex metrics with many flexible variables). Furthermore, there is a structural limitation: by framing environmental problems in terms of offsets, the TEEB accepts the economic model, instead of questioning the structural causes of degradation. Given this, the following question arises: if monetary quantification lacks robust and consensual metrics, and if the approach tends to treat the environmental crisis as a pricing problem, to what extent does the study achieve its objectives? In an essayistic and dialectical manner, through bibliographic and documentary research, it is inferred, as a partial result of the research, that the TEEB represents an attempt to make visible the economic costs of ecosystem loss. However, the methodological limitations of monetary quantification reveal that it alone is not capable of offering a solution, as the central issue remains political – beyond measurement, considering the human-nature relationship in a merely utilitarian way contradicts ecosystemic logic.

Keywords: Environmental conservation, natural capital, TEEB

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Risk sharing or risk transfer? Proximity patterns for environmental justice in agri-food supply chains

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Climate change, economic inequalities, shifting consumption patterns, and political disruptions are putting severe pressure on global food systems and threatening food security. In response, agri-food supply chain (AFSC) resilience has become an urgent research priority. In this study we investigate how companies strengthen AFSC resilience, with particular attention to dynamic resilience capacities – absorptive, adaptive, and transformative. To examine the relational underpinnings of resilience, the analytic proximity framework of Edelmann et al. (2020) is operationalized across its four dimensions: organisational, social, cognitive, and institutional. We employ an exploratory design, combining online desk research with semi-structured interviews. The sample comprises 21 agri-food companies involved in importing, processing, or distributing cash crops, including cocoa, coffee, cotton, fruits, herbs, nuts, spices, and tea.

We identified multiple indicators that help to evaluate proximity within global AFSCs. Apart from this, two resilience strategies emerged, each with characteristic proximity patterns. First, especially large and very large companies diversify their supplier networks based on climate risk assessments. This strategy is marked by low proximity between actors and upstream risk transfer. High proximity is confined to the subdimensions organisational agreements and certifications. Second, many micro and small companies intensify supplier collaboration by implementing environmental and social practices at origin to strengthen smallholders. This approach is characterised by high proximity between actors as well as risk sharing and risk reduction at origin. Here, proximity is lower in the subdimensions organisational agreements and certifications. Taken together, the findings offer initial insights into the nexus between companies and smallholders as well as resilience and proximity, highlighting proximity indicators and patterns that support adaptive and transformative capacities in the light of environmental justice issues. Further research is needed to include the supplier side and assess how these best practices can be adopted creating a level playing field and for decolonizing AFSCs. This need is amplified by recent political backlashes that have weakened regulatory requirements, increasing expectations that companies proactively foster AFSC resilience while simultaneously advancing sustainability and climate justice.

Keywords: Agri-food supply chains, environmental justice, proximity, resilience

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Scaling solar drying technologies for smallholder farmers in Kenya: Adoption barriers and policy interventions

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Postharvest losses remain a major constraint in Kenya's horticultural sector, with estimates of 30–40 % for fruits and vegetables and reported upper bounds as high as 70 %. Up to 80 % of fruits and vegetables are primarily produced and marketed by smallholder farmers and traders operating under fragmented and resource-constrained conditions, which exacerbate losses across the value chain. Solar-powered processing of fruits and vegetables has been shown to be viable for decentralised smallholder systems by reducing postharvest losses and lowering energy costs while improving farmer incomes. However, adoption of improved solar drying technologies in Kenya remains low. This study examined adoption barriers and willingness to invest (WTI) in solar drying technologies among 226 smallholder farmers in Nakuru and Meru counties, two key horticultural production areas in Kenya. A mixed-methods approach was used, combining household surveys, focus group discussions, key informant interviews and direct observations. Results show that awareness of improved solar drying methods is moderate, at 43 % of respondents, while most smallholder farmers still rely on open-sun drying, reported by 62 % of respondents. Adoption of improved solar drying technologies remains low, at 9.7 %. The dominant constraints are high upfront capital costs, reported by 52.7 % of respondents, insufficient technical skills (72.3 %) and weak market linkages for dried products (60 %). Nevertheless, WTI is significantly higher under collective ownership models, with 62 % willing to invest, than under individual ownership, at 38 % ($p < 0.01$), indicating that group-based investment improves perceived affordability. Cost-benefit assessment, considering an annual median income of KES 100,000 (€ 650), shows that an improved dryer costing KES 300,000 (€ 2000) is likely unaffordable for individual farmers. However, improved access to credit, market premiums and group ownership could make solar drying technologies more attractive with break-even achievable within 2.5 years. Realising these benefits requires targeted institutional support including tailored financing mechanisms, structured capacity building, improved technology access and organised market linkages to scale solar drying for horticultural processing and preservation. These interventions could strengthen local value addition while supporting more resilient and climate-smart horticultural value chains.

Keywords: Postharvest loss reduction, technology adoption, willingness to invest

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A discrete choice experiment to measure the potential market for baru nuts: Evidence from European consumer preferences

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The Brazilian Cerrado is a savannah of global importance that has been threatened by agricultural expansion and the conversion of forests into intensively managed pastures. The expansion of the international market for its non-timber forest products could help minimise current challenges. The creation of a European market for Baru nuts (Dipteryx alata Vog.) has the potential to improve rural livelihood and increase forest resilience in the Brazilian Cerrado. This work analyses consumer preferences for Baru nuts in the Netherlands, Sweden, and Portugal, using a discrete choice experiment with 1024 consumers of nuts. We designed a questionnaire for a fictitious Baru nuts product with 7 product attributes, including distribution location, number of certifications, physical presentation, collection site, and environmental and social information. Random utility theory in attribute choices will be designed to focus on important daily uses of products, such as ease of purchase, consumption form, visibility of Cerrado, and positive social impacts on rural communities, as a guarantee of no child labour during collection. Three conditional logit models are estimated, stratifying the sample by demographic, social, and individual preferences related to nutritional habits. Results show a significant difference among countries in the average marginal willingness to pay for different attributes. A conventional product distribution in supermarkets is associated with a higher willingness to pay in Sweden, whereas in the Netherlands, consumers rank products with strong environmental benefits highest in terms of willingness to pay. Product price is significant only in Portugal, and social guarantees have the highest positive impact on the Portuguese market.

Keywords: Brazilian Cerrado, discrete choice experiment, European consumer market, marginal willigness to pay, non-timber forest products

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Labour displacement and mechanised direct seeded rice from an intersectional perspective: A case from Odisha, India

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Rice in India is a source of livelihood for millions of farmers and labourers. Mechanised direct seeded rice (DSR) is increasingly promoted as a climate-smart alternative to puddled transplanted rice (PTR), offering water savings, reduced input costs, lower emissions, and reduced drudgery. Yet for the thousands of women in rural India who transplant rice for a living, this shift is set to reshape not only how rice is grown but also who earns from it. As machines begin to replace manual transplanting, the distribution of benefits and losses across caste, class, and gender lines, becomes a critical but underexamined question. In socially stratified agrarian settings like India, understanding who gains and who loses from a new technology is essential for ensuring that the transition to mechanisation is both climate-smart and socially 'just.'

DSR may have differential impacts on men and women, with concerns about labour displacement, un- and under employment, and lower wages, especially for landless women, who are more vulnerable as wage laborers. This can diminish women's bargaining power and empowerment, negatively impacting household income, food security, and the nutritional well-being of families, and thereby increase existing inequalities.

This study, conducted in four rice-producing districts in Odisha (Puri, Ganjam, Kalahandi, and Mayurbhanj) between April and August 2024, examines the opportunities, challenges, and trade-offs of mechanised DSR adoption. We distinguish between four distinct groups of farms and working households. The findings indicate that while DSR holds promise for larger farmers belonging to socially privileged caste groups, it can lead to labour displacement and lower wages, adversely affecting marginalised farmers who need to sell their labour.

While promoting subsidised farm mechanisation is important for improving agricultural productivity, ensuring that the benefits are distributed equitably among all farmers presents a complex challenge for policymakers. It requires careful consideration of the immediate and long-term implications for those who may not benefit directly from such technologies, such that the pursuit of growth and sustainability does not exacerbate existing inequalities.

Keywords: Climate adaptation, direct seeded rice, India, mechanisation, smallholder farmers, women farmers

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When technology restructures the fields: Rising wages, herbicide adoption, and the masculinisation of agricultural employment in India

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Labour-saving agricultural technologies are expanding rapidly across South Asia, driven partly by rising rural wages and seasonal labour scarcity. Yet the distributional consequences of this expansion for socially stratified rural workforces remain poorly understood, particularly when gender and caste intersect to govern who performs which agricultural tasks. This paper examines how herbicide diffusion in Bihar – India's most agrarian and among its poorest states – reshapes the entire task composition of cereal farming, with consequences that extend well beyond the displacement of manual weeding labour. Using rural wage data from 2006–2020 alongside two farm-household surveys covering rice, wheat, and maize production across 35 districts and over 2,400 households, we document a self-reinforcing dynamic: rising women's wages, which remain persistently below men's throughout the study period, possibly have incentivised farmers to adopt herbicides as a labour substitute, but adoption subsequently forecloses the primary income-generating activity for the very women whose rising wages triggered it. Crop-specific multinomial logit estimates confirm that female labourers from Scheduled Caste and Scheduled Tribe households are less likely than their male counterparts to be involved in chemical weeding operations (the expanding task) while being significantly more concentrated in manual weeding (the contracting one). More strikingly, an analysis of seven complementary on-farm tasks – land levelling, land preparation, sowing, fertiliser application, irrigation, harvesting, and threshing – reveals that herbicide adoption is associated with expanding male labour demand in fertiliser application and irrigation, while female labour registers no meaningful gains in any of the seven activities examined. This pattern constitutes a systematic masculinisation of the complementary task landscape, not merely a displacement from weeding. The net result is a contraction of women's on-farm presence across the production calendar, not a reallocation within it. These findings carry direct implications for the design of agro-ecosystem interventions that aim to be both productive and socially inclusive: technologies that raise system-level efficiency while systematically narrowing labour opportunities for already-marginalised groups challenge the premise that productivity-oriented agricultural transformation is inherently pro-poor. Embedding gender- and caste-disaggregated task assessments into ex-ante technology evaluation frameworks is a tractable first step toward more equitable agro-ecosystem transitions.

Keywords: Caste, gender, herbicide adoption, intersectionality, labour displacement, labour-saving technologies, rural India, task reinstatement

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Barriers to youth adoption of climate-smart agriculture in Liberia: A socio-technical systems approach

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Liberia, a West African nation of approximately 5.8 million people, faces escalating climate-induced livelihood barriers among disadvantaged, war-affected, and at-risk youth whose agricultural prospects are increasingly threatened. As rising crop failures, animal diseases, and soil degradation erode opportunities, many youth are compelled into precarious survival strategies, including informal labour, substance abuse, drug trafficking, and other illicit activities (Fortune, 2021; Wesseh, 2025). Despite sustained interventions by the Government of Liberia to Climate-Smart Agriculture (CSA), these efforts have not made any substantial impact on youth productivity, while young people remain largely excluded from CSA frameworks. This has reinforced the cycles of economic vulnerability and social instability. Against this backdrop, the study addressed two central questions: What are the barriers to CSA adoption across urban, peri-urban, and rural Liberia, and what climate-resilient empowerment framework is needed to enhance youth economic outcomes? The study adopted a mixed-methods approach using a convergent parallel design, with a target population of 68,304 disadvantaged youth across the 15 counties of Liberia. From the above population, 399 youth and 25 youth organisation representatives were sampled using multiphase techniques. Data were collected through a researcher-developed questionnaire and semi-structured interviews, with validity ensured through expert review and reliability confirmed (Cronbach's $\alpha = 0.93$). Quantitative data were analysed using descriptive statistics, mean rating, and ANOVA, while qualitative data were thematically analysed. Findings indicate severe climatic and systemic barriers, including economic, institutional, technical, social, and environmental constraints, notably high input costs ($\bar{x} = 1.97$), weak extension services ($\bar{x} = 1.99$), low awareness ($\bar{x} = 2.04$), gender inequality ($\bar{x} = 1.78$), and climate variability ($\bar{x} = 2.17$) respectively. Hypothesis testing showed no significant differences across locations for most variables, except for inadequate CSA training and capacity building ($p = 0.048$), weak extension services ($p = 0.038$), dissemination of CSA information ($p = 0.038$), and awareness ($p = 0.046$), with rural youth most affected (M = 4.28, SD = 1.68). The study concludes that integrating socio-technical systems into a coordinated, youth-inclusive CSA framework is essential for enhancing sustainable economic empowerment.

Keywords: Climate-smart agriculture, disadvantaged youth, economic empowerment, Liberia, socio-technical systems

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Strengthening stakeholders' capacities and behavioural change for sustainable land management: Lessons from the participatory learning platform in northern Ghana

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Promoting sustainable land management is crucial for achieving sustainable development, yet, sustainable land management is a complex socio-ecological solution involving different actors, competing interests, preferences and needs, and contested sociocultural norms and practices. Consequently, sustainable land management requires participatory approaches that enable the active participation of diverse stakeholders, thereby strengthening capacities and behaviour change for a collective action. The INTERFACES project funded by the German Federal Ministry of Research, Technology and Space sought to promote sustainable land management in Africa through a participatory learning platform (PLP) with diverse stakeholders. In Northern Ghana, INTERFACES established a PLP in 2023 following robust contextual systematic review and stakeholder mapping to identify diverse stakeholders for sustainable land management. Comprising of stakeholders drawn from government and policy, civil society organisations, traditional authority, farmer-based organisations, private sector, academia and research institutions, minority group and international development partners, the platform applied diverse approaches including joint reflection, participatory social learning, multi-annual workshops, co-developing gender-responsive theories of change, field visits and self-recommended trainings aimed at building stakeholders' capacities and behavioural change for sustainable land management. Lessons from over three-year engagement reveal that diversity in stakeholder composition of the platform and skillful facilitation were key features that facilitated democratic space for joint learning and co-creation, enabling stakeholders to deeply reflect on diverse lived and gendered experiences relevant for collective decision-making for sustainable land management. Integrating gender transformative approaches including gender-responsive theories of

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change, gender model family, and land tenure regimes enabled stakeholders to deeply reflect their positionality on gender, leading to gradual transformation in mindset, attitude and behaviour of stakeholders, particularly among men. These changes are crucial for sustainable land management, as stakeholders transfer the PLP approaches and lessons to their broader institutions and communities of practice, leading to a change in practices at both institutional and community levels. We recommend that interventions and policies for sustainable development need to prioritise the active participation of diverse and crucial stakeholders from the outset, provide the democratic space for joint learning and reflection, and integrate solutions and approaches that address context-relevant and gendered needs and challenges.

Keywords: Co-creation, gender transformative approaches, social learning, sustainable agriculture, theory of change

A triangulated perspective on labour conditions in certified vs non-certified coffee farms in Rwanda: Farmer reports, worker narratives, and gender dimensions

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This study examines working conditions on certified and non-certified coffee farms in Rwanda, with a focus on gender, dignity, and the role of voluntary sustainability standards (VSS). Using a mixed-methods approach, we combine survey data from 690 smallholder households with semi-structured interviews conducted with 20 hired workers across 4 coffee producing districts. This design enables triangulation of farmer-reported practices and worker experiences to assess both formal compliance and lived realities of work. Quantitative findings reveal persistent gendered divisions of labour. Women contribute significantly more labour per season than men (77.4 versus 70.3 days), concentrating in harvesting, weeding, and post-harvest processing, while men primarily undertake pruning and chemical application. Training on occupational hazards and equipment use is similarly high across certified and non-certified farms. Access to personal protective equipment (PPE) is slightly higher on non-certified farms, a pattern that may reflect the promotion of Integrated Pest Management (IPM) on certified farms, which reduces chemical spraying and potentially lowers the need for PPE rather than indicating weaker worker protection. Certification is associated with modest improvements in formal labour conditions: certified farms report slightly higher union membership, better access to drinking water and sanitation facilities, and a slightly higher prevalence of bonuses and contracts. Wage differences between certified and non-certified farms, however, remain modest. Non-certified farms exhibit higher rates of hiring pregnant and breastfeeding women, suggesting greater flexibility or inclusiveness in employment practices, although potentially outside formalized labour frameworks. Child labour incidence is very low across both certified and non-certified farms, with only slightly higher prevalence among non-certified farms. Average daily working hours are comparable (approximately 6.7 hours per day), and breastfeeding time shows substantial variation but similar averages across farm types, indicating broadly comparable labour intensity and family support practices. Overall, the findings suggest that while certification contributes to improved formal labour rights and infrastructure, it does not fully address gendered inequalities or guarantee dignified working conditions. The study underlines the importance of integrating worker perspectives and contextual labour practices into sustainability standards to better align certification with the goals of decent work, gender equity, and worker well-being.

Keywords: Voluntary sustainability standards, working conditions

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An intersectional analysis of gender equality and climate change vulnerabilities capacities and policy gaps in sub-Saharan Africa

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Gender disparities in sub-Saharan Africa (SSA) heighten the vulnerability of the women and marginalised groups to climate variation because they rely on climate-sensitive livelihoods. However, systemic barriers and entrenched norms hinder their roles in climate adaptation and mitigation efforts. This review paper explored how gender disparities intersect with climate change by examining vulnerabilities, the capacity of marginalised genders for adaptation and mitigation, and policy gaps hindering gender-responsive climate action in Sub-Saharan Africa. The paper methodically mapped studies on gender equality and climate change using the PRISMA-SCR methodological framework. The paper analysed twenty five (25) peer-reviewed articles published between (2016–2024) to explore intersections between gender disparities, climate impacts, and policies. Key findings indicate that compared to men, women experience heightened vulnerabilities. These gendered vulnerabilities to climate change in Sub-Saharan Africa are rooted in systemic exclusion, limited access to resources, insecure land tenure, cultural norms, and inadequate representation in decision-making processes. Despite these challenges, women play a crucial role in climate adaptation through their local knowledge, community initiatives, and innovative solutions, highlighting significant capacities that enhance climate resilience. However, critical policy gaps of lack of gender-responsive frameworks, absence of gender-disaggregated data, and limited capacity-building initiatives, which hinder effective climate action and inclusive climate action persist. Therefore, bridging these gaps through inclusive gender-sensitive policies is essential for fostering sustainable development and ensuring equitable climate resilience. Nevertheless, addressing these challenges requires coordinated global and regional efforts to mainstream gender in climate policies through targeted empowerment, inclusive governance, capacity-building, gender-inclusive and sensitive policies, and gender-disaggregated data collection.

Keywords: Capacities, climate change, gender equality, policy gaps, SSA, vulnerabilities

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Barriers and enablers to women smallholder farmers' adoption of agricultural innovations in Rwanda

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Agriculture is the main source of employment in Rwanda, and women represent more than half of the country's farmers. Despite their central role in food production, women smallholder farmers continue to face persistent constraints that limit their ability to adopt agricultural innovations. This study examines how women engage with selected agricultural innovations and identifies the barriers that hinder, and the conditions that support, their adoption. The research addresses two questions: which socio-economic, cultural, and institutional barriers prevent women from adopting small-scale irrigation, composting, and Juncao technology; and which policy, training, and support mechanisms can facilitate adoption.

A mixed-methods approach was applied. Eight potential innovations were initially identified and assessed using the Relevance, Opportunity, and Feasibility (ROF) framework in consultation with experts, and subsequently prioritised by women farmers. Three innovations were selected for in-depth analysis. Data were collected across five agroecological zones through structured interviews with 37 farmers, six focus group discussions, and 11 key informant interviews.

The findings show that women's adoption of agricultural innovations is primarily constrained by limited access to information and training, insufficient skills, high costs, and restricted access to credit. Social norms, time constraints linked to household responsibilities, and limited decision-making power further shape women's ability to engage with innovations. Across all three innovations, access to training and information emerged as the most important enablers, followed by financial support mechanisms.

Overall, the study highlights that improving women's adoption of agricultural innovations requires addressing financial, informational, and social constraints in an integrated manner. It underscores the importance of gender-responsive support measures that reflect women's daily realities and strengthen their agency within agricultural innovation systems.

Keywords: Agricultural innovation, gender barriers, innovation enablers, women farmers

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The gendered game: Effects of experiential learning on decision-making and water saving in India

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This paper addresses two key questions related to gender equity and sustainable natural resource management. First, given the importance of women's decision-making in agriculture for their own empowerment and agricultural outcomes, what are effective ways to strengthen women's participation in agricultural decision-making? Second, is women's participation in agricultural decisions associated with more water-conserving production choices? We analyse these questions by examining the impact of a novel experiential learning intervention with games, debriefing, and crop water budgeting, designed to address groundwater depletion in India. Results of a randomised control trial in 472 communities indicate that playing the game significantly increased women's participation in choosing the crops their household grows in the post-monsoon season, specifically their likelihood of deciding alone. Men who played the game were also more likely to make crop choice decisions alone, though the effect was smaller. Path analysis shows that women's involvement in crop decision-making is associated with more water-conserving decisions: women who decide alone report that their household grows significantly less water-consumptive crops and irrigates less land in the post-monsoon season, when groundwater is scarce. Even when women decide jointly with their husbands, households grow less water-consumptive crops, though the effect is smaller. By contrast, when men and women decide with other relatives, households cultivate more area overall, suggesting that the learning from the game is less effective when more people are involved in decisions. Experiential learning games are thus a promising strategy to strengthen women's agricultural decision-making, and this may also lead to more sustainable resource management.

Keywords: Groundwater, India, serious games, sustainability, women's empowerment

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Beyond inclusion: Gender-responsive nature-based solutions for climate-resilient agriculture in sub-Saharan Africa

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Climate change is placing increasing pressure on agricultural systems in sub-Saharan Africa, where many rural communities depend on rain-fed smallholder farming and natural resources for their livelihoods. These pressures are made worse by land degradation, biodiversity loss, water stress and persistent rural poverty, all of which threaten food security and community resilience. Women are at the heart of these agricultural systems. They contribute to farming, seed management, food processing, household nutrition and natural resource management. Yet, their ability to adapt to climate change is often limited by unequal access to land, finance, extension services, climate information, technologies, markets and decision-making spaces. This review examines how gender-responsive Nature-Based Solutions can strengthen climate-resilient agriculture and improve women's adaptive capacity in Sub-Saharan Africa. Using a PRISMA guideline, the article synthesizes peer-reviewed studies and high-quality institutional literature published between 2015 and April 2026. The review focuses on Nature-Based Solutions relevant to agriculture, including agroforestry, ecosystem restoration, soil and water conservation, biodiversity-based farming, sustainable land management, farmer-managed natural regeneration and ecosystem-based adaptation. The evidence shows that Nature-Based Solutions can support agricultural resilience by improving soil fertility, water retention, biodiversity, microclimate regulation, livelihood diversification and ecosystem services. However, these benefits are not automatic. Their success depends on inclusive governance, secure land and resource rights, access to finance, recognition of local knowledge and gender-transformative implementation. When women's labour, knowledge, rights and agency are not properly considered, climate-resilient interventions may unintentionally reproduce or even deepen existing gender inequalities. Gender-responsive Nature-Based Solutions should go beyond simply including women as beneficiaries. Women should be recognised as farmers, innovators, knowledge holders, restoration leaders and decision-makers. Strengthening women's access to land, climate information, finance, extension services, technologies and leadership opportunities is essential for building resilient, equitable and multifunctional agro-ecosystems in sub-Saharan Africa.

Keywords: Adaptive capacity, climate change, gender-responsive adaptation, nature-based solutions, resilience, sub-Saharan Africa, women

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Women's empowerment and climate adaptation in agro-food systems: Challenges and opportunities for inclusive resilience

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Women in rural agro-food systems play a central role in food production, household nutrition, resource management and climate adaptation. However, their contribution is often constrained by unequal access to land, credit, agricultural extension services, technical training, decision-making power, and climate-resilient technologies. This study examines the relationship between the adoption of Climate-Smart Agriculture (CSA) technologies and women dietary diversity in rural Bangladesh, with particular focus on Jamalpur, an area of river erosion. CSA practices followed in the region are homestead gardening, crop diversification, organic composting, and improved farm management Framed within the broader concept of gender-responsive agro-ecosystems, the study explores how climate-resilient agricultural practices can contribute to food security, poverty reduction, women's empowerment, and strengthened rural livelihoods. The study uses a mixed-methods approach that combines qualitative field insights with quantitative analysis. The Poisson regression assesses how socioeconomic and institutional factors such as age, education, income, farm size, household size, access to CSA training, and adoption of CSA practices influence women dietary diversity. The findings indicate that women from CSA-adopting households generally experience better dietary diversity, improved access to nutritious foods, and greater household food security compared with women from non-adopting households. CSA practices enhance the availability of nutrient-dense foods. At the same time, they support climate adaptation and livelihood resilience. The study further reveals that women's empowerment is closely linked with climate-resilient food systems. When women receive training, access productive resources, and participate in household and agricultural decision-making, they are better able to adopt adaptive practices and improve household nutrition outcomes. Nevertheless, persistent barriers such as gender based inequalities, limited technical knowledge, restricted mobility, inadequate infrastructure and weak institutional support continue to limit women's

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full participation in sustainable agro-food systems. The findings highlight the need for gender-sensitive agricultural policies and inclusive rural development strategies that integrate nutrition, climate adaptation, and women empowerment. To enable the households in addressing climate-resilient food security, targeted interventions should be women-focused CSA training, improved access to resources, strengthened extension services, and support for diversified farming systems. This study provides evidence for the relevant stakeholders seeking to build inclusive and resilient agro-ecosystems in climate-vulnerable rural regions.

Keywords: Bangladesh

Gender-based discrimination in service provision: Evidence from maize agro-input dealing in Uganda

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Existing literature highlights gender-based discrimination faced by farmers downstream in food supply chains, however, upstream service provision along food supply chains have not yet been explored enough to investigate gender-based inequities. This research contributes to existing literature on constrained access to good quality maize seeds and improved varieties for female farmers by providing evidence on gender-based discrimination faced by Ugandan maize farmers in service provision from agro-input dealers, further emphasising the importance of reliable service provision in agricultural yields. Furthermore, this study also tests for gender homophily.

Pooled data (over time) from maize supply chain surveys are used which includes several potential indicators for service provision from agro-input dealers. These include feasibility to return the seed and obtain a refund in the case of problems with the seed, credit provisions, receipt of training or suggestions on the usage of improved varieties of seeds, provision of home delivery, other after-sales services, options of various payment methods and possibility to buy smaller quantities of seeds among others. Exploiting the dyadic nature of the farmer-dealer, averages of the services received by female and male farmers are compared using OLS regression on farmer-level averages while controlling for farmer-level characteristics with standard errors clustered at the dealer level. Then, dealer-level fixed effects model is employed to remove all dealer level heterogeneity while controlling for farmer level characteristics with standard errors clustered at the farmer level. Gender homophily is evaluated by adding an interaction term for the dealer's gender. We find preferential treatment for male farmers in the provision of services from agro-input dealers, indicating disadvantaged positions of female maize farmers in service provision. However, gender homophily is not observed. Our results motivate policies for correction of gender-based discrimination in service provision to help form better and equal aspirations and expectations of both female and male farmers.

Keywords: Agricultural service provision, gender, Uganda

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Pricing inclusive digital extension services: Gender, delivery design, and farmers' willingness to pay in Zambia

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As digital agricultural advisory platforms transition from subsidised pilots to subscription-based models, user fees may exclude vulnerable groups, including women and resource-poor smallholders. This study examines gender differences in willingness to pay (WTP) for Atubandike, a phygital extension platform in Zambia that combines interactive voice response messages on climate-smart agriculture with in-person community support. Using data from 560 active users participating in a randomised controlled trial of five delivery models, we find that demand is highly price sensitive and declines sharply as fees increase. Women, particularly married women, exhibit significantly lower WTP than men, even after controlling for socioeconomic characteristics. Delivery design strongly influences women's demand: phygital models that combine digital advisory with village-based digital champions and community engagement generate higher WTP among women than digital-only models. However, the recurrent costs of socially inclusive delivery designs cannot be recovered through widely affordable user fees alone. The findings suggest that sustaining inclusive digital extension systems will require broader public and private financing mechanisms, with user fees playing a complementary rather than primary role.

Keywords: Digital extension, women

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Women's participation in the forage seed market in Vietnam: Progress and barriers

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Women play a central role in livestock production and forage management in Vietnam, yet their contributions remain undervalued due to persistent gender norms and structural inequalities. In forage seed systems, these dynamics shape access to resources, participation in markets, and decision-making power, ultimately influencing both women's empowerment and system performance. This study analyses the gendered dynamics of Vietnam's forage seed system, with a focus on identifying barriers, opportunities, and pathways to enhance women's participation and agency. The research adopts a qualitative approach based on 21 key informant interviews with stakeholders across the forage seed system, including private companies and research institutions. Using a multistakeholder and seed system framework, the study examines how gender influences participation in seed production, research, distribution, and adoption, as well as key system outcomes such as availability, quality, and commercialisation. Results show that women are actively involved in labor-intensive activities such as forage management, seed handling, and training participation, but remain largely excluded from higher-value roles, including breeding, seed purchasing, and market decision-making. Gendered divisions of labour, sociocultural norms, and limited access to land, capital, and information constrain their participation and agency. Women also tend to rely more on informal seed systems, which restricts access to improved forage varieties. At the same time, their preferences – particularly for labor-efficient and easy-to-manage forages – play a critical role in shaping adoption patterns but are insufficiently integrated into breeding and market strategies. The study concludes that gender inequalities not only affect equity outcomes but also create systemic inefficiencies that limit the performance and scalability of forage seed systems. Enhancing women's inclusion requires moving beyond participation toward strengthening agency through gender-transformative approaches, improved access to formal markets, and the integration of women's preferences into innovation processes. Addressing these structural constraints can contribute to more inclusive, efficient, and sustainable livestock systems.

Keywords: Forage seed systems, gender inequality, gender norms, improved forages, livestock, technology adoption, women's empowerment, women's participation

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The effect of a cocoa price increase on school enrollment in Côte d'Ivoire

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As the world's leading cocoa producer, Côte d'Ivoire's economy is highly dependent on the crop, which is a vital income source for many smallholder farmers. However, cocoa production in Côte d'Ivoire is also under scrutiny due to the occurrences of child labour, while many children at the age of obligatory schooling do not go to school. The literature presents an ambiguous picture of the underlying drivers of school enrollment. Earlier studies in Côte d'Ivoire (1980s/90s) suggest negative price and rainfall shocks reduce schooling due to lower income (dominating income effect), while recent evidence from Ghana indicates higher prices lower enrollment, as the opportunity cost of children's time increases (dominating substitution effect). We study the relationship of cocoa prices and school enrollment by analysing a policy that increased the nominal minimum farmgate price in Côte d'Ivoire by 21 % from the 2019/20 to 2020/21 cocoa season. Using data from national surveys, we create two pseudo-panels of individual school enrollment for two consecutive years. We estimate the causal effect of the price increase on children's school enrollment using a Difference-in-Differences (DiD) framework. Our model takes into account heterogeneous effects across gender and age groups, aiming to provide a clearer understanding of school enrollment and household labour trade-offs. A small but significant positive effect of the price increase on school enrollment supports the dominance of the income effect also in the recent Côte d'Ivoire context. This suggests that cocoa farmers remain income constraint and consistently higher available income may improve overall school enrollment.

Keywords: Cocoa value chain, development economics, education, household decision-making

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Beyond technology transfer: Co-creating climate-resilient agriculture with Indonesian youth

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Transitioning towards net-zero farming and securing the next generation of farmers are critical challenges for climate-resilient agroecosystems in the Global South. While conventional top-down extension models often fail to address these complex socio-ecological issues, participatory approaches offer a promising alternative.

This study evaluates two interlinked participatory extension methods – the Climate Business Field School (CBFS) and the Young Cool Farmer Challenge (YCFC) – implemented among rural youth in two agro-ecological zones in Indonesia. The evaluation utilises a holistic framework that includes profitability, motivation, and the ecological impact of farming, assessing greenhouse gas (GHG) reductions through climate-resilient agriculture.

Employing a mixed methods design, qualitative data from focus groups are analysed using MAXQDA, capturing the motivations of more than 20 CBFS participants. A purposive sample drawn from a broader pool of 137 YCFC applicants, representing 19 groups and including 73 women, was analysed to examine the socio-economic conditions, the motivations and prospects of net-zero farming.

The analysis reveals a strong synergy between the extension methods. The CBFS, a participatory training programme that equips youth with knowledge on climate change and agribusiness management, acts as a base for further development. Participants emphasised that they particularly benefited from drafting realistic business plans and mobilising village peers to apply for the YCFC. The challenge attracted various climate-resilient innovations, including permaculture and renewable energy technologies. The skills enabled not only the winners but also the other candidate groups to independently structure their farm enterprises.

Modern innovative technologies are one important motivational factor to engage youth in farming. The consequence approach of CBFS and YCFC proves an effective approach to engage youth farmers in exploring innovative net-zero farming technologies. For more sustainable impact, institutional governance is required to position young farmers as self-sustaining agents in climate change mitigation.

Keywords: Climate-smart agriculture, mixed-methods evaluation, net-zero farming, participatory extension, youth in agriculture

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Bridging supply- and demand-side stated preferences for designing sustainable youth-led aquaculture business models: Evidence from northern Ghana

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Northern Ghana faces persistent youth underemployment and seasonal food insecurity, particularly during the dry season when agricultural opportunities are limited by a unimodal rainfall regime. Despite the presence of over 2,000 small community reservoirs constructed primarily for irrigation, their potential for aquaculture remains largely underutilised. While recent pilots demonstrate the technical feasibility of cage aquaculture, the economic and institutional sustainability of existing project-driven models, often reliant on capital subsidies and limited technical training, remains uncertain, compounded by challenges related to governance, property rights, and power dynamics. This paper examines how aquaculture in small reservoirs can be developed into a viable, inclusive, and scalable economic activity. We propose and empirically implement a sequential framework that integrates technical piloting, business model co-creation, and ex ante economic assessment, explicitly incorporating community preferences into the design process. Using primary data from northern Ghana, we combine stakeholder-informed business model design with two discrete choice experiments (DCEs), each administered to approximately 500 households. The first (supply-side) DCE elicits preferences over alternative aquaculture arrangements, including employment modalities, payment structures, contract duration, market orientation, and community benefits. The second (demand-side) DCE captures consumer preferences for fish attributes such as species, product form, size, and price. Results show that community acceptance is strongly driven by tangible local benefits. Providing salaried employment reduces the compensation required for project acceptance by approximately USD 2,610 annually, while profit-sharing arrangements reduce it by about USD 1,870. Local market access further enhances acceptance, whereas contract duration has no significant effect. On the demand side, consumers exhibit a willingness to pay premiums for catfish, smaller-sized fish, and smoked products, with substantial heterogeneity across preferences.

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The study contributes methodologically by integrating pilot-based validation with stated-preference approaches for business model design. Substantively, it highlights the importance of employment generation and localised value chains in fostering socially acceptable aquaculture systems. The findings offer policy-relevant insights into leveraging small-scale water infrastructure to promote youth employment, attract private investment, and support agri-food system diversification in sub-Saharan Africa.

Keywords: Aquaculture, common-pool resources, discrete choice experiments, small reservoirs, youth employment

Co-design of touristic route in Colombian indigenous territory: GTA for landscape conservation and women transformation

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Within the CGIAR Science Program on Multifunctional Landscapes implemented in indigenous territory of Cumbal (Colombia), gender research is examining the role of women in biodiversity conservation. In particular, using gender transformative approach (GTA) and Feminist Political Ecology (FPE) we explore to what extent women's participation and leadership in indigenous agro-tourism can foster nature conservation at landscape level, while addressing gender inequalities. FPE offers a critical lens for understanding how environmental inequalities are shaped by gender, interrogating essentialist associations between women and nature and foregrounding the patriarchal structures that condition women to care for their livelihoods and environments. When combined with GTA – which actively co-designs solutions with women, feminist movements, and youth – this pairing has the potential to generate cutting-edge, action-oriented knowledge at landscape scale.

This study builds on participatory workshops, semi-structured interviews, participatory observation and literature review. Through the participatory method of co-designing a touristic route, women involved in indigenous agro-toursism initiatives improved páramo (unique high-mountain ecosystem, located primarily in the Andes mountain range in South America,) conservation while strengthening their cultural identity, self-esteem, empowerment, networking and income. The capacity strengthening process led by indigenous women was key to achieve engagement, legitimacy and relevancy of the process. Nevertheless, challenges remain related to the lack of women participation in indigenous local authorities, women land access and ownership.

We discuss the role of women led agrotourism in local nature governance and policy incidence toward environmental justice. Besides, we examine the risk of gender-based violence associated with agrotourism in terms of gender expectation of women, occupational self-segregation, gender stereotypes, limited access to and ownership of land, amongst other. The co-design of touristic route as a participatory methodological tool appears as innovative and relevant to address both conservation and gender issues, that could be reproduced in other contexts.

This study address knowledge gap for its understudied geographic area (Latin America and Colombia), and in particular in Andean and indigenous contexts where the traditional social and cultural structures can limit women's ability to empower themselves.

Keywords: Biodiversity conservation, Colombia, Feminist Political Ecology, gender transformative approach, indigenous agrotourism

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Determinants of profitability in youth-led net-zero farming: Evidence from the YCFC programme in Indonesia

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Climate change continues to challenge the sustainability of small-scale agriculture, particularly in developing countries with limited access to capital. In Indonesia, the Young Cool Farming Challenge (YCFC) operates as a competitive challenge by RYCAM where selected the best proposals receive a grant of Rp15 million to develop adaptive agribusinesses within a net-zero framework. Although the programme targets up to a 30 % economic increase, empirical evidence on how financial and non-financial factors jointly shape farm business profitability remains limited. This study examines how challenge grants, cost structure, farming experience, market access, and the network relate on farm business profitability. Drawing on the Agricultural Innovation Systems (AIS) framework, a quantitative-dominant mixed-methods approach was applied to 12 youth farming teams across Java, Sumatra, and Sulawesi (November 2025–April 2026) with approximately 50 % female participation. Data were collected through surveys and financial reports to measure profit margins and return on investment, complemented by in-depth interviews to identify network roles, access to information, and decision-making processes. Early observations indicate that profitability is shaped by several factors working together particularly Cost efficiency, cost structure, market access, and farmer involvement in innovation networks. Challenge grants appear to play a facilitating role. Their impact becomes more visible when the funds are directed toward productive assets rather than short-term operational expenses. Farming experience appears to strengthen resource use efficiency and managerial decisions. These factors are also correlated with the adoption of low-emission agricultural practices, including integrated farming and circular resources. However, the current funding level remains insufficient to sustain business viability beyond the initial production cycle. Overall, the results point to a broader pattern: profitability in youth-led agribusiness is not simply a matter of accessing funds. Instead, it is closely linked to how resources are managed, how farmers connect to markets, and how they engage with networks that support learning and innovation within a low-emission farming system.

Keywords: Challenge grant, climate change, cost structure, Indonesia, low-emission agriculture, market access, profitability, young farmers

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Hidden child labour use and gender in coca economies: Evidence from Peru

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Child labour in illicit crop production remains a critical challenge characterised by informality, vulnerability, and weak institutional presence. Under ILO Convention 182 and SDG 8.7, child labour is classified among the worst forms of labor; however, its prevalence in coca-producing regions remains poorly understood. In these regions, coca functions as a key cash crop and survival strategy for fragile households operating under economic and environmental uncertainty. Coca economies rely on family-based labour systems with gendered roles, often involving children. In Peru, the ENACO state monopoly limits legal commercialisation, and recent policy tightening since February 2023 has further constrained legal absorption, potentially affecting labour allocation and policy effectiveness. Existing studies rely on self-reported data, which may be biased in high-risk and stigmatized environments. To address this limitation, this study implements an original survey experiment using a list experiment with 734 households in La Convención, Peru. Indirect estimates are compared with direct questioning to identify underreporting of child labour use and gender differences, with robustness assessed through balance tests and randomisation inference. Results show substantial and strongly gendered underreporting. Among female-headed households, prevalence is 32.7 % using the list experiment versus 1.3 % from direct responses (misreporting: 31.4 percentage points), while no significant difference is observed among male-headed households. At the aggregate level, prevalence is 22.3 % versus 5.5 % (misreporting: 16.8 percentage points). Additional evidence reveals greater dispersion in female well-being, consistent with heterogeneous and fragile living conditions. These findings provide the first indirect evidence that child labour use in coca economies is systematically concealed, particularly among female-headed households. Indirect measurement and gender-sensitive approaches are essential for improving policy design. In contexts where coca functions as a survival-oriented cash crop, understanding hidden labour dynamics is critical for designing effective and inclusive development policies.

Keywords: Child labour use, coca, gender, list experiment, Peru, vulnerability

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Backyard poultry for food security: Smallholder women farmers in promoting multifunctional agro-ecosystems in Punjab, Pakistan

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Women in Pakistan face severe malnutrition and food insecurity. Rural women in Pakistan keep backyard poultry as it is a low-cost investment that is easily manageable and culturally acceptable. They actively participate in the care, handling, and management of their birds and poultry products. Previous studies have reported that backyard poultry not only enhances soil fertility and nutrient biodiversity but also increases crop productivity. Unfortunately, the role of smallholder women in keeping backyard poultry is poorly documented. Thus, this study evaluated the role and documented the indigenous knowledge of smallholder women regarding backyard poultry practices and their contribution to multifunctional agro-ecosystems that sustain the livelihoods of this vulnerable group.

The study was conducted in Tehsil Jalalpur Pirwala, South Punjab, Pakistan, a region with a high proportion of smallholder farmers. The study used a mixed-method approach combining household surveys and focus group discussions with smallholder female farmers. For this, approximately 100 women farmers in Jalalpur Pirwala were interviewed using survey-based questionnaires and focus group discussions. The research investigated the gendered perspectives on the use of backyard poultry to increase food security, improve livelihoods, and promote agro-ecosystems. The study also focused on the efficient use of kitchen waste and other residues for feeding backyard poultry. Data collected through surveys and focus group discussions were analysed statistically using stratified random sampling with multivariate regression models. The research results demonstrated the significant role of smallholder women farmers in promoting the agro ecosystem. The findings show that backyard poultry not only provides nutrition but also helps recycle organic matter, efficiently utilise crop residues, and support biodiversity. These findings underscore the need to recognise and integrate the knowledge of smallholder women farmers into broader agro-ecosystem management and food security policies.

Keywords: Agro-ecosystems, backyard poultry, food security, local knowledge, smallholder women farmers

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Multi-country evidence on gender gaps in sustainable rice cultivation performance indicators in sub-Saharan Africa

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This study examines gender gaps in five Sustainable Rice Platform performance indicators (PIs): yield, net profit, labour productivity, and the partial factor productivity of nitrogen and phosphorus (PFPN and PFPP) across ten sub-Saharan African countries (Burkina Faso, Burundi, Democratic Republic of Congo, Kenya, Madagascar, Nigeria, Rwanda, Sierra Leone, Tanzania, and Uganda). Data were collected from 3,081 rice farming households, including 2,042 male-managed and 1,039 female-managed fields across irrigated lowland (IL), rainfed lowland (RL), and rainfed upland (RU) production systems. Gender differences in the five PIs varied widely across countries and production systems. Average yield gap, defined as the difference between actual and attainable yields, was higher in female-managed farms than in male-managed farms (50 % vs. 43 %). Likewise, marked net profit gaps were observed in irrigated lowland systems, with gaps of 55 % in Burkina Faso. In rainfed systems in Nigeria, the gaps ranged from 48 % in RL and 33 % in RU. Labor productivity gaps were pronounced, ranging from 78 % in Uganda to 98 % in Nigeria, and were largely associated with lower access to equipment in female-managed farms. In terms of nutrient use efficiency, more than half of the farms surveyed recorded PFPN values above the optimal threshold (40 kg grain kg^{-1} N). Whereas for PFPP, 78 % of farmers exceeded the desirable level (250 kg grain kg^{-1} P), with women representing 32 % of this group. Access to irrigation, certified seed, fertilisers, training on sustainable practices, and labor-saving technologies emerged as critical drivers of productivity and profitability, particularly for women. These patterns highlight the need for gender-responsive intervention strategies that extend women's access to land and equipment, input, training on sustainable practices, and labor-saving technologies, while also improving input use efficiency and mechanisation options for all farmers according to the context.

Keywords: Gender gaps, performance indicators, sub-Saharan Africa, sustainable rice cultivation

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Women's roles in small ruminant production systems and *pestes des petits ruminants*' status in Indonesia

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This study focused on women's roles in small ruminant production systems and evaluated the current status of Peste des petits ruminants (PPR) in Bandung, Garut, and Indramayu, Indonesia. Those regions were chosen for their active small ruminant farming and previous serological evidence for PPR. The study conducted a mixed-method approach. The focus group discussions were conducted with 72 selected farmers to explore women's roles, meanwhile blood and nasal swab samples were collected from up to 151 sheep and goats to assess PPR presence using competitive ELISA and RT-PCR techniques. Roles of women varied across regions which are shaped by local cultural beliefs and household gender dynamics. While women's primary responsibility is traditionally household care, many households share farm-related tasks, including feeding animals, cutting grass, and managing livestock, with women also participating in decision-making. Balanced arrangements are common in Bandung, where women are often more directly involved in feeding and taking care of sick animals, while men manage other aspects on the farm. In Garut, although women are not directly involved in daily farm work, they also make decisions e.g., selling animals and sometimes take care of sick animals. Overall PPR seroprevalence was 0.66 % (1/151) across all regions. Only one sample was seropositive from a sheep aged 6–12 months in Garut. Fifteen samples from Garut were analysed by qRT-PCR to detect PPR antigen presence. The qRT-PCR showed negative results which concluded that there were no PPR antigen detected in any of the samples in this study. The PPR antibodies was detected, even at low level, indicates that previous exposure of the virus which highlights a potential vulnerability to PPR outbreaks within the smallholder farming system. The current finding shows the importance of preparedness through robust veterinary surveillance.

Keywords: Animal disease, goat, Indonesia, sheep, smallholder farmers

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Implementing gender transformative approaches (GTAs) in livestock systems: The case of eastern Africa

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Inequitable gender norms hinder the development of efficient and equitable agri-food systems. In chicken value chains, for example, inequitable gender norms, inhibit the ability of women smallholder farmers to engage in and benefit from chickens limiting the potential of the sector for supporting rural livelihoods and women's empowerment.
Gender transformative approaches (GTAs) have been used in different contexts to address restrictive gender norms and empower women. However, the processes to identify relevant norms and develop appropriate GTAs in agri-food systems, are still being developed and scrutinized, especially within smallholder livestock based farming systems where norms are pervasive.
In this paper, we provide a methodological guidance on how GTAs can be implemented with a starting point of norms exploration in target communities, intervention design, implementation and preparation monitoring of changes that can be attributed to GTAs following implementation. We adopt the case of GTAs implemented to address restrictive gender norms adopted by the International Livestock Research Institute (ILRI) in smallholder chicken value chains, pig and dairy value chains in recent years. We highlight the engagement of target communities in participatory processes of research to uncover the restrictive gender norms to target, participatory intervention formulation and intervention implementation and a post intervention exploration to identify how to improve the intervention for higher possibilities of changes in restrictive gender norms.
This paper makes a contribution of highlighting practical steps, which projects that seek to engage communities in adopting norms supportive of women's engagement in and benefit from livestock activities, can adopt from research to monitoring of changes attributable to interventions.

Keywords: Implementation, livestock systems

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Rethinking agricultural extension through knowledge co-creation

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Farmer research networks for food system innovations

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Transforming agricultural research and development systems towards sustainability and resilience outcomes while increasing agricultural production is critical for farmers in Sahelian West and Central Africa. The Farmer – Researcher Network (FRN) approach proposes to achieve this by strengthening farmers' and researchers' capacity to learn together and engage throughout the research process, conducting research in a rigorous and democratic manner, and facilitating knowledge sharing, iterative reflection and planning by network members.

Six Farmer Organisations (FO) in Mali, Burkina Faso and Niger engaged in dynamic collaborations between producer organisations, researchers, and other stakeholders over the past 20 years, funded by the McKnight Foundation Global Collaboration for Resilient Food Systems program. What influence did this type of collaboration have on the FOs themselves, and what lessons can be learned from their journey that could be of interest to research for development systems for resilience and sustainability?

Using a collaborative learning approach, with reviews of FO documents, interviews with members of the six FOs and a workshop we identified a wide range of changes the FO members experienced over the past 20 years. All FOs reported how they professionalized their operations in terms of the services

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offered to members, transparency in financial and programme management, and diversification of their partnerships and types of research undertaken. Additionally, the FOs described strengthened skills in multiple domains, such as variety co-creation, seed production, soil fertility, pest management, agricultural product processing, and nutrition. Over time, they diversified their approaches for sharing knowledge and information widely. As a result, farmers reported diversification of their crops, improved food security in their areas, and increasing incomes for both women and men. Furthermore, gender relations have changed considerably. These combined changes signify substantial progress towards agroecological transformation of agri-food systems in these three countries. The evolution of relationships with researchers and government services appeared to contribute to these fundamental changes. These major learnings indicate that the FRN approach anchored in professional farmer organisations, as documented here, supports locally relevant innovations contributing to agroecological transformation in complex and unpredictable environments, including in the current Sahelian context of crisis, reduced mobility and insecurity.

Keywords: Burkina Faso, farmer organisations, farmer research network, Mali, Niger

Knowledge acquisition in farmer field schools: Agroforestry knowledge co-creation processes in Kilifi county, Kenya

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Farmer Field Schools (FFS) are widely promoted as a participatory approach for enhancing agricultural knowledge among smallholder farming communities. However, the processes through which knowledge is acquired remain insufficiently documented. This study examined how an agroforestry project (AfriNutriForest) supports agroforestry knowledge acquisition within FFS groups in Kilifi County, Kenya. Knowledge acquisition among farmers occurred through Agro-Ecosystem Analysis (AESA) sheets, experiential learning, field observation, farmer-to-farmer exchange visits, and interaction with subject matter specialists. FFS participants tested growing amaranth under fruit trees compared to full sun, and using drip or traditional irrigation across four sites during October 2025 to April 2026. Data was collected through structured observation checklists, focus group discussions, and participatory matrix scoring and thematic analysis. The recorded activity time across 20 Farmer Field School sessions totalled 2,939 minutes, with each session lasting 90 to 270 minutes. Farmers spent 25 % of their time acquiring knowledge through hands-on practical activities (743 minutes), followed by 24 % in farmer-to-farmer discussions (700 minutes), facilitator questions (15 %), facilitator explanation (13 %), decision-making (12 %), and joint analysis (10 %). This shows that 49 % of knowledge acquisition time was practice-based and interactive. Farmers at each site collectively defined four criteria in a matrix scoring exercise, centred on water use efficiency, harvest quantity and quality, plant growth and vigour, time savings, input costs, and natural soil fertility from tree leaf litter. Under-tree drip irrigation ranked highest at three of the four sites: Mtwapa (55/160), Takaungu (66/160), and Malindi (75/160), driven by advantages in water conservation under shade, reduced labour time, better plant quality, and soil fertility. At Mavueni, open-field drip ranked highest (53/160) due to better harvest quality and drainage constraints under trees. Across all four sites, under-tree drip irrigation received the highest average score (59/160), while open-field traditional irrigation scored the lowest (25/160). In conclusion, farmers actively learned through structured observation and peer discussion, demonstrating that FFS can function as sites of knowledge co-creation. Strengthening FFS requires a clear feedback structure to capture farmer observations, translate them into experimental adjustments, and integrate farmer insights with scientific testing across continuous learning cycles.

Keywords: Agro-ecosystem analysis sheet, experiential learning

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What farmers already know: Outscaling indigenous innovations towards climate-resilient agro-ecosystems in South Punjab, Pakistan

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Smallholder farmers in South Punjab, Pakistan operate highly complex and adaptive production systems that extend well beyond subsistence. On plots as small as one hectare, these farmers simultaneously manage crops, livestock, agroforestry, and residue recycling. Such indigenous innovations form the foundation of resilient, multifunctional agro-ecosystems. Despite their important role in supporting livelihoods, indigenous farmer-led innovations remain poorly documented and are largely absent from formal policy and extension frameworks, which continue to favour top-down interventions. This study investigated the conditions, mechanisms, and pathways required to outscale socially and ecologically sustainable indigenous innovations among smallholder farmers in Punjab, with a focus on integrated crop-livestock production and agroforestry practices.

Data were collected through semi-structured interviews and focus group discussions with smallholder farmers, both practising and non-practising indigenous innovations. These were complemented by interviews with policymakers, agricultural departments, and public and private extension service providers. The research identified the policy support, input access, value chain linkages, and technical training required to facilitate broader adoption. Findings revealed that while indigenous integrated crop-livestock and agroforestry innovations demonstrate strong ecological and social sustainability, their outscaling is constrained by limited access to extension services, weak policy recognition, and inadequate value chain support. Farmer-to-farmer knowledge exchange emerged as a particularly effective and culturally accepted mechanism for horizontal scaling, while institutional and policy reforms were identified as critical enablers of vertical scaling. The study concludes that reorienting agricultural extension and policy frameworks towards bottom-up models that systematically recognise and build upon indigenous farmer knowledge is essential for achieving climate-resilient, multifunctional agro-ecosystems at scale in smallholder farming communities in Punjab.

Keywords: Local knowledge, multifunctional agro-ecosystems

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Strengthening participatory approaches for expanding and deepening learning about farmer preferences: Insights from farmer-managed seed systems in Malawi

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In sub Saharan Africa, top down outreach initiatives including extension demonstration gardens, on community land, working through community leaders, or with model farmers have not been effective approaches to increase adoption of improved varieties of neglected and underutilised crops in complex contexts where smallholder farmers' preferences are highly diverse. This study employed a Participatory Action Research (PAR) approach to map and identify farmer-preferred traits for Bambara nut and finger millet to understand how Malawian farmers' preferences and adoption to identify key varieties. The research was conducted over three rainfed agricultural seasons (2021-2023), engaged 150 farmers (57% female and 43% male) across five agro-ecological zones. Farmers evaluated 18 genotypes of the 2 crops at key growth stages (pre-planting, germination, vegetative and maturity). Panel data were collected using mixed methods that included individual interviews, focus group discussions, and observations of participants. We found that farmer varietal preferences exhibited spatial variability across geographic locations characterized by socio-economic and biophysical conditions. Moreover, these preferences were dynamic, shifting across seasons and crop growth stages, and inconsistently expressed between stated and actual choices of preferred Bambara groundnut and finger millet traits. These inconsistent patterns raise important questions about the effectiveness of farmer centered breeding programs that rely on participatory methods to engage farmers in decisions about which neglected and underutilised crop varieties should be integrated into farmer managed seed systems. There is a need to integrate PAR processes and principles into research and extension initiatives, despite the challenges the approach poses. The goals are to strengthen farmer managed seed systems and improve access to quality farmer preferred seed varieties of neglected and underutilised crop species in the diverse and complex contexts of sub Saharan Africa. The presentation will share the challenges of participatory variety selection with smallholder farmers, while also demonstrating how this approach informs the Water-Energy-Food (WEF) Nexus: farmer-preferred Bambara nut and finger millet varieties improve rainfed food production (water) without irrigation or synthetic fertilizers (energy), thereby strengthening farmer-managed seed systems (food).

Keywords: Adoption, Bambara groundnut, finger millet

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Scaling regenerative agriculture through peer-led extension: Causal evidence from the village-based advisor model in Kenya

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Sub-Saharan Africa's extension gap leaves smallholders without the localised support needed to adopt regenerative agriculture (RA) practices that build soil health, climate resilience, and multifunctional landscapes. We ask whether the Village-Based Advisor (VBA) model, a peer-led, locally embedded extension approach, causally raises RA adoption, and which practices it promotes most effectively. The data come from a 2024–2025 household survey of 1,932 farmers and 2,797 plots across four counties in eastern Kenya, covering the IKEA-funded Strengthening Regenerative Agriculture in Kenya (STRAK) project. We estimate intent-to-treat effects of residing in an intervention ward using probit models with county fixed effects, and correct endogenous self-selection into VBA participation through recursive bivariate probit. A multivariate probit captures interdependencies across seven RA categories: minimum tillage, mulching, soil fertility management, crop rotation, intercropping, agroforestry, and soil and water conservation (SWC). Propensity score matching and distance-based spillover tests provide robustness.

Living in a STRAK intervention ward raises plot-level adoption of six of seven practices. Effect sizes range from 6 percentage points for agroforestry to over 20 for crop rotation and intercropping. Effects are strongest for knowledge-intensive, low-capital practices and weakest for SWC structures, which require capital and collective action. Adoption among non-participants rises with proximity to VBA participants, so programme reach extends beyond direct beneficiaries. Recursive bivariate probit confirms a positive causal effect of direct VBA engagement once self-selection is corrected. Locally embedded peer extension can scale the knowledge-intensive components of multifunctional, climate-resilient agro-ecosystems but not capital-intensive ones. Pairing peer advisory with credit and collective-action support is the practical lever for scaling RA in smallholder systems.

Keywords: Egenerative agriculture, impact evaluation, Kenya, peer-led extension, smallholder farmers, technology adoption, village-based advisors

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Communication channels for accessing horticultural knowledge among smallholder farmers in Kilifi county, Kenya

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Timely access to horticultural knowledge remains challenging for smallholder farmers growing fruits and vegetables in Kilifi County. This results in low horticultural productivity and poor uptake of horticultural innovations despite ongoing agricultural interventions. This study investigated communication channels for promoting horticultural knowledge access among smallholder farmers participating in Farmer Fields Schools (FFS) in the frame of the AfriNutriForest project. The project promotes intensified, agro-ecological fruit-vegetable agroforestry systems using participatory, innovative methods. A descriptive cross-sectional mixed-methods design was employed. Quantitative data were collected through a survey of 100 farmers across four farmer groups in Kilifi County using a semi-structured questionnaire, while qualitative insights were obtained from four focus group discussions (FGDs). Data were analysed descriptively to examine preferences for communication channels and barriers to accessing certain channels. Farmer groups and elders/family members were named as first preferred communication channel by 26 and 23 % of the respondents, respectively, followed by radio programmes (20 %), neighbours/friends (10 %) and NGOs (9 %). Only few respondents preferred TV programmes (5 %), social media (5 %) or mobile apps (2 %), and no one government extension officers as first choice. The most preferred interpersonal communication channels were favoured due to their participatory, hands-on, and trust-based nature. Radio, as compared to other technical devices, was important due to its easy accessibility and use of local languages. Barriers to using these channels were mainly the limited availability of extension officers, low literacy levels, language problems and poor infrastructure (poor internet and electricity).Major constraints to digital channels use included lack of smartphones, preference for face-to-face learning, high data costs and lack of digital skills. FDGs revealed that barriers to intergenerational knowledge transfer were primarily the low interest of youth in farming and their limited availability. In conclusion, traditional channels like farmer groups, family/neighbours and radio are still important ways of horticultural knowledge dissemination and should be further strengthened. However, improving digital skills and addressing other barriers to the use of modern communication methods could improve effective horticultural knowledge access, foster the spread of innovative agro-ecological practices and build sustainable horticultural knowledge systems among smallholder farmers in Kilifi County and beyond.

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Behavioural determinants of farmers' willingness to end residue burning in Ghana: Evidence from a hybrid choice model

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Persistent reliance on traditional open-field burning of agricultural residues emits greenhouse gases (GHGs), resulting in adverse environmental, health, social, and economic impacts. Despite alternatives that exist to valorise and monetise crop residues, thereby boosting farmers' incomes, the willingness to adopt them remains inadequate. This indicates that mere availability is not enough to change behaviour.

Our study employed a hybrid choice model (HCM) to assess the psychometric factors influencing farmers' decision-making, using indicators of their willingness to adopt innovations. The research involved 200 tropical fruit farmers from six administrative regions of Ghana who participated in a choice experiment. Our findings show that farmers require substantial monetary compensation for participating in technology training (100.8 Ghana Cedis), village training (82.7 Ghana Cedis), and collective governance structures (65 Ghana Cedis). Additionally, the amount of monetary compensation needed to encourage farmers to stop residue burning in favour of sustainable practices decreases by 77 Ghana Cedis when they receive public recognition, indicating that social capital can substitute for financial incentives. Moreover, the disutility associated with government support, along with farmers' demand for a high-risk premium to accept such interventions, suggests that state-led governance overlooks farmers' opportunity costs and institutional distrust.

Ultimately, including psychometric factors such as innovation risk yields better predictive performance than standard choice models and provides a more realistic view of farmers' decision-making processes. By adopting an HCM, our study first contributes to the literature by advancing methodological insights into the analysis of discrete choice models with loss-framing effects in smallholder farmers' decision-making. Our study provides policy-relevant insights into incentive structures, reflecting behavioural insights, that inform the design of more effective environmental policies.

Keywords: Agricultural residue, Ghana, HCM, residue burning, WTA

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Analysing advisory and innovation support services for enhancing sustainable innovation processes in Ghana and Senegal

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In sub-Saharan Africa, agricultural transformation aimed at sustainable land management faces significant obstacles due to underdeveloped advisory and innovation support systems amidst challenges such as climate vulnerability, environmental degradation and persistent high rural poverty. There is a need to strengthen innovation support services (ISS) to promote sustainable intensification (SI) approaches to improve livelihoods and food security in smallholder farming communities. This study examines the role of pluralistic ISS on innovation processes in Northern Ghana (Tamale) and Northern Senegal (Podor) through the lens of service-based Agricultural Innovation Systems (AIS) frameworks. The study conceptualises innovation support as configurations of public, private, NGO, farmer-based, and informal providers offering seven types of ISS. The assessment of service performance is conducted on a three-dimensional basis where service effectiveness, service quality and providers' responsiveness are measured. The research design is based on qualitative case studies of eight innovation service situations. The data was gathered in the form of focus group discussions with 81 farmers, interviews with 16 providers and 4 key experts, and a systematic literature review. Findings revealed that there are dense multi-actor ISS networks with research institutions, extension agents, NGOs, FBOs, and private actors jointly delivering ISS; however, service coverage remains uneven, strongly project-driven, and extremely sensitive to donor funding cycles. The Ghanaian farmers consistently rated ISS effectiveness as remarkably high; similarly, the Senegalese farmers were generally positive but with slightly varying ratings. Service quality scored markedly in both areas. Analysis across innovation phases also reveals a characteristic "responsiveness tapering" as providers are most present and proactive during initiation, moderately responsive during implementation, and only residually engaged during diffusion, leaving beneficiaries to self-organise. This study recommends restructuring of ISS portfolios to be based on innovation levels and adoption of a services portfolio approach in policy formulation of AIS. Innovation Support Providers (ISPs) should explicitly integrate market access mechanisms, gender-sensitive strategies and sustainability considerations from the outset of support scheme designs. Collectively, these measures will strengthen the resilience and effectiveness of innovation support services in promotion of sustainable land management and food security in SSA.

Keywords: Agricultural advisory services, innovation support services and AKIS

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Operationalizing marine spatial planning in the Egyptian Red Sea: Implications for climate resilience and sustainable marine resource governance

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Marine Spatial Planning has been conducted for the first time in Egypt's Northern Red Sea as a pilot study Advancing Climate Adaptation and Biodiversity Protection through Integrated Marine Governance. Marine Spatial Planning (MSP) is increasingly recognised as a critical tool for addressing the interconnected challenges of climate change and marine resource degradation. This study presents the development of an MSP for the Northern Islands Protected Area (NISPA) in Egypt's Red Sea as a science-based and policy-relevant approach to support climate adaptation and biodiversity conservation. The initiative is aligned with Egypt Vision 2030, the National Biodiversity Strategy and Action Plan, and the Convention on Biological Diversity, while contributing to the national blue economy framework. The MSP functions as a decision-support tool to enhance climate resilience and protect marine ecosystems by applying ecosystem-based management principles. It aims to reduce spatial conflicts among competing uses, minimise cumulative environmental impacts, and safeguard ecologically sensitive habitats, particularly coral reef systems. In doing so, it strengthens the adaptive capacity of both ecosystems and coastal communities to climate-induced stressors such as sea-level rise, ocean warming, and habitat degradation. An iterative and participatory methodology was adopted, integrating multi-source environmental and socio-economic data derived from field surveys, satellite observations, and existing studies. Key parameters included shoreline dynamics, bathymetry, water quality, biodiversity indicators, and the spatial distribution of human activities (e.g., fisheries, tourism, and maritime transport). Stakeholder engagement was ensured through structured consultations and workshops. GIS-based spatial analyses resulted in the production of more than 70 thematic maps and 32 geospatial layers. The MSP generated key outputs, including a sectoral conflict matrix and a spatial zoning framework that prioritises biodiversity protection while enabling sustainable use. Scenario analysis produced two pathways: a conservation-oriented scenario and an integrated development scenario incorporating eco-tourism, aquaculture, and renewable energy. This work demonstrates how MSP can operationalize climate adaptation and resource governance, providing a replicable model for sustainable marine management in data-limited and climate-vulnerable regions.

Keywords: Biodiversity conservation, blue economy, climate change adaptation, coastal and marine governance, ecosystem-based management, marine spatial planning

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Socio-psychological determinants of smallholder farmers' intention to adopt climate-smart agricultural practices in south-western Uganda

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Increasing climate variability and associated hazards continue to undermine global progress towards the Sustainable Development Goals, particularly poverty reduction and zero hunger. With a large fraction of the population being smallholder farmers dependent on rain-fed agriculture, Sub-Saharan Africa's food production is highly sensitive to climate variability. Although climate-smart agriculture (CSA) has been widely promoted as a sustainable adaptation strategy, its adoption remains low. Several studies have documented the socio-economic determinants of adoption of CSA practices, but the influence of socio-psychological factors that shape farmers' adaptation decisions is less investigated. This study applies an integrated behavioural framework combining the Knowledge–Attitude–Practice model, the Protection Motivation Theory, and the Theory of Planned Behaviour to examine farmers' intentions to adopt CSA practices, in response to drought and flood hazards. Data were collected through a household survey of 583 smallholder farmers across three agro-ecological zones in south-western Uganda. Statistical analysis of the survey dataset shows that perceived behavioural control (PBC) and subjective norms (SN) are the strongest direct predictors of adoption intention for both drought and flood hazards. Knowledge of CSA practices has a significant indirect effect on adoption intention by strengthening farmers' perceived capacity (PBC) and, to a moderate extent, perceived social expectations (SN) to implement CSA practices. The direct influence of SN and PBC and their mediating role on adoption intention differs significantly across AEZs. Overall, the findings demonstrate that socio-psychological factors mainly PBC, SN and knowledge of CSA practices, play a critical role in shaping smallholder farmers' intentions to adopt adaptive strategies. Research interventions should therefore prioritise strengthening farmers' knowledge of CSA by demonstrating the effectiveness of the different practices in relation to hazard impact reduction. Policy interventions should widen opportunities for knowledge sharing about CSA practices, enhance farmers' capacity to implement CSA practices, and leverage social influence mechanisms to promote the adoption of climate-resilient agricultural practices.

Keywords: Agro-ecological zones, knowledge-attitude-practice

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Exploring agroecological transition pathways in a mountainous farming system in Morocco through fuzzy cognitive mapping

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Farming in North Africa faces interlinked sustainability challenges from water stress and land degradation to rural poverty and demographic changes. Transitioning to agroecological farming has been proposed to address those environmental and socio-economic challenges, yet transition pathways are difficult to achieve. They require coordinated action at multiple levels and an understanding of potential trade-offs and transition barriers. Scenario-based explorations can shed light on these issues supporting coordinated action. Fuzzy cognitive mapping (FCM) is a semi-quantitative scenario assessment tool that can facilitate communication regarding complex, not readily quantifiable issues for which there are no easy solutions. It studies changes in the functioning of socio-ecological systems based on people's knowledge using causal graph-structures.

The objective of this research was to explore potential agroecological transition pathways for a mountainous farming community in the Middle Atlas, Morocco, in face of climate change and outmigration. Considering three landscape zones with distinct access to land and water, an FCM-based scenario analysis was performed for each zone to identify landscape-specific transition levers and barriers. A business-as-usual scenario was contrasted with alternative scenarios examining changes in water and organic fertilisation management, and an upscaled cultivation of medicinal and aromatic plants (MAPs).

FCMs were built based on two causal graphs developed during a future thinking workshop in October 2025: one created with farmers and another with local food system actors. FCMs were complemented with observations and insights gained during field work activities between September 2023-April 2026. These included focus group discussions and interviews with farmers, community representatives and water managers, as well as a participatory GIS-based land-use and suitability analysis for the cultivation of MAPs with a local women cooperative.

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The study resulted in the formulation and participatory evaluation of multi-scale socio-technical innovation bundles that can contribute to an agroecological transition by combining agricultural practices, socio-economic and institutional innovations at farm, landscape and value chain level. Examples include an adapted surface irrigation at farm level facilitated by a coordinated water use across landscape zones; and the facilitation of on-farm organic fertilisation by a professional processing of organic biomass sources at landscape level into good quality organic fertilisers.

Keywords: Participatory evaluation, scenario-based exploration, socio-ecological systems, socio-technical innovation bundles

Community perception, willingness to pay, and governance of a local digital communication network for climate-resilient agriculture: Case of the Minodu project local network in three communities of the Kara region of Togo

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Limited access to timely and relevant agricultural information remains a major constraint to productivity and climate resilience in rural Sub-Saharan Africa. While digital advisory services have shown significant potential, their effectiveness is often hindered by infrastructural constraints, low literacy levels, and limited contextual adaptation. This study examines the case of the Minodu local communication network, an innovative low-tech and community-based information system designed to disseminate agricultural knowledge through audio and video formats in local languages in northern Togo.

The research aims to (i) analyse community perceptions of the Minodu network, (ii) estimate beneficiaries' willingness to pay (WTP) for its sustainability, and (iii) identify appropriate governance mechanisms to ensure long-term functionality. The study adopts an interdisciplinary framework combining development economics, information economics, and institutional analysis. A mixed-methods approach is employed, integrating quantitative household surveys (across three communities) and qualitative focus group discussions.

Community perception is analysed using an adapted Technology Acceptance Model (TAM), capturing perceived usefulness, ease of use, social influence, and institutional trust. Logit model is used to identify key determinants of adoption. WTP is estimated through a contingent valuation method using dichotomous choice formats, allowing for the calculation of mean WTP and identification of socioeconomic drivers.

Results suggest that locally adapted content formats and strong community engagement significantly enhance technology acceptance and usage. Moreover, social networks and trust in local governance structures are expected to play a critical role in both adoption and financial sustainability. The findings contribute to ongoing discussions on multifunctional agro-ecosystems by demonstrating how locally embedded digital innovations can strengthen knowledge systems, improve climate resilience, and support inclusive rural development. The study provides policy-relevant insights for scaling context-sensitive digital extension services in the Global South.

Keywords: Climate resilience, willingness to pay

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Farmers perceptions and barriers to adoption of solar-powered irrigation systems in Kenya

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Solar-powered irrigation systems offer a promising pathway to climate-resilient agriculture in Kenya's arid and semi-arid lands, where rain-fed farming is increasingly unreliable due to climate variability. Despite abundant solar resources and supportive policy frameworks, adoption rates among smallholder farmers remain persistently low. This study examines smallholder farmer perceptions on solar-powered irrigation, barriers to adoption, and establishes the current adoption gap within the Upper Ewaso Ng'iro Basin in Kenya, focusing on three Kenyan counties – Isiolo, Laikipia, and Meru. The basin is characterised by recurrent droughts, erratic rainfall, and increasing climate variability, which continue to undermine agricultural productivity and household food security among smallholder farmers. The study draws from a household survey data and qualitative insights from 180 smallholder farming households. The findings reveal overwhelmingly positive perceptions of solar irrigation technology, with 93.9 % of farmers agreeing that solar irrigation saves money and 96.1 % recognising sufficient sunlight for effective operation. However, a significant perception-adoption gap exists, as actual adoption stands at only 16.7 % overall, with the highest adoption in Isiolo (26.7 %) and lowest in Meru (6.7 %). Perceived affordability presents a major constraint, with 70.6 % of respondents agreeing that solar pumps are very expensive. Barrier analysis identifies four primary constraint categories: financial barriers including high upfront costs and limited credit access, followed by technical barriers related to inadequate knowledge and limited maintenance services, institutional barriers including weak extension support and land tenure insecurity, and awareness barriers stemming from limited exposure to demonstration. The barrier severity index shows financial barriers as most severe across all counties (0.74), followed by technical (0.47), institutional (0.42), and awareness barriers (0.41). County-level analysis reveals distinct profiles, with Isiolo farmers facing the most severe multi-dimensional barriers, Laikipia showing moderate barriers, and Meru exhibiting the lowest perceived barriers, though with the lowest SPIS adoption rate, suggesting possible unobserved constraints, or satisfaction with existing diesel-based systems. The study concludes that addressing the perception-adoption gap, equivalent to 77.2 % overall, requires integrated and county-specific interventions, including innovative financing models such as pay-as-you-grow and irrigation-as-a-service, strengthened technical support ecosystems, expanded demonstration and peer-learning opportunities, and integration of solar irrigation into agricultural extension services.

Keywords: Adoption barriers, farmer perceptions, Kenya, perception-adoption gap, solar-powered irrigation systems

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From knowledge to action: Quantifying the knowledge–action gap in smallholder extension systems in Malawi

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Agricultural extension systems (AES) are conventionally evaluated on the basis of knowledge dissemination, implicitly assuming that information leads to adoption. However, persistent discrepancies between awareness and sustained practice suggest a more fundamental problem: knowledge often fails to translate into action. This study advances a data-driven reconceptualisation of extension effectiveness by operationalising the Knowledge–Action Gap (KAG) as a measurable construct within smallholder farming systems in Malawi.

Building on the integration of the Knowledge–Action Gap framework with the Sustainable Livelihood Framework (SLF), the research conceptualises extension systems as knowledge translation systems, in which information is filtered through asset constraints, institutional arrangements, and socio-economic condition. A mixed-methods design is employed, beginning with a pilot study (n=20) in Ntchisi District using a digitally administered instrument (KoboToolbox). The tool generates two composite indices: a Knowledge Score (K-Score) and an Actionability Score (A-Score), enabling quantitative assessment of the transition from knowledge acquisition to sustained practice.

Study findings reveal a systematic divergence between knowledge and action. While farmers demonstrate relatively high knowledge levels (0.74), actionability remains lower (0.66), with feasibility emerging as the dominant constraint (0.39). This indicates the presence of a ' feasibility trap," where knowledge is available but not implementable under prevailing resource conditions. Further disaggregation shows that cooperative membership enhances perceived credibility and trust, yet does not eliminate structural barriers. Female-headed households exhibit significantly lower actionability despite comparable knowledge levels, reflecting gendered inequalities in access to productive assets.

These findings challenge linear models of extension and demonstrate that knowledge alone is insufficient to drive behavioural change. The study contributes methodologically by introducing a scalable diagnostic tool for evaluating knowledge systems and identifying translation bottlenecks. It argues for a shift from information delivery to data-informed, asset-sensitive extension design, with implications for improving resilience and inclusivity in line with Sustainable Development Goals (SDGs) 1, 2, and 13.

Keywords: Knowledge action gap, sustainable livelihood framework

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Farmers' self-reported impact of climate extremes on crop production and adaptation strategies in south-western Uganda

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Subsistence and smallholder farming systems constitute the primary rural livelihood in sub-Saharan Africa. These are highly exposed to climate-induced production risks, resulting in persistent food and income insecurity. Limited localised studies document the timing and impact of these risks at farm-level and farmers' adaptation strategies, hindering identification of appropriate interventions. This study employs a citizen science approach, a digitally-enabled, farmer-participatory approach, to assess the impact of climate extremes on crop production and farm-level adaptation strategies in south-western Uganda. Data were collected through a network of 25 farmer scientists in three agro-ecological zones (AEZs). These farmers were trained and equipped with smartphone-based questionnaires to record field-level cropping practices and abnormal weather events across the two growing seasons of March–May (Season A) and September–November (Season B), in 2024 and 2025. Detailed information for 197 fields, with 103 and 94 fields for seasons A and B, respectively, was recorded. Preliminary results show that climate impacts on crops were predominantly associated with rainfall deficits, mainly delayed onset and in-season droughts, and excessive rainfall. Rainfall deficits affected seasonal activities of more fields in Season A (53,%), with contrasts across AEZs, while excessive rainfall affected more fields in Season B (52,%), homogeneously across AEZs. Rainfall deficits primarily reduced crop germination, affecting an average of 39,% of the planted area, while excessive rainfall caused an average crop loss of 30,% of affected fields, mainly due to erosion. Farmers adopted a range of adaptation strategies. Overall, 63,% of fields were planted with improved crop varieties, mostly in Season A (52,%), with contrasts across AEZs. Other practices included organic manure (30,%), trenches (12,%), and terraces (10,%). Replanting was a short-term adaptation strategy (17,%), adopted when facing unfavourable climate conditions at the start of the growing season. These findings provide insights into spatio-temporal heterogeneity in climate risks and adaptation strategies, underscoring the value of citizen science for generating time-specific, localised data to inform climate-resilient interventions. Reported climate extremes will be triangulated with seasonal weather data to guide recommendations.

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Trader–farmer business relationships and their implications for varietal turnover, productivity, and grain commercialisation in Tanzania

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Scaling farm technologies and innovations have been viewed as a mechanism for revolutionizing agrifood systems, not only for food and nutrition but also for improving the productivity and incomes of farmers. Many technologies and innovations have been produced through research and disseminated through different extension and scaling approaches over the years. Unfortunately, uptake rates for the technologies remain low and, indeed, some do not even get to the farmers' fields. This is worsened by the fact that the role of traders, processors and aggregators in seed systems, crop productivity and commercialisation is often overlooked. Thus, we combine farm and trader level cross-sectional data from 960 and 976 farmers and traders, respectively, from sorghum, common beans and groundnuts corridors in Tanzania to assess the role of trader-farmer relationship. Controlling for both observed and unobserved heterogeneity, our study finds that a strong, open and trustworthy relationship between traders and farmers translates into higher varietal turnover and yields, a higher degree of commercialisation and incomes among smallholders. We also find that the size of trader business, connection with research institute, and willingness to promote improved varieties play an important role in influencing the traders' decision to support provision of services to farmers beyond purchasing grains from them. Our results suggest that improving the functioning of agricultural markets is critical in attracting farmers to engage in selling grains to traders. There is a need to invest in multi-stakeholder platforms (MSPs) led by large traders or processors as a vehicle for promoting uptake of improved varieties, productivity and enhanced commercialisation. Finally, gaining a deeper understanding of traders and their interactions with farmers is crucial for shaping policies that promote varietal turnover, boost productivity and commercialisation.

Keywords: Commercialisation, contract, governance norms, seed systems, smallholders, sub-Sahara Africa, trust, varietal turnover

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Bridging competency gaps for sustainability managers in food systems

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The transformation of food systems towards sustainability requires professionals equipped with diverse and context-specific competencies. However, limited integrative evidence exists on how these competencies are defined, developed, and applied across different contexts. This study contributes to advancing a competency framework for sustainability managers and changemakers in the food sector by synthesizing insights from multiple empirical sub-studies spanning labour markets, higher education, and stakeholder engagement.

The research integrates (1) content analyses of sustainability-related job advertisements and in Iran and Ghana (2) qualitative interviews with alumni of the International Food Business and Consumer Studies (IFBC) programme at the University of Kassel, (3) survey-based insights from current IFBC students, and (4) outcomes from a stakeholder workshop (WiTA) on competencies for sustainable food systems held in Giessen, Germany. These complementary data sources capture competency demands, educational outcomes, and practice-oriented perspectives across different stages of professional development.

Findings reveal convergence around key competency domains, including systems thinking, strategic management, implementation skills, and interpersonal competencies. At the same time, significant misalignments emerge. Labor market analyses indicate an underrepresentation of anticipatory, normative, and integrative competencies, despite their importance for addressing complex sustainable food system challenges. In contrast, higher education programmes effectively foster values-based and interpersonal competencies but show limitations in developing technical and implementation-oriented skills, such as life cycle assessment, carbon accounting, and regulatory compliance. Insights from alumni, students, and stakeholders further highlight difficulties in translating theoretical knowledge into practice, pointing to an "operational bottleneck" in competency application.

By integrating perspectives from employers, graduates, students, and practitioners across different geographical contexts, this study identifies critical gaps between competency demand, development, and application within food systems. The proposed framework provides empirically grounded insights for aligning curricula, industry expectations, and capacity-building initiatives to strengthen sustainability leadership and support transformative change in the food sector.

Keywords: Food systems transformation, higher education, labour market analysis, stakeholder engagement, sustainability competencies

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Strengthening participatory veterinary epidemiology and one health education networks for sustainable livestock based socio ecological systems

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Livestock systems play a critical role in rural livelihoods, food sovereignty, and socio ecological resilience, particularly in low and middle income countries. However, infectious animal diseases, environmental degradation, and limited access to veterinary and One Health expertise undermine sustainable natural resource management and disproportionately affect smallholder and marginalised farming communities. Addressing these interconnected challenges requires participatory, transdisciplinary approaches that integrate animal health, agroecology, and social systems.

The Asia Pacific Consortium of Veterinary Epidemiologists (APCOVE) offers a collaborative Global South–North education and research model that strengthens veterinary epidemiology and One Health capacity to support sustainable livestock systems and improved quality of life. Funded by the Australian Department of Foreign Affairs and Trade, APCOVE brings together animal health professionals from Australia, New Zealand, and eight Indo Pacific partner countries. The initiative focuses on building locally embedded capability to prevent, detect, and respond to animal disease threats that impact livestock productivity, wildlife conservation, public health, and rural livelihoods.

Between 2024 and 2028, APCOVE is implementing four integrated activities: (1) applied frontline field epidemiology training centred on participatory outbreak investigations and surveillance in livestock and wildlife systems; (2) intermediate training combining multilingual, open access eLearning with mentored field projects addressing locally defined priorities; (3) applied One Health training emphasising systems thinking, intersectoral collaboration, community engagement, and leadership; and (4) faculty development for epidemiology educators to strengthen long term regional teaching capacity. Training design is co produced with country partners using participatory methods, ensuring relevance to national agro ecological, socio economic, and cultural contexts.

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To date, APCOVE has produced 36 freely available training modules in six languages, supported over 200 trainees, and facilitated community and institution led field projects addressing livestock disease, wildlife health, and biosecurity. Early outcomes indicate strengthened local capacity, enhanced collaboration across agriculture, environment, and health sectors, and improved preparedness for disease events that threaten livelihoods and natural resources. APCOVE demonstrates how participatory education networks can support agroecological livestock systems, advance One Health operationalisation, and contribute to poverty alleviation and sustainable rural development.

Keywords: One Health, participatory capacity building, socio ecological resilience, sustainable livestock systems, veterinary epidemiology

Agricultural living labs: Bridging theory and practice through transformative learning

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This conceptual study addresses methodological and conceptual gaps in Agricultural Living Labs (ALLs) by integrating Mezirow's Transformative Learning (TL) theory into their design, aiming to enhance agricultural education and knowledge co-creation while enabling stakeholder-driven resilience amid climate volatility. Following a qualitative, conceptual, and meta-analytical design, the study was developed through a four-step, inductive–deductive process that constructed the proposed TRANSFORM-ALL framework. This approach integrates literature mapping and conceptual synthesis in the initial steps, followed by interpretative analysis and validation to align TL theory principles with the methodological architectures of ALLs. The resulting framework organises ALLs into six phases corresponding directly with Mezirow's TL steps: Initiation (disorienting dilemmas), Insight Research (critical reflection), Prototyping (collaborative experimentation), Field Testing (adaptive application), Feedback Loop (iterative discourse), and Scaling/Dissemination (systemic change). These phases bridge instrumental rationality with holistic innovation, fostering critical reflection and context-adaptive solutions. Practically, the study offers an actionable tool for designing ALLs that systematically foster transformative learning by prioritising dialogue, collective norm-creation, and stakeholder-aligned solutions. This flexible yet rigorous model empowers practitioners to strengthen agricultural resilience through learning and iterative adaptation. Theoretically, the research enhances pedagogical coherence in agricultural education by linking TL theory with participatory methodologies in ALLs. It clarifies how ALLs internalise TL principles, providing greater epistemological rigor to experiential approaches and addressing conceptual heterogeneity in the field. By complementing existing social and experiential learning perspectives with a systematic TL framework, the study advances current understandings of learning in ALLs. The originality and value of TRANSFORM-ALL lie in its unique integration of TL theory into Living Labs, positioning ALLs as tools for harmonising ecological stewardship with collective learning. Its structured yet adaptable architecture enhances agricultural systems' capacity to respond to climate challenges through stakeholder-driven innovation, contributing a novel model for sustainable transitions.

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Citizen science and digital tools for seed system development and agrobiodiversity monitoring

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Agricultural data for key indicators – varietal adoption, production, seed system dynamics, and agrobiodiversity – in smallholder farming systems is scarce, costly to collect, and infrequently updated, limiting effective decision-making on varietal deployment and seed support, and ultimately undermining food security and biodiversity conservation.

Digital tools and citizen science platforms such as VarScout can address these gaps. VarScout is an open-access, mobile and cloud-based platform enabling farmers, extension agents, and researchers to collect GPS-referenced data on crop variety use, seed quality, yield, and farm characteristics directly in the field.

We report on two use cases for VarScout: seed systems development in Kenya and agrobiodiversity monitoring in Peru.

In Kenya, VarScout was deployed in Nakuru County across two consecutive seasons (2024–2025), generating 47,000 data points for maize, potatoes, and beans from 12,000 unique households, collected by 45 trained county extension agents. Focusing on potatoes, results reveal a persistent structural dependence on the Shangi variety (>70 % adoption), a declining uptake of clean seed from 62.6 % to 48.8 %, and a statistically significant yield decline from 13.8 t/ha to 10.2 t/ha – despite clean seed users consistently outperforming non-users by up to 55 %. Rising mean varietal age (9.4 to 10.3 years) signals slow genetic turnover and limited diffusion of improved varieties.

In Peru, VarScout was part of the national citizen science contest "Guardians of Native Potatoes," held annually on International Potato Day. Across 2024 and 2025, 754 participants from 21 regions – many of them trained school children organised through science clubs – used VarScout to document native potato diversity. In 2025 alone, 1,589 unique varieties across Andean communities were recorded, with La Libertad, Puno, and Huánuco leading in variety counts.

Collectively, these use cases demonstrate how low-cost digital tools deployed through public extension and citizen science networks can close critical knowledge gaps, advancing data-driven decision-making for climate-resilient smallholder agriculture.

Keywords: Agrobiodiversity, digital tool, Kenya, Peru, seed systems

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The hidden layer of land-use change: Cognitive processes shaping agro-ecosystems in the Amazon

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Forest loss and land-use change in the Amazon are commonly explained by structural drivers such as agricultural expansion, cattle ranching, and infrastructure projects. However, less attention has been paid to the inner, personal sphere underlying land-use decisions among rural populations. This study addresses this gap by examining how human values shape land-use attitudes in the transboundary MAP region, spanning Peru, Brazil, and Bolivia – a setting characterised by shared ecological conditions but differing livelihood strategies. Drawing on social and environmental psychology and the cognitive hierarchy model, the study investigates how human values influence attitudes toward different land-use types. A mixed-methods approach combines baseline household data from 2022 with primary data collected during three months of fieldwork in 2024, including a value–attitude survey (n = 171) and key informant interviews (n = 9). Quantitative analyses are based on ordered logit and binomial regression models, complemented by qualitative insights. Results show that Self-Transcendence and Conservatism are the most prominent value orientations shaping land-use attitudes across the MAP region. While Self-Transcendence is positively associated with pro-forest attitudes, Conservatism unexpectedly constrains such attitudes, despite its intuitive association with conservation and protection. Cross-country comparisons further indicate that value orientations are more homogeneous across Peru, Brazil, and Bolivia than differences in dominant land-use practices would suggest. This suggests that while human values significantly shape attitudes, they do not directly translate into divergent land-use behaviour. These findings have two key implications. First, they highlight that cognitions within the personal sphere do not fully determine behaviour, requiring integrated approaches that combine individual, socio-economic, and institutional perspectives. Second, broadly shared value foundations across borders offer a potential basis for transboundary cooperation. Aligning sustainable land-use strategies with Self-Transcendence while addressing the constraining role of Conservatism may support the adoption of approaches such as agroforestry and silvopastoral systems, contributing to more multi-functional and resilient agro-ecosystems.

Keywords: Attitudes, cognitive processes, environmental psychology, inner world, MAP region, perceptions, personal sphere, rural livelihoods, social psychology, values

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Designing transitions: A systemic mapping of current practices of agricultural systems design

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Agricultural systems face unprecedented challenges in the Anthropocene, marked by increasing uncertainty, extreme climate events, and complex socio-ecological crises. Historically, farmers have adapted their practices to predictable conditions, but today's unknown unknowns demand innovative approaches to design resilient agricultural systems. Building on the notion of the "design turn", agricultural system design need to be reframed as a second-order process – one that focuses not merely on end products but on purposeful performances, learning systems, and adaptive practices capable of responding to unfolding uncertainties, prioritizing biosphere integrity and social purpose. This study aims to identify common characteristics of agricultural systems design to outline a general transition approach. Methodologically, the study employs a systemic review of key papers in agricultural systems design, analyzed through Strategic Options Development and Analysis (SODA) cognitive mapping. Cognitive maps were developed for each paper and subsequently aggregated into a single, comprehensive causal map, allowing a quantitative and qualitative assessment of the complexity and interconnectedness of current design thinking in agricultural systems. As result, the aggregated causal map shows a high degree of interconnectedness, pointing to the systemic nature of agricultural design. The adoption of the SODA method identified critical features with high systemic influence on agricultural systems design, such as co-design methods, modeling approaches, and farmer participation, which can be considered critical leverage points for transformation. Results demonstrate, therefore, that innovative transitions in agricultural systems design cannot rely on isolated practices; they require systemically integrated approaches. Furthermore, required are designs for transitions based on a design imagination that avoids the traps of systematic and dualistic thinking still pervasive in current design practices. This entails creating conditions to re-engage with the complexity of the living world through new and viable trajectories. It requires recognizing the interconnectedness of humans and the biosphere, and reframing agricultural systems as human-activity systems through which human-biosphere relations are enacted and transformed.

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From intentions to action: Explaining sustainable practice adoption among smallholder oil palm farmers in Indonesia

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The expansion of small-scale oil-palm plantations has been one of the most significant drivers of deforestation in Indonesia over the last decades. About 40 % of oil-palm plantations in Indonesia are managed by smallholder farmers, making them key players in the transition to sustainable oil palm. Understanding the behavioural mechanisms behind smallholder farmers' adoption of sustainable practices is therefore critical for policy effectiveness.

Building on a framework that combines the Theory of Planned Behaviour with the Technology Acceptance Model, this study investigates which behavioural mechanisms predict stated intention to adopt sustainable practices and the actual adoption of organic fertilisation, native tree planting and intercropping in oil palm cultivation. The analysis is based on survey data from 1,600 smallholder farmers across the four Indonesian regencies in Jambi with the largest concentration of smallholder oil palm plantations. Using structural equation modelling, I estimate how attitudes, social norms, perceived behavioural control and technology perceptions shape both adoption intentions and behaviour.

Preliminary results show that attitudes are primarily shaped by perceived usefulness of sustainable practices rather than environmental awareness. Similarly, behavioural control is positively associated with the perceived ease of use of sustainable practices. In addition, external pressures (e.g., buyers and government), rather than internal pressures (e.g., family and peers), dominate perceived environmental norms. Finally, while attitudes are a consistent and relevant driver across all outcomes, behavioural control strongly influences organic adoption and social norms are particularly relevant for tree planting.

These findings highlight the value of integrating behavioural and technology adoption theories to better understand decision-making in agricultural contexts and to inform more effective policies promoting sustainable oil palm management.

Keywords: Adoption behaviour, oil palm, sustainable agriculture

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Integration of indigenous and scientific knowledge for climate resilience and food security in Africa's urban agriculture: Learning from local communities for a sustainable future

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Climate shocks such as prolonged droughts and heat continue to threaten agriculture and biodiversity that also translates to significant health risks and perpetuates insecurities and inequalities. The impacts of climate change are more severe in poor and marginalised populations with limited resources to respond to climate shocks. Hence urban agriculture in Africa is increasingly becoming recognised for its contributions to fighting climate change. While this might be the case, the use of indigenous knowledge practices and crop species in urban agriculture has remained underutilised and neglected both in policy and practice. Most of indigenous knowledge in farming practices is less documented and limited to specific locations such as rural and indigenous communities. Interventions to integrate urban agriculture in Africa's urban development have been focused more on conventional agriculture that relies on scientific knowledge application and large-scale mechanisation to increase efficiency and yields in food production. Such approaches have significantly ignored the use of indigenous knowledge which contribute to climate adaptation, resilience, food security, and environmental conservation. Moreover, less is still known about what scientific knowledge can do to learn from, complement and be integrated with indigenous knowledges to enhance climate resilience and improve food security among marginalised urban communities. Most scientific knowledge applications to Africa's agriculture have been criticised for undermining local and indigenous knowledge and attempting to replace it. The aim of the study was to explore what modern scientific knowledge approaches can do to complement indigenous knowledge practices for climate adaptation, resilience and food security in home and community gardens. Using a mixed-method approach of interviews, surveys and remote sensing tools, evidence from a sample of 100 small scale farmers including gardeners in marginalised communities of Johannesburg, South Africa, was collected and analyzed. The findings of this study show that scientific knowledge complements indigenous knowledge systems by providing scientifically structured methods to visualise and test indigenous-informed hypotheses, enhancing climate forecasting and predictive modelling and maintaining local contexts and knowledge sources. While there are fundamental benefits of harmonising scientific with indigenous knowledge, scientific knowledge must be pursued with caution to ensure equity, data sovereignty, and the co-creation of knowledge.

Keywords: Adaptation, indigenous knowledge, urban agriculture

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Implementation of climate smart agricultural practices: An assessment of Uganda's lower secondary agriculture competence-based curriculum

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Climate change poses a significant threat to agricultural productivity, food security, and rural livelihoods in Uganda, where agriculture remains predominantly rain-fed and highly vulnerable to climate variability. In response, the Government of Uganda introduced a lower secondary school competence-based curriculum (CBC) to equip young learners with practical skills relevant to climate smart agriculture (CSA); however, empirical evidence on how effectively CSA principles are integrated and implemented to guide educators and learners remains limited. This study assessed the implementation of CSA practices within Uganda's lower secondary agriculture CBC, focusing on curriculum integration, teacher capacity, implementation constraints, and improvement strategies, using selected schools in south-western Uganda. Guided by curriculum implementation and pedagogical content knowledge theories, the study adopted a mixed-methods research design. Data were collected from 494 respondents, including agriculture teachers, head teachers, students, district education officers, and national level curriculum and policy officials drawn from 40 government-aided secondary schools, using structured questionnaires, semi-structured interviews, focus group discussions, lesson observations, and document analysis. Quantitative data were analyzed using descriptive and inferential statistics, while qualitative data were analysed thematically. Findings reveal that CSA concepts are moderately integrated into the curriculum, with stronger emphasis on productivity oriented practices and limited coverage of climate change adaptation and mitigation. Teacher capacity to implement CSA was uneven, characterized by adequate subject content knowledge but limited pedagogical skills for experiential learning, climate-responsive instruction, and competency-based assessment. Major constraints included inadequate instructional resources, limited practical facilities, insufficient in-service training, heavy teaching workloads, and weak institutional support. Nonetheless, the CBC has contributed to increased awareness among teachers and students of climate change risks and the relevance of CSA, motivating some educators and learners to address identified gaps through peer collaboration, workshops, self-directed learning, and engagement with online and external knowledge resources. Overall, while the CBC provides an enabling policy framework for CSA education, its effective implementation is limited by curriculum and teacher preparedness gaps, highlighting the need for targeted curriculum refinement, sustained professional development, improved practical learning resources, and stronger institutional support to prepare the next generation to understand climate change realities and respond through climate resilient agricultural practices.

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Reframing sustainability in locked-in social-ecological systems: Transdisciplinary T-Labs and pathway co-creation in smallholder oil palm

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Sustainability transformation in complex socio-ecological systems requires changes in how actors construct problem frames and deliberate shared values. However, little is still known about how transdisciplinary Transformation Labs (T-Labs) generate collective reframing, defined as a shared cognitive shift in problem perception and legitimate solutions, in structurally locked systems dominated by a single commodity. This study examines how collective reframing emerges through rural T-Labs and how this process enables the development of alternative sustainability pathways under structurally locked conditions. Using a transdisciplinary research approach grounded in co-creation and co-learning, we collaborated with 51 local actors, including smallholder farmers, women's groups, youth, and local leaders in Pematang Kabau Village, Jambi Province, Indonesia. Adopting a qualitative method that encompassed workshops, interviews, walkshops, and research journal notes, we collected data from March 2022 to October 2023. To map the established system, we use the Socio- ecological framework. Additionally, we use framing-reframing analysis to examine the shift in local actors' perspectives on sustainability. Eventually, as a post-lens analysis, we use the three-horizon method to design future transition pathways. Our results reveal that the participatory T-Lab process shifts the focus from single-loop learning, which focuses on adjusting practices within the existing palm oil-dominated system, to double-loop learning, which questions fundamental assumptions regarding daily cash- flow dependency, land-use choices, and normalized environmental degradation. The new framing emerging from the T-Labs process emphasizes autonomy, agricultural diversification (such as intercropping oil palm with home-garden crops), and local circular economies (such as organic compost), shifting away from the local actors' initial reliance on chemical fertilizers and fresh fruit bunch yields. To sustain these pathways, local actors formalized collective governance through village regulations and restrictions on elite dominance (multiple-position bans). This study shows how the transdisciplinary T-Lab process can serve as a socio-cognitive and institutional mechanism that links double-loop learning and collective reframing to the emergence and consolidation of alternative sustainability pathways. Breaking structural lock-in is not a top-down technocratic task, but an intentional process of nurturing local deliberative capacity and bottom-up institutional agency.

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Do financial subsidies improve farmers' innovativeness in northern Benin?

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Financial subsidies in the agricultural sector are usually intended to support farmers in increasing their yields and, therefore, their income. However, they often fail to improve farmers' production because they are often used to address producers' short-term needs. This study examines the effects of financial subsidies on farmers' innovativeness, conceptualised through their propensity to innovate, capacity to innovate, and innovation practices. Thus, a field survey with a Likert-scale questionnaire was administered to 146 farmers, and two focus group discussions were conducted. Data were analysed using descriptive statistics and multiple linear regressions. The results indicate significantly higher levels of innovativeness among subsidy beneficiaries than among non-beneficiaries. Subsidy beneficiaries' propensity to innovate (5.83 vs. 4.67), capacity to innovate (5.27 vs. 3.71), and practice of innovation (5.66 vs. 4.24) are significantly higher than those of non-beneficiaries. Indeed, financial subsidies enabled 28.63 % of beneficiaries to reduce financial constraints and eliminate the stress associated with seeking funding for their agricultural activities; it enables 37.33 % of beneficiaries to gain access to more efficient production resources and higher-quality inputs, as well as training in fund management and new technical production; and 25.48 % of beneficiaries effectively adopt new techniques and use acquired equipment. These innovativeness components are determined by education level, validated and received subsidy amounts, farmers' own financial contributions, and monitoring mechanisms, which affect each component. These findings suggest that financial subsidies can be an effective lever for enhancing agricultural innovativeness, provided that implementation mechanisms are better structured to match farmers' needs and promote co-investment, thereby strengthening engagement and sustaining innovation results.

Keywords: Capacity to innovate, farmer's innovativeness, innovate practice, propensity to innovate

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Reframing climate finance through community perception: Evidence from Muzarabani's semi-arid landscape in Zimbabwe

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Although international climate finance remains a fundamental pillar of global adaptation strategies, its success is frequently gauged using top-down macroeconomic metrics that ignore the granular realities of grassroots beneficiaries. This research challenges traditional paradigms by reconceptualising climate finance as a socially mediated resource, investigating how community-level interpretations influence developmental efficacy within the Muzarabani District of Zimbabwe. This semi-arid region, situated in the Dande Valley, serves as a critical case study due to its extreme vulnerability to cyclical climatic shocks.

Employing a sequential exploratory methodology, the study synthesizes ethnographic narratives, perception indexing, and systems-based modelling to move beyond reductive econometric analyses. Instead, it prioritises the roles of human cognition, lived experience, and institutional integrity in the climate discourse. Empirical evidence indicates that while financial interventions bolster localised infrastructural resilience – notably in hydraulic systems, artisanal irrigation schemes, and climate-hardened transport networks – their impact is contingent upon high levels of perceived accessibility and transparency.

The analysis delineates three pivotal transmission mechanisms: perception-anchored trust, communal agency, and the co-production of ecological knowledge. Findings suggest that when these socio-cognitive pathways are obstructed, even substantial financial inflows fail to yield sustainable adaptive outcomes. The study also demostrated that the community perception ca contribute neningfully to priorities tabled to climate finance to ensure community base decion making in climate change financing issues. By proposing a Perception-Centered Climate Finance Framework,this work argues that the utility of development capital is governed less by its sheer volume and more by its social legitimacy and alignment with indigenous priorities. Ultimately, these results provide a blueprint for crafting more equitable and context-sensitive financing mechanisms across the Global South.

Keywords: Adaptive capacity, climate finance, community perception, Muzarabani, semi-arid development, social legitimacy, Zimbabwe

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A natural experiment on small-scale farmers' adoption of 'New Theory Farming' in Ayutthaya, Thailand

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Thailand's agriculture, characterised by a mix of corporate and small-scale farmers, provides food and fibre to the economy. However, it faces climatic changes, resource depletion, and biodiversity loss in the ongoing epoch, the Anthropocene. This calls for farmers' stewardship in terms of their land management practices for sustainable livelihoods. In this context, Thailand follows 'New Theory Farming' (NTF) practices, requiring farmers to arrange their agricultural land in a ratio of 30:30:30:10 for pond, rice, orchard, and dwelling. Although the literature lauds their theoretical application to sustainable livelihoods, the practical implications of NTF practices still lack grassroots-level evidence. To this end, we utilise a natural experimental design to examine the adoption of NTF practices among 210 proportionally selected small-scale farmers from six districts in Ayutthaya, Thailand. Using the lens of Diffusion of Innovation Theory and the framework of Vijitwrannont et al. (2023) for NTF practices, we first develop an adoption index and then conceptualise socioeconomic, demographic, crop-specific, and institutional factors impacting the adoption of NTF practices and analyse them using a binary logit model. The adoption index suggests moderate-level (≈50 %) compliance with overall NTF practices and with each category, i.e., pond, rice, orchard, and dwelling areas. Adopters differ significantly from non-adopters on crop yield, crop income, and their access to information. The significant factors increasing the likelihood of adoption are farmers' access to information, higher yield (rai*), crop income (tonne), and age (higher). In contrast, the factors limiting adoption are farmers' access to information through government officials, marketers, and/or friends; gender (women); and personal business as a primary source of income. Our contribution comes in two ways: we provide ground-level evidence on small-scale farmers' adoption of NTF practices and develop an adoption index. The findings are useful for farmers, community leaders, officials, and policymakers in advancing Sustainable Development Goals (SDGs) to ensure sustainable livelihoods for Thai farmers.

* *Rai is a local land measurement unit, where 1 hectare equals 6.25 rai.*

Keywords: Ayutthaya, natural experiment, new theory farming, sufficiency economy philosophy, sustainable livelihoods, Thailand

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Integrating knowledge and practice: Enhancing soil health and agrobiodiversity for sustainable ecosystems and livelihood resilience

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Achieving multifunctional agro-ecosystems that support climate resilience requires integrated approaches that simultaneously address soil degradation, biodiversity loss, and livelihood vulnerabilities. This study presents a participatory, landscape-based agroecological model implemented in the Mt. Elgon region of eastern Uganda, a high-risk ecosystem characterised by severe soil erosion, declining soil fertility, and increasing climate variability. The research integrates local and scientific knowledge through co-creation processes involving farmers, researchers, extension actors, and local institutions to design and implement context-specific interventions. Soil and water conservation structures - including trenches, stone bunds, and vegetative barriers were collectively established and monitored, resulting in reduced soil loss and improved watershed stability. We assessed different agrobiodiversity components using the Platform for Agrobiodiversity Research tool to document species diversity, functional roles, traditional knowledge and socio-economic drivers influencing biodiversity maintenance across multiple watersheds. The study revealed high species richness and functional diversity, underpinning key ecosystem services such as soil stabilisation, pollination, pest regulation, and climate adaptation. However, there were significant differences in the diversity of insects (Hymenoptera) that are critical to pollination, biological control, and soil turnover. The study further demonstrates the critical role of indigenous and gendered knowledge systems, particularly women's expertise in plant diversity and ecosystem management, in strengthening inclusive and resilient agroecosystems. Positioned at the intersection of soil, water, and biodiversity management; climate change adaptation; and knowledge systems innovation, this study illustrates how participatory, data-informed approaches can drive agroecological transformation. The findings provide a scalable framework for developing resilient crop-livestock-agroforestry systems that enhance ecosystem functionality, improve food and nutrition security, and strengthen rural livelihoods. This work contributes to ongoing efforts to design climate-resilient, multi-functional agroecosystems in Uganda and beyond.

Keywords: Agroecology, climate resilience, landscape management, participatory approaches

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Farmers' self-efficacy and continued use of social media: An application of the expectation confirmation model

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Agriculture serves as a cornerstone of economic and social development in many developing countries, yet it faces growing challenges driven by climate variability, labour shortages, and limited access to information. The emergence of social media as an interactive digital communication tool presents new opportunities to enhance farmers' learning, knowledge sharing, and self-efficacy. They have a crucial role in enabling smooth
communication, enhancing global connectivity, distributing knowledge, and supporting content sharing
across digital platforms Through bidirectional communication and community engagement, social media platforms can foster a sense of collective identity and empowerment, which in turn strengthens farmers' job performance and supports the sustainability of agricultural practices.
Despite its widespread popularity, the use of social media for agricultural purposes remains limited, and farmers' willingness to continue using these platforms has not been adequately explained. To address this gap, the present study extends the Expectation Confirmation Model (ECM) by incorporating two additional variables – self-efficacy and job performance – to investigate the factors influencing farmers' continuance intention to use social media in Khuzestan Province, Iran. Data were collected through a researcher-designed questionnaire and analysed using Partial Least Squares Structural Equation Modelling (PLS-SEM) with SmartPLS v3. The results confirmed that self-efficacy has a significant positive effect on both farmers' satisfaction and their intention to continue using social media. Moreover, self-efficacy was found to positively influence job performance, underscoring its critical role in digital engagement and behavioural continuity. These findings contribute to the theoretical refinement of ECM in the agricultural context and provide actionable insights for policymakers and extension organisations aiming to promote sustainable digital adoption among farmers

Keywords: Expectation - Confirmation Model (ECM), job performance, self-efficacy, Social Media (SM)

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Landsat NDVI and Sentinel-2 for vegetation dynamics and maize field mapping in Kikuyu, Kenya

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Vegetation indices such as the Normalized Difference Vegetation Index (NDVI), Green Normalized Difference Vegetation Index (GNDVI), Normalized Difference Red Edge (NDRE), and Chlorophyll Vegetation Index (CMI) are widely used in agricultural monitoring, land use assessment, and environmental studies. However, despite the global availability of Landsat and Sentinel-2 imagery, their application in many sub-Saharan African contexts, including Kenya, remains limited, particularly in smallholder-farmer systems. This study integrates Landsat-derived NDVI, GNDVI, NDRE, and CMI with Sentinel-2 optical data to analyse vegetation dynamics and map maize field distribution in Kikuyu sub-County of Kiambu County, Kenya. The 27-year NDVI time-series captured interannual vegetation dynamics, reflecting rainfall variability, drought periods, and land-use change across the sub-County. Several years such as 2001, 2004, 2012, 2016, 2019, 2021 show low NDVI values consistent with regional drought conditions in central Kenya. The peaks observed in 2007, 2013, 2020, and 2025 align with periods of favourable rainfall. Spatially, the NDVI composites showed persistent high-vegetation zones in forested and densely vegetated areas, while agriculture landscapes displayed more variability due to seasonal cropping cycles and land-use dynamics.

A multi-method approach combining threshold based classification, unsupervised K-Means clustering, and a supervised U Net deep learning model was applied for the 2025 growing season. Model performance improved progressively across the three approaches: K-Means shows low accuracy (IoU=0.013, F1-score =0.025, precision=0.013, recall=0.451), U-Net Option A using proxy labels achieved moderate gains (IoU=0.397, F1-score =0.568, precision=0.607, and recall=0.533), and U-Net Option B trained with field-surveyed maize polygons delivered better and most balanced results (IoU=0.403, F1-score =0.574, precision=0.540, and recall=0.613). The integrated outputs enabled delineation of maize field extents and provided insight into long-term vegetation trends. Overall, this study demonstrates the effectiveness of multi-sensor satellite imagery for crop monitoring, land-use mapping, and environmental assessment, offering a cost-effective tool to support agricultural planning, land-use management, and mitigating the effects of environmental change.

Keywords: Agroecosystems, climate variability, deep learning, google earth engine (gee), k-means, land use land cover (lulc), landsat, maize crops, NDVI, semantic segmentation, Sentinel-2; optical remote sensing, u-net

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Mapping four decades of agricultural land abandonment in the Moroccan Anti-Atlas: A deep-learning approach combined with Landsat temporal segmentation

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Terraced agroecosystems (TAS) in the Moroccan Anti-Atlas Mountains have historically sustained local Amazigh communities. These rainfed systems integrate tree crops, cereals, and traditional water-harvesting infrastructure, providing essential ecosystem services such as erosion control and biodiversity support on steep slopes. During the last decades, these traditional landscapes have been steadily degrading due to rural out-migration, recurrent drought, and shifting agricultural priorities. Despite the widespread extent of this transformation, a spatially explicit, long-term record of land abandonment in the Anti-Atlas is still lacking. The absence of empirical data limits the ability of policymakers and conservation practitioners to plan targeted interventions. To address this, our study reconstructs agricultural land abandonment from 1985 to 2025 across a ≈1,200 km^2 corridor in the western Anti-Atlas (Ait Baha–Tanalt). We apply a two-phase remote sensing framework to map and monitor these changes. Phase 1 utilises a deep learning model integrating the Landsat archive with topographic features to classify land cover at 30 m resolution into four states: active terraces, abandoned terraces, natural vegetation, and bare surfaces. Trained and validated on a robust dataset of 2,000 ground-truth points, preliminary validation yields an overall accuracy of 90 %. Crucially, initial results indicate that abandoned terraces currently cover 68,073 hectares (41.9 % of the landscape), which is more than 2.5 times the extent of actively managed cropland (25,433 hectares; 15.6 %). Building on this validated baseline, Phase 2 applies the LandTrendr temporal segmentation algorithm to the multi-decadal Landsat series of three complementary spectral indices (NDVI, NBR, and MSAVI2) to identify the year of abandonment for each abandoned parcel, with results stratified by Landsat-sensor era to control for variation in observation density across the record. Our study delivers the first long-term empirical reconstruction of agricultural decline in the Anti-Atlas, comprising a validated 40-year map of abandonment and a per-pixel year-of-loss layer. These outputs establish the empirical baseline needed to assess the climate sensitivity of vegetation, understand landscape-pattern evolution, and design informed, climate-resilient restoration strategies for mountain agroecosystems.

Keywords: Agricultural land abandonment, Anti-Atlas Mountains, climate resilience, deep learning, Landsat time series, LandTrendr, Morocco, terraced agroecosystems

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Measuring reforestation success with very-high-resolution satellite imagery

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Forest landscape restoration is increasingly mobilised as a multi-functional strategy for climate-resilient land-use systems, simultaneously targeting carbon sequestration, soil and watershed protection, biodiversity recovery, and rural livelihoods. Yet many large-scale reforestation programmes fall short of their ecological objectives, and credible plot-level monitoring of tree establishment and survival remains a critical bottleneck. Without it, programmes risk being judged on planting effort alone, leaving establishment failures invisible and learning across sites impossible. A core obstacle is a resolution–coverage gap in satellite imagery: free, high-frequency global imagery is typically available only at moderate resolutions (10–30 m), too coarse to detect small or recently planted trees, while sub-meter very-high-resolution (VHR) imagery is costly and unevenly available. We introduce a two-stage machine learning framework that bridges this gap. A U-Net first learns to segment individual tree canopies on a limited sample of sub-meter VHR imagery; a second U-Net then transfers this signal to widely available 5 m Planet NICFI basemaps to produce wall-to-wall, plot-level fractional tree-cover estimates. The pipeline achieves a mean IoU score of 82 % on canopy segmentation and explains 83 % of the variance in fractional cover at 5 m. Benchmarked against the vegetation-index trend approach commonly used in restoration evaluation, our model captures 85 % of true tree pixels versus only 34 % for the vegetation-index trend baseline, with comparable false-positive rates. We apply the framework to Madagascar's PLAE afforestation programme (Phase III, 2014–2019), which planted roughly 7,000 ha across more than 5,800 smallholder plots in the Boeny, Betsiboka, and DIANA regions. Combining our tree-cover maps with a covariate-based matching design that controls for terrain, soil characteristics, accessibility, and pre-existing forest cover, we find moderate gains on planted plots: 5–8 years after planting, tree cover is 4.7–12.5 percentage points higher than on matched control sites, though a majority of plots remain largely treeless.
By enabling scalable, data-efficient plot-level monitoring, this approach delivers an empirical foundation needed to design, verify, and adaptively manage multi-functional restoration efforts in data-limited settings.

Keywords: Deep learning, impact evaluation, Madagascar, reforestation monitoring, remote sensing

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Land use and land cover dynamics and its implications for agrifood systems among smallholder farmers in central Malawi

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In central Malawi, the increasing conversion of forests and grazing land into cropland and settlements is significantly altering the landscape, which in turn shapes the productivity limits of smallholder farming and household food security. This study aimed to assess the effects of land use and land cover changes on maize productivity, household dietary diversity, and food insecurity among smallholder farmers in areas surrounding Lilongwe City. The study integrated multi-temporal Landsat imagery (2004, 2014, and 2024) with cross-sectional household survey data collected from 279 households in Mpingu and Malingunde Extension Planning Areas. Changes in land use were quantified using proportional changes in key land cover classes, alongside household-level exposure indicators that captured the loss of forested and grazing lands in the surrounding landscape. The analysis revealed that cropland expanded by more than 450 % between 2004 and 2024, while forest and grazing land decreased by up to 70 %, which also coincided with a 61 % reduction in average household farm size. Econometric analysis indicated that exposure to forest loss significantly reduces dietary diversity and increases the likelihood of moderate-to-severe food insecurity by 63 % for each 10-percentage point increase in forest loss. Additionally, grazing land loss was found to contribute to livestock decline and reduced manure availability, which negatively impacted maize yields and exacerbated soil fertility challenges. Dietary diversity emerged as the strongest protective factor, reducing the probability of food insecurity by 42 % for each additional food group consumed. The findings highlight that peri-urban land conversion creates interconnected land-livestock-soil-nutrition feedback loops that undermine agricultural resilience in land-scarce smallholder systems. Policy responses should address land governance, protect forest and grazing resources, promote nutrition-sensitive agricultural diversification, and integrate peri-urban planning to mitigate the risk of persistent food insecurity in low-income agrarian economies.

Keywords: Agrifood systems, dietary diversity, food insecurity, land use and land cover change (LULCC), urban expansion

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A multi-dimensional pasture condition index (PCI): Integrating bioclimatic and functional vegetation signatures to assess rangeland health

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Rangeland monitoring programmes in Central Asia face a critical challenge: distinguishing climate-driven variability in vegetation changes from grazing impact. Standard assessments, mainly based on Soviet legacy frameworks, often attribute poor rangeland condition to overgrazing without accounting for rainfall variability, leading to misguided management interventions.

We developed a Pasture Condition Index (PCI) from field-measured fractional cover indicators (n = 439) in the Nurota District of Uzbekistan and modelled its variability using Random Forest (RF) models with Principal Component Analysis (PCA) PC1 loadings (e.g. precipitation, soil moisture) across both mapping-compatible (compact) and full predictor sets to identify the drivers. The RF-compact drivers consist of bioclimatic (Short-Wave Infrared bands (SWIR), land surface temperature (LST), precipitation) and topographic (elevation, slope) variables. The RF-full set includes field-measured grazing proxies, dung deposits, hoof marks, and distance to camps in addition to the compact set. Model robustness was assessed using spatial cross-validation (CV) to evaluate the transferability beyond sampled conditions.

The PCI captured a wide gradient of rangeland conditions with a modelled range from 0 to 1 (25^{th} percentile = 0.30, 75^{th} percentile = 0.67, mean = 0.49), indicating its performance across study site. Robustness testing revealed a significant transferability gap, with model performance (full model $R^2 = 0.95$) dropping by 61 % under spatial validation (CV $R^2 = 0.58$), indicating limited generalisability of learned relationships beyond sampled conditions. The dominant signal of pasture condition was explained by remote sensing-derived bioclimatic factors (soil moisture, precipitation, LST) in the RF-compact set, while grazing proxies (especially hoof marks) gained high importance in the RF-full set, indicating localised effects are difficult to map con-

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tinuously and thus limiting their suitability for regional monitoring.
Our machine learning modelling efficiently mirrors the PCI, based on field-derived vegetation data and indicates that pasture condition in Nurota's semi-arid landscape is primarily constrained by moisture availability, with physical signs of grazing becoming difficult to detect by remote sensing. As a result, apparent PCI patterns reflect climatic variability rather than grazing impact or management failure alone, necessitating the need of further development of the PCI as a robust and replicable single indicator for assessing the rangeland health.

Keywords: Bioclimatic variables, grazing proxies, pasture health, Uzbekistan, vegetation

Spatial dynamics of values, rules, and knowledge in restoration governance: Insights from western Rwanda

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Forest and landscape restoration (FLR) is widely promoted to address environmental degradation while supporting rural livelihoods, yet its outcomes remain uneven across contexts. These differences are not only ecological but also reflect how restoration interventions interact with local values, institutional rules, and knowledge systems. Despite increasing recognition of these human dimensions, they are rarely examined spatially, limiting the ability to identify where restoration aligns with or conflicts with local priorities.

This study aims to examine how values, rules, and knowledge (VRK) are spatially distributed and interact to shape restoration dynamics in Western Rwanda. Specifically, we ask: (1) how are VRK elements mapped across restoration landscapes? (2) How do they interact to produce spatial patterns of alignment or mismatch with restoration interventions? and (3) how do these patterns influence perceived legitimacy and engagement?

Drawing on participatory geographic information systems (PPGIS), the study collects data from approximately 400 respondents across multiple villages engaged in interventions such as terracing, agroforestry, and woodlot management. Using a methodological framework for participatory mapping data (Fagerholm et al., 2021), we analyse spatial patterns of mapped values and examine how they relate to institutional rules and local ecological knowledge.

Expected results identify spatial "hotspots" of alignment, adaptation, and contestation within restoration landscapes. Areas where institutional arrangements reflect local values and knowledge are associated with higher perceived legitimacy and engagement, while mismatches correspond to zones of resistance or disengagement. These patterns are shaped by differences in access rights, rule enforcement, and locally grounded practices.

By integrating VRK with spatial analysis, this study advances a process and place-based understanding of restoration governance. It highlights the importance of aligning interventions with local priorities and recognising spatial variability in knowledge and institutions to support more legitimate and effective restoration outcomes.

Keywords: Knowledge, landscape restoration, participatory mapping, public participation GIS (PPGIS), rules, values

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Mapping mobility barriers in pastoral rangelands: Assessing the impact of *Prosopis juliflora* invasion on access to grazing and water resources

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Pastoral livelihoods depend on the ability of livestock and herders to move freely across rangelands to reach grazing areas and water. In many dryland regions, however, the rapid spread of the invasive tree *Prosopis juliflora* is transforming rangeland landscapes. Dense thickets formed by this species can block livestock movement, reduce access to resources, and alter traditional grazing routes. Despite growing concern about its ecological and livelihood impacts, the spatial extent to which *Prosopis* invasion limits access to key pastoral resources remains poorly understood. This study uses geospatial analysis to assess how *P. juliflora* expansion affects access to grazing areas and water points in pastoral rangelands of Ethiopia. Satellite imagery from Sentinel-2 was used to map the distribution of *Prosopis* across the landscape using a machine-learning classification approach. These maps were combined with spatial data on water points, grazing areas, and road networks derived from participatory mapping exercises and existing datasets. Overlay and buffer analyses were then used to identify locations where *Prosopis* thickets intersect with movement routes or occur near critical pastoral resources. Initial results show that several grazing areas and water points are located within zones increasingly affected by *Prosopis* invasion, indicating potential barriers to livestock mobility. Mapping these hotspots provides new insights into how invasive species can reshape pastoral landscapes and influence resource accessibility. The approach demonstrates how satellite data and local spatial knowledge can be combined to support rangeland monitoring and guide targeted management and restoration efforts.

Keywords: Geospatial, invasive species, livestock, local knowledge, participatory mapping, rangelands

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Land cover changes, prediction modelling and decline of ecosystem services in Lubigi wetland, Kampala, Uganda

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Urbanisation and agricultural expansion often result in degradation of natural wetlands, leading to significant ecological impacts. The study integrated the concepts of ecosystem service theory, positing that land cover changes driven by anthropogenic pressures alter ecological processes. This framework assumes that wetlands function as critical nodes in provision of ecosystem services. By linking land cover dynamics with ecosystem service outcomes, the study adopted a coupled human–environment perspective to understand and predict the consequences of wetland degradation in Lubigi Wetland, Kampala, Uganda. The objectives were to assess the dynamics of land cover changes between 1999 and 2022, predict future land cover scenarios for 2030, and identify the ecosystem services under threat due to wetland degradation. Sentinel^{-2} and Landsat imagery were processed using ArcGIS and the Land Change Modeler (LCM) to assess land cover transitions. Multi-Layer Perceptron (MLP) neural network and Markov Chain analysis were employed to model future land cover scenarios. Land cover transitions were quantitatively calculated in terms of gains, losses, and net change. Regression analysis was used to identify key drivers of wetland degradation. The ecosystem services evaluated were categorised into regulating, provisioning, cultural, and supporting services. The findings reveal significant land cover changes in Lubigi Wetland from 1999 to 2022, with built-up areas increasing by 1,140.60 % from 10.74 km^2 in 1999 to 122.5 km^2 in 2022, while wetland areas decreased by 49.5 %, from 453.54 km^2 to 228.96 km^2. By 2030, built-up areas are predicted to expand further to 279 km^2, and wetland areas are projected to shrink to 200 km^2. The loss of wetland area has had a profound impact on ecosystem services, particularly in flood regulation, water quality, and biodiversity support, all of which have been significantly degraded due to increasing anthropogenic pressures. The results suggest that population growth and urban expansion are major drivers of wetland degradation, and urgent conservation measures are necessary to mitigate further damage. The MLP neural network demonstrated an accuracy rate of 87.64 %, supporting its use in land cover change modelling. The study concludes that without intervention, continued expansion of anthropogenic land cover will threaten the ecological stability of Lubigi Wetland.

Keywords: Kampala, land change modeler, land use land cover, Lubigi wetland, Markov chain, multi-layer perceptron, remote sensing, Uganda, wetland degradation

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Accuracy constraints of GEDI-based biomass models in heterogeneous coffee agroforestry

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Greater pressure on African forests has meant that they are now a source, rather than a carbon sink, driving an urgent need for land-use systems that restore biomass. While coffee agroforestry is one means to promote carbon sequestration, its quantification in smallholder systems remains highly uncertain. A systematic literature review conducted for this study indicated that global remote sensing models applied to heterogeneous landscapes frequently suffer from range compression, characterised by signal saturation and scale mismatches.

We evaluated the suitability of a remote sensing-derived aboveground biomass (AGB) product for monitoring, reporting, and verification (MRV) in coffee-based agroforestry on Mount Gorongosa, central Mozambique. Field data were collected from 36 circular 400 m^2 plots in smallholder Arabica coffee agroforests established since 2014, spanning a range of stand ages and shade-tree compositions. Field AGB was estimated from woody stem measurements using species-specific, regional and pantropical allometric equations, then scaled to Mg ha^{-1} at the plot level. Remote-sensing AGB was derived from a model trained on GEDI LiDAR AGB footprints and multisource inputs (Sentinel-2, ALOS-2 PALSAR, Digital Elevation Model, land cover map) from outside of the study area.

The empirical results confirmed the structural biases identified in the literature. The model showed strong structural bias and poor agreement with field AGB: mean bias was 16.96 Mg ha^{-1}, RMSE 52.86 Mg ha^{-1} and relative RMSE 91.22 %. The regression slope (0.253) and high intercept (60.23 Mg ha^{-1}) revealed systematic overestimation at low biomass and underestimation at high biomass.

These findings illustrate a critical calibration gap where current GEDI-based products fail to capture the structural complexity of smallholder systems. Locally grounded calibration data remain essential for credible AGB accounting in these heterogeneous landscapes.

Keywords: Aboveground biomass, carbon sequestration, Miombo, Mozambique, remote sensing, smallholder farming

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Seasonal root dynamics and satellite-derived canopy responses in full-sun and agroforestry coffee systems in Costa Rica

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Climate variability increasingly challenges coffee production, creating a need for management systems that enhance resilience to changing environmental conditions. Agroforestry systems are often promoted as a climate-resilient alternative to full-sun coffee cultivation, yet knowledge of seasonal root dynamics and their relationship with aboveground canopy responses remains limited.
This study investigated the spatial and seasonal dynamics of coffee root length density (RLD) in full-sun and agroforestry systems in the Western Central Valley of Costa Rica and examined their relationship with canopy responses derived from Sentinel-2 vegetation indices. Root measurements were conducted across seasons and soil depths, while satellite imagery was used to monitor canopy condition and stress responses. Both production systems exhibited pronounced seasonal changes in RLD, with a marked decline during the transition from the dry to the rainy season followed by recovery during the rainy season. However, recovery patterns differed between systems. In the full-sun system, canopy greenness recovered rapidly after the onset of rainfall, whereas root recovery occurred more gradually. In contrast, the agroforestry system showed a rapid recovery of RLD shortly after the beginning of the rainy season, while canopy recovery was slower. Spatial differences were also observed: coffee plants in the agroforestry system exhibited significantly higher RLD in the upper soil layers (0–30 cm) than those in the full-sun system, indicating contrasting belowground resource acquisition patterns.
These findings demonstrate that aboveground and belowground responses to seasonal climatic variability may occur asynchronously and that their temporal relationships differ between coffee production systems. Integrating field-based root observations with satellite-derived vegetation indices provided insights into whole-plant responses that would not have been apparent from belowground measurements alone. Such knowledge can support the development of more climate-resilient coffee production strategies and improve resource-use efficiency through better alignment of fertiliser timing and placement with temporal and spatial root dynamics.

Keywords: Coffee agroforestry, Costa Rica, NDVI, root length density, seasonal dynamics, Sentinel−2, vertical root distribution

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Conflict and agricultural resilience in Afghanistan's river basins: A remote sensing assessment of irrigated cropland dynamics (2001–2024)

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Armed conflict is often assumed to uniformly disrupt agricultural systems, yet empirical evidence on how violence interacts with hydrological variability and institutional conditions to shape irrigated cropland dynamics remains limited. This study examines irrigated cropland change across Afghanistan's major river basins from 2001 to 2024, a period encompassing prolonged insurgency, political transitions, and recurrent drought, to assess how conflict intensity influences agricultural land use. A multi-scale analytical framework is applied at basin and sub-basin levels, integrating geospatial and statistical datasets. Annual irrigated cropland estimates are derived from the USGS FEWS NET eMODIS NDVI irrigated area product (250 m resolution), while long-term cropland dynamics are assessed using the GLAD Landsat-based cropland dataset (30 m resolution). Conflict data from the Uppsala Conflict Data Program (UCDP) Georeferenced Event Dataset are aggregated annually at basin and sub-basin scales through GIS-based spatial overlay analysis. Spatial processing is conducted in QGIS, and statistical analysis in R. Results reveal substantial spatial heterogeneity in the conflict–cropland relationship, with no uniform national pattern. The Helmand and Kabul basins experienced the largest reductions in irrigated area, linked to high-intensity conflict and declining surface-water availability during drought periods. In contrast, parts of the Helmand sub-basins show increases in irrigated cropland during peak violence years, likely reflecting adaptive groundwater use and locally embedded water governance. The Northern Basin exhibits a positive association between conflict intensity and irrigated area, supported by relatively stable surface-water resources, while the Amu Darya basin shows partial recovery after 2021, indicating localised post-conflict resilience. Overall, the findings demonstrate that agricultural resilience under conflict is associated not just with conflict intensity alone but also by basin-specific hydrological conditions, institutional arrangements, and strategic responses taken by local governments. The study highlights the value of integrating multi-source remote sensing and conflict datasets in monitoring agricultural land-use change in data-scarce, fragile environments. This example of multi-source data analysis provides evidence for context-specific resilient agricultural planning.

Keywords: Agricultural resilience, irrigated cropland, land-use change, military conflict, remote sensing

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Market access shapes social-ecological transformation in mountain oases of Gilgit-Baltistan, Pakistan

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Land use transformation in mountain regions is strongly influenced by infrastructure development, which improves access to distant markets and promotes tourism. However, little is known about the social and ecological implications of transformation processes in remote high-mountain oasis systems such as in Gilgit-Baltistan, Pakistan. This study focuses on two valleys with contrasting levels of connectivity: Karimabad in Hunza Valley and Shimshal. While Karimabad is well-connected to regional markets and tourism flows, Shimshal remains comparatively isolated. Through the analysis of time-series satellite imagery (Corona, Landsat, and high-resolution reference data from Google Earth) and semi-structured household surveys in both valleys (n = 200) this study aims to assess how connectivity affected agricultural land use changes and social-ecological transformation processes over the past 5 decades. Preliminary findings reveal marked differences between the two valleys. In Karimabad, Normalized Difference Vegetation Index (NDVI) analysis for the 427 ha study area showed that dense vegetation (NDVI≥0.37) increased from 30 ha in 1993 to 136 ha in 2016, reflecting an expansion of cultivated land, before declining to 92 ha in 2025 due to infrastructure development and related decrease in cropland and tree cultivation. Survey results confirm widespread agricultural land use changes after the opening of the China-Pakistan Economic Corridor (CPEC) in 2015, as stated by 83 % of the surveyed households. The reported changes include a decline in agricultural land area driven by infrastructure development (48 %) and population growth (35 %). In addition, there has been a transition from subsistence-oriented staple-crop cultivation to market-oriented horticultural crops. In the past, 74 % of households cultivated staple crops, whereas at present, 99 % of households cultivate marketable horticultural crops. In Shimshal, preliminary NDVI analysis indicates no substantial change in dense vegetation, and survey results show greater land use stability, with 71 % of the households reporting no major changes and a continued reliance on subsistence-oriented production. These findings suggest that infrastructure development is a key driver of transformation processes in Gilgit-Baltistan, accelerating the shift from subsistence farming to market-oriented production. While these changes create new economic opportunities, they may also increase pressure on land resources and lead to increased dependence on market demands.

Keywords: Land use changes, oasis agriculture, rural-urban transformation, time-series analysis

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Environmental survey of rural properties in Goiás: The use of remote sensing as a governance instrument

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Environmental monitoring is a strategy for managing rural properties. The Federation of Agriculture and Livestock of the State of Goiás uses remote sensing technologies to identify evidence of infractions. This approach detects deforestation, fires, and irregular land use conversions, strengthening the adoption of preventive and corrective measures. In this context, the objective of this research is to analyse the possibilities and limitations of using MapBioma to support producers. It was identified that the use of geoprocessing tools as integral parts of governance practices, thus, through literature and documentary review, in light of Elinor Ostrom's idea of shared protection of the commons. Data collection, organisation, and interpretation were carried out, highlighting the contribution of this technology in supporting environmental regularisation and monitoring. The experience originated from demands from producers seeking clarification on the environmental situation on their properties, often impacted by denials in financing processes or obstacles in commercial transactions. Thus, FAEG began offering environmental surveys using MapBiomas in 2025. The procedure begins with the delimitation of the area of interest, based on the provision of the Rural Environmental Registry or the geographic coordinates of the property. Filters are applied in the system for the period from 2008 to 2025, in order to identify deforestation alerts and changes in vegetation cover. These alerts are cross-referenced with CAR data, IBAMA and SEMAD-GO records, in order to verify the existence of embargoes or infraction notices. Afterwards, validation is carried out with Google Earth Pro images, confirming or discarding the occurrences. Each validated case is recorded, containing the alert code, coordinates, affected area and whether or not an infraction has been issued. The results showed that approximately 65 % of alerts in private areas corresponded to unauthorised interventions, some in Legal Reserve and Permanent Preservation Areas. It is concluded that the use of MapBiomas is efficient in screening and can support environmental governance, being replicable in different regions. As a limitation, the dependence on secondary data and remote validation stands out, which may restrict accuracy and require supplementation with field verifications.

Keywords: Environmental compliance, geospatial analysis, land use monitoring, rural consultancy, rural consulting services

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Leveraging deep learning with very high resolution satellite imagery to map *Faidherbia albida* (DEL.) trees, and support agroforestry decision-making in northern Cameroon

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Faidherbia albida is a key agroforestry species widely distributed across the Sudano-Sahelian zone of Cameroon, where it plays a crucial role in enhancing soil fertility, providing fuelwood, and strengthening climate resilience. Since the 1990s, several initiatives have promoted the expansion of agroforestry systems through farmer-managed natural regeneration (FMNR), supported by financial incentives. However, rapid population growth, climatic constraints, and restrictive forestry regulations have often limited the effectiveness of these interventions. In addition, the lack of accurate, long-term spatial data has constrained the monitoring of the species' distribution and dynamics. This study aims to improve the mapping of individual tree crowns (ITCs) of *F. albida* using very high-resolution (VHR) satellite imagery. A deep learning-based approach (CNN) was applied to a sub-metric spatial resolution imagery (0,5 m) Wordview-2 to detect and accurately delineate ITCs (crown area $> 3\,m^2$) across a 15,000 ha (150 km^2) over the study area. Using a georeferenced field inventory dataset, five classifiers (CART, kNN, Random Forest, SVM-L, and SVM-R) were trained to predict species map at the individual tree level. Predictor variables included statistical metrics derived from spectral bands and vegetation indices. Model performance was assessed using an independent ground-truth dataset collected during a dedicated field campaign.

The results show strong agreement between field inventory and remote sensing estimates of tree density (31 vs. 33 individuals ha^{-1}). Among the tested models, the linear SVM achieved the best performance ($r = 0.83$), followed by Random Forest and radial SVM. Species mapping accuracy was also satisfactory ($r = 0.79$), confirming the robustness of the proposed approach for individual tree detection and classification.

By combining remote sensing with field-based data, this study provides a starting point for investigating the spatiotemporal dynamics and keys drivers of F. albida regeneration or decline. The approach offers a scalable framework to support evidence-based decision-making for sustainable agroforestry management and climate change mitigation in dryland regions.

Keywords: Cameroon, CNN, deep learning, machine learning, tree crown segmentation, tree species classification

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Analysing the drivers of land use change from forest to agriculture in Ethiopia

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Land use and land cover (LULC) change is a major driver of environmental degradation and climate vulnerability in many developing countries, including Ethiopia. Understanding the underlying causes and consequences of these changes is critical for designing sustainable land management strategies. However, despite the rapid pace and complexity of LULC transformations, their socioeconomic and environmental drivers and impacts remain insufficiently examined and poorly articulated across diverse local contexts. This study analyses the drivers and impacts of LULC change, particularly the conversion of forests to agricultural land, in seven districts of Ethiopia: Jawi, Burie Zuria, Adami Tulu, Shebe Sembo, Gera, Gursum, and Shabeeley, using the Driver–Pressure–State–Impact–Response (DPSIR) framework. A mixed-methods approach was employed, combining data from 1,098 randomly selected household surveys, 14 focus group discussions, 28 key informant interviews, and a review of relevant literature. Participants in qualitative components were purposively selected based on their knowledge and experience with land use practices. Data were analysed using descriptive statistics and the DPSIR framework to examine linkages among drivers, pressures, environmental states, impacts, and responses. The results reveal that small-scale agriculture, charcoal production, and firewood collection are the primary direct drivers of LULC change, while poverty, weak enforcement of forest regulations, and settlement expansion act as key indirect drivers. District-level analysis highlights important spatial variations: large-scale agriculture and energy demand dominate in Adami Tulu; biomass dependence drives deforestation in Shebe Sembo and Gera; climate stress and unsustainable land use are critical in Shabeeley and Gursum; and smallholder expansion and fuelwood demand are prominent in Jawi and Burie Zuria. Across all districts, increasing demand for farmland (82.7 %), competition over communal resources (76.5 %), and reliance on forest-based energy (72.6 %) exert significant pressure on ecosystems. These pressures have resulted in widespread soil degradation, biodiversity loss, declining agricultural productivity, and increased vulnerability to climate variability and extremes. The study recommends context-specific interventions, including strengthening land tenure security and regulatory enforcement, expanding access to renewable energy, promoting agroforestry and reforestation, and supporting climate-resilient agricultural systems. Enhanced institutional coordination and community-based natural resource management are essential to achieving sustainable and inclusive land use outcomes.

Keywords: Deforestation, DPSIR, Ethiopia, land use change, sustainable land management

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Using unmanned aerial vehicles to identify and quantify aquatic macrophytes in shallow lakes of the Amazon region

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Freshwater ecosystems are sensitive to environmental changes, and aquatic macrophytes play an important role in the ecological dynamics of Amazonian floodplains by regulating nutrient cycling, contributing to sediment stabilisation and providing habitat structure for diverse aquatic organisms. These plants are highly susceptible to environmental disturbances; therefore, they are considered good bioindicators of aquatic ecosystem health, functioning, and biodiversity. The importance of the aquatic macrophytes in freshwater ecosystems is linked to their spatial distribution, which depends on many environmental factors. Their spatial distribution and species composition can indicate water quality and habitat integrity. Therefore, monitoring macrophyte communities is important for enhancing our understanding of ecosystem functioning and identifying changes related to environmental disturbances. In this study, high-resolution unmanned aircraft vehicle (UAV) imagery was used to analyse and classify the spatial distribution in seven floodplain lakes from the Peruvian Amazon, four lakes located inside the Pacaya-Samiria Natural Reserve and three outside of the protected area. The use of UAVs allows for a combination of spatial ecology with landscape-scale observations, offering a powerful tool for capturing fine-scale heterogeneity in dynamic floodplain systems. The study further compares protected and non-protected lakes to assess whether conservation status influences spatial habitat complexity and biodiversity patterns. High-resolution UAV imagery is used to map aquatic vegetation and derive spatial metrics describing habitat structure. We hypothesise that higher spatial heterogeneity is associated with higher macrophyte diversity and that protected lakes exhibit stronger structure – diversity relationships due to reduced anthropogenic disturbance and management plans in the area. Our findings highlight the potential of UAVs to support ecological research and biodiversity assessments in tropical aquatic environments, with implications for long-term ecosystem monitoring and management.

Keywords: Amazon floodplains, random forest, remote sensing, unmanned aerial vehicle

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The flash-flood paradox: Digital twin modelling of hydro-climatic regime boundaries for climate-resilient agro-ecosystems in South Africa

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Ephemeral catchments in arid and semi-arid regions underpin the water security of vulnerable agroecosystems. Adaptation planning in these regions is increasingly challenged by the simultaneous and potentially competing effects of land degradation and anthropogenic climate change. Conventional impact assessments often assume that increasing surface barrenness (e.g., vegetation loss and soil crusting) linearly amplifies runoff coefficients and flash flood magnitude. This study tests this assumption by introducing a reproducible Tri Engine Digital Twin to quantify the Flash Flood Paradox: conditions under which severe meteorological drought suppresses spillway-generating floods despite a progressively more runoff-prone landscape.

Applied to the Karee Dam catchment (16.91 km^2) in South Africa's Northern Cape, the framework couples (i) Earth-observation land-cover baseline mapping from ESA WorldCover, (ii) bias-corrected daily hydro-climatic forcing from CHIRPS and ERA5 Land extracted via Google Earth Engine, perturbed with CMIP6 monthly delta mapping from MPI ESM1 2 HR (SSP2 4.5 and SSP5 8.5), and (iii) a daily reservoir mass balance emulator optimised using Differential Evolution (monthly KGE = 0.618). Future analogue simulations for 2021–2050 show that under an extreme coupled pathway (SSP5 8.5 with a degradation trajectory toward a 30 % barren fraction by 2050), the cumulative 30 year spillway overflow declines from 0.23 to 0.08 Mm^3 (−67.5 %) relative to a moderate baseline (SSP2 4.5; static 2.58 % barrenness). In parallel, water supply reliability deteriorates sharply, with days below 20 % storage increasing from 18.6 % to 49.4 % and empty reservoir days rising from 5.7 % to 13.7 %. A two-dimensional regime map further identified a substantial drought-limited domain in which overflow was entirely suppressed, regardless of land conditions (132 of 561 stress-test cases).

These findings indicate that for extremely dryland agro-ecosystems, the dominant hazard can shift from episodic flood extremes to chronic water deficits, implying that flood-centric grey infrastructure may become maladapted without concurrent landscape rehabilitation and demand-side adaptation. The proposed digital twin workflow provides a transparent, transferable approach for mapping hydro-climatic regime boundaries to support climate-resilient planning.

Keywords: Climate resilience, CMIP6, dryland hydrology, ephemeral catchments, hydro-climatic regimes, land degradation, reservoir reliability

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Validation of remotely sensed drought indices from Google Earth Engine using *in situ* observations

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Drought poses a significant environmental challenge in the arid and semi-arid regions of South Africa, primarily due to low and erratic rainfall coupled with rising temperatures. Effective monitoring of drought conditions requires continuous spatial and temporal data; however, this is often compromised by uneven distribution and malfunctioning ground stations, leading to inconsistent datasets. Remote sensing offers a promising alternative, providing extensive spatial coverage and near-real-time data, although its use in South African dry regions remains underexplored.

The current study evaluates the performance of remotely sensed drought indices derived from Google Earth Engine (GEE) by validating them against data from ground stations. Additionally, the study examined the spatio-temporal variations of drought using the Standardized Precipitation Index (SPI) and the Standardized Precipitation Evapotranspiration Index (SPEI) at 3-, 6-, and 12-month timescales. The results indicate that the SPI derived from CHIRPS data shows moderate to strong agreement with ground observations, particularly at longer timescales, achieving R^2 values of up to 0.88 and demonstrating reduced Root Mean Square Error (RMSE) and Mean Absolute Error (MAE) values. However, some spatial inconsistencies remain at certain stations. In contrast, the SPEI demonstrates consistently strong agreement across all stations and timescales, with R^2 values ranging from 0.95 to 0.99 at shorter and medium timescales, indicating high reliability.

Spatial analysis reveals that drought severity increases with longer accumulation periods. The SPI indicates widespread dry conditions across central, northern, and eastern regions, while the southwestern areas remain relatively wetter. The SPEI highlights a persistent west-east gradient, showing wetter conditions in the west and more severe drought in the central and eastern regions. Temporal analysis identifies a prolonged drought from 2015 to 2020, followed by wetter conditions beginning in 2021 onwards. Overall, GEE-derived indices, particularly the SPEI, are effective tools for monitoring drought in data-scarce environments.

Keywords: Drought, standardised precipitation evapotranspiration index, standardised precipitation index

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Do water bunds work? Remote sensing-based impact evaluation and pastoral community voices on soil and water conservation in Kenya

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Land degradation in semi-arid sub-Saharan Africa poses a growing threat to ecosystem function and rural livelihoods. Water bunds, low earthen structures that slow surface runoff and promote infiltration, have been widely promoted as a low-cost nature-based solution for land restoration, yet rigorous causal evidence of their environmental effectiveness and socio-economic benefits remains scarce. This study evaluates the impact of water bund interventions implemented across 32 project sites in Kenya (approximately 689,000 bunds constructed between 2016 and 2025) using a mixed-methods design that combines remote-sensing-based impact evaluation with qualitative fieldwork. The quantitative component employs a spatial panel design using a 1 km ×× 1 km grid observed annually from 2014 to 2025. Treatment is defined at the grid level based on the presence of bunds within a 500-meter buffer. Control cells, i.e., never-treated grids beyond 1,000 m from any bund, are selected by propensity score matching to be comparable to treated cells on pre-intervention observables including elevation, slope, rainfall, temperature, vegetation cover, and nightlight. To ensure robustness, we also test alternative control group selection procedures. Environmental outcomes, including vegetation greenness (NDVI from Sentinel-2), soil moisture (SMAP), and evapotranspiration (FAO WaPor), are estimated using a staggered event-study Difference-in-Differences estimator following Callaway and Sant'Anna (2021), which avoids contamination bias under staggered rollout. Pre-treatment parallel trend tests serve as validity checks. The qualitative component draws on Key Informant Interviews (KIIs) and Focus Group Discussions (FGDs) conducted across project sites. These capture socio-economic outcomes not visible in satellite data, including impacts on pastoral productivity and livelihoods, forage and water availability for livestock, and household food security. The qualitative work also documents community-perceived timelines of benefit and reveals heterogeneity in outcomes across wealth groups, gender, and proximity to bunds. Together, the quantitative and qualitative strands provide a comprehensive picture of how landscape restoration translates into environmental recovery and livelihood improvements. This evidence directly supports scaling decisions by restoration practitioners and policymakers pursuing climate-resilient, multifunctional agroecosystems across arid and semi-arid landscapes in Africa.

Keywords: Difference-in-differences, landscape restoration, pastoral communities

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Spatiotemporal dynamics of informal sharecropping and ecosystem degradation in the Ankarafantsika national park peripheries, Madagascar

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Ankarafantsika National Park, located in the Boeny Region of northwestern Madagascar, is a major biodiversity hotspot. It is increasingly threatened by anthropogenic pressures, particularly agricultural expansion in its surrounding areas. In these agricultural frontier zones, informal land arrangements, especially insecure sharecropping, shape land-use trajectories and may accelerate deforestation. The land-tenure insecurity inherent to such arrangements often encourages short-term exploitation strategies, discouraging sustainable investments and promoting the opening of new agricultural plots. This study examines how land-tenure insecurity (risks of eviction, verbal agreements) drives short-term land-use decisions, combining low adoption of sustainable practices with speculative parcel expansion, thereby intensifying ecosystem degradation. The socio-ecological framework adopted here models the causal chain linking economic vulnerability, informal sharecropping, land-tenure insecurity, and deforestation. The methodology combines remote sensing, spatial analysis, and socioeconomic data. Land-cover changes were assessed using Sentinel-2 satellite imagery from 2016 and 2025. A supervised classification based on the Random Forest algorithm was applied to map land-cover types and detect deforestation dynamics. Spatial analysis was organised along a distance gradient from the park, using buffer zones of 0–2.5 km (direct pressure zone), 2.5–5 km (agro-forest transition zone), and 5–10 km (broader influence zone). Changes were examined through diachronic comparison and transition matrices. Spatial datasets were integrated with structured, GPS-assisted land-tenure surveys conducted with 215 agricultural operators (110 landowners and 105 sharecroppers), complemented by qualitative interviews with 12 local authorities. The analysis aims to identify spatial relationships between the distribution of informal sharecropping and areas experiencing deforestation. Results indicate that the direct pressure zone exhibits a forest-to-agriculture conversion rate 2.3 times higher than areas with secure land rights ($r = 0.65$; $p < 0.001$). This heightened conversion is driven both by the search for fertile forest soils and by economic behaviours aimed at minimising investment on insecure land. Together, these dynamics confirm that land-tenure insecurity strongly shapes land-use strategies and accelerates environmental degradation around protected areas. These findings highlight the need to integrate land-tenure considerations and sustainable land-management approaches into conservation policies to reduce anthropogenic pressures and enhance the long-term resilience of surrounding socio-ecological landscapes.

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Mapping soil moisture and organic carbon with Landsat 8 for productivity assessment in Boeny, Madagascar

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The spatial characterisation of the Soil Moisture Index (SMI) is a valuable tool for numerous applications, including agriculture, soil conservation, ecological monitoring, climate analysis, and land degradation assessment. Despite its importance, access to SMI datasets at national and subnational scales remains limited. Yet such information is particularly crucial for developing countries like Madagascar, where land degradation, especially erosion and climate-related stresses such as recurrent drought are becoming increasingly severe.

The Soil Moisture Index (SMI) of the Boeny region in northwestern Madagascar was modeled using Landsat-8 OLI/TIRS imagery and two key parameters: the Normalized Difference Vegetation Index (NDVI) and Land Surface Temperature (LST). Based on these outputs, potential soil productivity, an estimate of maximum yield potential, distinct from actual productivity, was assessed using a ΔSMI variation model combined with a Soil Organic Carbon (SOC) content model. Here, ΔSMI represents the change in soil moisture between April and August 2021 year of available data).

The analysis shows that SMI values in the Boeny region range from 0.23 to 0.36, depending on land use. These results indicate generally low soil moisture conditions, largely driven by the region's high temperatures and the predominance of sparsely vegetated savannah landscapes. In contrast, areas with dense vegetation, such as forests, mangroves, and wetlands, present significantly higher moisture levels.

Several studies highlight ΔSMI as a key indicator of potential soil productivity. In this study, the negative correlation ($R^2 = 0.05462$) between soil organic carbon (SOC) content and temporal variation in SMI (ΔSMI) confirms that ΔSMI can serve as a meaningful estimator of soil productivity potential. This relationship suggests that higher SOC levels in surface soils are associated with smaller fluctuations in soil moisture. The ΔSMI model, derived from the difference in SMI between the wet and dry periods of 2021, therefore provides a practical tool for identifying potential soil productivity at the subnational scale.

Keywords: Land surface temperature, Madagascar, normalised difference vegetation index, potential soil productivity, soil moisture index, soil organic carbon

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Monitoring post-fire vegetation recovery using AUV: A successional analysis from the Ankarafantsika national park Madagascar

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Ankarafantsika National Park contains one of the largest remaining blocks of semi-deciduous dry dense forest in western Madagascar. Like most vegetation formations in the region, it is regularly exposed to wildfires. Yet, information on post-fire vegetation structure remains scarce and is almost entirely absent for this site. To address this gap, we used UAV technology as a modern tool to analyse post-fire vegetation succession. Burned areas within the park from 2000 to 2022 were mapped by reconstructing fire history using three satellite data sources: MODIS, LANDSAT-8, and SENTINEL-2. Nineteen transects representing vegetation of different post-fire ages (1 to 21 years), along with one unburned reference transect, were established. Each vegetation formation was represented by a 6-hectare transect (300 m × 200 m) surveyed using a UAV. Data processing included generating Digital Terrain Models (DTMs) and Digital Canopy Models (DCMs), followed by Individual Tree Detection (ITD) and extraction of structural profiles from dense point clouds. Tree detection accuracy, assessed using the F score, reached 0.8, indicating robust and reliable performance. Vegetation was classified into five successional age groups (G) based on dominant tree height. G1 (1–5 years) is characterised by regenerating individuals less than 2 m tall. G2 (6–7 years) includes vegetation between 2 and 5 m. G3 (8–9 years) corresponds to stands reaching 5–7 m. In G4 (10–18 years), vegetation shows full colonisation and increasingly taller structures. G5 (20–21 years) resembles G4 but is distinguished by trees approaching 10 m in height. Statistical analyses using Spearman's rank correlation revealed strong relationships between stand age and both average tree height ($R^2 = 0.92$) and dominant tree height ($R^2 = 0.87$), enabling the development of successional models. According to Lebot's evaluation scale, these models are considered reliable and indicate that, following a single fire event and in the absence of subsequent disturbances, forest structure in Ankarafantsika may return to reference conditions within approximately 30 years. These findings emphasise that effective fire-landscape management must be tailored to local ecological realities, beginning with a deeper understanding of forest patch heterogeneity and species composition.

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Biodiversity conservation, restoration and value chain development for underutilised crops

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Biodiversity transitions in coffee and cacao toward climate-resilient agroecosystems in Mexico, Guatemala and Dominican Republic

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Coffee and cacao are tropical crops of major economic, social, and environmental importance worldwide, supporting millions of farming families in Latin America, Africa, and Asia. However, these production systems face growing threats from climate change, including rising temperatures, altered rainfall patterns, increased incidence of pests and diseases, and loss of ecosystem functions. Because coffee and cacao are often grown within or near tropical forest landscapes, biodiversity can play a key role in strengthening the resilience and sustainability of these agroecosystems. In addition to the ecosystem services that agroecological systems can get from biodiversity.
In this context, the BioFinCas project assesses the current state of biodiversity on coffee and cacao farms in Mexico, Guatemala, and the Dominican Republic, with the aim of identifying transition pathways toward more climate-resilient production systems. Field assessments were conducted on 60 coffee farms in Mexico, 16 coffee farms and 24 cacao farms in Guatemala, and 16 coffee farms and 24 cacao farms in the Dominican Republic.
A standardised protocol was applied across all farms to evaluate shade tree diversity, pollinators, ground cover, bromeliads, and biomass of cultivated and associated trees. These indicators help explain how biodiversity contributes to ecosystem services such as microclimate regulation, soil protection, pollination, and overall system stability under changing climatic conditions.
The comparative analysis identifies how coffee and cacao systems can transition toward more multifunctional and biodiverse agroecosystems. The results provide valuable inputs for producers, researchers, and decision-makers in designing adaptation strategies that strengthen productivity, conserve biodiversity, and improve rural livelihoods in tropical regions exposed to climate uncertainty.

Keywords: Agroecosystems, biodiversity, cacao, climate resilience, coffee

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The potential of farmer-managed natural regeneration for restoration in agricultural landscapes

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65 % of Africa's agricultural land is degraded, making restoration more urgent than ever. Farmer-managed natural regeneration (FMNR) is an agroforestry practice where farmers combine naturally regenerating trees with agricultural production. It has received a lot of attention as a cheap and effective way to restore degraded farmland, particularly in Africa. However, we currently do not know what species regenerate in what context and whether this meets needs of farmers.

Mechanistic understanding of natural regeneration comes from studies on ecological succession, which control for human influences. How farmers modify successional processes and what the consequences are for ecosystem functionality is unclear. We systematically compare ecosystem properties across field ages in actively managed FMNR fields and in unmanaged secondary forests in Migori (FMNR maize systems) and Baringo (FMNR grazing systems) counties of Kenya. In addition, interviews with field owners were carried out to understand farmer's individual preferences and needs.

The benefits associated to FMNR are diverse and contain many subsistence needs (firewood, medicine, timber and fodder) underlining its suitability in smallholder landscapes. Compared to unmanaged secondary forests, FMNR maize fields had only a fraction of the tree densities, yet stand basal area (biomass) was about half the biomass of similar-aged secondary forests. FMNR grazing systems tree densities were much larger and could attain biomass values comparable to unmanaged secondary forests, suggesting grazing systems are more compatible with trees than maize cropping systems. Trees are consistently taller in FMNR systems compared to unmanaged systems, indicating that farmers promote height-growth of selected trees, in order to make them more compatible with agricultural production objectives. Species richness in FMNR maize systems was relatively high, given its lowered tree densities, and differ remarkably across different fields, highlighting farmers' autonomy and individual preferences expressed in tree selection. A characteristic that is vital for its upscaling potential.

Farmer managed natural regeneration has great potential to increase tree diversity in smallholder agricultural landscapes both at the field level, and at the landscape level. Understanding where natural regeneration is sufficient to meet subsistence needs and where additional tree planting is required is an important step towards effective restoration planning.

Keywords: Africa, agroforestry, farmers, Kenya, restoration

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Whose restoration? Direct mobile-money payments, intra-household dynamics, and the limits of digital equity in farmer-led tree restoration in Kenya

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Large-scale tree-based restoration in sub-Saharan Africa has often delivered uneven benefits across gender and socio-ecological gradients, with women, pastoralists, and land-constrained smallholders under-represented in species choice and payment flows. Mobile-money disbursements routed directly to individuals are widely assumed to resolve such inequities by bypassing intermediaries. This study asks whether direct mobile-money payments, combined with a progressive payment model, in fact broaden who benefits from restoration – and identifies the intra-household conditions under which they do not. We analyse MyFarmTrees, a co-designed digital platform piloted from 2022 across three contrasting zones in Kenya: smallholder farmlands in Siaya, semi-arid community rangelands in Laikipia, and arid pastoral landscapes in Turkana. The platform links seed collectors, nurseries, and farmers through three mobile applications, a QR-code traceability system from seed to surviving on-farm tree, and M-Pesa payments tied to verified planting milestones. Evidence comprises administrative data from 3,692 enrolled farmers, payment transaction records from two disbursement cycles, and 13 in-depth farmer interviews conducted in the Siaya cluster in November 2025. By June 2025, 210,920 seedlings of 30 mostly native species had been distributed across approximately 2,500 hectares, supported by 27 registered tree nurseries and 85 village-based monitors enabling non-smartphone participation. Two payment cycles were implemented between December 2024 and August 2025: an initial flat-rate cycle that piloted the digital payment system and surfaced equity insights across ecological zones, followed by a progressive tier system designed to guarantee a meaningful minimum payout for all participants regardless of farm size or agro-ecological context. Interview evidence indicates that payments were reinvested in school fees, farm inputs, livestock, housing, small enterprises, and tree protection. Critically, however, equity outcomes were conditional on household structure: female-headed households retained full control of incentives, whereas in patrilineal households, husbands sometimes captured the cash despite the direct-to-individual payment design. These findings qualify the dominant narrative that mobile-money incentives automatically advance gender equity and suggest that direct payments must be paired with household-level gender sensitisation to deliver on their equity potential in climate-resilient restoration.

Keywords: Gender equity, intra-household dynamics, Kenya, landscape restoration, mobile-money incentives, progressive payments

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Understanding the farmers' stewardship of neglected and underutilised crops in Timor's drylands

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Neglected and underutilised species (NUS) primarily consist of wild or semi-domesticated varieties that have adapted to their local environments, as well as neglected varieties of mainstream crops. They are also referred to as traditional crops, orphan crops, lost or forgotten food crops, and minor crops. Understanding the biocultural significance of NUS and how communities have managed them is a key strategy for mainstreaming them in crop production while conserving the traditional and local knowledge associated with them. We address these research gaps through a study of farmers' stewardship of NUS on mainland Timor Island, Indonesia. In this area, smallholder farmers cultivate NUS as staple crops and for many other purposes. Although some of these species originated in forests and remain connected to forest-based knowledge systems, farmers today manage them primarily in agricultural landscapes. We conducted a photo-elicitation survey involving 224 farmers across five crop types: corn, lima beans, vegetable-hummingbirds, rice beans, and yams. We appraise 1) how farmers steward NUS, 2) the influence of farmers' motivations, capacities, and actions on ecological and social outcomes, and 3) the pathways to enhance biocultural conservation and food system transformation by utilising mixed-effects logistic regression with false discovery rate correction. Farmers steward NUS mainly to provide local food for their families and to preserve their food culture. By sharing seeds and knowledge within their communities, they practice traditional farming methods. Respondents highlight key benefits such as improved food security, greater dietary diversity, and better soil quality. We identified that traditional practices, knowledge sharing, and social support mechanisms emerged as the strongest predictors of ecological and cultural outcomes. These findings illustrate that the potential for transforming the food system can be unlocked by understanding the actions, motivations, and capacities of farmers in their stewardship practices. Our findings further indicate that interventions of local stewardship should address multiple capacity dimensions as they are mutually reinforcing. Recognizing farmers as stewards rather than mere resource users provides a practical approach to biocultural conservation, as their stewardship is rooted in reciprocal relationships between humans and nature.

Keywords: Biocultural conservation, food system transformation, mixed-effects logistic regression, neglected and underutilised species, stewardship, Timor

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Seeds of the future: Youth participation, community seed banks and agrobiodiversity in Cumbal, Colombia

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Community seed banks and youth engagement are emerging as critical strategies for strengthening agrobiodiversity, food security, and cultural identity in Indigenous territories. In the resguardo (reserve) of Cumbal (Nariño, Colombia), community seed banking efforts in which youth play an important role intersect with local knowledge systems, indigenous identity, and gender dynamics, under increasing environmental and socio-economic pressures. This study examines the role of youth participation in recently established community seed banks in Cumbal in sustaining agrobiodiversity and facilitating intergenerational knowledge transmission. The research draws on a qualitative methodology combining Gender Equality and Social Norms Assessment (GEN-SoNA) workshops, semi-structured interviews with community members and institutional actors, ethnographic field visits, and literature review. Findings highlight that community seed banks, particularly those established within local educational institutions, play a central role in conserving native seed diversity, enhancing food security and sovereignty, strengthening their indigenous cultural identity and promoting resilience in agricultural systems. These seed banks operate through collective mechanisms of seed exchange and restitution, strengthening social cohesion and local governance around plant genetic resources. Youth participation is a key component of these initiatives: students actively engage in seed collection, conservation, and planting activities, transforming seed banks into spaces of experiential learning and community research. Additionally, intergenerational collaboration – through interactions with traditional elders (taitas and mamas) – facilitates the transmission of traditional ecological knowledge, reinforcing cultural identity and agroecological practices. However, the study also identifies important challenges. Despite these initiatives, youth engagement in biodiversity conservation remains uneven, with many young people migrating for education and employment opportunities and not returning to the territory (reserve). Limited institutional support, lack of resources such as thematic teaching materials, and insufficient integration of youth in local decision-making processes further constrain the scalability and sustainability of these efforts. The study concludes that community seed banks, when linked to youth participation and educational processes, represent powerful platforms for advancing agrobiodiversity conservation and social inclusion. Strengthening these initiatives requires sustained institutional support, investment in youth-oriented programs, and the integration of local knowledge into formal education systems. Such efforts are essential for fostering resilient, inclusive, and culturally grounded agri-food systems in Indigenous territories.

Keywords: Biodiversity conservation, community seed banks, youth

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Vegetation structure and diversity under farmer managed natural regeneration: A comparison of silvo-arable and silvo-pastoral systems in Kenya

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Farmer Managed Natural Regeneration (FMNR) is a low-cost, adaptable agroforestry practice that enhances land restoration by promoting systematic integration of naturally regenerating trees within farming systems through tree selection and management. Despite its increasing adoption in sub-Saharan Africa, comparative evidence across land uses remains limited. This study empirically compares tree and woody regeneration density, species richness, and composition between silvo-arable (maize cultivation) and silvo-pastoral (grazing) FMNR systems in semi-arid Kenya. Sixty-three plots were established across these two land uses, within which a total of 1409 trees and 505 woody regeneration individuals were recorded. Tree density was higher in silvo-pastoral FMNR systems (558 ha^{-1}) than in silvo-arable systems (150 ha^{-1}), though the difference was not statistically significant. In contrast, woody regeneration density was significantly greater in silvo-arable systems (2450 ha^{-1} vs. 727 ha^{-1}). Rarefied species richness of trees was the same in silvo-arable FMNR and silvo-pastoral FMNR systems, while richness of regeneration was either significantly higher than the tree community, like in silvo-arable systems, or significantly lower than the tree community, like in silvo-pastoral systems. Non-metric multidimensional scaling showed that silvo-pastoral FMNR systems exhibited similar species composition between trees and regeneration, whereas silvo-arable FMNR systems displayed greater variability in tree composition across fields, reflecting less variable preferences by farmers. Given that regeneration represents future tree communities, reduced regeneration diversity in silvo-pastoral systems may constrain long-term species richness. These findings suggest that silvo-arable and silvo-pastoral FMNR systems follow distinct restoration pathways, with implications for biodiversity conservation, livelihoods, and the scaling of FMNR as a restoration practice.

Keywords: Dryland restoration, farmer managed natural regeneration, silvo-arable, silvo-pastoral, smallholders, sub- Saharan Africa

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Expansion of invasive plant cover in the rural highlands of Galapagos

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Invasive plant species pose a major threat to biodiversity and ecosystem integrity in the Galapagos Islands. At the same time, they are a threat to rural livelihoods, as controlling them represents an investment of around 30 % to 40 % of their income. While efforts to track and control these invasives have focused on protected areas, the rural highlands need more attention, since they harbor many endemic species, and are essential for a sustainable local economy. To close this knowledge gap, we produced an updated high-resolution land cover map and a land cover change analysis (2018–2024) across the rural highlands of Santa Cruz, San Cristobal, Isabela, and Floreana. Using object-oriented and machine learning classification, we mapped canopy-level vegetation changes with an overall accuracy of 97,13 %. Results show a net increase of approximately 6800 hectares (+43 %) of invasive vegetation in the rural highlands, primarily driven by the expansion of "mixed forest" cover, which often includes the invasive *Cedrela odorata* and *Psidium guajava*. Despite the overall expansion, we observed localised contractions in the cover of these two species, in many cases likely caused by wood harvest, land-use change and canopy succession. Model limitations, such as spectral confusion and misclassification in complex vegetation zones, may have resulted in a slight overestimation of the invasive vegetation cover. Overall, the findings highlight continued expansion of invasive vegetation, particularly in Santa Cruz, and signal an ongoing transformation of highland ecosystems. These results underscore the need for continued land cover monitoring to inform invasive species management the archipelago. Information derived from this study is also important for ecological research to be able to refine conservation strategies for endangered plant and animal species being threatened by invasive plant species.

Keywords: Conservation, Galapagos, invasive species, land cover change, machine learning, threatened species

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Shaping future forest conservation in Latin America: A systematic review of potential other effective area-based measures

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Achieving global biodiversity goals can be supported by recognising conservation contributions from areas beyond Protected Areas (PAs), including those identified as Other Effective Area-Based Conservation Measures (OECMs). Focusing on Latin America, this systematic literature review synthesizes 93 publications that assess the effectiveness of area-based conservation measures outside formal PA systems in reducing deforestation. First, we identify and classify area-based measures that may qualify as potential OECMs into six types based on their conservation objectives and characteristics: (i) Strict Biodiversity Conservation Areas, (ii) Set-Aside Areas for Ecosystem Services, (iii) Indigenous Territories, (iv) Local Community Territories, (v) Managed Sustainable-Use Areas, and (vi) Ancillary Conservation Areas. Second, we synthesize the available evidence on their effectiveness in reducing deforestation. Indigenous Territories are the most frequently evaluated, whereas Strict Biodiversity Conservation Areas have received relatively little attention. Methodologically, most evidence relies on non-experimental comparisons of forest-cover trends; quasi-experimental designs are less common but provide stronger causal inference of conservation effectiveness. Disaggregating outcomes by comparator type reveals important patterns: Indigenous Territories consistently show reduced deforestation relative to both PAs and non-PAs, while Local Communities' Territories generally outperform non-PAs but underperform compared with PAs. Set-Aside Areas for Ecosystem Services show predominantly negative outcomes, largely reflecting weak enforcement. Despite this growing evidence base, very few of these areas have been formally recognised as OECMs, highlighting a disconnect between available research and reporting under the Kunming–Montreal Global Biodiversity Framework. Bridging this gap will require stronger causal evidence, broader geographic coverage, and inclusive recognition processes that account for the governance rights of those who manage these territories.

Keywords: Area-based conservation, conservation effectiveness, deforestation, indigenous territories, local communities

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Aridity drives woody plant functional spaces across land-use gradients in the Dry Chaco Forest

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The Dry Chaco Forest, a critical yet understudied deforestation hotspot, is undergoing rapid land-use change, with deforestation and agricultural expansion threatening its ecological integrity. Woody plant functional traits are key indicators of ecosystem function and resilience, but their variation across environmental and anthropogenic gradients in this region remains poorly understood. This study aims to assess how functional trait diversity and functional spaces of woody plants vary along a 400 km aridity gradient, across land-use categories, and between protected and unprotected areas in the Dry Chaco. We sampled 58 woody species at 5 sites (spaced 80 km apart) and 3 protected areas, with 400 sqm plots established in forest strips, forest borders (0–200 m), and forest interiors (>200 m). For each species, we measured a set of functional traits: maximum height, wood density, stable isotopes (δ^{13}C, δ^{15}N) in wood and leaves, C:N ratios, dry matter leaf content, and specific leaf area. Community-weighted means (CWM) and multidimensional functional spaces were calculated to characterise trait variation. Preliminary analyses explore whether functional spaces differ among land-use categories, protection status, and sites along the aridity gradient. By identifying the relative influence of aridity, land use, and protection on functional trait diversity, this study seeks to contribute to the development of evidence-based conservation strategies for the Dry Chaco. Understanding these patterns is essential for prioritising areas for protection and restoration, particularly in the face of increasing aridity and anthropogenic pressure. This study provides a foundation for integrating functional ecology into conservation planning, offering insights into how woody plant communities may respond to environmental and land-use changes in one of the world's most vulnerable dry forests.

Keywords: Aridity gradient, Dry Chaco forest, functional diversity, land-use change

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Edaphyc attributes in the cultivation of organic medicinal plants in Itapuranga, Goiás, Brazil

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The cultivation of aromatic plants in organic farming constitutes an alternative to enhance agricultural biodiversity, generating income while preserving the environment. This study evaluated biometric and edaphic attributes of three aromatic and medicinal plant species cultivated under organic management at the farm Sítio Morada do Sol, in Itapuranga, Goiás, Brazil. The farm supplies organic raw materials to Livealoe Cosmetics, a company based in farm certified organic natural cosmetics. The selected plants were carqueja (*Baccharis trimera* var. carqueja DC. - Asteraceae), Alecrim-Pimenta (*Lippia origanoides* Kunth - Verbenaceae), and Paribaroba (*Piper marginatum* Jacq. - Piperaceae). Sítio Morada do Sol supplies organic raw materials to the company Livealoe Cosmetics, a pioneering Goianian company in the production of natural cosmetics with organic and certified production in Brazil. Soil samples were collected from the 0–0.20 m layer and plant heights of these three species in the winter of 2023. Samples were collected from beds irrigated by sprinklers, according to the crop's needs. Soil samples were collected in winter 2023 from the 0–0.20 m layer in irrigated beds managed according to crop water requirements. Soil analyses followed EMBRAPA recommendations. Plant height was measured for the three species. The biometric data for height indicated means and standard deviations as follows: carqueja - 52.3 +/- 4.9 cm; Alecrim-Pimenta - 62.6 +/- 13.5 cm; Paribaroba - 114.4 +/- 78.13 cm, respectively. The phosphorus levels extracted by Mehlich 1 were higher in Paribaroba and Carqueja (60 mg dm^{-3}) than in Alecrim-Pimenta (29.1 mg dm^{-3}). The potassium levels extracted by Mehlich 1 were above 100 mg kg^{-1} in all species. The calcium (Ca) and magnesium (Mg) levels extracted by potassium chloride were 4.0 cmolc dm^{-3} for Ca and 1.0 cmolc dm^{-3} for Mg. These values indicate medium to adequate levels of soil fertility for plant growth and biological activity. The results suggest that agroecological soil management and organic fertilisation at Sítio Morada do Sol are associated with favourable soil chemical conditions for the cultivation of aromatic and medicinal plants. The study also highlights the potential of these species as components of diversified organic production systems in the Brazilian Cerrado.

Keywords: Agroecology, Cerrado soils, sustainability indicators

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A millennium of anthropogenic impact: Sedimentary biomarker evidence from Lake San Pablo, Ecuador

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In Ecuador, the concept of Rights of Natureïs constitutionally anchored, granting ecosystems legal personhood with the right to exist and regenerate. Following decades of untreated wastewater discharge and pollution, Lake San Pablo became the subject of a landmark legal case in 2025, resulting in the formal recognition of its rights and mandates for ecological restoration. Lake San Pablo, located in the Imbabura province at an altitude of 2,660 meters, is vital for the local population but has been under anthropogenic pressure over time. The main focus of this contribution is on how changes in land use and settlement expansion within the catchment have impacted the lake and its associated ecosystem services.

This study offers a temporal reconstruction of anthropogenic environmental change in Lake San Pablo using organic geochemical biomarkers preserved in sediments, based on a sediment core collected in 2024 that captures environmental changes over the past millennium. The analysis of n-alkanes and polycyclic aromatic hydrocarbons (PAHs) enables differentiation between terrestrial and aquatic organic matter inputs as well as combustion sources. While n-alkanes indicate changes in vegetation composition and land-use changes, PAHs serve as markers for combustion processes (such as biomass and fossil fuel burning) and the direct input of fossil fuels due to increasing urbanisation. Preliminary results and interpretations show a clear shift in the distribution of n-alkanes, indicating increasing aquatic primary production due to eutrophication. PAH records show persistent biomass-burning signals over centennial timescales, followed by a recent transition toward fossil-fuel–derived inputs associated with urbanisation, motorisation, and agricultural mechanisation. A significant increase in PAH concentrations for the recent decades further indicates intensifying anthropogenic pressure and its compounding impact on the lacustrine environment.

Ultimately, this millennial-scale investigation provides a baseline of human-induced environmental change, linking molecular proxy records with regional anthropogenic activities and land-use changes (agricultural intensification, forest clearance, etc.). This long-term ecological and environmental perspective provides critical scientific evidence that could support the restoration strategies and helps the stakeholders in lake management and its restoration.

Keywords: High-altitude lakes, land-use change, N-alkanes, pollution history, polycyclic aromatic hydrocarbons (PAHs)

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Microclimatic variability in diversely used landscapes of the northern Ecuadorian Andes: An exploratory investigation of the sites Atahualpa and Mojanda

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Mountain regions are among the most dynamic climate spaces on Earth. In the tropical Andes of Ecuador in particular, the complex topography leads to pronounced differences in temperature, moisture, and radiation over very short distances. Microclimatic conditions are closely linked to vegetation structure, influence local biodiversity, and may buffer or amplify species exposure to broader climatic changes. Therefore small-scale microclimatic differences are thus directly relevant to the preservation of regional biodiversity. However, systematic field measurements at the scale of a few hundred metres are largely absent in the Ecuadorian Andes.

This bachelor's thesis aims to record and characterise temperature and soil moisture differences at a small spatial scale in order to comparatively describe microclimatic variability between pastureland, paramo grassland, and mountain cloud forest. The study draws on data from 27 TOMST sensors (model TMS-4) installed in September and October 2025 at the sites Atahualpa (2,100 m a.s.l.) and Mojanda (4,010 m a.s.l.). These sensors continuously measure near-surface temperature at three depths (6 cm below the surface, 2 cm above the surface, and 15 cm above the surface) as well as soil moisture at ten-minute intervals, enabling high-resolution recording of microclimatic conditions directly within the habitat of organisms. In addition, terrain parameters such as elevation, aspect, vegetation cover, and slope form are recorded, alongside remote sensing data from Sentinel-2 imagery and digital elevation models.

The analysis of the TOMST data is carried out using descriptive statistics as well as variance and correlation analyses in R, employing the myClim package in R. The results aim to show how strongly soil and near-surface temperature and soil moisture vary over short distances between the study sites and which terrain properties drive these differences. A better understanding of these small-scale microclimatic patterns provides an empirical basis for assessing habitat quality, modelling biodiversity patterns, and developing land management and climate adaptation strategies in the northern Ecuadorian Andes.

Keywords: Biodiversity, land use, microclimate, mountain cloud forest, northern Ecuadorian Andes, Paramo, soil moisture, soil temperature, Tomst sensors

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Understanding the wildfire risk landscape: Implications for forest ecosystem conservation in Tolima, Colombia

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Altered wildfire regimes caused by anthropogenic disturbances and global warming are a growing concern in tropical ecosystems. Indeed, critical ecosystems such as the Andean moorlands and different forest types were severely impacted by fires that burned over 73,000 hectares in 2017, with 95 % of these events in Colombia caused by human activities. Despite efforts by public and private Colombian institutions to assess the impact of forest fires over the years, a reliable protocol for evaluating these disturbances remains to be established. To address this, we aimed to evaluate the effects of forest fires through multi-temporal analysis and climate variability over seven years in the Tolima Department, Colombia. We integrated MODIS and VIIRS thermal sensor data with CHIRPS climate datasets and CORTOLIMA (the regional environmental authority) vegetation cartography. We applied the national IDEAM protocol alongside Kernel Density Estimation (KDE) with Natural Breaks (Jenks) to transform discrete hotspot points into continuous spatial density maps, enabling the identification of critical risk clusters. Our findings reveal that in 2017, rainfall was insufficient to counter the fires, whereas in 2022, record-high precipitation drastically reduced active hotspots. However, our mapping from 2016–2023 shows that fires consistently occurred in the same critical ecosystems each year. Ultimately, our research contributes to regional contingency planning mechanisms, providing a strategic framework for adapting to climate change and mitigating wildfire impacts in Tolima, Colombia.

Keywords: Forest fire

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Ecosystem restoration and social cohesion interlinkages: The case study of western Rwanda

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Ecosystem restoration (ER), often referred to as restoration, is recognised as a response to global land degradation. Common approaches to ER include agroforestry, watershed protection, woodlots and homegarden. However, ER is complex, and each approach can sometimes produce unpredictable outcomes. While increasing attention is being given to social dimensions in ER design, the dynamics between ER and social cohesion (SC) can differ from context to context, and this remains insufficiently explored, particularly in post-conflicts countries. This study investigates the interrelations between ER and SC for the case of Western Rwanda. We apply the methodology based on systems thinking to explore how each ER approach: agroforestry, watershed protection, woodlot and homegarden interrelates with SC dimensions. The results depicted through causal loop diagrams revealed that ER, depending on different drivers, can produce both negative and positive feedbacks. ER enhances different dimensions of SC, such as social relations such as social interactions, cooperation and trust, social integration, shared norms and values, and collective wellbeing, as well as a sense of belonging for the financially marginalised community members. SC dimensions also support the effectiveness and enhance ER community ownership. Differently, ER also reinforces resource competition, spatial marginalisation and conflicts among the community members. Based on these findings, policymakers and practionners should move beyond a tokenistic community participation to co-designing ER with the community beyond, empower traditional institutions to resolve conflicts, aligning ER design with local livelihood needs and promoting local resource sharing such local knowledge and skills sharing, tools and materials, through ER policies and implementation strategies to enhance restoration resilience.

Keywords: Agroforestry, causal loop diagram, homegarden, social cohesion, watershed protection, woodlot.

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Socio-economic determinants of farmer managed natural regeneration (FMNR) adoption among smallholders in semi-arid Kenya

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Land degradation threatens ecosystems and rural livelihoods, especially in Africa's drylands. Farmer Managed Natural Regeneration (FMNR) is a low-cost land restoration practice that regenerates trees, improves soil and water retention, and enhances resilience. Yet adoption remains uneven, and its drivers are poorly understood. This study examined determinants of FMNR in semi-arid Baringo County, Kenya, using survey data from 288 smallholder households (145 FMNR adopters and 143 non-FMNR adopters) in different parts of Baringo County. Structured interviews captured demographic, socioeconomic, institutional, and farm-level factors.

Descriptive statistics compared groups, and logistic regression identified adoption predictors. Longer residence strongly increased FMNR adoption, reflecting how tenure security and ecological knowledge encourage long-term restoration. Female-headed households were more likely to adopt (β = -0.665, $p = 0.043$), while household labour availability, proxied by household size ($\beta = 0.115$, $p = 0.031$) and spousal support ($\beta = 0.171$, $p = 0.002$), was critical. Education of the household head also enhanced uptake. Contrary to portrayals of FMNR as a pro-poor agroforestry practice, adopters were wealthier, suggesting labour and assets drive adoption. Access to extension services was a key predictor of FMNR adoption, underscoring the role of institutional support. FMNR adoption was significantly driven by both on-farm native tree diversity ($\beta = 0.197$, $p = 0.007$) and benefits from non-native trees ($\beta = 0.161$, $p = 0.031$). Overall, FMNR adoption is shaped by tenure security, household labour, education, and extension services. Scaling FMNR to combat land degradation requires government-led extension, support for poorer households, and gender-responsive, locally adapted restoration strategies.

Keywords: Adoption, FMNR, Kenya, land degradation, smallholders, socio-economic determinants

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Social norms drive conservation intentions in Indonesia's songbird trade system

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Wildlife trade represents a major driver of biodiversity loss, yet conservation interventions often fail when they do not account for the behavioural and social dynamics underlying resource use in multifunctional landscapes. In Indonesia, the songbird trade is deeply embedded in socio-cultural practices and semi-formal market systems, linking rural bird capture with urban demand and competitive bird-keeping. These dynamics unfold within forest–agriculture mosaics where biodiversity, livelihoods, and land-use practices intersect. This study examines conservation intention among actors involved in the songbird trade in Central Java using an integrated behavioural framework. A total of 827 respondents were surveyed across six rural forest-adjacent villages and the urban centre of Purwokerto. Structural equation modelling was used to analyse the influence of attitudes, subjective norms, and perceived behavioural control on intentions to stop wild bird capture. To contextualize these relationships, 30 semi-structured interviews were conducted with key actors, including bird catchers, traders, breeders, hobbyists, and competition participants. Across both rural and urban contexts, subjective norms emerged as the strongest predictor of conservation intention (rural $\beta = 0.63$; urban $\beta = 0.57$), while attitudes and perceived behavioural control showed comparatively weaker effects. Qualitative findings indicate that behaviour is shaped by social expectations, reputational dynamics, and systems of collective legitimacy rather than individual evaluation alone. While pro-conservation attitudes and environmental awareness were widespread, these did not consistently translate into behavioural intention, highlighting an attitude-behaviour gap. Perceived behavioural control further reflected structural constraints, particularly among economically dependent actors. These findings suggest that conservation behaviour in wildlife trade systems is strongly socially embedded and shaped by both normative environments and structural feasibility. Interventions that leverage peer influence, shift social expectations, and improve access to viable alternatives are likely to be more effective than approaches focusing solely on awareness or individual attitudes. More broadly, the results highlight the importance of integrating behavioural insights into the governance of multifunctional socio-ecological systems.

Keywords: Behavioural change, conservation behaviour, rural-urban dynamics, wildlife trade

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Soil macrofauna and land use in Mékrou watershed: FLR implications

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Soil degradation and drought threaten the sustainability of livelihoods in rural Benin, where deforestation for agricultural purposes may create a vicious cycle. Forest and Landscape Restoration (FLR) practices – such as agroforestry – could mitigate these effects in the region. However, the influence of these practices on soil ecosystem services through these region watershed, particularly soil living hoods communities, remains insufficiently studied. This study assessed the influence of three land use types (2–4-year-old cropland, fallow land and shea tree agroforestry) on soil related fauna through the altitudinal gradient of the Head of Mékrou watershed. Surface-active soil macrofauna abundance, taxonomic composition and Community richness, varied significantly across watershed sections ($p \leq 0.001$). On the other hand land use influenced abundance, with lower values recorded in cultivated land than in agroforestry systems ($p = 0.041$). Community composition was significantly structured by watershed location (Upper part, middle and down stream) (PERMANOVA, $R^2 = 21.7\,\%$, $p = 0.001$), and several indicator taxa were associated with specific watershed sections. This suggest that the FLR practice of preserving shea and néré trees in agroforestry parklands and natural regeneration promotes the presence of surface macrofauna, thus contributing significantly to improved long-term soil quality compared to conventional cropping systems. This makes them relevant early indicators of future developments not only in soil quality but also in the state of microclimates within watersheds. In the context studied, agroforestry systems and short-term natural regeneration therefore offer greater potential than continuous cultivation for the sustainable maintenance of soil health and associated ecosystem services. These results offer valuable insights for guiding forest landscape restoration (FLR) strategies implemented by local actors, particularly in similar systems in sub-Saharan Africa and other subtropical regions.

Keywords: Agricultural sustainability, agroforestry parkland, forest and landscape restoration (FLR), hydrological unit, macrofauna, sub-Saharan Africa

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Enrichment planting and soil-water conservation: Restore degraded dryland agro-ecosystems in Ethiopia

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Degraded dryland agro-ecosystems threaten food security, livelihoods, and climate resilience across semi-arid sub-Saharan Africa. In Ethiopia's Banaka-Bako sub-watershed (Malle district, South Ethiopia Region), decades of deforestation and overgrazing have rendered vast areas nearly bare, undermining the multi-functional services these landscapes could provide. This study evaluated four land restoration approaches to identify optimal strategies for rehabilitating degraded agro-ecosystems while enhancing climate resilience and rural livelihoods: T1 (natural regeneration, no soil and water conservation [SWC]); T2 (natural regeneration + SWC); T3 (enrichment planting, no SWC); and T4 (enrichment planting + SWC). Established in 2021 under area-exclosure using a randomised complete block design, treatments were monitored over four years (2021–2025) through participatory methods engaging 50 farmers and 10 community members. Indicators included vegetation diversity and growth (tree density, DBH, species richness, and Shannon-Wiener index); soil health (organic matter, total nitrogen, available phosphorus, CEC, and bulk density); socio-economic outcomes (income and adoption rates); and remote sensing indices (NDVI and NDMI via Sentinel-2). Initially, all plots were near-bare (tree density: 4–-6 trees ha^{-1}; NDVI: 0.12–0.18; soil OM: 0.14–0.21 %). By 2025, T4 demonstrated outstanding ecosystem recovery: tree density reached 350 trees ha^{-1} (+6,900 %); species richness, 10; NDVI, 0.65 (+30 %); soil OM, 1.21%; and household income, 8,400 ETB ha^{-1} year^{-1}, with 60 % farmer adoption. T2 performed comparably (300 trees ha^{-1}, NDVI 0.60, OM 3.44 %, income 7,200 ETB ha^{-1}), significantly outperforming both T1 and T3 ($p < 0.01$). Fanya juu terraces and stone bunds proved critical, enhancing soil moisture retention and stabilisation. These results demonstrate that combining enrichment planting with SWC structures creates a powerful synergy for transforming degraded wastelands into productive, multi-functional agro-ecosystems – delivering biodiversity gains, climate adaptation, and improved rural incomes simultaneously. The approach aligns with Ethiopia's Green Legacy Initiative and offers a scalable, community-driven model for climate-resilient landscape restoration across the Horn of Africa.

Keywords: Area closure, forest landscape, rehabilitation, soil and water conservation practices

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The relative abundance of the target species with the impacts of fishing gears on red sea fisheries sustainability, Egypt

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The depletion of fish stocks in the world's oceans and the use of increasingly sophisticated industrial fishing techniques are resulting in heavy damage to precious marine ecosystems. Ocean resources are diminishing dangerously due to overfishing, pollution and global warming. This depletion is of particular concern in all world's countries, where fish, a source of revenue for millions of people, takes on major importance in terms of food security.
Fishing is one of the most important employers and sources of cheaper protein for people in Egypt. Three main fishing methods are deployed in Egyptian Red Sea fisheries; bottom trawl; purse seine and artisanal ones. Bottom trawls constitute about 19 % of the Egyptian Red Sea fisheries forming about 51 % of the gross revenue due to the high price of shrimp and cephalopods while purse seine constitutes about 65 % and artisanal fishery shared by 16 % of the Red Sea catch in Egypt. The Egyptian Red Sea fisheries are multispecies – multifleet fisheries with destructive fishing gears that impacted the fish production and harm the marine environment.
The present research will focus on the Egyptian Red Sea biodiversity and will describe some of the most vulnerable marine ecosystems and the types of damage that may be caused, either directly or indirectly, by fishing gears and how to reduce these harmful impacts. Also, the relative abundance of target species will estimated based on catch per unit effort. The impacts of fishing activities on the functioning of ecosystems (catching juvenile fish, damaging the seafloor, harming coral reefs, sharks, and sea turtles that attract valuable tourism to Egypt) will be discussed.

Keywords: By-catch, catch per unit effort CPUE, fisheries management, fishing gear selectivity, habitat loss, red Sea

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Deforestation-driven changes to hydrological dynamics in West Africa: A systematic review

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West Africa is experiencing one of the fastest rates of forest loss globally, with major implications for hydrological processes and sediment dynamics. Understanding these impacts is critical for evidence-based land-use planning and sustainable water resource management. This systematic review following PRISMA methodology (n=32) synthesizes and evaluates current evidence on deforestation in West Africa, specifically its effects on hydrological processes and sediment dynamics. The review shows that research has predominantly focused on hydrological and sediment transport processes at broader landscape levels with mayor study publish at the watershed level. It find that the average deforestation rate in West Africa (1.27 % yr^{-1}) substantially exceeds recent global averages reported by the FAO (0.2–0.3 % yr^{-1}) and the continental African average (0.6–0.7 % yr^{-1}), with rates ranging from 0.1 to 4 % yr^{-1} depending on forest type and period. Forest loss and subsequent conversion, particularly to cropland and built-up areas, consistently drive changes in hydrology, including increased surface runoff, higher peak discharges, increased sediment export, and concurrent reductions in baseflow and groundwater recharge. The review further indicates that increasing forest cover may enhance overall water availability without necessarily amplifying surface runoff, however overall hydrological responses are highly context-dependent and vary with forest type, post-conversion land use, and climatic conditions. The review also identifies three key research gaps: limited empirical evidence from West Africa, insufficient isolation of deforestation as a distinct driver, and a strong reliance on modelling approaches. Addressing these gaps is essential for strengthening the evidence base underpinning water resource management and Forest Landscape Restoration (FLR) initiatives in the region.

Keywords: Deforestation, forest landscape restoration, governance, hydrological dynamics, land-use change, West Africa

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Peri-urban cropland sustains avian biodiversity in tropical cities: Evidence from urban India

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Rapid urban expansion in India, projected to add over 350 million urban residents by 2050, occurs through converting peri-urban croplands, plantations and fallows into built-up land. While these croplands sustain food production, their impact on urban biodiversity remains poorly understood, despite relevance to multifunctional land-use design in the Global South. Most urban ecology evidence comes from temperate cities with diverse agricultural systems. This study examines whether peri-urban croplands support bird communities comparably to built-up and other vegetated covers across three tropical Indian cities representing distinct biogeographies. Bird data came from 360 fixed-radius point counts (120 per city) during December-February of 2020–2021 (Bhopal, Patna) and 2023–2024 (Coimbatore), yielding 14,576 individuals across 155 species. Observations were paired with land-cover data (Bhuvan Level-II) within 100 m of each site, and a multi-scale framework combined community-level richness with species-level occurrence and abundance models to disentangle impervious cover from vegetated and agricultural matrix. City-wide change was quantified in Google Earth Engine using GHSL built-up (2000–2020) and ESA WorldCover cropland (2021). Within sampling buffers, cropland accounted for 67 % of vegetated cover, indicating birds encountered an agricultural rather than remnant natural matrix. City-wide built-up expanded 23–49 % (2000–2020; Bhopal 49 %, Coimbatore 37 %, Patna 23 %), while cropland still occupied 7–32 % of municipal area in 2021. Negative binomial mixed-effects and species-level probit and negative binomial regressions spanned 55,800 species-by-site observations. Site-level richness declined with built-up cover, but disappeared once vegetation and water cover were included (ΔAIC = 24.2), with vegetation remaining a positive predictor. The cost of impervious surface, therefore, operates through loss of the vegetation it replaces. Replacing 1 % built-up with 1 % cropland raised occurrence probability by 0.020 and abundance by 0.16 individuals per species per site (both $p < 0.001$); cropland was statistically equivalent to fallow and plantation, with only scrubland supporting significantly higher abundance. Built-up cover also restructured composition through turnover rather than nested loss (partial Mantel r=0.098, $p = 0.001$), with declining multivariate dispersion, a signature of biotic homogenisation that cropland retention helps offset. For tropical cities, where most of this century's urban growth will consume peri-urban agriculture, these findings reframe cropland as multifunctional land delivering biodiversity alongside food.

Keywords: Cropland, land-use planning, tropical cities, urban birds

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Impacts of perennial plants diversity on carbon stock and bird species in Maradi city, Niger

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Past studies have clearly pointed out the importance of residential urban forests to support carbon storage and food production. Only a few studies have focused on the presence of perennial plant species diversity on bird diversity in West Africa Sahel cities where the construction of homes is subjected to limited government regulation. Our study evaluated urban residents' perceptions of perennial plants (trees and shrubs)) at their yards and evaluated their impact on carbon storage and bird biodiversity across different neighbourhoods in the city of Maradi, Niger. We surveyed 102 homes within 17 neighbourhoods with 6 houses per neighbourhoods then added a data set ($n = 21$) of one additional study providing a total of 123 household visits. All respondents were able to cite the local names of the perennial species. Shading was the main reason (54 %) for tree planting in housing areas ($p = 0.027$). A total of 583 perennial were inventoried. Collectively, there were 63 perennial species belonging to 52 genera and 23 botanical families. The carbon stock density resulted in a total of 25.8 t ha^{-1} and varied ($p \leq 0.001$) in each perennial species; *Azadirachta indica* (Neem) had the highest carbon stock density (13.4 t ha^{-1}) followed by *Terminalia mantaly* (3.3 t ha^{-1}), *Balanites aegyptiaca* (1.9 t ha^{-1}), and *Eucalyptus camaldulensis* (1.2 t ha^{-1}). Neem dominated in the 17 neighbourhoods within the city ($p < 0.05$) and was most visited by birds (9 bird species), followed by *Mangifera indica* (5 bird species). Ten bird species belonging to 8 families and 10 genera were observed, where the village weaver (*Ploceus cucullatus*, 31%) and the laughing dove (*Spilopelia senegalensis*, 20 %) were the most dominant. There was a pronounced difference between the number and diversity of bird species across the 17 neighbourhoods influenced by the number of perennial species ($p \leq 0.001$, each). The study recommends to increase planting of indigenous perennial species in the residential areas' tree planting programs and should be part of recommended actions to address climate changes and biodiversity loss in Niger. Knowing the urban tree and bird species diversity is connected to the Water-Energy-Food (WEF) nexus by acting as a foundational ecosystem indicator and active regulator.

Keywords: Bird diversity, carbon storage, green city, residential urban forests, semi-arid climates, urban trees

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Community seed banks and the emergence of multifunctional agroecosystems in climate-vulnerable smallholder systems: Evidence of sustainability trade-offs in Kenya

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Background: Agroecological transitions are increasingly promoted as pathways to climate-resilient and sustainable food systems, yet empirical evidence on how specific interventions shape multidimensional outcomes remains limited. Community seed banks (CSBs) are widely recognised for strengthening local seed systems and agrobiodiversity, but their broader contributions to agroecosystem transformation are not well understood.

Methods: This study evaluates the role of a nutrition-sensitive CSB intervention in driving agroecological transitions and sustainability outcomes among smallholder farmers in Vihiga County, Kenya. Using cross-sectional data from 239 households, we apply the FAO Tool for Agroecology Performance Evaluation (TAPE) combined with propensity score matching and mixed-effects regression models to estimate intervention effects and isolate relationships between agroecological elements and sustainability outcomes.

Results: Results show that CSB participation is associated with significantly higher agroecological transition levels, with mean CAET scores of 54.2 in intervention sites compared to 41.1 in non-intervention areas ($p < 0.001$). Over half (55 %) of participating households reached transition stages, compared to 16.8 % in comparison sites, and 7.5 % achieved advanced agroecological status, while none did in non-intervention areas. The intervention strongly improved knowledge co-creation, governance, and circular economy practices. However, direct impacts on sustainability outcomes were uneven. While pesticide exposure reduction improved significantly (+12 percentage points, $p = 0.019$), effects on income, dietary diversity, and soil health were limited or non-significant. Instead, overall agroecological transition levels showed stronger and more consistent associations with key outcomes, including food security ($B = 0.45$, $p = 0.001$), soil health ($B = 0.19$, $p = 0.009$), and agricultural biodiversity ($B = 0.24$, $p < 0.001$).

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Disaggregated analysis reveals important trade-offs. Diversity practices were positively linked to economic performance, while efficiency improved environmental outcomes but reduced income. Resilience practices enhanced land tenure and women's empowerment but were associated with lower short-term economic returns.
Conclusions: These findings demonstrate that while CSBs can catalyze agroecological transitions, sustainability outcomes depend on how different agroecological elements interact. Improvements in transition levels and key elements such as diversity and efficiency also suggest potential gains in adaptive capacity within smallholder systems. Designing climate-resilient agroecosystems therefore requires integrated, context-specific strategies that balance ecological, economic, and social objectives.

Keywords: Agroecological transitions, climate-resilient agroecosystems, community seed banks, multidimensional sustainability, smallholder farming systems

Harnessing underutilised legumes for climate-resilient, nutrition-sensitive agroecosystems: The case of African yambean

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Underutilised legumes offer significant opportunities for building climate-resilient and multifunctional agroecosystems in the Global South. Among these species, the African yambean (*Sphenostylis stenocarpa*) stands out for its adaptability to marginal soils, dual-purpose (tuber and seed) productivity, and high-quality protein. Despite these advantages, its potential remains underexploited due to limited research investment, low farmer awareness, and processing constraints. This study synthesises over two decades of biochemical and processing research on African yambean, including improvements achieved through solid-state and lactic acid fermentation, as well as novel non-traditional methods that enhance nutritional value, reduce antinutritional factors, and improve functional properties essential for food applications. The analysis evaluates African yambean's role within climate-smart agricultural systems, with emphasis on its contributions to soil fertility through biological nitrogen fixation, its suitability for intercropping designs that support biodiversity, and its resilience under increasing climatic stress. Evidence indicates that the crop's enhanced nutritional profile – particularly after fermentation – positions it as a viable component of nutrition-sensitive food systems aimed at addressing malnutrition and micronutrient deficiencies. Furthermore, the study explores opportunities for integrating African yambean into local value chains through small-scale processing enterprises, improved seed systems, and policy incentives that support underutilised crops. These pathways align with the CGIAR Multifunctional Landscapes agenda by linking food production, soil health restoration, and livelihood diversification. The crop's versatility also supports circular bioeconomy approaches, including the use of processing residues for livestock feed. Overall, African yambean emerges as a strategic crop capable of strengthening multifunctional agroecosystems, enhancing dietary diversity, and contributing to sustainable land-use transformation. The study concludes by recommending interdisciplinary research, participatory varietal development, and community-driven processing innovations to mainstream African yambean within climate-resilient agrofood systems.

Keywords: African yambean (*Sphenostylis stenocarpa*), underutilised legumes

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Mobilising agrobiodiversity in India to support planet-friendly school meal programs: Insights from participatory crop selection

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India's mid-day meal scheme reaches over 112 million children daily, yet a persistent disconnect between school menus and local agrobiodiversity limits its nutritional quality, ecological sustainability, and cultural relevance. Addressing this gap is at the heart of a broader effort, led by the Alliance of Bioversity International and CIAT under the CGIAR Multifunctional Landscapes and Policy Innovation Science Programmes, that seeks to reimagine school feeding by integrating local agrobiodiversity into public procurement and building agrobiodiverse food systems aligned with India's commitments under the Convention on Biodiversity (CBD).

To advance this agenda, a participatory crop selection exercise using a quadrant-based prioritisation framework was conducted in Mandla district, Madhya Pradesh, a tribal-dominated region, as a part of the ongoing school meal initiative. In the activity, key community stakeholders such as producers, school cooks, parents and school faculties collectively evaluated 53 locally available species across four dimensions: agroecological performance, nutritional value, farmer and consumer experience, and procurement feasibility. Shortlisted crops then underwent structured deep-dive discussions to map practical leverage points for school meal integration.

From this exercise, 13 priority crops were selected. Pumpkin (Cucurbita pero), colocasia (Colocasia esculenta), and cowpea (*Vigna unguiculata*) emerged as the strongest candidates, valued for their low input demands, locally saved seed systems, and broad acceptance among children. However, the exercise also surfaced persistent challenges, including seasonal volatility and labour-intensive processing for certain species such as jackfruit (*Artocarpus heterophyllus*).

Our observations demonstrate that embedding underutilised crops into school feeding programmes can simultaneously advance nutrition and agrobiodiversity. Beyond identifying locally appropriate crops, the participatory quadrant approach generated a community-owned roadmap, surfacing practical entry points, shared priorities, and co-created pathways for integrating agrobiodiversity into school meals. This positions the approach not merely as a crop selection tool, but as a foundation for sustained, community-driven action with direct relevance for nutrition-sensitive agricultural policy, public procurement reform, and integrated landscape planning.

Keywords: Agrobiodiversity, nutrition, participatory crop selection, school meal

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Agrivoltaics an incentive mechanism for the WEFE nexus: A perspective from Colombia's just energy transition

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This study presents a perspective on agrivoltaic (APV) systems as incentive mechanisms to align energy access, agricultural production, ecosystem conservation, and local value addition within the Water–Energy–Food–Ecosystem (WEFE) nexus. It draws on the design of the JET-AgriSOL project, implemented in Colombia in alignment with the country's Just Energy Transition (JET) agenda, and argues that APV can move beyond a technological innovation to function as a governance instrument that structures incentives across sectors and actors.

In the Amazonian deforestation frontier of Caquetá, APV systems are conceptualised as embedded within dairy value chains to link on-farm energy access with zero-deforestation commitments of downstream buyers. The perspective highlights how value-chain finance mechanisms can connect the energy needs of milk producers (such as reliable electricity for milk cooling) with responsible sourcing strategies of dairy companies. By structuring co-investments in APV infrastructure, energy access can be made conditional on compliance with zero-deforestation requirements, creating a direct economic link between climate-smart production and market incentives.

In parallel, in the highland agrobiodiversity systems of Cumbal (Nariño), APV installations are framed as complementary to Payments for Agrobiodiversity Conservation Services (PACS), in collaboration with the CGIAR Multifunctional Landscapes Science Program. Here, energy access and processing capacity are linked to the conservation of underutilised native crops, while enabling local value addition and entrepreneurship through small-scale processing and product diversification.

Building on these cases, the study proposes a framework of adoption and outcome indicators to assess how APV systems may influence decision-making across WEFE domains, including energy use, inclusion, land management, water interactions, biodiversity conservation, and value creation. The framework integrates insights from existing literature with the design of monitoring systems for upcoming pilots.

The perspective advances the argument that APV systems can serve as a lever for integrated resource governance by embedding energy infrastructure within value-chain conditionality and conservation incentives. It outlines how such mechanisms can be empirically tested and refined, contributing to a more systemic understanding of how energy innovations can catalyze synergies across WEFE domains in contexts characterised by weak conservation incentives.

Keywords: Agrivoltaic, incentive, just energy transition, nexus, perspective

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Neglected and underutilised crops as drivers of climate-resilient food systems: A comparative total factor productivity analysis in Uganda and South Africa

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Agricultural systems in Sub-Saharan Africa face increasing pressure to enhance productivity while adapting to climate change and resource constraints. Current food systems remain heavily dependent on a narrow range of input-intensive staple crops, contributing to environmental degradation, reduced biodiversity, and vulnerability to climatic shocks. In this context, neglected and underutilised crops (NUCs) offer significant potential to support climate-resilient and sustainable food systems due to their adaptability, low input requirements, and nutritional value. However, their economic productivity relative to staple crops remains insufficiently quantified.

This study addresses this gap by providing empirical evidence on whether NUCs can contribute to climate-resilient food systems through a comparative analysis of Total Factor Productivity (TFP) in Uganda and South Africa. A sequential mixed-methods approach was employed. First, an integrative literature review synthesizes evidence showing that NUCs enhance climate resilience, improve soil health, support agrobiodiversity, and contribute to nutritional diversity in smallholder systems. Second, a quantitative analysis applies Data Envelopment Analysis and the Malmquist Productivity Index on a harmonised panel dataset (2010–2022).

The findings reveal that NUCs achieve statistically comparable TFP to staple crops, challenging perceptions of their economic inferiority. Distinct productivity pathways emerge in South Africa, productivity growth is driven by technological progress, whereas in Uganda it is sustained through efficiency gains under low-input conditions. Importantly, NUCs maintain competitive productivity with lower external input use, indicating higher resource-use efficiency.

These results demonstrate that NUCs can support climate-resilient food systems through sustainable intensification and diversification. Strengthening policy support, value chains, and investment in NUCs will be essential.

Keywords: Agro-biodiversity, climate-resilient food systems, Malmquist index, neglected and underutilised crops, resource-use efficiency, South Africa, sustainable intensification, total factor productivity, Uganda

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The role of community-based ecosystem restoration in forest structure dynamics and livelihood improvement in Indonesia: An integrated geospatial and structural equation modelling approach

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The Conservation Partnership in Ecosystem Restoration (CPER) is an Indonesian government programme that aims to restore damaged ecosystems in conservation areas by integrating a community-based social and ecological approach. Although interest in restoration is growing, few studies link livelihood outcomes to ecosystem performance. This study looks at how effective CPER has been after almost ten years by examining its impact on the livelihoods of participating communities and its role in helping forests recover. Using the Sustainable Livelihood Approach, the research focuses on five types of livelihood capital: human, social, physical, natural, and financial, and explores how these affect community socioeconomic outcomes. To study the ecological side, the research uses Geographic Information Systems, object-based image analysis, Random Forest classification, high-resolution satellite images, and drone surveys to track changes in land cover and improvements in forest structure. Partial Least Squares Structural Equation Modelling was used to study the links between livelihood capitals and socioeconomic conditions. The results show that most participants had high levels of human capital (81.5 %), social capital (73.1 %), physical capital (75.0 %), and natural capital (73.1 %), but financial capital was only moderate, with few people reporting strong financial resources. The model shows that physical capital has the biggest positive effect on socioeconomic outcomes ($\beta = 0.362$, $p < 0.001$), followed by natural capital ($\beta = 0.259$, $p = 0.001$) and financial capital ($B = 0.212$, $p = 0.016$). Human and social capital did not have significant direct effects. Spatial analysis found that forest cover increased steadily at the study sites, especially in Lempang Balong and Muntjul Masigit. This suggests that restoration efforts were effective, with overall accuracy between 95 % and 98 % and kappa values from 0.89 to 0.97, supporting the reliability of the geospatial methods. The decrease in secondary forest points to structural succession, while the growth of critical land seems linked to local farming rather than widespread degradation. These results suggest that CPER has positively contributed to forest recovery and local socioeconomic conditions, through practical livelihood assets. The study presents a combined social and ecological evaluation framework and gives evidence-based recommendations to improve community-led ecosystem restoration policies in Indonesia.

Keywords: Conservation partnership in ecosystem restoration, forest cover change

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Carbon accumulated after 11 years with two native species in an agricultural area in Colombia

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The lowlands of the Andean Mountains in Colombia have acidic, low-fertility soils, necessitating conservation practices to mitigate natural degradation. This study evaluated carbon stocks in above-ground biomass (AGB) and soil in land used for pasture, sugarcane, and cocoa for 60 years. In September 2014, three monoculture plots (each 30 × 30 m) were established with *Cariniana pyriformis* (abarco) and *Schizolobium parahyba* (paricá) in the Santander department, Colombia. The planting spacing was 5 m × 5 m. After 11 years, soil samples (0–10 cm deep) and tree measurements (DBH, height, and survival) were collected in each plot.

A nearby secondary forest without human intervention for about 40 years was also evaluated with three plots. AGB was estimated using allometric equations developed locally for abarco and paricá, while the equation of Chave et al (2014) was used for the secondary forest. AGB was converted to stock carbon using a factor of 0.5. Soil carbon stock at 10 cm depth was determined from carbon concentration (Walkley-Black method) and bulk density. The mean values for soil carbon, AGB, and forest system (soil + AGB) were analysed using ANOVA and Tukey's test ($p < 0.05$). The paricá plantation (55.4 Mg ha^{-1}) accumulated significantly more carbon in the soil than the secondary forest and the abarco plantation (mean = 37.1 Mg ha^{-1}). There were no differences between the native species in any component. However, carbon in the AGB (mean = 31.1 Mg ha^{-1}) and forest system (mean = 78 Mg ha^{-1}) for both native species was 5.7 and 2.8 times lower than in the secondary forest, respectively. The results show that both species could be viable options for soil restoration in these degraded areas. However, in terms of AGB, this process remains slower than in the reference secondary forest.

Keywords: Aboveground biomass, *Cariniana pyriformis*, forest restoration, tropical ecosystems

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Economic potential and trade dynamics of medicinal plants: Implications for biodiversity conservation and climate-resilient livelihoods

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Medicinal plants play a crucial role in supporting rural healthcare systems and livelihood diversification in many parts of sub-Saharan Africa. However, increasing commercialisation of wild-harvested medicinal plants raises concerns about the sustainability of harvesting practices and the conservation of plant biodiversity. This study assessed the economic potential and market dynamics of two commonly traded medicinal plant species, Zanthoxylum chalybeum and Commiphora species, in northern Tanzania. The research was conducted in Arusha Municipal Council, Karatu District Council, and Babati District Council, areas located near ecosystems where these species naturally occur and where traditional medicine markets are active. A cross-sectional mixed-methods approach was employed, combining quantitative market surveys with qualitative interviews of traditional medicine practitioners and vendors.

Data were collected from 227 respondents using structured questionnaires administered through KoboToolbox. Information gathered included plant species sold, plant parts used, diseases treated, dosage duration, quantity traded, and price per unit. To enable standardised economic analysis, commonly sold retail units such as spoonfuls and small bundles were converted into grams and kilograms using digital weighing scales. The results indicate active commercialisation of both species across the study area. Monthly trade volumes were estimated at approximately 15.25 kg for Zanthoxylum chalybeum and 4.65 kg for Commiphora species, with corresponding market values of about TZS 1.5 million and TZS 862,600, respectively.

The findings highlight the significant economic contribution of wild medicinal plants to local livelihoods and traditional healthcare systems. However, the reliance on plant parts such as roots and resin raises sustainability concerns due to destructive harvesting practices. Strengthening sustainable harvesting guidelines, promoting cultivation of high-value medicinal plants, and integrating traditional knowledge into biodiversity conservation strategies could enhance the role of the medicinal plant trade in supporting climate-resilient and multifunctional agro-ecosystems in Northern Tanzania.

Keywords: Biodiversity conservation, climate resilience, livelihoods, medicinal plants, sustainable use of natural resources, traditional knowledge

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Mapping waste flows and leakage pathways in the Lake Victoria basin

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Sustainable waste management is increasingly critical for maintaining the integrity of agro-ecosystems, particularly in rapidly urbanizing regions where mismanaged waste contributes to soil, water, and ecosystem degradation. In many parts of sub-Saharan Africa, including the Lake Victoria Basin in Kenya, waste planning is constrained by limited and fragmented data on waste generation, composition, and leakage pathways. This restricts the ability to assess environmental risks and design effective interventions to protect water bodies and surrounding agricultural systems. This study examines the application of WasteWise, a web-based decision-support tool, to analyse waste burdens within the Kenyan Lake Victoria Basin. The tool integrates spatial and non-spatial data inputs to generate outputs including waste flow profiles, spatial distribution patterns, and estimates of waste leakage into the environment. These outputs are used to quantify waste burdens and identify high-risk zones contributing to pollution of the lake and its surrounding landscapes. The analysis provides location-specific insights into waste generation rates, composition, and spatial variability, with particular attention to organic fractions that affect both environmental quality and resource recovery. By mapping leakage pathways and identifying hotspots, the tool supports a better understanding of how urban waste systems interact with aquatic ecosystems and downstream agricultural environments.

The findings highlight the scale and spatial concentration of waste-related pressures within the basin and demonstrate how improved data structuring can support more informed planning and environmental management. In particular, the results underline the importance of integrating waste management into broader agro-ecosystem and water management strategies. This study contributes to the ongoing CGIAR Multifunctional Landscape Science Program in Kenya and discussions on climate-resilient and multifunctional agro-ecosystems by illustrating how digital tools can support the quantification of environmental pressures and inform context-specific responses in data-constrained settings.

Keywords: Agro-ecosystems, decision-support tools, environmental pollution, leakage pathways, resource recovery, waste flows

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Agroecology, conservation, and restoration in farming landscapes

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Agrobiodiversity as a conservation mechanism in protected highland landscapes: A socioecological perspective from the Colombian Andes

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Agricultural activities have long been regarded as major contributors to biodiversity loss, particularly within and around protected areas. Consequently, over the past few decades, one of the main challenges in managing these areas has been designing incentives that enable rural communities to conserve ecosystems while maintaining their livelihoods. This tension is evident in the páramos of Colombia, which have been designated by law as strategic ecosystems primarily due to their role in water provision and regulation for the vast majority of the country's population. At the same time, their inhabitants are now subject to special constitutional protection because of their relationship with the land and food production.

In this context, this study examines agrobiodiversity as a key factor in biodiversity conservation within the areas of influence of two protected páramo areas in the department of Boyacá: the Siscunsi-Oceta Regional Natural Park and the Pisba National Natural Park. Using a mixed-methods approach based on socio-ecological systems (SES) theory, we characterised the agroecological structure of 46 farms in three municipalities (Sogamoso, Socha, and Tasco) within the areas of influence of the natural parks. Concurrently, three distinct conservation agreements were being developed with the communities in these areas, each led by a different institution at the regional or national level. This institutional heterogeneity allowed us to examine how context shapes the relationship between farming communities, agrobiodiversity, and conservation.

Preliminary results reveal the prevailing role of the sociocultural dimension of agrobiodiversity, which determines the potential contribution of each farm to landscape conservation. In addition to management knowledge and practices, this includes political stances regarding land use and other productive activities that compete with agriculture in protected areas. This study contributes to current debates on multifunctional landscapes and conservation beyond the boundaries of protected areas, and has direct implications for the integration of agrobiodiversity into biodiversity conservation mechanisms.

Keywords: Agrobiodiversity, conservation, incentives, protected areas

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State formation and grassroots collective action: Historical governance of grasslands and savannahs in Argentina, Colombia, and Paraguay

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Grasslands and savannahs cover around one third of the Earth's terrestrial surface and underpin large biodiversity and diverse agricultural livelihoods. Despite their importance, they remain largely overlooked in research on land governance and food systems. Their evident deterioration reinforces the urgency of approaches that foreground sustainable community-based resource management and food sovereignty as central to resilient land-use pathways. This study examines how national governance structures and historical state-building processes have shaped – and often constrained – opportunities for grassroots collective action in managing these landscapes. Using Argentina, Colombia, and Paraguay as comparative cases, we analyse how different state configurations condition the capacity of rural communities to exercise control over land use and production decisions. We apply historical institutional analysis examining both formal governance structures and the political and administrative techniques through which states consolidated territorial control, identifying how these processes have enabled or hindered spaces for community-based decision-making. Our methodology combines systematic literature review with triangulation through complementary data sources, reconstructing key stages of institutional development and their impacts on collective action. Our findings reveal that agricultural frontier expansion across all three countries systematically displaced Indigenous and campesino communities and promoted agro-industrial extractive models. These dynamics took distinct forms: agro-industrial consolidation with capital accumulation

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in Argentina, an export-oriented model with highly unequal land tenure in Paraguay, and state-sponsored colonisation amid armed conflict in Colombia. In all cases, these processes transformed landscapes while undermining pre-existing forms of collective land management and community-based autonomy. While recent policy and political shifts occasionally create openings for grassroot-led initiatives, they still conflict with institutional legacies that favour large-scale production and centralised decision-making over distributed, community-controlled food systems. We argue that recognising these historical dynamics is essential for understanding both the structural barriers facing collective action and the limited but critical opportunities for advancing governance frameworks that genuinely support community autonomy and food sovereignty. Yet the persistence of grassroots movements across centuries of dispossession and repression testifies that transformation, while constrained, remains an active and ongoing possibility.

Keywords: Agroecology, governance models, historical institutional analysis, public policies, South America

Aligning restoration with social systems: How household preferences shape social cohesion in landscape restoration in western Rwanda

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Landscape restoration is widely recognised as a key strategy for addressing land degradation, enhancing climate resilience, and improving rural livelihoods across the Global South. In Rwanda, restoration approaches such as agroforestry, woodlot establishment, watershed protection, and home gardening have been actively promoted to restore degraded landscapes and support smallholder production systems. While considerable attention has been given to the ecological and economic benefits of these interventions, their social dimensions – particularly how they influence relationships within households and communities – remain insufficiently explored.
This study investigates how household-level preferences for different restoration practices, and the degree of alignment of these preferences among household members, shape social cohesion in rural western Rwanda. Drawing on primary survey data from 300 households across eleven villages in two districts, the analysis combines descriptive statistics, composite index construction, and regression-based methods to assess impacts on both horizontal (community-level) and vertical (institutional) dimension of social cohesion.
Preliminary findings suggest that agroforestry and watershed protection are the most preferred restoration options, reflecting their perceived livelihood and environmental benefits. Crucially, households exhibiting aligned preferences among members report significantly higher levels of trust, cooperation, and effective conflict resolution. In contrast, intra-household preference divergence is associated with weaker horizontal cohesion and a greater reliance on local leadership and institutional mechanisms to mediate disagreements. Moreover, participation in restoration activities is positively associated with improved perceptions of institutional support and engagement.
These results underscore the importance of recognising households as sites of negotiation rather than unitary decision-making entities. They suggest that restoration initiatives that actively incorporate local preferences and intra-household dynamics are more likely to foster social cohesion and sustain collective action. Integrating these social considerations into restoration planning can enhance both ecological effectiveness and the inclusiveness of landscape transformation efforts.

Keywords: Community-level cooperation, household-level preferences, intra-household, landscape restoration, social cohesion

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Integrating agrobiodiversity with area-based conservation strategies to deliver effective multifunctional landscapes

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Protected areas are among the most extensively applied tools to tackle global biodiversity loss, but agro-ecosystems are largely absent from area-based conservation frameworks. This under-values and overlooks agrobiodiversity - the diversity of plants and animals that we use for food – currently maintained by millions of small-holder farmers and the foundation of future food system resilience. Here, adapting tools from wild biodiversity conservation and applying them to agro-ecosystems, we identify spatial hotspots of threatened agrobiodiversity across the Ethiopian Highlands. We integrate multiple empirical data sources, including >20,000 species records from thousands of farm surveys, crops origins, multi-decade production time-series, *ex situ* germplasm collections, and the distributions of co-occurring crop wild relatives and wild edible plants. We produce an expert-validated map, identifying regions rich in threatened indigenous crops that are declining and poorly conserved *ex situ*. These areas are priorities for host countries to sustainably manage locally evolved agricultural natural capital alongside traditional protected areas for a coherent biodiversity conservation network. We show that area-based agrobiodiversity conservation provides substantial co-benefits for the conservation of indigenous knowledge and provides spatial prioritisation for the targeting of agricultural support measures by host countries. Where monitoring can evidence effective area-based agrobiodiversity conservation, we show that these sites meet criteria for 'Other Effective Area-based Conservation Measures', supporting high agrobiodiversity countries in meeting Target 3 (30×30) of the Global Biodiversity Framework. Community managed high-agrobiodiversity landscapes, together with traditional protected areas and productivity focused landscapes can result in socially just multifunctional landscapes, that maximise food and biodiversity, while tackling development and conservation goals equitably and in unison.

Keywords: Agrobiodiversity hotspots, crop diversity, crop domestication, Ethiopia, indigenous knowledge, protected areas

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Stakeholder perspectives in forest and landscape restoration and their interaction patterns

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The Global Partnership on Forest Landscapes Restoration (FLR) defines FLR as "a process that aims to regain ecological functionality and enhance human well-being in deforested or degraded landscapes". While the concept appears straightforward, restoration choices often mirror specific concerns, objectives, and mandates of individual stakeholders. These perspectives remain insufficiently articulated in global restoration literature, even more so in Sub-Saharan Africa. To address this, we focus our case in Kenya and ask two questions:1) what are the perspectives on degradation, restoration pathways, outcomes and challenges across FLR stakeholders? and 2) what are the interlinkages and interactions of stakeholders within FLR? We conducted content analysis of data from 37 stakeholder interviews and 10 focus group discussions to explore the stakeholders and their perspectives. To assess stakeholders' interaction and interlinkages in FLR we applied social network analysis (SNA) and generated networks based on different stakeholder roles. We categorise stakeholders by type (communities, government, development, and research) and scale (local, sub-national, national, and international). FLR stakeholder roles are largely distributed across implementation, coordination, and technical support, with communities, government, and research organisations playing central roles respectively. Stakeholders broadly agree on degradation patterns but differ in how they explain its causes. Restoration is viewed as a portfolio of practices; local communities prioritise individual approaches, while development and research stakeholders emphasise integrated landscape approaches. Although all recognise the multifunctionality of restored landscapes, their valuation varies: communities prioritise immediate, tangible benefits; government focuses on ecosystem services and resource management; development partners frame restoration within broader economic systems; and research institutions emphasise long-term, system-level sustainability. Challenges to FLR are interconnected, including financial constraints, governance and policy gaps, capacity limitations, and trade-offs between short-term needs and long-term objectives. Given that FLR operates as a coupled social-ecological system, where outcomes are shaped by ecological processes, governance structures, economic incentives, and social dynamics, the effectiveness of FLR depends on the alignment of stakeholder priorities and the strengthening of feedback across scales. Addressing existing mismatches between local realities and stakeholder expectations will be critical for achieving sustainable and scalable restoration outcomes.

Keywords: Forest and landscape restoration, Kenya, social network analysis, stakeholders

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Institutional change grounded in socio-bioeconomies for leaving no one and no forest behind in Amazônia?

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This research aims at understanding and addressing processes of access restrictions to livelihood-relevant resources by traditional local communities, and at what it takes to have equitable socio-bioeconomies in a context of high natural occurrence of non-timber forest products (NTFP) and a low Human Development Index. Given limitations of resource and market access reported by traditional local communities of Quilombolas (Afrodescandant Peoples), and a limiting institutional environment for forest-reliant livelihoods in Amazônia, the main questions are: how do institutions (re)shape natural resource and market access by Quilombolas in the protected area of the Trombetas River Biological Reserve (TRBR)? How can access-implications be addressed or redressed? Implications of the TRBR Term of Compromise (TC) – a formal institution written by Chico Mendes Institute for Biodiversity Conservation (ICMBio) – on livelihood-relevant access to socio-biodiversity products (Brazil nuts) and markets are analyzed. Methods include semi-structured interviews (n=96) focusing on NTFP-gatherers, and observation and focus-group interviews for data triangulation. An analytical framework is developed, combining access theory, institutions and property rights scholarship. Findings reveal that the TC overwrites institutionalized norms of Quilombola communities, which regulated such livelihood-relevant access long before the TRBR establishment (1979). The TC not only formalizes BN use but also unintentionally leads to a oligopsonic market structure to the detriment of Brazil nut gatherers. It further restricts natural resource and market access, limiting Quilombolas' bioeconomy-benefits. This calls for addressing and redressing institution-based access limitations faced by Quilombolas, including through inclusive co-management of PAs and the TC. Achieving an inclusive socio-bioeconomy in aciently and collectively owned forests overlapping with protected areas (PAs) requires recognising the traditional use of livelihod-relevant NTFPs on a sustainable basis. In Brazil, socio-biodiversity products (e.g., Brazil nuts) are vital for traditional livelihoods, yet PA regulations frequently override customary norms, limiting equitable benefits. As an outlook, the National Bioeconomy Development Plan featuring socio-bioeconomy prominently (Brazil, 2026) offers a concrete entry-point not only for inclusively implementing Brazil's Bioeconomy Strategy but also for policy uptake of learnings from this case. It can further inform similarly contested forest landscapes and social-ecological systems in other geographies for leaving no biodiverse area nor anyone behind.

Keywords: Bioeconomy, indigenous peoples and local communities, non-wood forest product, sustainable livelihoods, sustainable use of natural resources

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The socioeconomic performance of agroecology case of DR Congo, Burundi, and Cameroon in Central Africa

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The global agricultural sector faces unprecedented challenges as a result of climate change, soil degradation, and food insecurity, necessitating a transition toward sustainable food systems. While agroecological practices offer a promising ecological alternative to smallholder farmers. However, their economic performance and business viability remain underexplored in Sub-Saharan Africa. This study evaluated the socioeconomic performance of agroecological practices, drivers of context-specific agroecological practices (AEPs) implemented across the Kabare-Biega, Bujumbura (Burundi), and Ntui (Cameroon) Agroecological Living Labs (ALLs) within the CANALLs project.

The research employed a mixed-methods approach, integrating quantitative household surveys with qualitative focus group discussions (FGDs). Primary data were collected from 50 households in Kabare-Biega (coffee-based), 60 in Bujumbura (maize-based), and 66 in Ntui (cacao-based), totaling a robust representative sample across Central Africa. Statistical analysis included descriptive methods, t-test for gender disparities, and a double-censored Tobit model to identify determinants of farmer profitability. Additionally, a detailed cost-benefit analysis (CBA) was conducted to assess the financial viability of prioritised practices.

Preliminary results demonstrate significant productivity gains across all ALLs. In Kabare-Biega, coffee yields rose from 0.8 to 3 $^{kg}/_{plant}$, and beans surged from 2.5 to 22 $^{kg}/_{plot}$ through composting and cover cropping. In Bujumbura, maize productivity increased through the innovative use of human urine as biofertiliser, reducing dependence on synthetic inputs. In Ntui, AEP-driven crop diversification improved food security and cacao quality, although it induced high labour requirements. Despite these benefits, structural constraints including limited equipment access, high labour intensity, and fragmented market organisation persist.

The findings suggested that AEPs are economically superior to conventional methods when yield improvements offset labour costs. To ensure long-term adoption, policies must prioritise specialised market linkages for agroecological products and strengthen cooperative training on biofertiliser products. Scaling these transitions requires an integrated policy framework that addresses land tenure security and provides financial incentives for sustainable practices.

Keywords: Agroecological transition, Central Africa, living lab, smallholder farmers, socioeconomic performances

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Spatial incentives to upscale the benefits of tree islands in small oil palm plantations in Indonesia: Evidence from a spatially explicit coordination game

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Biodiversity loss in tropical agricultural landscapes is accelerating, driven in part by the expansion of oil palm monocultures. Integrating conservation into these systems is therefore a key challenge. Tree islands – small patches of natural vegetation within plantations – have been shown to enhance biodiversity and ecosystem functioning while maintaining economic viability. However, their effectiveness depends not only on adoption by individual farmers but also on spatial coordination across individual farms, as many ecosystem services exhibit greater benefits from connectivity. This study investigates how different types of payments for ecosystem services (PES) schemes influence both, conservation behaviour and spatial coordination among smallholder farmers. We conduct a framed lab-in-the-field experiment with oil palm farmers in Jambi, Indonesia, using a spatially explicit coordination game. Participants repeatedly decide whether to maintain monoculture production or establish tree islands on stylized plots. The experiment includes three stages: 1) a baseline without incentives; 2) a PES stage in which payments are offered either regardless of the number of tree islands established (action-based), or contingent upon the establishment of a minimum number of tree islands that ensures environmental outcomes (results-based); and 3) a final stage in which a spatial agglomeration bonus is offered to reward the establishment of a minimum number of tree islands grouped into a single cluster. Results show that offering PES increases the establishment of tree islands overall, with results-based payments being more effective than activity-based payments in achieving environmental outcomes. However, neither scheme induces spatial coordination. The introduction of a spatial bonus significantly increases both the number and clustering of tree islands across both types of payments, indicating improved coordination among participants. These findings highlight that conventional PES designs may be insufficient to generate ecologically effective landscape patterns when spatial externalities are present. Incorporating spatial incentives, such as agglomeration bonuses, can substantially enhance coordination and environmental outcomes. The results provide practical insights for designing policies that promote sustainable land-use transformation in smallholder oil palm systems and similar tropical agricultural landscapes.

Keywords: Payments for ecosystem services, smallholders

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How actor networks enable agroecology transitions: Comparative insights from Tolon and Savelugu districts, northern region, Ghana

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Agroecology is increasingly promoted to address climate vulnerability, food insecurity, social inequalities, and to enhance youth engagement in farming. Yet its adoption remains low in Africa, particularly in Ghana, due to gaps in farmers' technical knowledge and weak collaborative efforts to bridge the divide between traditional knowledge and scientific methods. This study addresses this gap through a comprehensive examination of the actor-networks supporting the transition to agroecology through a comparative analysis of two districts (Tolon and Savelugu) in the northern region of Ghana.

The study employed Social Network Analysis and multi-stage qualitative methods involving a key informant interview with the Ministry of Agriculture, a multi-actor workshop, and semi-structured interviews with 84 individual actors involved in agroecological transition in the region.

Our results revealed a landscape of multi-actor networks promoting agroecology with agricultural extension/veterinary officers, NGOs, local media, and lead farmers in various communities as key actors, occupying centralised and brokerage positions, ensuring the rapid dissemination of support. While these key actors play a crucial role in the actor-networks, they also conceal the knowledge of marginalised individuals or groups. Both districts showed a fully connected network, but low density where support flows primarily one-way from experts to farmers, limiting trust-building and social learning in the broader network. Gender dynamics further play crucial support exchanges: women provide substantial agroecological support but remain less visible as recipients in both networks, indicating their key role in agroecological transition in the region.

These findings suggest that the agroecological transition relies not only on support but also on how actor-networks distribute power, enhance learning, and facilitate inclusion, with implications for designing more equitable and resilient agroecological systems. This study recommends institutionalising mechanisms to recognise small peer-to-peer learning groups in communities, strategic reorientation and equipping of agricultural extension and veterinary officers to facilitate network-building and social learning among farmers, and a crucial need for more NGOs and Media platforms to reinforce their roles as bridging and brokering actors in the region.

Keywords: Agroecology, collaborative agriculture, knowledge diffusion, social network analysis, sustainable agriculture

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Regenerative agriculture and eco-efficiency: An on farm study in Goiás, Brazil

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Since the United Nations Conference on the Human Environment in 1972, through the Sustainable Development Goals (SDGs), launched in 2015, researchers have studied sustainability, seeking to develop cleaner production practices and to measure them. Since 1990, the concept of eco-efficiency has been used to advance sustainability. Eco-efficiency can be defined as the delivery of competitively priced goods and services that satisfy human needs while progressively reducing ecological impacts. One of the main tools used by researchers during recent years to analyse eco-efficiency has been the Data Envelopment Analysis (DEA). DEA is a nonparametric, linear-programming-based technique that assesses the relative performance of a set of units. Another current methodology used by researchers is the combination of DEA and econometric regression analysis. Researchers have implemented this methodology to pursue eco-efficiency in several fields, including farming, coffee, well-being, the beef cattle sector, the forest sector, and sugarcane. Recently, Regenerative Agriculture has emerged as an alternative sustainable production system. Regenerative Agriculture can be defined as an alternative food production system with lower or even net-positive environmental and/or social impacts. To contribute to this debate, this paper examined the eco-efficiency of 30 soybean farms in southern Goiás, Brazil, that employ regenerative and traditional systems, with a focus on minimising chemical inputs. To verify its eco-efficiency and identify opportunities for improvement, data were collected on the farms during the 2022-2023 and 2023-2024 production years. After collecting the data, two Slack-Based Measure Data Envelopment Analyses (SBM-DEA) were performed: first with Total Production as the output, and second with Total Production (desired output) and CO_2 emissions (undesired output). A second-stage regression analysis was performed to explore how contextual factors influence eco-efficiency. Inputs used, climatic data and a dummy indicating if the field employed regenerative practices or not were used as independent variables. SBM-DEA analysis indicates that regenerative fields were less eco-efficient in both analyses. Econometric regression shows that fungicides and herbicides have a negative and significant impact on Total Production Efficiency and Total Production + CO_2 Efficiency, indicating a decline in soybean production eco-efficiency. Regenerative practices did not present any significant results in the regression analysis. This paper contributes to achieving the Sustainable Development Goals (SDGs) 2, 6, and 12.

Keywords: Eco-efficiency, environmental impact, regenerative agriculture, soybeans

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What do smallholders value in a reforestation project? Evidence from a choice experiment in Madagascar

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Effective development projects depend on community engagement and local ownership, yet smallholder-focused initiatives have repeatedly delivered mixed results. A key open question remains how to design programmes that better align with local needs. Our study addresses this gap by eliciting smallholder preferences over reforestation programme design in northern Madagascar, with particular attention to how past participation determines demand for future interventions.

We conduct a discrete choice experiment (DCE) with over 2,700 respondents across three regions, spanning both participants and non-participants in an earlier reforestation programme. Respondents chose among hypothetical project designs varying along four attributes: cash payment levels, payment structure (individual versus group), tree species (native versus exotic), and land certification support. Comparing preferences across the two groups allows us to identify experiential learning effects among past participants and test for social-learning spillovers to their neighbours.

Our findings reveal that cash payments, while valued, are not the primary driver of programme demand. Instead, secure land tenure emerges as the dominant preference: beneficiaries value comprehensive certification support – including follow-up with local authorities – almost as highly as the maximum cash payment of 100,000 Ariary over 2.5 years. This preference is sharpest among households in areas where the prior programme failed to deliver promised land certificates, and is concentrated among respondents who perceive corruption or land grabbing as prevalent. Past programme exposure thus generates experiential learning that intensifies demand for institutional support precisely where local governance is weakest – a dynamic not observed among non-participants. Preferences over payment mechanisms and tree species exhibit meaningful heterogeneity, with intra-group trust attenuating, rather than reversing, the general dispreference for group payments and a substantial share of respondents favouring native trees, contrary to prior evidence from Madagascar.

These results offer practical guidance for designing more effective and scalable smallholder reforestation programs, while contributing to a growing literature using DCEs as tools for evidence-based development project design.

Keywords: Choice experiment, community-based projects, land tenure security, reforestation

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Do trees grow better on certified land? Evidence from a smallholder programme in Madagascar

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This paper examines whether land rights formalisation enhances the effectiveness of reforestation programs. Specifically, we ask whether securing a land certificate (i) improves tree growth on reforested plots and (ii) affects associated socio-economic outcomes. We study the Programme de Lutte Anti-Érosive (PLAE), a smallholder forest restoration initiative implemented in northern and northwestern Madagascar between 2014 and 2019. Drawing on primary household data collected in 2024 and combined with geospatial and administrative data, we employ a quasi-experimental approach to estimate the program's medium-term effects. For our identification strategy, we exploit the fact that due to a lack of transparent land tenure system neither programme implementers nor programme participants were systematically aware of the presence and extent of overlapping historical land titles at programme onset. These titles were issued during the colonial and early post-colonial periods and reflect the legacy of successive land tenure reforms implemented in Madagascar since the colonial era. Combined with other legally obsolete land statuses, these historical titles now present a significant barrier to land certification. We use the share of reforested plots overlapping with these historical titles at the fokontany – or Madagascar's lowest administrative subdivision – level as an instrument for individual land certification success.

Our instrumental variable estimates show that land certification substantially improves tree growth outcomes on reforested plots: at the fokontany level, a 10-percentage point increase in the share of beneficiaries with land certificates is associated with around three percentage point increase in the tree canopy cover change as captured by remotely sensed data. In parallel, we observe increases in self-reported tree growth among households that managed to obtain a land certificate for their reforested area. However, certification is also associated with a higher incidence of tree theft, potentially reflecting heightened social tensions. Beyond these environmental impacts, we find weak evidence of certification's effects on household socio-economic outcomes, including the wealth index and access to formal banking. Overall, our results underscore the potential of land certification to incentivize long-term reforestation investments, while also highlighting its limitations in improving broader socio-economic outcomes without complementary interventions.

Keywords: Land certification, reforestation, smallholders, tenure reform

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Implicit principles, explicit gaps: Systemic design for multifunctional agroecosystems

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Agricultural systems are increasingly required to deliver multiple functions simultaneously, a challenge especially relevant for tropical agriculture, where climate risks, biodiversity loss, land-use change, and livelihood vulnerability interact within farming systems and exceed single-solution adaptation approaches. Although systemic and participatory approaches are promoted, it remains unclear whether systemic design principles are being considered, by whom, and through which methods in agriculture.

This study presents a systematic review assessing the extent to which systemic design principles are present in agricultural systems research. Following a PRISMA process, literature was retrieved and screened against predefined criteria. From 4605 identified records, 121 studies were selected and analysed through descriptive synthesis and inductive coding. Publication trends, geographical distribution, farming-system types, systemic design principles, methodologies, design objectives, and practitioner involvement were investigated.

The literature has expanded since the mid-2010s, but remains concentrated in Europe, with limited representation of tropical regions, and focused mainly on arable and horticultural systems. Systemic design principles were identified implicitly in the selected papers, but no paper explicitly referred to systemic design. This indicates limited formalisation and systematic application of these principles in agricultural systems design. The most frequent associated principles were appreciating complexity, idealisation, purpose finding, and boundary framing, while principles related to generative emergence, system ordering, and self-organisation were less addressed. Methodologically, the field combines participatory workshops, co-design protocols, simulation modelling, scenario planning, conceptual frameworks, and evaluative

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approaches. Practitioner involvement was dominated by researchers, farmers, extension agents, and policy-makers.
A central finding is that systemic design is not used as a framework for the (re)design of agricultural systems. Instead, the investigation identified partial and fragmented engagement with related principles, such as complexity framing, co-design, and system redesign, with weaker evidence of long-term transformation, emergence, and self-organisation. The strong European concentration of evidence reveals an important gap for tropical agriculture, where multifunctionality and climate resilience are pursued under constrained institutional, ecological, and livelihood conditions. This work supports strengthening systemic design research in tropical agriculture by moving from short-term problem framing toward implementation, evaluation, and transformative adaptation in multifunctional agroecosystems.
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Keywords: Agricultural systems design, climate-resilient agriculture, multifunctional agroecosystems, systemic design principles, tropical agriculture

Farmer managed natural regeneration (FMNR) for climate resilience and livelihood improvement in drylands of Kenya

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Dryland ecosystems in Mandera, Kenya, are characterised by low and erratic rainfall (250–350 mm annually), severe land degradation, and unsustainable fuelwood extraction. Livestock rearing remains the primary livelihood but is highly vulnerable to climate extremes. To address these challenges, from 2014 to 2021, Adventist Development and Relief Agency and the Canadian Foodgrains Bank implemented a rangeland restoration project promoting Farmer Managed Natural Regeneration (FMNR) among 2,000 households. FMNR, which encourages natural regrowth of trees through systematic pruning and management, was implemented through participatory, behaviour change–oriented approaches, including farmer champions, Pastoral Field Schools, FMNR learning sites, and peer exchange visits. The approach integrated FMNR with broader rangeland management practices, including enrichment planting, grazing planning, dry season fodder production, and herd management. Learning sites played a crucial role in demonstrating visible changes, promoting peer-to-peer uptake. Results demonstrate substantial ecological and livelihood benefits. The area under FMNR expanded to over 11,000 acres, with improvements in fodder availability, particularly during the dry period. Participating households reported a twofold increase in milk production alongside increased herd sizes. A mixed-methods post-project assessment in 2025 confirmed continued adoption and spontaneous expansion of FMNR practices beyond initial participants. Among five soil health characteristics, soil organic matter was significantly higher in FMNR plots (0.95%) compared to non-FMNR plots (0.56%). However, no significant differences were observed in slake, hoe, and Solvita tests or bulk density. While plant diversity was not assessed and insect measurement was inconclusive, community observations consistently reported increased species and the return of small fauna, alongside emerging concerns over human–wildlife interactions. Qualitative assessment showed that FMNR enhanced climate resilience through improved drought preparedness from fodder stockpiles, reduced soil erosion through vegetative cover, and better soil moisture retention. Livelihood diversification emerged through honey production, fodder and gum arabic sales, reduced reliance on purchased feed, and decreased seasonal livestock migration due to improved dry-season fodder availability. The approach also stimulated locally developed rules for managing regenerated areas and increased youth engagement in beekeeping. These findings highlight FMNR as a scalable, low-cost nature-based solution for restoring degraded drylands and strengthening agro-pastoral resilience in arid and semi-arid lands.

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Toward optimised soil tillage: Exploring biophysical drivers of yield variability under conservation agricultural practices

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Conservation agriculture (CA) is widely promoted as a sustainable farming system that supports soil health, environmental protection, and climate adaptation and mitigation in agricultural landscapes. It is based on three core practices: minimised soil disturbance (no-till or reduced tillage), permanent soil cover through crop residues or cover crops, and crop rotation. When implemented together, these practices are expected to deliver multiple agronomic and environmental benefits. However, the universal applicability of CA across diverse biophysical and socioeconomic contexts remains contested due to inconsistent agronomic performance, and the underlying biophysical drivers of this variability are not yet well understood. Here, we investigate these drivers, particularly those related to changes in soil-plant-water relationships, that underpin yield variability under no-till (NT) and reduced tillage (RT) with and without residue retention (RR) relative to conventional tillage (CT), based on a global meta-analysis of 328 studies spanning 361 experimental sites. Our findings reveal clear trade-offs associated with adopting minimised tillage alone, alongside agronomic benefits when combined with residue retention. Overall yield outcomes relative to CT ranged from a significant reduction of 6.3 % ($p = 0.02$) under NT without RR to near-neutral effects under RT with RR, with yield penalties diminishing as tillage intensity increased (from NT to CT) and with the inclusion of residue retention (trend $p = 0.046$). Sensitivity analysis indicates that yield reductions under NT are primarily linked to compaction-induced changes in soil hydraulic and mechanical properties, which constrain soil water movement (infiltration, redistribution, and drainage), retention, plant availability, and root growth. In particular, NT increased soil penetration resistance by 39.6 % ($p < 0.001$) and altered pore size distribution, resulting in smaller air capacity and larger wilting points. In contrast, when NT or RT is combined with RR, soil organic matter emerges as a key driver of yield variability, reflecting its multiple benefits, including alleviation of compaction, improved nutrient supply, and enhanced biological activity. However, in many contexts, such as smallholder farming systems, residue retention is often not feasible, limiting these benefits. This underscores the need to optimise tillage practices in a context-specific manner to reduce yield penalties where residue retention cannot be implemented.

Keywords: Infiltration, no-till, plant-available water, reduced tillage, residue retention, yield

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Large-scale land acquisitions and customary land rights: Post-closure dynamics of biofuel investments in Ghana

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In the early 2000s, significant portions of customary land in Ghana were leased to foreign investors for biofuel feedstock production, reflecting broader market-driven transformations of tropical landscapes. However, rather than becoming a success story, many of these investment projects failed over time, exposing critical gaps in governance and policy frameworks. This study adopts a single-case study approach to examine the post-closure dynamics and their impacts on host communities involved in large-scale land acquisitions for biofuel feedstock production. The focus is on how such investments, and their subsequent failure have impacted the land governance regime and what the implications thereof are for the different community members. Primary data was collected from Wassa Manso division in the Western region of Ghana. The data were analysed using thematic analysis with the support of MAXQDA software. Findings show that post-closure dynamics are characterised by intensified struggles over access, use, and control, coupled with the emergence of new forms of collective organisation and local autonomy as chiefs, landlords, tenants, new investors, and illegal miners sought to reposition themselves within an evolving land governance landscape. Practices such as intensified cultivation, strategic crop choices, and physical occupation became key practices through which community members sought to assert and secure land claims, transforming everyday farming into a visible assertion of ownership and resistance.

The study demonstrates that the closure of large-scale agricultural investments does not mark an endpoint but rather initiates a prolonged and contested post-closure phase characterised by increased vulnerability, opportunities for institutional innovation and strengthened community solidarity. Based on these insights, participatory and inclusive mechanisms in customary land leasing processes should be mandatory, alongside more comprehensive evaluation of large-scale agricultural investments beyond narrow economic metrics to incorporate social, environmental, and livelihood outcomes in tropical landscapes.

Keywords: Agriculture, biofuel, customary land, land acquisitions, post-closure, property rights

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Indigenous farmers' reflections on livelihood sustainability under monocropping, mixed, and Hangadi practices

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The increasing climate change conditions are affecting the stability of small and marginal indigenous farmers in the tribal region of Western Central India, which affects crop productivity, food security, and livelihood sustainability of farmers.

In this context of climate variability, the study titled "An analysis of farmers reflection on livelihood sustainability performance of prevailing monocropping, mixed-cropping, and Hangadi within climate change induced weather variability during Kharif 2025" examined the performance of monocropping, mixed cropping, and traditional "Hangadi" practices, which is a combination of more than five food group crops, under climate induced weather variability during the Kharif or monsoon 2025 season.

The study was conducted across the tribal tri-junction region of Gujarat, Madhya Pradesh, and Rajasthan using a participatory research approach grounded in agro-ecological principles. The primary data were collected through focus group discussion in 26 villages, involving 626 small and marginal farmers, practicing traditional farming. The farmers involved assessed the performance of these cropping practices in line with various parameters such as sowing conditions, crop establishment, input costs, pest incidence, yield outcomes, food availability, and market dependency.

The findings of the study revealed that diversified, agro-ecology based practices help increases the resilience under climate stress. Under conditions of delayed sowing and erratic rainfall, 52 % of farmers, practicing 'Hangadi farming' identified this practice as a reliable due to its crop diversity ensuring that even if some crops fail, others continue to survive.

As shared by 73 % of farmers, this traditional farming practice led to improved soil fertility and reduced input dependency. In terms of food availability, Hangadi practice ranked highest (58 %), followed by mixed cropping (30.8 %). In contrary, monocropping of soyabean was the most vulnerable, as 78 % of farmers reported significant losses due to prolonged dry spells, while 54 % of farmers reported negative income impacts, due to higher input costs.

• Traditional diversified farming practices such as Hangadi farming enhance multi-functional agro-ecosystem performance, improving food and nutrition security while reducing climatic and market risks.

• In contrast, monocropping practice with high market dependency show greater vulnerability and limited long-term sustainability.

Keywords: Agroecology, climate variability, cropping systems, Hangadi, indigenous farming, Kharif 2025, livelihood sustainability, West Central India

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Understanding the relationship between large-scale land acquisitions and land inequality: A systematic review

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In recent decades, there has been growing interest in farmland in numerous regions worldwide reflected in large-scale land acquisitions (LSLAs). However, despite a large body of case-specific evidence investigating the impacts of LSLAs on local communities and extensive documentation of LSLA processes, research rarely engages explicitly with the question of land inequality and current literature lacks a systematic and comparative synthesis of how LSLAs shape land inequality across contexts. Our systematic literature review examines the nexus between LSLAs and land inequality, with a regional focus on Africa. Africa is the global focal point for international land investors, while at the same time, the continent exhibits a high level of land inequality. Following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, we searched three databases (Scopus, Web of Science, AgEconSearch) for peer-reviewed journal articles in English that were published between 2000 and 2024. From an initial set of 1,422 papers, we removed duplicates and screened titles, abstracts and full texts for relevance, resulting in 142 papers coded using a systematic coding scheme. In our analysis, we identified two major strands of the literature: One strand that primarily focus on governance mechanisms and institutional processes that enables the implementation of LSLAs, restructure land access, reallocate control over productive resources, and reinforce existing power asymmetries. And a second strand that concentrates on case-specific socio-economic outcomes for local communities. Studies measuring shifts in farm size, landholdings, or access to commons reveal that investments often reinforce or exacerbate pre-existing inequalities. This review offers researchers and policymakers a critical synthesis of what is known, contested, and unresolved regarding the distributional outcomes of LSLAs, thereby making an important contribution to the debate on their regulation.

Keywords: Land acquisitions, land concentration, land deal, land governance, land inequality, large-scale agricultural investment

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Multi-functional landscapes in Lake Bosomtwe: Tree diversity and land use as drivers of NTFP provision and climate resilience

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Land-use change in forest landscapes plays a critical role in influencing ecosystem functionality, with consequences for biodiversity conservation, rural livelihoods, and climate resilience. This study examines how tree species diversity and composition across four dominant land-use systems, including closed forest, fallow/secondary forest, cocoa farms, and arable land, drive the provision of non-timber forest products (NTFPs) and contribute to climate-resilient landscape dynamics in the Lake Bosomtwe landscapes of Ghana. A purposive stratified sampling design involving nine quadrats, each of size 25×25 m, was established in each land-use type for the enumeration of trees and their ecological attributes. All inventory tree species were identified to species level by a botanist and confirmed with the help of a photo guide (manual) of trees in Ghana. The data were analysed to estimate diversity indices (species richness and Shannon diversity) and assess compositional variation across land uses. These ecological attributes were then linked to the availability and diversity of key NTFPs of socio-economic importance to local communities. The results reveal significant variation in tree species diversity and composition among land-use types. Closed forests and fallow/secondary forests exhibited the highest levels of species richness and structural complexity, supporting a wider range of NTFPs. Cocoa farms, while less diverse than natural forests, retained considerable tree cover and contributed meaningfully to NTFP provision due to the integration of shade trees. In contrast, arable lands showed markedly reduced tree diversity and limited NTFP availability. Importantly, higher tree diversity and structurally complex systems were positively associated with indicators of climate resilience, including enhanced carbon storage potential and the presence of functionally diverse, stress-tolerant species. These findings underscore the importance of maintaining and promoting tree diversity within multifunctional landscapes to sustain ecosystem services. Integrating tree-based systems such as cocoa agroforestry and conserving secondary and closed forests can enhance NTFP provision while strengthening climate resilience. The study highlights the need for landscape-level management strategies that reconcile agricultural production with biodiversity conservation and climate adaptation goals in tropical regions.

Keywords: Climate resilience, Lake Bosomtwe, land-use, NTFP, tree diversity

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Integrating climate-smart agriculture into multi-functional agro-ecosystems: Evidence from smallholder farming systems in western Kenya

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Climate change continues to exert significant pressure on smallholder farming systems in sub-Saharan Africa, undermining productivity, ecosystem stability, and rural livelihoods. As the need for sustainable and resilient agricultural systems intensifies, the concept of multi-functional agroecosystems – capable of simultaneously delivering food, income, and ecosystem services – has gained increasing prominence. The study, thus, examines how the integration of Climate-Smart Agriculture (CSA) practices can enhance the multi-functionality and climate resilience of smallholder agroecosystems. The study adopted a mixed-methods research design combining quantitative and qualitative approaches. Household survey data were collected from 320 smallholder farmers, complemented by 10 focus group discussions and key informant interviews with extension agents, agribusiness service providers, and county-level policymakers. The analytical framework was structured around three core dimensions: (1) agricultural productivity and income generation, (2) ecosystem service provision, and (3) resilience to climate variability. Econometric analysis, including a multivariate probit model and stochastic frontier analysis (SFA), was applied to assess CSA adoption patterns and their effects on farm-level efficiency and system performance. The findings indicated that farmers adopting integrated CSA practices – such as agroforestry, conservation agriculture, crop diversification, and improved soil fertility management – demonstrate significantly enhanced agroecosystem performance relative to non-adopters. CSA adopters exhibit a 26 % increase in technical efficiency and a 32 % improvement in composite ecosystem service indices, particularly in soil organic matter and moisture retention. Moreover, diversified farming systems contribute to a 30 % reduction in yield variability under climate stress conditions, highlighting their role in stabilising production and incomes. Access to extension services and climate information emerges as a critical driver of both adoption and system transformation. Further revealed that institutional support systems play a pivotal role by facilitating knowledge exchange, input access, and value addition. However, persistent constraints – such as limited access to finance, inadequate extension coverage, and fragmented policy implementation – continued to hinder widespread adoption. This study contributes to the evolving discourse on sustainable agricultural transformation by demonstrating that CSA serves as a practical entry point for operationalizing multifunctional agro-ecosystems in smallholder contexts. It underscores the importance of integrated policy frameworks, investment in advisory services, and strengthening of local innovation systems to support climate-resilient agricultural futures in tropical regions.

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Assessing deforestation risk and carbon emission mitigation in commodity frontiers through integrated land system modelling

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Global agricultural trade dynamics increasingly displace production across world regions. This is particularly relevant for trade relationships connecting the EU-27 with Southern America and Southeast Asia where export-oriented agriculture can intensify pressure on forests that serve as critical terrestrial carbon pools. This study investigates how alternative land use scenarios can mitigate deforestation risk and reduce associated carbon emissions in two tropical production frontiers with a strong export orientation: Mato Grosso state, Brazil, dominated by soy and cattle production, and Kalimantan, Indonesia dominated by palm oil and industrial pulp production. For the purpose of study, future production demands for both regions are derived from the MAGNET global economic model while scenarios focused on the period of 2025 to 2050. Drawing on these projections, we conducted stakeholder interviews with actors in both study regions to identify preferences of locally grounded mechanisms for reconciling agricultural production with conservation objectives. Stakeholder insights were integrated into scenario parameterisation within CLUinPy (a novel open-access in-house Python implementation of the CLUMondo land-use model). Carbon emission impacts resulting from future land-use change were assessed using a spatially-explicit carbon accounting framework. Across both regions, stakeholders consistently identified multifunctional and integrated production systems, including agroforestry and cattle ranching combined with silviculture, as important mechanisms to achieve sustainable land-use futures. Modelling results indicate that transitions towards such integrated systems reduces the probability of future deforestation compared to a reference scenario, with corresponding reductions in carbon emissions. However, the magnitude of these benefits is highly sensitive to assumptions about the productivity of integrated systems and their capacity to meet future production demand without displacing agricultural expansion into remaining forest areas. From a modelling perspective, improved spatial mapping of agroforestry and silvopastoral systems, together with broader empirical datasets on their productivity, is essential to better constrain scenario outcomes. This study contributes to the evidence base for designing climate-resilient, multifunctional agro-ecosystems capable of meeting production needs while safeguarding tropical carbon stocks. More broadly, it provides a transferable modelling framework for assessing deforestation and carbon-emission trade-offs in export-oriented tropical agriculture–forest mosaics.

Keywords: Carbon accounting, Kalimantan, land use modelling, Mato Grosso, scenario modelling, spatial modelling, telecoupling

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Integrated crop–livestock–tree systems in Africa and Asia: A systematic review of resilient, climate-smart, and multifunctional agro-ecosystems

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Integrated crop–livestock–tree (ICLT) systems, also known as agro-silvo-pastoral systems, have been promoted as sustainable land-use strategies capable of addressing the interconnected challenges of food security, environmental degradation, and climate change in smallholder farming systems. However, evidence regarding their ecological, socio-economic, and climate resilience outcomes remains dispersed across disciplines, regions, and production contexts, limiting a comprehensive understanding of their multifunctional performance. This systematic review addresses three key questions: (i) What ecological, socio-economic, and climate resilience outcomes are associated with ICLT systems in Africa and Asia? (ii) How do these outcomes vary across agro-ecological and socio-economic contexts? and (iii) What factors facilitate or constrain the adoption and scaling of ICLT systems? Following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework, we systematically screened peer-reviewed literature published between 2000 and 2025 and analyzed 186 eligible studies from diverse agro-ecological regions in Africa and Asia. Studies were coded and synthesized using a thematic framework encompassing ecosystem services, farm productivity, livelihood outcomes, climate adaptation, and institutional drivers of adoption. The review reveals that ICLT systems consistently enhance soil fertility, biodiversity conservation, nutrient cycling, and carbon sequestration while improving farm productivity, income diversification, and resilience to climatic shocks. However, the magnitude of these benefits varies considerably across agro-ecological zones and management intensities. A key finding is that socio-economic and institutional factors – including land tenure insecurity, limited access to extension services, inadequate policy support, and high initial investment costs – are more influential in determining adoption than biophysical constraints alone. Furthermore, the review identifies important geographical and thematic research gaps, particularly regarding long-term system performance, trade-offs among ecosystem services, and the integration of climate adaptation metrics into system evaluation. By synthesizing evidence across ecological and socio-economic dimensions, this review provides a more integrated understanding of how ICLT systems contribute to sustainable agricultural intensification and climate resilience. The findings highlight the need for context-specific policies, interdisciplinary research, and inclusive governance mechanisms to support the wider adoption and scaling of multifunctional agro-ecosystems in Africa and Asia.

Keywords: Africa, agroecology, agroforestry, Asia, climate-smart agriculture, mixed farming systems, resilience, sustainable land use

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Designing ecotourism-based financing for protected areas: A discrete choice experiment in Ben en national park, Vietnam

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Protected areas protect species and habitats while also providing ecosystem services and preserving natural landscapes and cultural values. Their management, especially in developing countries, relies heavily on state budgets, which are often inadequate and unstable. Ecotourism has therefore been promoted as a practical way to supplement conservation funding. By generating revenue from visitors' willingness to pay for nature-based experiences, ecotourism can align conservation objectives with economic incentives

The geographical focus of this study is Ben En National Park, located in Thanh Hoa Province in north-central Vietnam. Established in 1992, it is the only national park in the country situated in a lowland mountain ecosystem with high biodiversity. This study surveyed 1,062 tourists using a convenience sampling approach and applied a discrete choice experiment (DCE) to estimate willingness to pay (WTP) for ecological improvements and to assess the revenue potential of a conservation surcharge embedded in the boat fee system. An interaction-augmented multinomial logit model was employed to capture observed heterogeneity in preferences, and policy simulations were conducted to assess likely uptake and revenue under different surcharge levels. The findings indicate the predominance of domestic, middle-income visitors. Tourists exhibited broad but uneven awareness of the ecosystem services provided by the national park. While biodiversity and carbon-related functions were relatively well recognised, watershed protection was the least understood. Estimated WTP values were positive, amounting to 20,255 VND for increasing forest restoration by 4 hectares, 5,793 VND for conducting two biodiversity monitoring rounds per year, and 6,962 VND for improving water clarity by 1 meter. Policy simulations, based on 19,266 visitors per year, show that uptake declines monotonically with higher surcharges, generating a concave revenue profile that peaks at a fee of 30,000 VND (161.8 million VND per year). Benchmarking against official cost norms suggests that this peak revenue could finance approximately two biodiversity monitoring rounds per year and about 2 hectares of under-canopy forest enrichment. However, it would be insufficient for large-scale restoration, implying the need for complementary public and partner funding.

Keywords: Protected areas, DCE, ecotourism, Vietnam, willingness to pay

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Understanding community awareness, perceptions and attitude toward protected areas: Evidence from Gambella national park

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Protected areas increasingly depend on the support of surrounding communities to achieve long-term conservation success. However, limited evidence exists regarding how local awareness, perceptions, and attitudes interact to shape conservation support in Gambella National Park. This study investigated community awareness, perceptions, and attitudes toward the park and evaluated how these factors influence willingness to support conservation. Data were collected from 333 randomly selected respondents across seven villages surrounding the park using a structured questionnaire administered via the KoBoToolbox application. Ordinal logistic regression was used to assess the influence of socio-demographic characteristics on awareness, perceptions, and attitudes, while Structural Equation Modelling (SEM) was employed to examine the effects of perceptions and attitudes on willingness to support conservation. Residents living near the park were significantly more likely to report greater awareness of the park and its management structures, more positive perceptions, and more favourable attitudes toward the park. Distance from the park significantly predicted awareness ($\beta = 5.50$, $p < 0.001$; OR = 244.98), perceptions ($\beta = 2.66$, $p < 0.001$; OR = 14.24), and attitudes ($\beta = 19.06$, $p < 0.001$). Higher educational attainment also contributed to more positive perceptions and attitudes, while government employees demonstrated greater awareness than farmers. Structural equation modelling further revealed that perceptions strongly influenced attitudes ($\beta = 0.61$, $p < 0.001$). Attitudes had a modest positive effect on willingness to support conservation ($\beta = 0.17$, $p = 0.020$), while perceptions also exerted a direct positive effect on willingness ($\beta = 0.17$, $p = 0.032$). Attitudes partially mediated the relationship between perceptions and willingness to support conservation. Overall, the findings indicate that support for conservation is shaped not only by socio-demographic factors but also by how communities experience and evaluate the park.

Keywords: Community awareness, conservation attitudes, Gambella National Park, local perceptions

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Social stratification and livestock access: Rethinking equity in integrated agro-ecological farming systems

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The transition towards resilient and multifunctional agricultural systems has accelerated in response to the ecological and economic limitations of chemical-intensive farming. Agro-ecological approaches such as Natural Farming promote the integration of crops, livestock, and locally derived bio-inputs to enhance soil health, reduce input costs, and strengthen farm-level resilience. Central to these systems is the availability of livestock-derived inputs – particularly cow dung and urine – which underpin the preparation of bio-formulations such as Beejamrutham and Jeevamrutham. Despite increasing institutional support for such transitions, the uneven distribution of livestock assets raises critical concerns regarding the inclusivity and scalability of these models.

This study investigates the relationship between social stratification and livestock ownership within the broader context of integrated farming systems. Using cross-sectional household data from Andhra Pradesh, we examine whether access to cattle, an essential component of agroecological production systems, varies systematically across caste groups. Results from a Pearson chi-square test indicate a statistically significant association between social category and ownership of big ruminants ($X^2 = 17.00$, $p < 0.01$), with Scheduled Caste households demonstrating notably lower ownership rates relative to other groups.

These findings highlight a structural constraint within agro-ecological transitions: while integrated crop–livestock systems are promoted as pathways to resilience, their adoption is contingent upon access to productive assets that remain socially differentiated. In contexts where livestock ownership is limited, particularly among historically disadvantaged communities, reliance on in situ input production may restrict participation in sustainable farming initiatives.

By situating livestock not merely as a productive asset but as a critical enabler of agro-ecological integration, this paper contributes to ongoing discussions on resilient agro-silvo-pastoral systems and inclusive rural development. It underscores the need for policy innovations that expand equitable access to livestock and decentralised input systems, ensuring that the transition towards integrated and resilient agricultural landscapes does not reproduce existing social inequalities but instead fosters broad-based participation and sustainability.

Keywords: Agro-ecological transitions, caste stratification, crop–livestock integration, livestock inequality, natural farming, resilient agriculture

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Importance of land tenure for agricultural development: A review

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Over the past 25 years, a growing body of research on land tenure has showed that tenure security is critical to various development outcomes, including adoption of technologies and natural resource management practices that contribute to equitable, efficient, and sustainable food production, resilient livelihoods, and empowerment of rights holders. Research has also shown complex interactions between tenure and a range of outcomes, especially in cases of legal pluralism or land tenure reforms.
In a systematic review of 178 empirical papers encompassing 215 country case studies in Sub-Saharan Africa and South Asia, we synthesize evidence from the literature regarding the effects of land tenure security on several agricultural development outcomes in areas with agriculture, pastoralism, and forestry land uses. Specifically, we analyse land tenure effects on technology adoption, agricultural productivity, income, climate resilience, women's empowerment, food and nutrition security, migration and livelihood diversification, and conflict, across a wide range of land tenure indicators and interventions.
We classify the associations between land tenure security and the various development outcomes considered, noting positive, negative, mixed, and inconclusive or insignificant effects. Our review shows clear positive patterns between land tenure security and technology adoption, especially for long-term investments. The evidence is also largely positive for productivity, income and food security. The majority of cases examining women's empowerment also found positive outcomes, but there were a several negative effects, highlighting the importance of context and nuances of tenure arrangements for women. Fewer studies addressed migration/ livelihood diversification and conflict. Of those that do, the majority of cases, especially in agriculture land use cases, showed positive effects, but the proportion of negative links to tenure was higher for these two types of outcomes compared to other outcomes studied. Negative effects on conflicts and migration/ livelihoods were also often associated with pastoralism land uses.
Understanding existing contextual tenure arrangements is key for practitioners, to anticipate whether tenure is likely to limit the uptake, impact, or equity of outcomes from their interventions. Land titling interventions should beware of potential negative consequences for certain groups and with presence of other customary systems, especially in contexts with multiple land uses.

Keywords: Adoption, empowerment, land rights, productivity, resilience, tenure

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Socio-technical challenges and opportunities for forest-protecting bioeconomies in the Brazilian Amazon: An integrated assessment of Rede Terra do Meio

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Bioeconomies in the Terra do Meio region of Pará rely on traditional, community-based, and seasonal livelihood systems, including the extraction of Brazil nuts, rubber, and babassu, as well as fishing and small-scale agriculture (*roça*) for self-consumption. As climate events and market instability intensify, traditional communities face economic constraints and an urgent need to increase local income retention and reduce dependence on external intermediaries by diversifying and adding value to local products while conserving the multifunctionality of landscapes and cultural diversity. In this context, public and private initiatives to develop technological solutions have emerged to support these goals and improve livelihoods. However, understanding traditional knowledge systems, practices, and technologies remains essential to building on community strengths and co-developing culturally appropriate, sustainable alternatives. Using a bottom-up socio-technical systems framework and a qualitative approach, including semi-structured interviews, focus groups, and participant observation, this study assessed the complexity of local interplay between social and organisational factors and technical systems, evaluating how potential co-developed technological elements may enhance production performance while ensuring the feasibility and appropriateness of community needs are met. The assessment finds that the socio-technical systems of bioeconomies in Amazonian regions, such as Terra do Meio, are embedded in traditional community knowledge systems and depend heavily on collective practices, often combined with modern infrastructure such as miniusinas and community cantinas. In addition, it identifies critical challenges, including climate-driven production risks, logistical barriers, and the need for improved access to clean water and reliable energy to support feasible technological upgrades. The study also concludes that effective technological interventions should not be treated as isolated, top-down technical upgrades. Instead, solutions must be incremental, territorially adapted, and focused on strengthening locally understood socio-technical systems rather than introducing complex new equipment. Moreover, aligning technology with long-term institutional support, fair market access, and community governance is essential for sustainable adoption and resilient local sociobioeconomies. In sum, technological interventions must be understood as elements influencing production relations, labour dynamics, and resource access and use. Neglecting these interactions often results in underutilised or abandoned technologies, especially in resource- and logistics-constrained Amazonian settings, such as those under consideration in this study.

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The Triple F agroecology model (TFAM): An integrated systems architecture for university-led agroecological innovation

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Agricultural and food systems face interlinked challenges and pressures from climate change, biodiversity loss, land degradation, food insecurity, and constrained rural livelihood opportunities. Although agroecology, living laboratories, experiential learning, circular bioeconomy, and enterprise incubation each offer important pathways for sustainability, they are often implemented as distinct interventions, limiting their combined capacity to support systemic food-systems transformation. This paper introduces the Triple F Agroecology Model (TFAM), a systems architecture for operationalising the Food-Feed-Forest philosophy through integrated ecological production, learning, enterprise and community knowledge co-creation pathways. The Model was developed through an integrative conceptual synthesis encompassing agroecology, food-systems transformation, experiential learning, living laboratories, university co-creation, and circular bioeconomy scholarship. Its application is illustrated through the proposed Triple F Green Enterprise Incubation and Living Laboratory Programme in Uganda. The model comprises four interacting domains- Normative, Biophysical, Socio-economic, and Innovation and Learning - supported by system inputs and an enabling institutional context. Resource and information flows, feedback loops, and co-creation connect these components to ecological, socio-economic, educational, and institutional outcomes. TFAM therefore provides a coherent conceptual basis for designing university-led agroecological innovation ecosystems and a framework for future empirical evaluation across diverse socio-ecological contexts.

Keywords: Agroecological innovation, agroecology, circular bioeconomy, ecosystem restoration, experiential learning, green enterprise incubation, living laboratories, sustainable food systems, youth employment

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Crop / tree genetics and conservation

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Enhancing genetic diversity and climate resilience in *Brassica juncea* using crop wild relatives and progenitor species through integrative pre-breeding

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In India, *Brassica juncea* is the major oilseed crop, securing the first position among all oilseed crops. Despite its dominance, domestic production remains insufficient, leading to substantial imports to meet national demand. Among various constraints, climate change has emerged as a critical factor, intensifying heat, drought, and disease pressures, thereby threatening productivity. *B. juncea*, which contributes over 90 % of rapeseed–mustard production, is amphidiploid with a narrow genetic base, which limits the development of high-yielding varieties with more heterotic potential. In this context, crop wild relatives (CWRs), landraces, and diploid progenitors serve as invaluable reservoirs of adaptive alleles for climate resilience. At ICAR–National Institute for Plant Biotechnology (NIPB), New Delhi, a comprehensive pre-breeding framework integrating wide hybridisation, cytogenomics, and mutation breeding has been implemented to harness genetic diversity from CWRs and parental diploid species. A diverse panel comprising *B. rapa, B. nigra*, and multiple wild species was systematically evaluated using phenotypic, molecular, and cytogenetic approaches under variable environmental conditions. Resynthesized *B. juncea* (RBJ) lines and alien introgression lines derived from Diplotaxis erucoides (ERJ) were developed to broaden the genetic base and enhance tolerance to both abiotic and biotic stresses. To overcome reproductive barriers in wide hybridisation, a novel genotype, "NRCPB rapa 8," facilitated efficient *in vivo* hybrid seed development, significantly improving introgression from wild taxa. Furthermore, mutation breeding using gamma irradiation generated additional variability, particularly when amphihaploid seeds derived from *B. rapa* × *B. nigra* crosses were treated prior to chromosome doubling using colchicine. Data-driven evaluation of these populations revealed substantial genetic and phenotypic variation, including improved tolerance to heat and drought stress at early growth stages, as well as resistance to *Alternaria* blight, supported by physiological and biochemical indicators. The integration of phenomics, genomics, and cytogenetic analyses enabled the identification of stable, climate-resilient lines. Overall, this study demonstrates that CWR-assisted pre-breeding, coupled with integrative approaches, is an effective strategy for genetic diversification, trait-specific improvement, and climate change adaptation and mitigation. The developed genetic resources provide a strong foundation for breeding resilient *B. juncea* cultivars, contributing to sustainable productivity, enhanced agro-ecosystem stability, and reduced dependence on edible oil imports.

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Tree diversity enhances leaf water status and soil moisture during dry periods: Evidence from IDENT-Ethiopia

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Soil moisture critically limits forest growth and restoration success in drylands. While tree diversity enhances ecosystem functioning and productivity, its effects on plant and soil moisture status have not been explored in tropical dry forest. This study examined how tree diversity influences leaf water and soil moisture status during dry period using a six-year-old IDENT- Ethiopia tree diversity experiment. The experiment includes 270 plots across six blocks, with varying species richness (1, 2 and 4) and functional diversity (low, medium and high) in mixtures, established with nine native tree species. Data on leaf water content (LWC) and volumetric soil water content (VWC) were collected and calculated, and midday leaf water potential (LWP) was measured to assess leaf and soil water status across a species-diversity gradient during the dry period. Relative LWC was estimated from 6,440 leaves, and midday LWP of 2,866 leaves were measured using a pressure bomb. VWC was estimated from 264 soil water samples. Relative LWC and VWC data were analyzed using Generalized Linear Mixed-Effects Models with a logit link, and LWP with a log link. Our results showed that four-species mixtures significantly increased relative LWC compared with two-species mixtures ($p < 0.001$), while LWP was significantly reduced in the four-species mixtures ($p = 0.002$). Relative LWC in four-species mixtures (71.8 %) was higher than in two- species mixtures (69.1 %), demonstrating improved leaf water status. Midday LWP in four-species mixtures (−2.44 MPa) was higher than in two-species mixtures (−2.55 MPa), indicating that trees in four-species mixtures experienced less water stress. Soil moisture analysis partially supported these patterns, with four-species mixtures showing a 6 % higher likelihood of increased VWC compared with two-species mixtures. In conclusion, greater species richness underpins plant–soil water regulation. Higher mixtures improved leaf water status, increased soil moisture, and reduced water stress, highlighting that higher mixtures were better hydrated and more resilient than less species-rich mixtures during dry period. These advantages likely stem from complementary rooting, where different tree species access water from distinct soil layers, and from hydraulic lift by deep-rooted trees that draw water from deeper horizons and rehydrate upper soil layers for shallow-rooted species.

Keywords: Leaf water potential, mixed-species, plant water relations

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Polyploidy induction in 'Bentong' ginger as a strategy for genetic improvement

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Ginger (*Zingiber officinale* Roscoe) is a globally important crop valued for its culinary, medicinal, and industrial applications. Its bioactive compounds, particularly gingerols and shogaols, are well documented for their antioxidant, antimicrobial, anti-inflammatory, and anticancer properties. Despite its significance, poor natural flowering and seed set severely limit conventional breeding efforts in ginger, resulting in persistently low productivity and narrow genetic diversity. This study explored *in vitro* polyploidy induction as an alternative genetic improvement strategy for 'Bentong' ginger, a premium ginger cultivar widely grown in Malaysia. Oryzalin and amiprofos-methyl (APM) were applied at 20, 40, 60, 80, and 100 μM, while colchicine (5 mM) served as a positive control. All treatments were supplemented with 2 % dimethyl sulfoxide (DMSO) in Murashige and Skoog (MS) basal medium to enhance cellular uptake of the antimitotic agents. Two control treatments, MS liquid medium with and without 2 % DMSO, were included for comparison. Putative polyploid plants were initially screened based on stomatal size, stomatal density, and chloroplast number per guard cell as indicators for polyploidy. Selected candidate plants were subsequently confirmed for ploidy level using flow cytometry analysis. Among all treatments, APM at 60 μM proved the most effective antimitotic agent, achieving the highest tetraploidy induction rate of 55.56 %. Confirmed tetraploid plants demonstrated superior growth and physiological performance compared to their diploid counterparts, including earlier rhizome initiation and significantly higher rhizome yield. Furthermore, tetraploid plants exhibited improved accumulation of bioactive compounds and enhanced antioxidant activity, suggesting greater medicinal and nutritional potential. These findings demonstrate that polyploidy induction is a viable and sustainable strategy for improving ginger productivity, enhancing its nutritional and medicinal value, and supporting long-term food security.

Keywords: Amiprofos-methyl, flow cytometry, oryzalin, tetraploid, *Zingiber officinale*

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Linking consumer preferences, processing performance and demand-driven cassava breeding for inclusive food systems in sub-Saharan Africa

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Cassava is an essential stable crop that contributes substantially to food security and rural livelihoods in sub-Saharan Africa. Building on earlier gains in yield, diseases resistance, and adaptation, cassava breeding programs are increasingly prioritizing consumer- and processing- relevant quality traits to support adoption, value addition, and market competitiveness. This requires reliable and scalable methods to measure the traits that matter to end users, while also recognizing that preferences are socially differentiated by gender, age, ethnicity, livelihood role and consumption practices. This study examined how consumer-informed quality traits can supports demand-driven cassava breeding, strengthen value chain and improve livelihoods. Eighty cassava genotypes grown across three agroecological zones in Nigeria were processed into gari using participatory methods that reflect local practices. The final product (gari/eba) quality was assessed using both instrumental and sensory descriptive methods, including high-throughput near-infrared spectroscopy (NIRS), which offers a non-destructive and rapid multi-traits analysis method using the principle of interaction of chemical component of a material with light. A large-scale consumer study ($n = 600$) captured preferences across diverse social and cultural groups. Results indicate that key attributes such as colour parameters (a* and b*), gari solubility, textural cohesiveness drive consumer acceptance and are closely linked to processing efficiency, consistency and market competitiveness. Significant correlations were observed between instrumental and sensory attributes of gari/eba in-

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cluding hardness ($r = 0.79$) and cohesiveness ($r = 0.75$). NIRS also showed high prediction performance ($r^2 = 0.94$) for some traits, demonstrating potential for rapid screening and scalability in breeding programmes. By linking measurable quality traits with consumer preferences, this study provides cassava breeders a data-driven pathway for developing varieties with greater potential for adoption, thereby supporting inclusive value addition, improved livelihoods and enhancing food security through consumer-aligned breeding.
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Keywords: Cassava, cassava value addition, consumer preference, food security, rural livelihood

Breeding for portfolios: A risk-oriented perspective on yield stability and food security

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Breeding programs usually aim to develop new crop varieties that outperform the current market leader. In practice, however, farmers often grow multiple varieties on the same farm, which tends to mitigate environmental risk through response diversity: varieties respond differently to environmental hazards, such as heat. Breeders tend to introduce new varieties into this system without considering their contribution to the overall portfolio available to farmers, potentially missing a benefit for climate adaptation as climate risk increases. To explore this foregone benefit, we combined modelling with an analysis of empirical data. Our model represents breeding programs and farmers as sequential decision-makers: breeding programs select new genotypes for release within genetic and budgetary constraints, while farmers choose among available varieties to maximize risk-adjusted yield. We evaluated four breeding strategies: one that maximized yield and yield stability of the total portfolio, and three that maximized, for the new variety only, expected yield, expected yield and stability, or market share. Strategy performance was measured as the gain in total farmer utility. We evaluated each strategy across 195,000 scenarios. Portfolio-oriented breeding outperforms the stability-seeking strategy by at least 20 points of normalized gain in 24% of scenarios, and the yield-maximizing strategy in 42%. Gain is highest when existing varieties already respond differently to environmental conditions or are strongly biased toward one set of conditions. An analysis of Kansas wheat data from 1993 - 2006 shows that the most widely planted varieties ranked 6th, 7th, and 11th in mean yield but had low mutual yield correlation. Even against high pool-wide correlation, portfolio-oriented allocation delivers a 10% utility premium over any other strategy. This suggests decades of replacement breeding narrowed environmental responses, so the 10% premium reflects what remains extractable from a narrowed pool. Breeding explicitly for complementary responses could yield considerably more. Our findings suggest that portfolio-oriented breeding could substantially reduce climate risk, a benefit that may grow as climate variability increases, though current strategies limit it. Capturing it requires explicit risk analysis by breeding programs, and policy makers may wish to revise release criteria to balance yield gain against correlation with varieties on the market.

Keywords: Climate risk, food security, genotype × environment interaction, plant breeding strategies, varietal portfolios, yield stability

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Sustainable production of health-promoting compounds from melatonin-elicited cultures of *Echinacea purpurea*

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Echinacea purpurea (purple coneflower), a medicinal plant of the Asteraceae family, is valued for its antioxidant, anti-inflammatory, and enzyme-modulating compounds, which have potential applications in functional foods and nutraceuticals. Sustainable and controlled production of these bioactives can strengthen nutrition-sensitive value chains and support rural livelihoods while reducing pressure on wild plant populations. Such approaches are particularly relevant in tropical and subtropical regions, where climate change and land-use pressures challenge the availability of high-quality medicinal crops. This study established *in vitro* callus cultures of *E. purpurea* using thidiazuron and evaluated melatonin as a bio-elicitor for enhancing biomass, secondary metabolites, and functional activity. Callus cultures treated with 25 μM melatonin exhibited the highest biomass (FW: 208.62 g L^{-1}, DW: 11.87 g L^{-1}), total phenolics (132.8 mg GAE L^{-1}), and flavonoids (585.9 mg QE L^{-1}). Antioxidant activity peaked at this concentration, with 92.7 % DPPH scavenging and 63.2 μg AAE mg^{-1} total antioxidant capacity.

The enzyme inhibitory effects, which modulate lipid and carbohydrate metabolism, highlight the potential of *E. purpurea* bioactives to be incorporated into functional foods and nutraceuticals that improve dietary quality, support healthier diets in local communities, and help manage obesity and type 2 diabetes: pancreatic lipase (68 % at 50 μM), α-glucosidase (22 % at 25 μM), and α-amylase (40 % at 10 μM). UPLC-MS profiling confirmed enhanced secondary metabolite production at 25–50 μM melatonin, while amino acid accumulation peaked at 1 μM.

These findings highlight melatonin-mediated elicitation as a biotechnology-based strategy for sustainable production of health-promoting compounds, contributing to agricultural value chains and local livelihoods, and demonstrating a pathway for integrating plant biotechnology into tropical food and health systems.

Keywords: Bioactive compounds, *Echinacea purpurea*, elicitation, functional foods, health, melatonin, plant biotechnology, sustainability

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Genomic prediction highlights the *aus* and *subtropical japonica* clades as reservoirs of favourable lateral root architectures in rice

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Rice is a major staple crop of increasing importance in sub-Saharan Africa (SSA), particularly Madagascar. In Madagascar, phosphorus (P) deficiency and drought in rainfed systems are major production constraints. As rice production in Madagascar is predominantly smallholder-based, increasing production inputs is not feasible for most farmers. The rice root system comprises small (S- type) and large (L-type) lateral roots, whose abundance and length are linked to P uptake, making them targets for selective breeding. Breeding programmes rely on identifying superior donor germplasm. However, despite extensive genetic variation in gene banks, the labor-intensive nature of root phenotyping limits its application. To enable comprehensive characterisation of gene bank material for key root phenotypes, we generated root image datasets for 494 accessions grown under hydroponic and field conditions. We further developed a software tool for semi-automated, high-throughput phenotyping of lateral root traits, allowing the creation of detailed datasets for complex root characteristics in rice. Genomic prediction (GP) achieved moderate to high accuracy in predicting root phenotypes for an additional 2,076 accessions, with accuracies consistent across growth conditions for some traits. These phenotypes facilitated identification of donor germplasm with superior lateral root branching patterns without compromising potential drought adaptation. Donors for S-type lateral root traits were primarily found in the *aus* subclade, whereas L-type donors originated from the *subtropical japonica* clade. The resulting software, image datasets, and genomic estimated breeding values (GEBVs) provide valuable resources for studying root ideotypes and selecting donor germplasm for breeding in marginal environments.

Keywords: Genomic prediction, plant genetic resources, rice breeding, root research

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Securing the future of root and tuber crops: Genetic and agronomic strategies for stress resilience

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Cassava, sweet potato, yam, taro, cocoyam, elephant foot yam and arrowroot are essential staples and income sources for smallholder farmers across sub-Saharan Africa, Asia and Latin America. Accelerating biotic and abiotic pressures now threaten productivity across all major production systems, demanding coordinated genetic and agronomic responses.

Virus diseases – notably cassava mosaic disease, cassava brown streak, and yam mosaic – alongside root-knot nematodes, sweet potato weevil and taro leaf blight constitute the most damaging biotic constraints. The threat landscape is dynamic: new incursions such as witches' broom of cassava and climate-driven range expansion of root rots, scales and mites are compounding established pest complexes. Natural resistance sources identified within the genepool of cassava, taro and other species provide a foundation for genetic control, while biological control agents and elicitor-based immune priming expand integrated management options. Advances in QTL mapping, resistance gene cloning and CRISPR/Cas-mediated editing are opening credible accelerated breeding pathways for crops historically constrained by polyploidy, long breeding cycles and vegetative propagation.

Abiotic stress presents an equally critical challenge. Cassava yields decline significantly above 35–36°C; yam, sweet potato and taro are more heat-sensitive, with sharp productivity losses above 30°C. Erratic rainfall, waterlogging and terminal drought disrupt crop cycles and drive fungal root rot epidemics. Whole-genome sequencing and pan-genome approaches are enabling the translation of germplasm diversity into functionally characterised climate-adaptive traits, while cross-species comparative genomics offers pathways to novel resilience alleles. Complementing genetic strategies, improved water and soil management and stress-adapted agronomic practices are essential components of a integrated resilience framework.

Underpinning all of these advances is access to diverse, healthy, well-characterised germplasm. Sustained investment in genebank conservation, phytosanitary certification and open international distribution of genetic resources and associated genomic data remains the indispensable foundation for securing the long-term productivity and adaptability of root and tuber crops.

Keywords: Climate variability, cross-population sequencing, disease resistance, germplasm diversity, resilience allels

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Extension-led early-generation testing for faster, demand-driven bean breeding in East Africa

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Common bean improvement in East Africa is constrained by a mismatch between the environments in which breeding decisions are made and those in which smallholder farmers grow the crop. On-station trials remain essential, but they cannot fully capture variation in soils, climate, farmer management and market demand. We argue that testing early-generation genotypes under on-farm conditions can strengthen selection before candidate varieties approach release. We implemented an extension-led platform linking breeders, agronomists, research institutions, extension officers, farmers and market actors. Unlike conventional participatory variety selection, which commonly engages farmers when candidate varieties are close to release, the platform incorporates farmer preference, agronomic performance and market requirements while breeding decisions can still be changed. Following the tricot approach, each farmer grows and compares three randomly assigned Stage 1 genotypes in their own field. Breeders provide seed, protocols, digital tools and oversight, while extension officers facilitate trial establishment, periodic assessment and farmer evaluation. Farmers manage and monitor the trials under local conditions, using the same practices applied to their own bean crops. During extension visits, farmers and extension officers collect data together, and farmers share accumulated observations, indicating which genotypes they prefer and why. Open Data Kit forms, GPS coordinates and plot photographs support data quality and traceability, while continued training strengthens implementation. In 2024 and 2025, 426 Yellow, Red Mottled and Large Red bean genotypes were tested over two seasons across 309 farmer-managed sites in Tanzania's Northern Highlands, Southern Highlands and Lake Region. In 2026, a new cohort of 575 Yellow bean genotypes was tested across 503 farmer-managed fields in the same Tanzanian regions and in Kenya, supported by more than 50 extension officers. The methodological evaluation examines trial retention, data completeness, timeliness, workload, costs, agreement between farmer and extension assessments, and consistency between on-farm and on-station performance. It also tests whether combining on-farm and on-station evidence can improve selection accuracy and expected genetic gain. The platform provides a framework for testing whether earlier farmer input and agronomic learning can strengthen selection, shorten the breeding cycle from 7–10 years to 3–4 years, and support more inclusive, demand-driven crop improvement.

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Improvement of taxonomical classification of the Lauraceae family using DNA barcoding and RAD-seq approaches

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The economically and ecologically significant Lauraceae family is a predominantly woody plant family comprising roughly 50 genera and up to 3,500 species. However, the systematic classification of Lauraceae has been controversial due to the poorly resolved taxonomy of this family, which makes it difficult to accurately identify species for their conservation management, proper uses and understanding of their ecological function. In order to address the establishment of a reliable barcoding reference database and phylogenetic relationships within the family, leaf samples had been previously collected from four different land use types: (1) logged-over primary rain forest (old growth forest), (2) jungle rubber agroforestry, (3) rubber plantations, and (4) oil palm plantations in Jambi Province, Sumatra, Indonesia. In addition, their nucleotide sequences were also generated using the *rbcL* and *matK* genes. The phylogenetic tree constructed from the *rbcL, matK*, and their concatenated sequences show the distinct phylogenetic placements among the examined Lauraceae species, as well as authenticate the morphologically identified Lauraceae species. The *trnH-psbA, rpb2* and ITS genes will also be used to generate sequencing data for initial species identification. However, closely related species are not well resolved at these markers. Therefore, RAD-seq (restriction site-associated DNA sequencing) will be applied to provide a more in-depth view of the phylogenetic relationships among the species within the family, to develop SNPs without relying on the reference genomes and to identify species-diagnostic markers. The results will be instrumental for a better understanding of the evolutionary history of the Lauraceae and the assessment of species diversity for the conservation of the tropical forest ecosystem.

Keywords: DNA barcoding, Lauraceae, phylogeny, RAD-seq, SNP markers, species identification

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Hidden diversity in a perceived uniform crop: Linking farmer perception and phenotypic variation in amaranth

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Urban farmers in Niger cultivate amaranth (*Amaranthus* spp.) primarily as a leafy vegetable and commonly use seed colour (black versus white) as a practical proxy to distinguish and maintain local seed lots. However, the extent to which this farmer-defined category reflects underlying biological diversity remains poorly understood. This study investigates a widely cultivated black-seeded landrace known locally as *Tchapata* (Zarma) or *Aleyyahou* (Haussa) in Niamey, by combining field-based phenotyping with structured farmer interviews.

A field experiment conducted on 180 plants revealed substantial intra-population variation in key vegetative traits. Plant height ranged from 5.0 to 32.5 cm (CV = 39.4 %), while leaf number also showed considerable dispersion (CV = 27.2 %). Robust Principal Component Analysis captured 93.5% of total variance along a single axis, indicating a continuous gradient of vegetative vigour rather than discrete morphotypes. Clustering analyses further revealed a dominant phenotypic core with peripheral variation but no extreme outliers, consistent with a cohesive yet internally differentiated population.

Farmer interviews (n = 40) revealed a striking paradox. While 80 % of respondents described their fields as phenotypically uniform, 77.5 % reported actively selecting seeds based on plant height, growth rate and leaf abundance, precisely the traits exhibiting the highest variability in the experiment. Seed sourcing was highly convergent, with most farmers renewing their stock each cropping cycle from the same local markets (83 %), a pattern that helps explain population cohesion but may also limit the introduction of new diversity. The black-seeded type was consistently valued for rapid growth, resilience and strong market demand.

These results show that a visually uniform, farmer-named landrace can function as a reservoir of structured and functional diversity maintained through informal seed systems and active farmer selection. The alignment between farmer selection criteria and measured phenotypic variation highlights clear entry points for participatory selection and decentralised crop improvement. More broadly, this study underscores the need to recognise farmer-defined categories as dynamic management units rather than fixed varieties, with important implications for agrobiodiversity conservation and the design of resilient urban food systems in West Africa.

Keywords: Agrobiodiversity, farmer knowledge, informal seed systems, intra-population variation, neglected and underutilised species, urban agriculture

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Genotypic morphological traits affecting ion partitioning and tuber formation in salt stressed sweet potato

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Sweet potato (*Ipomoea batatas* L.) is one of the major foods, feed and vegetable crops globally with a total global production of 93.52 million tons per annum over an estimated land area of 7.57 million hectares. However, increased soil salinity driven by climate change is significantly constraining its productivity worldwide. This study aimed to evaluate the differential responses of sweet potato genotypes under varying salinity levels, and if genotypic variation in source-sink regulation determines salinity tolerance and yield stability.

A greenhouse experiment was conducted at University of Hohenheim using six genotypes viz., BARI SP 8, CIP 194281.2, CIP 188002.1, Bita, BARI SP 12 and Bie exposed to 0, 40, and 80 mM NaCl for a period of 100 days grown in soil-compost substrate. Morphological traits including vine, leaf, petiole length and biomass, leaf area, biomass portioning and tuber yield were measured to assess physiological responses to salt stress.

The results show that CIP 188002.1 had the strongest vegetative performance under both non-saline and saline conditions. At 40 mM NaCl, it produced the highest dry weight (42.07 g plant^{-1}), vine biomass (21.28 g plant^{-1}), side-branch biomass (14.07 g plant^{-1}) and petiole length (10.12 m plant^{-1}). A similar trend was observed at the highest salinity of 80 mM NaCl. Interestingly, CIP 188002.1 did not produce any tuber at any salinity level, including 0 mM, suggesting that its tuberisation failure was not caused by salinity alone. In contrast, BARI SP 12 produced the highest tuber dry weight (9.78 g plant^{-1} at 80 mM NaCl) among the tested genotypes regardless of the salinity levels. This indicates that differences among genotypes in tuber yield formation under salt-stress conditions are likely due to variation in Na□ and K□ uptake, as well as ion partitioning mechanisms across different organs, where Na□ may be preferentially accumulated in older leaves, while K□ might be retained in leaf blades or petioles to sustain metabolic activity. However, the analysis of Na and K concentrations in different organs are ongoing. Therefore, the results will be discussed on the poster in view of ion partitioning, biomass allocation and tuber yield formation among the genotypes.

Keywords: Salt stress, source-sink, sweetpotato, tuber formation

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Multi-environment QTL mapping reveals the genetic architecture of drought tolerance in elite African sorghum lines

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Drought severely limits sorghum productivity, and its impact is expected to intensify with climate change. This study leveraged a BCNAM (Backcross Nested Association Mapping) population derived from crosses between three Senegalese elite varieties and the drought-tolerant parent B35 to identify genomic regions controlling grain yield, thousand grain weight (TGrW), and stress tolerance index (STI). Phenotypic data were collected over two growing seasons (2023 and 2024) across three contrasting locations under rain-fed, well-watered, and water-stressed conditions. A total of nine QTLs for grain yield were detected primarily on chromosomes 2, 3, 6, and 9, but their expression was strongly environment-specific, revealing pronounced genotype-by-environment (GxE) interactions. These QTLs exhibited moderate to strong effects (LOD 3.85–7.50), underscoring the polygenic nature of yield under drought. Similarly, nine QTLs for thousand grain weight, identified on chromosomes 2 and 9, also displayed environment-dependent expression, aligning with the recognised influence of assimilate supply and water availability during grain filling. Importantly, eight QTLs for the stress tolerance index on chromosome 2 were consistently detected across both seasons at one location, suggesting stable loci that contribute to drought resilience. Co-localised QTLs for TGrW and STI indicate possible pleiotropic effects or tight genetic linkage affecting yield components and stress adaptation simultaneously. Candidate gene analysis revealed key genes linked to these traits, such as Sobic.002G339200 encoding chlorophyll a-b binding protein 3, which may enhance photosynthetic efficiency under stress, and Sobic.002G340100, an ADP-ribosylation factor linked to vesicle trafficking and stress signalling. Additional candidates involved in cell cycle regulation and hormonal pathways were also identified, providing insights into the biological mechanisms underpinning drought tolerance and grain development. Functional enrichment highlighted pathways related to chloroplast function, phosphate metabolism, and secondary metabolite biosynthesis, reflecting critical physiological processes for sustaining yield under drought. These stable and environment-specific QTLs improve the understanding of drought adaptation in sorghum and provide valuable targets for marker-assisted breeding to develop resilient, high-yielding varieties.

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Genomic diversity of Peruvian llamas: Population structure and SNP identification for resilient Andean livestock systems

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The llama (*Lama glama*) is a key genetic resource in high-Andean ecosystems, exhibiting resilient adaptive biology in response to conditions of hypoxia, low-nutritional-value forage, water scarcity and high climatic variability. Despite its biological and socioeconomic importance, its genomic diversity and population structure remain insufficiently characterised. Therefore, this study aimed to identify single nucleotide polymorphisms (SNPs) and assess the population structure of llamas in Peru. A sample of 200 llamas from central and southern regions of Peru was used for SNP calling by genotyping-by-sequencing (GBS). A reduced representation library was prepared using double digestion of the DNA with the restriction enzymes PstI-MspI. Single-end sequencing (1×101 bp) generated an average of 4.2 million high-quality reads per sample. Sequence alignment was performed with the alpaca reference genome VicPac4 due to its genetic similarity to the llama, its chromosomal assembly, and its greater accuracy among South American camelids. A total of 412,459 SNPs were identified with a minimum quality score of 10, a genotyping rate ≥ 0.10, and a minor allele frequency ≥ 0.01. Of the SNPs identified, 97.97 % are located on autosomes. The analysis of population structure using multivariate methods revealed clear genetic differentiation between populations from central and southern Peru. This elevated diversity may be explained by the presence of three phenotypic varieties, K'ara, Chaku and Intermedia, within the study areas. This study provides a comprehensive assessment of genomic diversity in Peruvian llamas, establishing a robust framework for characterising population structure and guiding resilient management and conservation strategies in Andean livestock systems.

Keywords: Genomic diversity, sequencing based genotyping, South American camelids

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Harnessing molecular breeding to develop climate-smart crops for future agro-ecosystems

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Global food security is severely threatened by climate change and unpredictability, which destabilise agro-ecosystems through increased abiotic and biotic pressures, altered rainfall patterns, and rising temperatures. These modifications disturb the ecological balance and functional diversity of agricultural systems in addition to lowering crop output. The shift from single output farming methods to multi-functional agro-ecosystems that incorporate productivity, resilience, sustainability, and ecosystem services is becoming increasingly necessary in this setting.

The use of molecular breeding to create climate smart crops that support resilient and adaptable agro-ecosystems is examined in this paper. It examines current developments in genome editing, quantitative trait locus (QTL) mapping, genomic selection, and marker-assisted selection, emphasising their contributions to hastening the creation of crop varieties suited to intricate the changing climate circumstances. These methods make it possible to find and use genes linked to pest and disease resistance, drought and heat tolerance, salinity resilience, yield stability, and improved reactivity to increased carbon dioxide (CO_2).

To improve breeding efficiency and ecological flexibility, a special focus is on combining high-throughput phenotyping, climate informed breeding targets, and multi-environment genetic data. Case studies show how molecular technologies can assist crops that perform consistently across varied and stress-prone conditions, such as the production of rice varieties combining submergence tolerance (SUB1) with yield stability and genomic selection for drought and heat tolerant maize. In order to improve photosynthetic efficiency under future climate scenarios, emerging targets for CO_2 responsiveness, such as allelic variation in Rubisco activase and sedoheptulose^{-1},7-bisphosphatase, are also highlighted. Beyond technological advancements, this paper examines socioeconomic, legal, and ethical factors that affect adoption, especially in poor nations, in order to place molecular breeding into the larger agro-ecosystem framework. It highlights how crucial it is to match breeding practices with regional farming systems, preserve biodiversity, and use resources sustainably. This review has forward looking roadmap for developing crop varieties that not only withstand climate stress but also improve the functionality and resilience of agro-ecosystems by connecting molecular breeding with climate foresight, ecosystem based approaches, and enabling policy environments.

Keywords: Climate resilient crops, food security, genome editing, genomic selection, molecular breeding, sustainable agriculture

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Elucidating *R*-gene-mediated resistance to wheat dwarf virus in *Triticum aestivum* genotypes

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Wheat dwarf virus (WDV) poses a major limitation to global cereal production, yet reliable genetic sources of resistance remain scarce. In this study, 12 genetically diverse wheat (*Triticum aestivum* L.) genotypes exhibiting differential susceptibility to WDV were evaluated under controlled inoculation conditions. Viral titre and the expression profiles of nine candidate resistance genes – representing *NBS-LRR* family, kinase family and transcription factor families – were quantified using reverse transcription quantitative polymerase chain reaction. Phenotypic parameters, including plant height and biomass, were assessed to relate molecular responses to disease severity. Statistical analysis using one-way ANOVA revealed significant genotype-dependent differences in viral accumulation and resistance gene expression. Notably, genotype VS-H 09–4/3 exhibited an approximately 80 % reduction in virus titre relative to susceptible lines, accompanied by a 2.5-fold upregulation of key *R*-genes associated with innate immune responses. In contrast, susceptible genotypes such as Ludwig displayed elevated viral loads and downregulation of these defence-related genes. Transcriptional modulation of kinase and transcription factor genes (e.g., *MYB, GRAS*) further supported the involvement of complex regulatory networks in WDV resistance. Collectively, these findings reveal actionable genetic markers and distinct resistance phenotypes, providing valuable resources for marker-assisted selection aimed at developing durable WDV-resistant wheat cultivars and enhancing crop resilience under changing environmental conditions.

Keywords: Expression profile, *R*-genes, resistance, WDV

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Scaling deep and out: Inclusive AI-driven and voice-based digital extension systems for smallholder farmers in East Africa

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Smallholder farmers in low- and middle-income countries often face a "knowledge gap" due to underfunded and overstretched traditional extension services. While digital tools are frequently proposed as a solution, their impact is often limited by a lack of local grounding, gender-blind designs, and technical barriers such as low digital literacy or poor connectivity. In the context of the SNF-funded CIRNA project (CIRcularity of Nutrients in Agroecosystems), this study demonstrates how localised digital innovations can be designed to inclusively address the knowledge gap. We conducted a baseline assessment of ICT access among livestock-rearing smallholders in Kenya and Uganda, revealing a comprehensive basic phone ownership (99 %) but a stark digital divide in smartphone adoption (82 % in Kenya vs. 28 % in Uganda). We thus developed two distinct technological pathways in collaboration with a Kenyan social enterprise: (1) An AI-driven WhatsApp chatbot for the Kenyan context, utilising natural language processing to provide interactive advice. (2) An Interactive Voice Response (IVR) hotline for Uganda, specifically designed for feature-phone users and those with limited literacy. The chatbot also includes an SMS dial-in option to ensure maximum reach and are built on a social business model where revenue is reinvested into platform maintenance. Early demand testing in Uganda has already engaged over 29,000 farmers, highlighting a strong appetite for localised digital advisory services. We aim to reach (i.e. "scale out" to) over 120,000 farmers in the first two years of operation, including gathering feedback on our service utility and complementary demands. By specifically targeting women and youth, these tools aim to "scale deep" – transforming social norms and enhancing the participatory exchange of knowledge between research and practice. In our presentation we share the results of a literature review, market study as well as practical lessons learnt on digital extension. Our approach provides a scalable model for how digital knowledge systems can foster sustainable land-use and equitable rural development in the Global South.

Keywords: Digital extension, Kenya, scaling deep, scaling out, smallholder, Uganda, women, youth

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Digitalisation in livestock farming: Impacts, trends, and barriers to adoption

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The global livestock sector faces mounting pressure to increase production while reducing environmental impacts, improving animal welfare, and adapting to climate change. This study provides a comprehensive synthesis of how digitalisation can drive sustainable livestock production, based on a systematic literature review of 201 peer-reviewed publications (2010–2024). Digital technologies – particularly within the framework of Precision Livestock Farming (PLF) – integrate sensors, Internet of Things (IoT) systems, artificial intelligence (AI), and data analytics to enable real-time monitoring and decision-making at the individual animal level. These innovations enhance productivity and efficiency through early disease detection, optimised feeding, improved reproductive management, and automated monitoring of animal behaviour and environmental conditions. The findings highlight significant environmental benefits, including reduced greenhouse gas emissions through improved feed efficiency, fertility management, and animal health monitoring. Economic gains are also evident, with technologies contributing to increased productivity, reduced labour costs, and improved resource use efficiency, although these benefits often depend on effective implementation and long-term investment strategies. Social impacts are more nuanced: while digitalisation can improve working conditions and animal welfare, it may also reshape labour demand and exacerbate inequalities between large and small producers. Despite rapid technological advancements, adoption remains uneven. Developed countries lead in implementing advanced systems such as robotics, AI, and blockchain, whereas the Global South primarily relies on lower-cost mobile-based solutions. Key barriers include high upfront costs, limited infrastructure, low digital literacy, and insufficient access to training and extension services. The study underscores the need for targeted policies and investments to bridge this adoption gap. Critical strategies include strengthening rural digital infrastructure, enhancing capacity building and digital literacy, promoting affordable and locally adapted technologies, and fostering inclusive innovation systems that engage youth and women. In conclusion, digitalisation offers transformative potential to align livestock production with sustainability goals, including improved food security, climate resilience, and rural development. However, realising this potential requires coordinated efforts across technological, institutional, and socio-economic dimensions to ensure equitable and context-specific implementation, particularly in developing regions.

Keywords: Artificial intelligence, digital agriculture, Internet of Things (IoT), precision livestock farming, sustainability, technology adoption

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Co-designed scenarios to spatial futures: Integrating CLUMondo and invest to assess divergent multi-stakeholder land-use and NBS priorities

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Conflicting land use demands and diverging interests among local and regional stakeholders remain persistent challenges for sustainable land use and forest management. This is of particular importance for the planning and implementation of Nature-based Solutions (NBS) in complex socio-ecological and forest-agricultural mosaics of tropical regions. Although participatory co-design land-use scenario approaches are increasingly used to capture stakeholder visions of the future, limited empirical studies have systematically traced how co-designed multi-stakeholder scenario narratives are translated into quantitative spatial model parameters. Less attention has also been given how divergent stakeholder-defined land-use and NBS priorities across jurisdictional scale shape future land use patterns and ecosystem service outcomes. This study addresses these gaps by adopting a GeoAI-assisted parameterisation approach that systematically structures and translates co-designed stakeholder narratives into quantitative parameter sets for spatiotemporal land-use modelling. These scenario-specific inputs drive dynamic land-use simulations in the CLUMondo model. The resulting simulation results are coupled with the InVEST approach within a unified modelling environment, CLU-VEST, to assess ecosystem service trade-offs and synergies across alternative NBS-driven land use pathways developed with local and regional stakeholders. The study examines whether divergent stakeholder-defined land-use and NBS priorities produce distinct different future land use patterns and ecosystem service outcomes. Specifically, it addresses two core questions: (i) how can co-designed multi-stakeholder NBS-driven land use narratives be systematically translated into quantitative parameters sets? and (ii) what spatial overlaps and ecosystem service trade-off changes emerge when comparing local versus regional-driven CLU-VEST outcomes? The research focuses on four landscapes of diverse socio-ecological contexts: Penablanca, Balasig Watershed, Maasin, and Silago, located in the Cagayan Valley and Eastern Visayas regions of the Philippines. These landscapes face compounding environmental and socio-economic pressures associated with forest degradation, agricultural expansion, and climate-related risks. By integrating participatory co-design, GeoAI-assisted parameterisation, and coupled land-use change and ecosystem service modelling, this study advances a replicable and transparent framework for linking multi-stakeholder narratives to spatially-explicit futures. The study provides decision-makers with empirically grounded evidence for reconciling competing land-use priorities, and offers a transferable methodological blueprint for inclusive land use and NBS planning in complex forest mosaic landscapes in the Philippines and other tropical regions.

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Digital knowledge systems and farmer adoption: Evidence from post-conflict Syria

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The digital agriculture literature has identified numerous factors that influence the adoption of information technologies. However, only a limited number of studies examine the role of integrated digital knowledge systems, especially in the case of emerging artificial intelligence tools. This dimension may be essential due to the growing interconnections between digital access, institutional support, and knowledge dissemination in shaping agricultural decision-making, particularly in post-conflict agricultural systems where traditional knowledge channels are often disrupted or weakened. In such contexts, digital platforms may play a critical role in rebuilding information flows and supporting farmers' adaptive capacity. This study investigates the patterns of digital platform adoption and their determinants using survey data from 400 farmers in a post-conflict setting in Syria. It specifically focuses on the combined use of artificial intelligence tools, social media, and search engines as complementary sources of agricultural knowledge. The study employs a multivariate probit estimation approach to examine the joint adoption of multiple digital platforms and to capture potential complementarities or interdependencies in their use, as well as the factors influencing adoption decisions. The study finds that access to digital infrastructure, particularly mobile internet and Wi-Fi, significantly increases the likelihood of adopting digital knowledge platforms. Farmers with better connectivity are more likely to engage in diversified digital information systems and to rely on multiple sources simultaneously. Furthermore, institutional support, especially extension services, is found to have a stronger effect on platform adoption compared with traditional household and farm characteristics, highlighting the importance of organised knowledge dissemination even within digital environments. Further robustness analysis confirms the consistency and reliability of these findings. The study has important implications for promoting inclusive digital agriculture in post-conflict settings. Expanding reliable internet access and strengthening digitally integrated extension services are recommended to enhance farmers' participation in digital knowledge ecosystems and to accelerate the effective and sustained use of diverse agricultural information sources.

Keywords: Adoption of innovations, agricultural extension systems, digital agriculture adoption, information asymmetry, rural digital divide, smallholder farmers

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From agents to algorithms: A four-pillar assessment of the journey to AI-based advisory for climate-resilient smallholder agriculture

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Agricultural information delivery in the Global South has moved through three technological waves over fifty years. Training-and-Visit (T&V) and demonstration trials dominated the 1970s-1980s. Digital extension followed in the 2000s through SMS, IVR, and apps. A new era has begun: over 60 AI-based extension tools are operational or piloted across India and sub-Saharan Africa. This study compares the three systems on what they deliver to smallholders, and asks where AI must be redesigned to avoid past exclusion.

Conventional extension reaches a fraction of farmers; digital systems risk reproducing exclusion at lower marginal cost. Public coverage is thin: under 10 % of Indian agricultural households reached a government extension worker in 2018–19, and 13 % of Malawian farmers received Lead Farmer advice over two years. Lead-farmer and contact-farmer models are widely critiqued for elite capture, with information rents accruing to richer, male, better-connected farmers. A survey of 2,068 smallholders in Bihar and Odisha exposes the digital divide. Mobile-phone endowment is 86 % among men, 39 % among women. Online-payment competence differs by a factor of 7.5. About 99 % have never received digital training. Latent demand is high: 77.8 % want to learn.

The study assesses the journey across four pillars: effectiveness (SCAR: speed, cost, accuracy, reach); inclusivity; trust and developer-farmer feedback; and farmer agency and data sovereignty. Methods combine a 40-tool review, the Bihar-Odisha survey, and 82 gender-balanced interviews in India, Sri Lanka, Kenya, and Malawi. Cost per farmer falls from US$30 (conventional) to US$3 (digital) to US$0.30 (AI). Site-specific accuracy remains weak. Exclusion has shifted from social elite capture to digital, now algorithmic. The feedback loop closes in real time for the first time. Three insights converge. Extension officers certify AI advice they cannot verify, eroding trust. Agritech founders cite cost-per-active-user, not reach, as the binding constraint, depending on philanthropy to serve smallholders. Farmers value AI most when an extension agent or village-level woman entrepreneur mediates between them and the algorithm. Investment must shift from devices to in-village, voice-first, women-targeted skills training, embedded in hybrid models pairing AI with trusted human agents. Climate-resilient farming requires not just better information, but more equitable access.

Keywords: Artificial intelligence, climate-resilient agriculture, digital extension, gender gap, smallholder farmers

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Cocoadoctor: deep learning-based cocoa disease detection system

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Cocoa production in smallholder systems is increasingly affected by climate variability and the spread of fungal and bacterial diseases, leading to yield losses. Early and accurate disease detection is important for better crop management and more resilient cocoa systems. Recent progress in deep learning makes automated image-based diagnosis possible in field conditions.

This study presents a deep learning framework for classifying cocoa pod conditions using field images. An EfficientNet-B4 model pretrained on ImageNet was fine-tuned using a curated dataset. The dataset combines images from the Cocoa Localisation dataset (Kaggle) with additional non-cocoa vegetation samples to improve robustness. It contains about 5,956 cocoa-related images across six classes: Healthy Cocoa, Moniliasis (Frosty Pod Rot), Phytophthora (Black Pod Rot), Witches' Broom, Corncob Disease, and non-cocoa vegetation. Around 1,000–1,500 background images were also included.

The training process used data augmentation, class balancing, and a two-stage optimisation approach. The model was exported in ONNX format and deployed in a Progressive Web App (PWA) for offline use on mobile devices in the field.

The model achieved an overall test accuracy of 93.95 % and a weighted F1-score of 0.94. Performance was higher for healthy cocoa and non-cocoa classes, with F1-scores of 0.97 and 0.98. Disease classes showed lower but acceptable performance, with F1-scores between 0.74 and 0.89. Adding non-cocoa samples reduced false positives and improved reliability in field conditions.

A mobile and web application, CocoaDoctor (https://cocoadoctor.containers.wur.nl/), was developed to support real-time disease detection and field use. The system provides a practical tool for cocoa disease screening in smallholder farming. Future work will focus on improving performance for underrepresented disease classes, expanding dataset diversity, and testing across different regions. Integration with geospatial decision-support tools will also be explored.

Keywords: Cocoa disease detection, deep learning, image classification, mobile application, smallholder agriculture

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A novel digital twin system combining earth observation, field monitoring and artificial intelligence for maize production in South Africa

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The rapidly growing global population, together with climate variability and resource constraints, is intensifying the demand for higher and more resilient food production systems. Maize production is central to South Africa's food security and is facing increasing pressure from climate extremes and suboptimal management. Digital technologies, in particular, digital twins offer near-reality frameworks needed to integrate heterogeneous data and enhance the understanding of agricultural landscape conditions.

We present a new project (SAI-Crop) in the frame of the newly established South Africa-German collaboration on artificial intelligence for societal transformation (ZADE-AI). The project integrates crop modelling, data assimilation, Earth Observation (EO) and artificial intelligence to improve agricultural data acquisition, evaluate crop conditions, and assess the viability of alternative agronomic management strategies.

The system combines multiple-source datasets, including EO data, drone-based imagery, meteorological datasets from station observations and reanalysis products data, and *in situ* crop characteristics and soil conditions. These inputs are assimilated into process-based models and enhanced through machine learning algorithms to enable continuous monitoring, yield estimation, stress detection, and scenario analysis. The digital twin is implemented in the Free State province, South Africa's primary maize-producing region, serving as a living lab prototype designed for transferability to diverse agroecological regions across the country. Additionally, the project will deploy an information delivery platform to guide farmers' management decisions across South Africa's maize-growing regions. The SAI-Crop project represents the first holistic operational digital twin for maize production in South Africa. Consequently, the system aims to improve maize productivity, climate resilience and sustainable agricultural management in the region.

Keywords: Crop modelling, digital twin, precision agriculture

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Enabling data-driven agricultural transformation: GARDIAN and FAIRagro

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Agriculture faces increasing pressure from climate change, resource constraints, and competing land-use demands. Developing climate-resilient agroecosystems requires interdisciplinary and data-driven approaches. Modern technologies generate large volumes of agricultural and environmental data, but reuse and integration remain limited. This is largely because agricultural data are often siloed, poorly documented, and rarely shared. Limited interoperability and Global South–North barriers further restrict knowledge exchange. Experiences from large-scale data initiatives show that technical solutions alone are insufficient; cultural, organisational, and governance barriers continue to limit data sharing and reuse. This contribution presents CGIAR's GARDIAN and FAIRagro's Search Hub as complementary initiatives enabling improved data sharing and reuse. GARDIAN supports global agricultural data discovery, reuse, and interoperability through a digital platform enabling access to datasets, publications, and standardised data. GARDIAN provides access to over 470,000 publications, 26,000 datasets, and nearly 570,000 analysis-ready data points. These resources span over 20 entities, with about 180 institutions, including CGIAR research centers and their global partner networks, covering disciplines such as agronomy, crop breeding, livestock, socioeconomics, climate adaptation, and agroforestry. FAIRagro supports community-driven research data management in the agrosystem sciences within the German National Research Data Infrastructure (NFDI), with the FAIRagro Search Hub as part of its service and support portfolio. Serving as a technical backbone, it integrates distributed research data infrastructures and enables access to datasets and repositories. The FAIRagro Dataset Finder provides access to over 2,000 datasets from five agricultural research institutes and is expanding to connect additional infrastructures, strengthening data discovery and reuse. Both initiatives and their services for researchers will be presented, with selected success stories and concrete use cases to illustrate how FAIR data management and sharing strengthen collaboration across disciplinary, institutional, and regional boundaries and act as catalysts for urgently needed evidence-based transformation processes, particularly in the AI era. The contribution highlights key lessons learned, emphasising the importance of investing in cultural change alongside technical solutions. These include training, capacity building, community engagement, and use-case-driven development. Together, CGIAR GARDIAN and FAIRagro Search Hub demonstrate how coordinated efforts can unlock the potential of agricultural data and support data-driven innovation for climate-resilient multifunctional agroecosystems.

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UKUDLA: Data-driven innovation for sustainable and resilient food systems in Africa

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UKUDLA, the African German Centre for Sustainable and Resilient Food Systems and Applied Agricultural and Food Data Science, addresses a central challenge of agri-food research: transforming food systems toward greater sustainability, resilience, and equity while strengthening the evidence base for action. Based in Southern Africa, the centre brings together food systems research and applied data science in an interdisciplinary framework linking ecosystems, agricultural production, food environments, value chains, governance, and human capacity development. Three research clusters provide an integrated framework for understanding how environmental, social, institutional, technological nutritional dimensions of food systems interact and shape sustainability and resilience.

UKUDLA's innovative contribution lies in linking food systems research with data-driven methods to generate actionable evidence across scales. For different farming systems this includes remote sensing, geospatial analysis, and sensor-based monitoring to assess resource management efficiency, crop and livestock health parameters, and climate-related risks. These approaches support the analysis of production systems under increasing pressure from drought, land degradation, and variable rainfall. With regard to policy and governance, data science can strengthen evidence-based decision-making through policy analytics, network analysis, and participatory digital platforms that capture stakeholder perspectives and institutional dynamics. These tools can help identify governance bottlenecks, evaluate policy trade-offs, and improve coordination across actors and sectors. For post-harvest processes, food quality and nutrition, data-driven approaches such as image analysis, traceability systems, and predictive modelling can improve monitoring of food

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losses, quality deterioration, and nutritional outcomes along value chains.
A defining feature of UKUDLA is its commitment to research, capacity building, and knowledge transfer. The centre aims to equip students, early-career researchers, and practitioners with the methodological skills needed to work at the interface of agricultural and food systems research and data science. This includes training in data collection, integration, analysis, visualisation, and interpretation, as well as transdisciplinary collaboration and stakeholder engagement.
By fostering collaboration between African and German partners, UKUDLA contributes to the co-production of knowledge for sustainable and resilient food systems. The centre positions data science not as a standalone technical field, but as a strategic instrument for improving food system performance, informing policy, and supporting equitable and context-sensitive transformation.

Keywords: Agricultural resilience, data science, food systems, research & training network, southern Africa

AI-based enhancement for mapping invasive *Prosopis juliflora*

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Rangelands in sub-Saharan Africa support over 60 million people through extensive livestock grazing but face significant challenges due to irregular rainfall and the spread of invasive species. Effective pasture management requires timely and accurate vegetation data; however, common remote sensing tools, such as the Normalized Difference Vegetation Index (NDVI), cannot distinguish between palatable forage and unpalatable invasive species, such as *Prosopis juliflora*.
This study aims to improve vegetation analysis by isolating and removing *P. juliflora* from NDVI maps derived from satellite imagery to provide a more accurate representation of usable pastures.
The research site encompasses approximately 100 square kilometers in the northern rangelands of Kenya, near the village of Ngurunit. To achieve a scalable solution, this study combines Sentinel-2 satellite imagery with high-resolution multispectral data acquired via unmanned aerial vehicles (UAV) and ground-truth data collected through a smartphone application and geo-tagged photographs. Different machine learning and deep learning algorithms are utilised to extend a small training dataset via semi-supervised learning, which is then used to train the final deep learning model.
Preliminary results indicate the successful generation of an improved NDVI map that highlights the specific distribution of *P. juliflora* in the area. Analysis of the mean spectral reflectance across Sentinel^{-2} bands revealed distinct signatures for *Acacia* spp. and *P. juliflora*, particularly in the near-infrared (NIR) spectrum, enabling the AI to filter out invasive biomass. While the remoteness of the study area poses challenges for collecting large-scale ground truth data, this AI-based enhancement of NDVI maps provides pastoralists and managers with a critical tool for identifying usable pasture and controlling invasive encroachment.

Keywords: Deep learning, drone mapping, NDVI enhancement, rangelands, Sentinel-2

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Predicting climate-resilient habitats for *Vicia faba* L.: A data-driven approach to enhance multifunctional agroecosystems

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Faba bean (*Vicia faba* L., Fabaceae) plays a multifunctional role in sustainable agroecosystems, providing high-quality dietary protein while enhancing soil fertility through symbiotic nitrogen fixation with *Rhizobium* spp. *Vicia faba*, domesticated around 10,000 years ago, has a distribution driven by climate and human activities. Under climate change, its capacity to improve soil health, reduce dependence on synthetic fertilisers, and support crop diversification makes it a key component of climate-resilient agriculture.

Species distribution models (SDMs) offer a robust framework for assessing habitat suitability and predicting future spatial distribution patterns. Although traditionally applied to wild species, SDMs are increasingly recognised as a data-driven approach for sustainable crop production and conservation planning. However, applying SDMs to cultivated crops introduces specific challenges, including managing heterogeneous occurrence data, adapting niche assumptions to human-mediated distributions, and accounting for non-climatic drivers such as agricultural management. Despite growing availability of modelling tools, integrated methodological guidance remains limited. This study examines these challenges using *Vicia faba* as a case study, delineating its current and projected suitable habitats under climate change scenarios and identifying the key environmental drivers governing its global distribution.

Occurrence records (n = 105,390) were downloaded from GBIF (www.gbif.org) following taxonomic backbone verification via *rgbif* (name_backbone; taxonKey 2974832). Records were screened for taxonomic errors and filtered to retain only records relevant to the study objectives. A systematic coordinate quality pipeline using *CoordinateCleaner* addressed missing coordinates, spatial biases, coordinate errors, geographic outliers (quantile method), and sampling biases. Coordinate uncertainty and temporal (≥ 1970) filters retained 36,939 high-quality records (35 %). Nineteen WorldClim 2.1 bioclimatic variables (30 arc-seconds; ~1 km) were stacked using terra, with CRS

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compatibility verified before environmental extraction. Collinearity was reduced (Pearson r $>$ 0.8; *caret*) and environmental outliers identified via Mahalanobis distance (97.5th percentile) and *flexsdm*. Subsequent steps include model tuning using machine learning algorithms (e.g., Maxent), future projections, and transferability assessment, are currently in progress.
The reproducible framework addresses key methodological challenges of applying SDMs to cultivated crops, offering a transferable foundation for land suitability assessment. Suitability maps and variable importance analyses will inform agricultural planning and *in-* and *ex situ* conservation strategies for *Vicia faba*.

Keywords: Land suitability, Maxent, species distribution modelling

Exploration of use cases for an AI-based coffee yield estimation tool

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AI-based computer vision in handheld devices has been postulated to be transformational for agriculture. Yet, scaled applications for smallholder agriculture are sparse. Yield estimation is a fundamental practice in the coffee value chain, with applications ranging from the agronomic assessment of plantations to the financial planning of regional organisations and compliance with certification requirements. However, conventional methods based on manual cherry counts are costly, require skilled labour, and are prone to errors, limiting the ability of stakeholders in the chain to make informed and timely decisions.

We piloted a mobile app that uses artificial intelligence to automatically count coffee cherries from images captured with a smartphone, generating yield estimates quickly, in a documented and reproducible manner. However, understanding who its potential users are, what their needs are, and in what contexts it can generate real value is a necessary condition for its scalability

This study presents an initial exploration of Croppie's use cases, based on the perspectives of stakeholders in the coffee supply chain and the early experiences of pilot users. The study employed a qualitative methodology in two complementary phases, including an exploratory survey and semi-structures interviews with different types of actors in Colombia, Peru, and Ecuador. The study began with prior hypotheses regarding use cases, with the dual purpose of validating them and identifying unanticipated emerging applications.

The findings reveal a diversity of needs that suggests the relevance of differentiated solutions depending on the type of stakeholder. Cooperatives represent the segment with the greatest willingness to adopt the technology, valuing cost reduction, speed, and accuracy exceeding 80 %. They also identified data centralisation and technical interoperability with external producer management platforms as priorities. Another cross-cutting requirement identified was flexibility in the sampling protocol, given that some stakeholders use different methods for tree selection. National trade associations, having their own digital infrastructure, require API integration rather than a standalone application. Pilot projects with farmers, cooperatives, research and development and national extension partners illustrate concrete applications ranging from decision-making at the farm level to national harvest forecasts and genetic improvement processes, demonstrating a broader scope than initially anticipated for the tool.

Keywords: Coffee value chain, computer vision, decision-making, use cases, yield estimation

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Foundation-model segmentation for automated annotation of plant species

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Manual annotation of vegetation in field-based rangeland imagery is slow, subjective, and difficult to standardise. These challenges are particularly acute in remote environments where complex plant structures and visually cluttered scenes limit the efficiency of traditional mask generation for training purposes, particularly due to spectral overlap and spectral heterogeneity. This research addresses these bottlenecks by introducing a generative semantic reconstruction method designed for the automated annotation of indigenous forage species. The study utilises proximally acquired RGB imagery sourced from diverse rangeland ecosystems in Marsabit County, Kenya, and various regions across Namibia.

The workflow reconstructs raw field images into annotation-ready priors using the Gemini Nano Banana Pro 2 model. To ensure class completeness for images with occlusions or poorly captured features, multiple perspectives of these priors were also generated to recover missing fine-scale details. These outputs then undergo automated mask generation with SAM 3, followed by validation using YOLOv8, YOLOv11, and RF-DETR. An ablation study was conducted to verify the reconstruction stage's robustness. Qwen Edit 2512 and ChatGPT 5.4 were used, applying identical prompting logic and evaluation protocols.

The analysis showed that the Gemini Nano Banana Pro 2 produced the most reliable results, demonstrating subject preservation and usable segmentation priors. This model also showed high downstream detection accuracy. This approach shifts the annotation burden from manual pixel-wise delineation to generative preconditioning coupled with foundation-model segmentation. This establishes a scalable framework for vegetation datasets in challenging environments. The research provides a transferable strategy for accelerating ecological computer vision workflows where conventional labeling is expensive.

Keywords: Generative AI, image-to-image translation, pixel purity, style transfer

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Integrated digital extension and capacity building strategy to improve manure management among smallholder farmers in Kenya and Uganda

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Effective manure management is critical for soil health and farm hygiene in smallholder farming systems, yet evidence on current practices, constraints, and effective pathways for improvement in East Africa remains limited. We have conducted household surveys to assess current manure management practices and constraints and drivers of improved manure management practices among smallholder pig farmers in Uganda and cattle farmers in Kenya. We found that in Kenya, 85 % of households reported using cattle manure for fertilisation, and in Uganda, 81 % of the surveyed households use pig manure for fertilisation. However, we also observed sub-optimal manure management practices among most farmers, characterised by improper storage and application practices. In addition, we frequently found inadequate use of protective gear and disinfectants, low awareness of manure-borne pathogens, and lack of understanding how management affects manure nutrient losses, all of which can contribute to increased disease transmission, environmental contamination, low manure-fertiliser quality, and greenhouse gas emissions. A lack of information emerged as the major barrier to improved manure management (Relative Importance Index [RII] = 0.65), representing a key entry point for extension interventions. Despite this constraint, farmers are highly motivated to adopt safer practices, particularly those that reduce zoonotic disease risks (RII = 0.70) and improve the fertilising quality of their manure (RII = 0.60).

In response to this farmer demand, we have developed an integrated outreach strategy to address informational, accessibility, and capacity constraints. First,

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tailored and inclusive digital tools will be deployed in the forms of an AI-powered WhatsApp chatbot in Kenya and an Interactive Voice Response (IVR) hotline in Uganda to deliver accessible, inclusive, and scalable advisory services adapted to varying levels of digital access and literacy. Second, capacity building activities including training of trainers, farmers and stakeholders workshops on improved manure management, identification of model farmers who integrate manure improvements with existing management practices, and assessment of farmer acceptability and uptake of promoted practices, will be conducted. This multi modal approach aims to bridge knowledge gaps, overcome logistical constraints, and support adoption of safer and more efficient manure management among smallholder farmers in East Africa.

Keywords: AI, chatbot, crop-livestock integration, extension, interactive voice response, socioeconomic barriers

Adoption of digital tools by African farmers for sustainable intensification of cropping systems: A case study of Nigeria

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This study examines the adoption of digital tools by African farmers for the sustainable intensification of cropping systems, using Nigeria as a case study. Agriculture remains central to rural livelihoods and food security in Nigeria, yet productivity is constrained by climate change, poor infrastructure, limited access to finance, weak extension services, pest and disease pressures, and low adoption of modern technologies. Digital tools, including mobile applications, artificial intelligence (AI), sensors, weather forecasting systems, and precision agriculture technologies, offer important opportunities to improve farm decision-making, input efficiency, productivity, climate resilience, and market access. However, their use among smallholder farmers remains limited. The study adopted a mixed-method and participatory research approach involving a five-day stakeholder workshop in Port Harcourt, Rivers State, Nigeria. Data were collected from various stakeholders, including farmers and agricultural stakeholders from farmers' organisations, government agencies, research institutions, private companies, and agricultural development bodies. Questionnaires and focus group discussions were used to assess farmers' awareness, perceptions, preferences, and barriers related to digital agriculture. Quantitative data were analysed using descriptive statistics and a maximum difference model in JMP Pro Version 16.0, while qualitative responses were analysed thematically. Findings show that although farmers recognise the potential of digital tools to improve crop yields, reduce input use, support pest and disease detection, improve weather forecasting, and enhance farm management, adoption remains constrained by limited network connectivity, high costs of mobile devices and AI tools, insufficient training, lack of funding, and weak communication between researchers and farmers. The maximum difference model revealed that proper network connectivity and reducing the unit cost of mobile devices and AI tools were the most important factors for enhancing sustainable intensification through digital tool adoption. Collaborative research, funding opportunities, and communication of research outcomes in simple language were also identified as important enabling conditions. The study concludes that digital agriculture can support sustainable intensification in Nigeria, but its adoption requires affordable technologies, stronger infrastructure, farmer-centered training, participatory innovation processes, and inclusive policy support. These findings provide practical insights for researchers, policymakers, and development actors seeking to scale digital solutions for climate-resilient and sustainable farming systems in Africa.

Keywords: Agricultural intensification, AI, digitalisation

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Beyond the optimisation trap: Redefining AI as maladaptation sentinels for resilient agro-ecosystems

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Across the Global South and beyond, Agriculture 4.0 has rapidly gained prominence as a cornerstone of climate-resilient development, promising higher precision, adaptive decision-making, and improved resource efficiency. Yet the accelerating climate crisis reveals a more complex reality: artificial intelligence (AI) embedded in digital agriculture not only supports adaptation but may unintentionally generate new forms of maladaptation. This analytical review addresses this underexamined tension by synthesizing insights from agrarian political economy, digitalisation studies, resilience theory, and the emerging literature on algorithmic governance. Our aim is to clarify how AI-driven decision systems – when deployed in ecologically fragile and socially heterogeneous agro-ecosystems – can lead adaptation trajectories in directions that heighten long-term vulnerability. The review identifies several interlocking mechanisms of risk. First, efficiency-driven algorithms can intensify resource extraction through rebound effects, as seen in irrigation technologies that inadvertently accelerate water depletion. Second, AI's reliance on standardised models and training data tends to homogenize practices, thereby reducing agrobiodiversity and narrowing the scope of adaptive responses. Third, data infrastructures underpinning digital agriculture often encode political biases: "weak data," exclusionary classifications, and the marginalisation of local and Indigenous knowledge. Fourth, the concentration of digital platforms among a small number of corporations reinforces algorithmic lock-in, limiting farmers' autonomy and constraining alternative adaptation pathways. Together, these dynamics produce structural conditions in which AI does not merely misguide individual decisions but reshapes entire socio-ecological systems toward maladaptive lock-ins. In response, this paper advances a theoretical reorientation of AI's role: from a tool of optimisation to a potential "maladaptation sentinel." Rather than proposing operational frameworks, we articulate a conceptual lens through which AI can be used to detect emerging vulnerabilities by integrating diverse data ecologies, tracing long-term feedback, and foregrounding plural knowledge systems. This shift emphasises that the contribution of AI to climate resilience depends not on technological advancement alone, but on whether its design and governance follow principles of responsible innovation, enabling AI to widen rather than constrain the horizon of adaptive futures.

Keywords: Agriculture 4.0; algorithmic lock-in, agrobiodiversity, data politics, rebound effects, resilience

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Automated morphometric quantification of maize cob kernels via lightweight RGB image analysis and cellpose-based deep learning segmentation

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Maize (*Zea mays* L.) constitutes a cornerstone of food security and agricultural livelihoods across tropical and subtropical farming systems, where accurate kernel quantification and morphometric assessment are indispensable for yield evaluation, varietal selection, and climate-adaptive breeding programs. Conventional manual enumeration methods, however, remain inherently limited by operator subjectivity, poor scalability, and incompatibility with the throughput demands of contemporary crop improvement pipelines. Here, we present a low-cost, image based computational workflow employing Cellpose deep learning architecture for automated instance segmentation, enumeration, and morphometric characterisation of individual kernels from standard RGB photographs of intact maize cobs. The preprocessing pipeline isolates the kernel bearing cob region through sequential colour space filtering (HSV masking) and connected component analysis, followed by Cellpose driven instance segmentation to delineate individual kernel boundaries. For each segmented kernel, the workflow extracts pixel area, centroid position, and relative size class, such as small, medium, or large, based on area percentiles, and generates individual kernel image tiles for visual inspection. Interquartile range based outlier detection is subsequently applied to flag morphologically anomalous or potentially mis segmented kernel instances. The pipeline operates entirely on standard RGB images without specialised imaging hardware, cloud infrastructure, or internet connectivity, making it well suited for deployment at tropical research stations and resource constrained breeding facilities. Preliminary testing on a representative set of cob images demonstrates consistent kernel localisation and outlier flagging; however, formal statistical validation of morphometric outliers across diverse varieties and imaging conditions has not yet been performed. The segmentation approach was designed to accommodate variable cob orientations and heterogeneous field lighting conditions, though systematic generalisation tests remain for future work. Compatibility with minimal imaging setups facilitates rapid deployment and enables real time kernel phenotyping directly at the point of harvest, a critical capability for advancing precision agriculture in low resource tropical and subtropical environments. The workflow also produces visual outputs, including numbered kernel maps, size class overlays, and kernel montages, sorted or grouped by size, supporting manual quality control and downstream analysis.

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Riceadvice Lite: A digital advisory tool for improving irrigated rice yield and profitability across West Africa

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Rice is a major staple and strategic commodity in West Africa. Yet, productivity in key producing countries, such as Burkina Faso, Côte d'Ivoire, Ghana, Mali, Nigeria, and Sierra Leone, remains constrained by sub-optimal agronomic practices, inefficient fertiliser management, and increasing climate variability. Digital decision-support tools can help close yield gaps by translating local information into actionable, site-specific recommendations. Here, we assessed the agronomic and economic performance of a digital rice agronomy advisory, so-called RiceAdvice Lite (RAL), relative to farmers' practice (FP) across six countries under irrigated lowland and rainfed conditions. RiceAdvice Lite substantially improves both rice productivity and profitability relative to farmers' current practices. Overall, RiceAdvice Lite increased farmers' grain yield by an average of 1.2 t ha^{-1} (53 %) and raised net profit by US\$153 ha^{-1} (52 %) across the region. Under irrigated lowland conditions, yield gains attributable to RiceAdvice Lite were 1.1 t ha^{-1} (29 %) in Nigeria, 0.6 t ha^{-1} (10 %) in Burkina Faso, 1.7 t ha^{-1} (56 %) in Mali, and 1.3 t ha^{-1} (45 %) in Côte d'Ivoire. Corresponding increases in net profit were US\$137 ha^{-1} (29 %), US\$71 ha^{-1} (10 %), US\$206 ha^{-1} (56 %), and US\$160 ha^{-1} (45 %), respectively. In the rainfed lowland system, RiceAdvice Lite produced yield advantages of 0.8 t ha^{-1} (21 %) in Nigeria, 1.4 t ha^{-1} (115 %) in Sierra Leone, and 1.9 t ha^{-1} (36 %) in Ghana, translating into net profit gains of US\$93 ha^{-1} (20 %), US\$176 ha^{-1} (115 %), and US\$235 ha^{-1} (36 %), respectively. Collectively, these results confirm that RiceAdvice Lite can enhance rice yields across irrigated and rainfed lowlands by 10–115 %, while generating additional net profits of US\$71–235 ha^{-1} compared with prevailing farmer practices. The consistent agronomic and economic benefits across countries and production systems highlight the value of RiceAdvice Lite as a scalable digital advisory approach to accelerate sustainable rice intensification and improve smallholder livelihoods in West Africa and, more broadly, sub-Saharan Africa.

Keywords: Farmers' practice, irrigated lowland rice, nutrient use efficiency, riceAdvice Lite, site-specific recommendation, West Africa

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Data-driven technologies and innovations for climate-resilient agro-ecosystems

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Inferring socio-ecological influences on smallholder conjunctive irrigation patterns

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Water scarcity is a pressing global challenge, with agriculture accounting for the largest share of freshwater use and contributing significantly to water stress. In developing countries such as Pakistan, this issue is particularly acute, where unreliable surface water supplies necessitate widespread groundwater extraction to meet crop water demand amid climate variability and drought risks. Direct measurement of farmer-level conjunctive groundwater use remains infeasible due to the absence of metering infrastructure, heterogeneous pumping technologies, and limited observational data. This study addresses this gap by focusing on a smallholder irrigation watercourse in Central Punjab, Pakistan, where farmers operate under a shared surface-water allocation system while simultaneously drawing from a common groundwater aquifer to meet crop water demand. We integrate data from an indigenously developed soil moisture sensor network (WITSMS), rainfall records, farm boundaries, and irrigation rosters to develop a data-driven framework for inferring farmer-level groundwater reliance without direct measurements. By combining field-scale soil moisture dynamics with a seasonal soil-water balance model, we reconstruct the relative contributions of surface water, rainfall, and groundwater. This hydrological accounting, complemented by groundwater level observations, enables the analysis of farmer interactions and pro-ecological behaviours within a coupled socio-ecological system (SES). More specifically, we employ a parametric socio-ecological model to infer farmer-level water-use decision responses and examine how these responses are associated with emergent groundwater extraction patterns and potential long-term resource stress. The study offers both a scalable methodology for estimating groundwater use under data-scarce conditions and an SES perspective for understanding how water stress propagates within shared irrigation systems, with implications for groundwater governance in smallholder contexts, leading to effective advisory systems, equitable water allocation, groundwater regulation, and the promotion of participatory governance. Moreover, water conservation and other climate-resilient practices discourage intensification, promote biodiversity, and support the emergence of truly multifunctional agro-ecosystems.

Keywords: Climate smart agriculture, groundwater, Pakistan, precision irrigation, smallholder farmers, socio-ecological systems, water accounting

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Automating a near real-time satellite rainfall pipeline for digital pastoralist decision support app

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Timely and accessible climate information is critical for pastoralist communities operating in highly variable dryland environments. This study presents the design and implementation of an automated, near real-time rainfall data pipeline that integrates satellite-derived precipitation data into a decision support application tailored for pastoralists in selected areas in Kenya and Namibia. The system leverages dekadal rainfall estimates from the TAMSAT dataset, distributed in NetCDF format. A Python-based backend pipeline was developed to automatically retrieve newly released datasets upon availability (published every ten days) and store them on a dedicated server hosted at the University of Kassel. To optimise data transfer and usability within web and mobile environments, a Python script is used as a secondary processing step to convert the NetCDF files into GeoJSON format, significantly reducing data size while preserving spatial structure. The processed rainfall data are then made available through an API endpoint, enabling seamless integration with the frontend of the Inforange application, a pastoralist decision support app. Within the user interface, rainfall patterns are visualised as blue-shaded rasterized polygons over predefined bounding boxes encompassing the target areas in Kenya and Namibia. This approach ensures complete spatial coverage despite irregular administrative boundaries. The rainfall module represents one component of a broader pastoralist decision support system that integrates multiple data streams; however, this work focuses specifically on the backend architecture, data transformation workflow, and frontend integration of satellite-derived rainfall information. The proposed pipeline demonstrates how automated geospatial data processing and lightweight data formats can enhance the timeliness and accessibility of climate information services in data-scarce regions. The system is scalable and adaptable to other geographic contexts and environmental variables, offering a practical framework for strengthening climate resilience among pastoralist communities.

Keywords: API, digitalisation, geospatial data processing, mobile app, near real-time pipeline, pastoralism, satellite-derived rainfall data

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Performance analysis of a solar-storage hybrid system in a remote oil extraction SME in Senegal

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This study evaluates the technical performance of a solar–grid hybrid energy system installed at a remote small and medium-sized peanut oil extraction enterprise (SME) in Passy, central Senegal. Within the framework of the BioStar project, which developed innovative bioenergy solutions to strengthen agri-food industries in West Africa, the SME Yaye Aïssatou was equipped with a 19.8 kWp photovoltaic (PV) system and 17.8 kWh of lithium-ion battery storage. The installation aimed to reduce operating costs and lessen dependence on unreliable grid electricity with frequent outages that had previously caused significant production shortfalls. Using operational data (total PV power, battery state of charge, and energy yield) over a period of one year at a 15 - minutes resolution, we quantify the contribution of PV and storage to the site's total energy demand and the resulting cost savings. The observed performance is compared with initial design simulations to identify key discrepancies, and control strategies. The PV system delivered an average power of 0.96 kW and reached a maximum instantaneous output of 14 kW during the production season at the SME. The recorded state of charge (SoC) of the batteries was on average 84.2 % and dropped during the night hours to recover the next day, suggesting the PV generation capacity matched well the connected load under typical conditions. The corresponding daily energy yield averaged 8.8 kWh, with a maximum recorded value of 55.1 kWh in February. These results show that the hybrid system can reliably supply up to 90 % of the SME's total daily energy demand of 60 kWh, as initially specified during the design phase. Overall, the results confirm that properly sized and operated solar-storage hybrid systems offer a technically viable and economically attractive option for enhancing energy security and productivity in similar SMEs across sub-Saharan Africa.

Keywords: Agro industry, off-grid energy, peanut oil extraction, photovoltaic

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Rainwater harvesting practices among residents of Mutama-Bweengwa, Pemba district, southern province, Zambia

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Rainwater harvesting is an important coping strategy in rural areas characterised by limited and unreliable water supply. This study investigates rainwater harvesting practices among residents of Mutama-Bweengwa in Pemba District, Southern Province, Zambia, with a focus on the methods employed, the factors influencing their adoption, and the associated benefits and constraints. The study is informed by the need to understand how local communities respond to water scarcity under conditions of climate variability, particularly within the context of rural water supply challenges. A mixed-methods approach was adopted, combining household surveys, key informant interviews, and field observations to generate both quantitative and qualitative data. The findings reveal that rainwater harvesting practices in Mutama-Bweengwa are predominantly traditional and reflect traditional water management approaches that are closely linked to the nature of the catchment. Common methods include the use of buckets, wells, dams, trenches, soil bunds, ponds, contours, and limited use of storage tanks. These methods are largely catchment-based systems, adapted to local environmental conditions. Rooftop rainwater harvesting is largely absent, as most households are constructed with grass-thatched roofs, which are unsuitable for effective water collection. The study further establishes that rainfall variability is a key determinant of rainwater harvesting practices. Irregular and insufficient rainfall significantly limits water availability and reduces the effectiveness of harvesting systems. Additional factors influencing adoption include the nature of the catchment, high installation and maintenance costs, limited storage capacity, and lack of technical knowledge on system design and management. Water quality concerns, arising from contamination during collection and storage, also present notable challenges. Despite these constraints, rainwater harvesting provides several benefits to the community. It serves as a supplementary source of water for domestic use, reduces pressure on conventional water sources, and supports smallholder agriculture, particularly dry-season gardening. The practice contributes to improved household resilience and has the potential to enhance food security. However, its effectiveness remains constrained by environmental, technical, and socio-economic limitations. The study highlights the need for context-specific interventions that strengthen existing systems through technical support, community education, and improved water management strategies.

Keywords: Catchment-based systems, climate variability, rainwater harvesting

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Equitable agricultural mechanisation: A gender perspective of socio-economic benefits of grain shelling in Tanzania

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Agricultural mechanisation of smallholder farms in Sub Sahara Africa (SSA) has received notable attention with most studies have focusing on the tillage operations and scanty attention to postharvest activities. Post-harvest threshing remains a labour-intensive and loss-prone activity for smallholder farmers. Using gender lens, this study analyses the socio-economic benefits that accrued to all the actors engaged in mechanical threshing services, including the service providers, equipment repairers, transporters, and small-scale farmers in Tanzania. It specifically, examines perceived changes associated with using multi crop thresher (MCT) on grain quality, labour drudgery, creation of employment, incomes and reducing post-harvest losses. Primary data was sourced from 442 farmers, 66 service providers, 30 repairers, and 31 transporters. Service providers (88 %), repairers (97 %), transporters (100 %) and farmers (55 %) were male, despite women seeking shelling services more frequently than men. This has made women participation in providing threshing services disproportionately skewed in favour of men. Farmers reported improved quality of grains, lower levels of labour drudgery, and reduced post- harvest losses associated with the use of MCTs. Postharvest losses were reported to be lower by 44 %, 33 % and 22 % for maize, sunflower and sorghum, respectively, contributing to perceived improvements in the household food availability. Service providers recorded benefit to cost rations greater than 1, indicating the potential financial viability of threshing service provision. Investment in MCTs can be recouped within a year if the service providers engage in threshing multiple crops rather than specialising in threshing a single crop. Therefore, strengthening linkages among service providers, repairers and transporters would enhance wider impacts. Upscaling training for repairs and service providers, with emphasis on women, would enable greater participation across mechanisation roles.

Keywords: Cost benefit analysis, gender, multi crop thresher, post harvest

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Functional assessment of vegetation using knowledge-grounded scene graphs

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Spatial arrangement carries ecological meaning in semi-arid rangelands, where invasive shrubs like *Prosopis juliflora* suppress useful neighbouring species while canopies such as *Acacia tortilis* facilitate understory forage. Conventional computer vision tasks, specifically detection and segmentation, often struggle to represent the functional affordances defined as the action possibilities for grazing livestock encoded within this vegetation structure. We address this by proposing a knowledge grounded pipeline that extracts relational scene graphs directly from ground-based rangeland imagery. Our framework utilises a schema of nodes (taxa and cover) and edges (predicates such as shades, facilitates, and dominates) derived from local community knowledge and rangeland ecology literature. Through constrained inference using a state-of-the-art vision language model API, the pipeline enforces strict validation against a community informed schema to mitigate hallucination. To align visual perception with ecological logic, the framework incorporates contextual heuristics that refine assessments based on species specific risks and seasonal dynamics. This allows for dry season overrides that recognise leaf litter from palatable species as a resource and prioritise toxicity signals that are often overlooked by purely visual classifiers. Evaluation on 1,120 images from Marsabit County provided schema valid graphs for every image. Agreement with site-curated quality labels reached a weighted Cohen's kappa of 0.70, with minimal systematic confusion between the Good and Poor rangeland assessment classes. Disagreements predominantly occurred at the Medium to Poor boundary, where the invasive species logic can override aggregate visual features and shift scenes toward Poor. This method maintains a verifiable decision trace by integrating pastoralist logic directly into the analytical process. The results demonstrate that the pipeline captures the relational topology of vegetation patches and offers high model explainability, establishing a foundation for formal reasoning and functional affordance modelling in future ecological research.

Keywords: Functional rangeland assessment, local community knowledge

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Comparative analysis of biogas technology profitability and adoption dynamics by rural households in West Africa

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Transitioning toward sustainable and resilient food systems in sub-Saharan Africa requires integrated solutions that address energy access, soil fertility, and farm productivity. Biogas technology represents such an option by simultaneously providing renewable energy and organic fertiliser. However, its adoption in West Africa remains limited and uneven. This study investigates how economic, and institutional factors shape the profitability and adoption of biogas technology within smallholder farming systems, using a comparative analysis of Benin and Burkina Faso.

Household-level data were collected from six villages across both countries. Results show that biogas adoption is financially viable in both contexts, generating positive net returns. However, average annual net returns differ substantially, with households in Burkina Faso (202,602 FCFA) earning approximately 25 times more than those in Benin (8,229 FCFA). This gap is largely driven by higher firewood prices in Burkina Faso, which increase the economic benefits since biogas is substituting firewood.

The contribution of biogas-derived organic fertiliser to total profit also differs markedly, accounting for 78 % of net benefits in Benin compared to 29 % in Burkina Faso. This suggests a higher relative value of compost in Benin. However, a paradox emerges: Most adopters in Benin are pastoralists who rely on direct manure deposition during grazing in their farms and are therefore less likely to utilise biogas slurry. In contrast, adopters in Burkina Faso are predominantly crop and vegetable farmers with a high demand for fertilisers. Biogas adoption has enabled them to reduce chemical fertiliser use by an average of 93 kg annually.

Beyond economic factors, qualitative findings highlight the importance of institutional support. The presence of peer user groups in Burkina Faso enhances biodigester functionality and long-term adoption, while in Benin, weak support structures contribute to lower system sustainability. Nevertheless, 90 % of adopters in Benin express willingness to commercialise biogas slurry, highlighting untapped market opportunities.

These findings underscore the need for context-specific biogas development strategies that align with local farming systems. Strengthening biogas value chains and local support institutions can foster circular economies that simultaneously improve energy access, soil fertility, and rural incomes.

Keywords: Adoption, biogas technology, circular economies, farming systems, organic fertiliser, profitability

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Evaluation of tractor specific volumetric fuel consumption during harrowing in loamy-sand and clay-loam soils

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Efficient fuel utilisation is very important in mechanised agriculture, particularly during soil tillage operations such as harrowing, where fuel makes up a large part of farm operational cost. This study measured the specific volumetric fuel consumption (SVFC) of a tractor during harrowing in loamy sand and clay loam soils under varying depths (10, 13 and 16 cm) and forward speeds (4, 6 and 8 km/h). Field measurements included soil bulk density, cone index, draught force, power output, and moisture content to observe how they affect the SVFC. Results show that loamy sand soil had lower draught resistance, which resulted to the use of less power and lower fuel consumption (2.92–4.19 L/h (liter/hour) at 10 cm depth). However, SVFC decreased from 0.72 to 0.44 L/kWh with increasing speed, indicating improved fuel efficiency despite fluctuations in fuel usage. In contrast, clay loam soil showed higher draught resistance because it is denser and more cohesive in nature, leading to higher fuel consumption (3.08–4.31 L/h at 10 cm and up to 9.34 L/h at 16 cm depth). Specific volumetric fuel consumption similarly decreased with speed (from 0.59 to 0.35 L/kWh at 10 cm and 0.48 L/kWh at 16 cm), showing the engine performed more efficiently under increased load. Analysis of variance (ANOVA) and paired t-tests, confirmed clear differences in SVFC between the two soil types ($p < 0.05$). These findings tell us that soil type and tractor settings is important when trying to save fuel in mechanised tillage. The study provides empirical data to inform tractor operation strategies, contribute to the optimisation of fuel and support small scale agricultural production. In addition, field conditions are not continuous, and several factors affecting fuel consumption during tillage operations change continuously. Therefore, it is necessary to evaluate tractor performance during ploughing and harrowing operations. Improving the accuracy and efficiency of fuel use in these operations can help reduce costs, save time and enhance overall productivity.

Keywords: Draught, harrowing, soil type, specific volumetric fuel consumption, tractor

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Use of *Hylocereus undatus* waste for post-treatment of swine wastewater at the biodigestor efluent

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Biological treatment using biodigesters, although effective in reducing organic pollution of swine wastewater, is insufficient on its own to meet water quality standards. Therefore, complementary methods such as coagulation, adsorption, or advanced oxidation are required to remove residual contaminants. Coagulation is typically performed with inorganic coagulants based on aluminum and iron, but these have disadvantages such as high costs, environmental impact, and health risks. Therefore, this study proposes a novel line of research: the use of agricultural waste from Dragon fruit (*Hylocereus undatus*) stems or cuttings as a source of natural coagulant for polishing treated swine wastewater after biological treatment with biodigesters. The natural coagulant was obtained from a dragon fruit plantation by cleaning the cuttings, removing stems and thorns, cutting them into small pieces, and drying them for subsequent grinding into a fine powder. Tests were conducted using a jar tester, and analytical measurements of the variables were taken before and after treatment. The biodigester outflow was obtained from two tubular biodigeters of 4 m^3 feeded with pig slurry with 45 days of hydraulic retention time. Turbidity, apparent colour, and total suspended solids removals exceeded 65 %, BOD and COD removals exceeded 14 %, nitrogen removals exceeded 30 %, and total solids removals reached 59 %, with no impact on pH (7.1). Considering the planted area in the state of Yucatán, more than 874 tons of agricultural waste could be generated annually. For each kilogram of Dragon fruit cuttings waste, an average of 122 g of coagulant could be generated, which could treat 2,000 liters of wastewater. This study evaluated the use of agricultural waste from Dragon fruit cuttings to obtain a natural coagulant for polishing pig wastewater resulting from biodigester treatment. This represents a new treatment alternative that is natural, economical, environmentally friendly, accessible, and promotes the circular economy.

Keywords: Biodigester, Dragon fruit cuttings, *Hylocereus undatus*, natural coagulant

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Enhancing health monitoring of energy harvesting systems through edge analytics in off-grid smart irrigation systems

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Energy harvesting offers a sustainable solution by utilising ambient energy to efficiently capture, convert, and store power, particularly vital for off-grid devices that rely on limited battery power, susceptible to rapid depletion from computationally intensive applications demanding low latency and real-time responses. Ensuring the operational health of energy harvesting systems is critical; thus, this study evaluates an edge-computing architecture logic that leverages real-time sensor data for fault detection, early fault identification, and predictive maintenance to reduce downtime and enhance system reliability. The framework employs algorithms to optimise energy consumption, prolong operational lifespan, and ensure sustainability. Continuous analysis of energy input/output, environmental factors such as temperature and solar intensity, and energy trends at the edge enables detection of shading, faults, and failures. Results indicate that 90.5 % of the energy harvested reflected stable operation, with shading accounting for 7 %, faults 1 %, and failures 1 %. Additionally, the study identifies critical energy management points such as charge depletion and peak consumption hours, facilitating adaptive responses to changing energy patterns. A comparative analysis between standard edge analysis and integrated edge-predictive methods shows that the integrated system achieves an accuracy of 91.6 %, compared to the edge analytics model with an accuracy of 86.2 % effectively stabilising short-term fluctuations, generating fewer and more stable alerts, with a coefficient of determination R^2 of 0.98. Overall, this approach enhances the scalability and sustainability of solar energy harvesting, particularly in off-grid scenarios, by providing timely fault detection, improving operational efficiency, and promoting sustainable energy practices that minimise waste and maximise energy use.

Keywords: Edge analytics, IoT-based monitoring, off-grid renewable energy systems, predictive maintenance, real-time analytics

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Application of geographic information systems in the diffusion of biogas technology: A systematic review

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The transition to green economies is a priority for both developed and developing countries, with renewable energy playing a central role. While developed and emerging economies have made notable progress in deploying renewable energy technologies such as solar, wind, tidal, and biogas, many developing countries continue to lag despite abundant resource potential. This gap highlights the need for enhanced research, innovation, and technology diffusion strategies. In the context of biogas technology, governments, organisations, and private actors have made substantial investments; however, further efforts are required to accelerate adoption.
Geographic Information Systems (GIS) offer significant potential to support the planning and diffusion of biogas technology, yet their application remains limited in practice. This study systematically reviews the role of GIS in advancing the diffusion of biogas technology. Using the PRISMA protocol, 39 peer-reviewed articles were selected and analysed through systematic review, data extraction, and thematic synthesis.
The findings indicate that GIS-based methods play a critical role in land suitability analysis, site selection for biogas plants, estimation of resource potential and production capacity, and decision support. The geographical distribution of studies shows a strong concentration in Europe (over 51 %), followed by Asia (28 %), Africa (over 13 %), and the Americas (over 8 %), with more than 99 % conducted at the local scale.
This review highlights the growing importance of GIS in biogas development while revealing regional and methodological gaps, particularly in developing countries. It underscores the need to expand the use of GIS tools to support informed decision-making and accelerate the global diffusion of biogas technology.

Keywords: Anaerobic digestion, GIS, multicriteria analysis, remote sensing, spatial analysis

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Design and fabrication of self–propelled agricultural spraying machine for small scale farmers

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Farmers can control pests and diseases with agricultural spraying machines, which is a big benefit. Even though the spraying machine is very important, farmers who use regular spraying machines get very tired because they have to carry the machine on their backs. Moreover, the advanced existing spraying machines including drones are very expensive for farmers in under developing and developing countries to purchase and use to control pests on their crops. The goal of the study was to create, build, and test a self-propelled spraying machine for small-scale farmers that would help to address the challenges small scale farmers goes through when spraying their crops, including, operator fatigue, chemical spillage, stability during operations, and safety. The self-propelled machine was tested on a 0.5-hectare maize farm and a 0.5-hectare pepper farm. The average time spent using the new machine on the farms was 0.84 hours, which shows that it works well.

During the operation, 8 L out of 16 L of chemical solution loaded in the tank was discharged, showing that the developed machine used chemicals well. The operator fatigue test showed a low average hand-arm and strain score of 1.20, which clearly shows that small-scale farmers are less tired. Ten farmers who were part of the safety evaluation indicated that the mean score for chemical exposure was low at 1.40, and the mean score for instability during operation was low at 1.70.

The results showed that the machine that was made is safe, stable, and comfortable to use. The self-propelled spraying machine that was developed worked well in terms of operator fatigue, chemical use, and safety.

Keywords: Agricultural spraying machine, fatigue, operator fatigue, self-propelled sprayer, small scale farming

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CGIAR Science Program on Multifunctional Landscapes: Towards multi-functional agro-eco-systems promoting climate-resilient futures

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Facilitating multi-actor planning towards aspirational multifunctionality of landscapes

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Vibrant, diverse, healthy landscapes managed holistically can support resilient livelihoods, healthy diets, and planetary boundaries through sustainable eco-agrifood systems. Enhancing multifunctionality requires collaboration among diverse landscape actors to co-design technological, socioecological, and institutional innovations with transformative potential. The CGIAR Multifunctional Landscapes Science Program fosters inclusive stakeholder conversations for shared visions, medium-term transition pathways, and concrete action plans outlining behavioural commitments. Under this program, the Vision to Action (V2A) approach - a multi-actor (producers, traders, enterprises, consumers, policymakers), multi-dimensional (agricultural, environmental, economic, social), and multi-scalar engagement process - was developed and is being tested and implemented in Kenya, Ethiopia, Tunisia, Zimbabwe, Peru, and India. It starts with aspirational visions and backcasts required behaviour changes. The process is always facilitated through close long-standing national civil society–CGIAR collaborations. The resulting action plans are owned by the landscape actors, with responsibility for implementation lying with them. At the same time, the plans point to opportunities and entry points for responsive external support - including by research-for-development partners such as the CGIAR. This paper shares experiences from a multi-method assessment of prior V2A steps. In India, for instance, actions toward the aspirational future were mainly motivated by societal and environmental benefits rather than economic gains - though tangible benefits mattered more to farmers. Key barriers included insufficient finance, inadequate tools/machinery, and limited water access. Skills and knowledge were not major bottlenecks, which contrasts with the widespread perception that training and capacity development are critical to drive change. Market constraints like unfair prices for natural produce were seen as government responsibilities. The landscape actors involved saw only a limited role for the private sector in moving toward the vision. Our experiences highlight the need for reflecting on change narratives to guide investment priorities by governments, development partners, and donors. The effort further demonstrates an innovative approach to identify most demanded and most effective strategies to support transformative change.

Keywords: Behavioural change, multi-actor engagement, multifunctional landscapes

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Multifunctional landscapes drive biodiversity and ecosystem services in small-holder farms

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Agricultural intensification has led to significant biodiversity loss, undermining ecosystem services essential for sustainable food production. The decline of insect communities threatens pollination and biological pest control, which are critical for maintaining crop yield, quality, and resilience. Approximately 35 % of global crops depend to some extent on animal pollination, highlighting the importance of conserving agricultural biodiversity. Nature-based solutions that enhance habitat diversity within agricultural landscapes preserves biodiversity and optimises ecosystem services.
Deforestation and landscape simplification further reduce habitat availability for beneficial insects. Although pesticide use mitigates pest damage, it can negatively affect pollinators and natural enemies, disrupting ecological balance. Sustainable farmland management must therefore integrate biodiversity conservation with production goals through landscape-level approaches that strengthen ecological interactions.
This study examines how local and landscape-scale factors influence insect biodiversity and ecosystem services in smallholder agroecosystems, using homestead gardens in Mandla district, Madhya Pradesh, India, as a model system. In landscapes undergoing community-led reforestation, we test the hypothesis that forest cover and on-farm diversity jointly enhance insect-mediated ecosystem services in winter croplands. Pollinator and natural enemy diversity, along with indicators of pollination and biocontrol, were assessed across gradients of forest cover and farm diversification.
Results reveal strong complementarity between forests and farms. Proximity to forests increased insect diversity and abundance, while diversified farms provided essential foraging and nesting resources. Together, these factors enhanced pollination and biological pest control, supporting more resilient agroecosystems.
Our findings highlight the role of habitat heterogeneity as a nature-based solution for strengthening agricultural biodiversity and ecosystem services. Integrating forest conservation with diversified farming can enhance ecological resilience and contribute to sustainable intensification in smallholder landscapes.

Keywords: Biocontrol, ecosystem services, forest, habitat heterogeneity, landscape, nature-based solution, pollination

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Digital tool for landscape investment planning: Identifying context specific agronomic, land and water management practices

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The sustained multifunctionality of agricultural landscapes often relies on the synergistic implementation of land, water and agronomic practices. However, planners and stakeholder often lack integrated decision support systems to identify context specific interventions that cuts across both agricultural production system and land-water management. Existing tools typically address the challenges in isolation. This fragmented approach often leads to siloed implementation and thin distribution of resources. To prioritise and implement context specific and integrated agri-land-water interventions, it is essential to understand their local suitability.

To address these challenges, we developed a comprehensive tool, that integrates agricultural production recommendations with land and water management practices. Within this analytical framework, the biophysical suitability of crops, livestock, and land-water interventions is quantified using core environmental parameters – specifically rainfall, temperature, topographical slope, and essential edaphic factors. These variables are evaluated using trapezoidal scoring aggregated with Liebig's law of minimum, ensuring environmental limiting factors are accurately modelled.

Following the biophysical suitability, candidate species – including crops, livestock and aquatic foods - are subsequently evaluated using weighted, multi-criteria functional trait matrix across agronomic and socioeconomic challenge domains, including land degradation, drought, monocropping, nutritional insecurity, chemical dependence, economic constraints, and livestock integration. To evaluate the landscape's food and nutritional security, a landscape-level nutrient adequacy model calculates the collective dietary output of the optimised crop-livestock-aquatic recommendations. Land and water management practices are scored against the same challenge domains and matched to recommended production systems by spatial, temporal, and functional compatibility.

By operationalizing landscape multifunctionality into a quantifiable, empirical matrix, this DSS enables stakeholders to transition from fragmented planning of agricultural production system and land-water management to a data driven and landscape level resource optimisation. Designed to translate complex methodologies into the language of practitioners and farmers, the tool prevents siloed recommendations and aims to foster resilient, nutrition-sensitive landscape management.

Keywords: Digital tools, food security, land and water management, multifunctional landscapes

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Exploring consumer behaviour, attitudes, and willingness to pay for agroecological products in Tunisian urban areas

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Agroecology is increasingly recognised as a transformative approach to sustainable food systems. In Tunisia, however, despite growing institutional support, agroecological products exhibit weak market penetration due to limited consumer awareness, perceived price premiums, and insufficient differentiation from organic and conventional foods. This study investigates the determinants of urban consumers' attitudes toward agroecological food, purchase intentions, and willingness to pay a premium price, with particular emphasis on psychological, perceptual, and socio-demographic factors. Survey data collected from 400 consumers in Greater Tunis were analysed using descriptive statistics and partial least squares structural equation modelling. Descriptive results indicate that consumers generally acknowledge the environmental and health benefits of agroecological food, perceive its quality positively, and display high price sensitivity. Willingness to pay a premium price remains limited, with approximately 53 % of respondents expressing such willingness in the olive oil case study. Most respondents belong to the urban middle class, are well educated, perceive themselves as physically fit, and show a preference for fresh foods sourced directly from producers and cooperatives. Empirical results reveal that green psychological benefits are the strongest predictor of willingness to pay a premium price, with a standardised coefficient of 0.455, followed by purchase intention and attitude toward agroecological food. Attitudes are significantly shaped by perceived value, green psychological benefits, price sensitivity, and general perceived quality, while purchase intention is influenced by green psychological benefits, perceived value, general perceived quality, health consciousness, and attitude toward agroecological food. In contrast, environmental concern and environmental values do not significantly affect attitudes or purchase intentions, highlighting a gap between environmental awareness and actual consumer behaviour. Mediation analysis further demonstrates that psychological and perceptual factors, particularly green psychological benefits, perceived value, health consciousness, and perceived quality, indirectly influence willingness to pay a premium price through their effects on attitudes and purchase intentions. These findings underscore that in weakly institutionalized markets, consumer behaviour is driven less by environmental values and more by perceived personal benefits, relational trust, and identity-based psychological rewards. The results offer practical insights for policymakers and market actors seeking to enhance consumer engagement with agroecological products and support sustainable food system transitions.

Keywords: Agroecological food, consumer behaviour, structural equation modelling

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How are multifunctional landscape impacts evaluated? A systematic review of approaches, indicators, and evaluation gaps

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Scholars and practitioners promote Multifunctional Landscapes (MFL) as an integrated framework for reconciling agricultural production, biodiversity conservation, restoration, and thriving equitable livelihoods. Despite research efforts, there is limited systematic understanding of how multifunctionality is actually defined, measured, and evaluated in empirical research. Furthermore, a consensual definition of MFL is not found in the current literature. This paper presents findings from a systematic literature review examining the state of the art on assessing multifunctionality in landscapes.

Following the PRISMA 2020 protocol, we searched the Web of Science and Scopus databases using three complementary search strings combining terms for landscape multifunctionality, assessment, and agriculture, yielding 234 eligible documents after deduplication and filtering. Title and abstract screening by four independent reviewers, supported by AI-assisted classification, resulted in 36 papers retained for full-text extraction. Inclusion required papers to explicitly operationalize multifunctionality, empirically measure landscape functions, and conduct some form of assessment based on past or current empirical data (modelling studies were excluded).

Analysis of the corpus, with studies from 2006 to 2025, spanning Europe, Sub-Saharan Africa, Asia, Latin America, and Oceania, reveals three main patterns. First, spatial analysis dominates the methodologies employed, with GIS-based mapping present in nearly half of all studies; participatory and social methods appear in 25 % of studies in the corpus. Second, biodiversity and ecosystem services are the most frequently measured functional dimensions, while social, institutional and governance dimensions are underrepresented. Third, and critically, robust impact assessment is almost entirely absent: counterfactual designs are absent, and most papers characterise landscape states at a single point in time without isolating the effect of any intervention. A recurring pattern across the corpus is the normative invocation of MFL as a framing concept without operationalisation or measurement that clearly relates to a definition of functions. We discuss implications for impact assessment of interventions aiming at increasing multifunctionality in landscapes, policy implications, and future research priorities.

Keywords: Impact assessment, landscape approaches, multifunctionality, performance

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BMFTR session: The Indo-German Science and Technology Centre (IGSTC): international cooperation as a catalyst for sustainable solutions in the applied sciences

Oral Presentations

Carsten Montzka, Alka Singh, Benno Ommerborn Avino, Ajit Patel, Rohit Prabhakaran, Lucas Brenneis, Rahul Raj, Pooja Jain, Bagher Bayat:
AI-based quantification of availability and sustainability of renewable energy and groundwater for irrigation across India (AQUASURGE) 736

AI-based quantification of availability and sustainability of renewable energy and groundwater for irrigation across India (AQUASURGE)

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Ensuring drought resilience and sustainable agricultural production is one of the most pressing challenges in India. Groundwater underpins irrigation across the country, yet its long-term availability under climate change remains uncertain, while the growing expansion of renewable energy and green hydrogen production is creating new demands on water and energy systems. In response, our Indo-German consortium is developing an interactive online map service that provides high-resolution information on groundwater sustainable yield for agriculture and the renewable energy required for pumping. The platform will offer seamless, spatially explicit insights into current conditions and future projections, supporting farmers, planners, policymakers, and investors in making informed decisions. At the scientific core of the project is a novel physically-informed AI framework that combines process-based land surface water and energy balance equations with advanced machine learning techniques. By integrating *in situ* groundwater measurements, hydrogeological data, remote sensing products, and climate projections, the system generates spatially continuous maps while maintaining physical consistency, such as mass balance and ecological flow requirements. The AI foundation model incorporates both spatial and temporal neural network architectures and explicitly accounts for human water use and future demand trends. Using transfer learning, it will simulate groundwater sustainable yield under different climate scenarios, enabling on-demand assessments for selected years between 2030 and 2100 and ensuring robust long-term planning for sustainable irrigation. Beyond agriculture, the project lays the groundwork for evaluating groundwater and renewable energy resources for green hydrogen production, an area where no comparable integrated planning tool currently

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exists for India. Renewable energy assessments, including wind and solar resource analysis and cost estimates, are coupled with groundwater availability and carbon accounting to explore long-term climate-resilient investment pathways. Field-based hotspot investigations using advanced geophysical and geochemical surveys will validate the AI results and strengthen scientific credibility. Within three years, the consortium will deliver a fully operational, open-access web platform that advances transparent science, fosters Indo- German collaboration, and provides, for the first time, an integrated perspective on the water– energy–climate nexus for sustainable agriculture and future green energy development.

BMZ session: Science and innovation for women farmers: Pathways to climate-resilient, multifunctional agri-food systems

Oral Presentations

Theresa Herbold:
Science and innovation for women farmers: Pathways to climate-resilient, multifunctional agri-food systems 740

Science and innovation for women farmers: Pathways to climate-resilient, multifunctional agri-food systems

Theresa Herbold
Federal Ministry for Economic Cooperation and Development, Germany

To transform agricultural and food systems into climate-resilient, multifunctional systems, we need the right levers and actors for change - and women farmers are among the most critical of these. As producers, entrepreneurs, custodians of biodiversity and drivers of resilient local economies, they are central to achieving the objectives of all three Rio Conventions.

Yet women farmers continue to face systemic barriers: limited access to land, finance, technologies, services and markets, compounded by unpaid care work and harmful socio-cultural norms.

Science has a crucial role to play in addressing these barriers and enabling women to shape agri-food systems. German development cooperation works closely with international research institutions to co-develop, test and scale gender-transformative approaches.

On the occasion of the United Nations' International Year of the Woman Farmer 2026, this 90-minute session brings together the voices of women farmers, youth representatives, academia and practitioners.

The discussion will focus on scientific solutions and scaling pathways to advance gender-responsive, inclusive agri-food systems by 2030 - and how research, policy and practice can work together more effectively to achieve this. Speakers and panelists from science, policy, youth networks and German development cooperation will discuss priorities for research and scaling.

Welcome: Aliénor De Cuypère, GIZ

Opening remarks: Theresa Herbold, BMZ

Impulse: Elizabeth Nsimadala, President of the Eastern Africa Farmers Federation and Elizabeth Maanda Sianga, award-winning Agronomist, Farmer and Founder of Agro Queens, Zambia (online)

Evidence input: Karen Nortje, IWMI

Panel discussion:

- Adeola O. Olajide, University of Ibadan
- Frank Rasche, IITA
- Genna Tesdall, YPARD
- Janna Luisa Pieper, Georg-August-Universität Göttingen
- Stéphane De Mfouangoum, GIZ

Open discussion with audience: Aliénor De Cuypère, GIZ and panel

Keywords: Agricultural innovation, climate-resilient agri-food systems, gender equality, gender-responsive research, gender-transformative approaches, science-policy dialogue, women farmers

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BMLEH Session: Exploring ways to strengthen resilience and health of humans, animals and crops – presentation and discussion of project results

Oral Presentations

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Exploring ways to strengthen resilience and health of humans, animals and crops – presentation and discussion of project results

Maja Clausen[1], Edith Simeit[2]

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The German Federal Ministry of Agriculture, Food and Regional Identity (BMLEH) established several funding instruments of global reach, such as project grants in the frame of "Research Cooperation for Global Food Security and Nutrition" as well as a PhD-programme targeting German departmental research institutions and the BMLEH-affiliated Leibniz Institutes. The goal is to contribute to improving global food security and nutrition through practice oriented trans- and interdisciplinary research. The Federal Office for Agriculture and Food (BLE) acts as project executing agency.

Given the continuing unsustainable utilisation of natural resources and increasing pressures from pests and diseases due to climate change, ensuring a steady supply of healthy and safe food – as well as its accessibility – pose a major challenge. The BMLEH-session will highlight three different projects that are developing innovative solutions for increasing the safety of food and feed as well as understanding the exposure to health hazards, such as mycotoxins: In Ethiopia, the project "SUSCAMI" strives to improve the handling and safety of camel milk along the value chain; in Kenya, the project "SoL-FOOD" holistically fights against fungal infestation and aflatoxins in maize; and the project "Mycotoxins_Ghana" investigates the relationship between dietary patterns and internal exposure to mycotoxins.

The session will provide insights into different approaches and discuss challenges and barriers as well as opportunities for improving food safety and health of humans, animals, plants and the environment (One Health).

The following research consortia will present:

1. Bekele Megersa
   University of Addis Ababa
   Project: "Sustainable camel milk production through improved husbandry practices and milk value chain (SUSCAMI)"
2. Katharina Neumeier

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Max Rubner-Institute, Federal Research Institute of Nutrition and Food (MRI)
Project: "Ecological, Technological, and Capacity-Building Strategies for Sustainable Optimisation of Local Maize-Based Food Systems and Climate-Resilient Food Production for Smallholder Farmers in Kenya (SoLFOOD)"

3. Michael Oppong
German Federal Institute for Risk Assessment (BFR)
Project: "Associations between diet and internal exposure to mycotoxins among adults in Ghana and Ghanaian migrants in Europe (Mycotoxins_Ghana)"

Keywords: Aflatoxins, camel milk, food safety, food security, maize, mycotoxins, nutrition, sub-Sahara Africa

CGIAR Gender Equality and Inclusion Accelerator: Gender equality and inclusion in food, land, and water systems by 2050: Projections and solutions

Online presentations

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Envisioning a more equitable future for food, land, and water systems by 2050

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Food, land, and water systems (FLWS) in low- and middle-income countries are under mounting pressure from a polycrisis. By 2050, global food demand is projected to increase significantly, climate shocks to intensify, pressure on natural resources to mount, and urbanisation and youth populations in many regions to expand rapidly. Without a shift in current trajectories, these pressures will compound existing inequalities, deepening vulnerabilities and hindering women, youth, and socially excluded groups to achieve their full potential in terms of productivity and resilience. The coming decades will determine whether FLWS evolve into engines of equality, inclusion, and resilience, or reinforce patterns of exclusion and instability.

We envision a 2050 future in which FLWS are inclusive and just by design, with equitable access to land, water, markets, information, and decision-making spaces; inclusive economic development; recognition of care work; digital inclusion; and strengthened and equitable resilience capacities. It is a future where social norms foster equal opportunity to benefit from and meaningfully participate in FLWS In this 2050 future women, youth, and socially excluded groups are empowered and have a voice as decision-makers, innovators, and drivers of change.

This presentation introduces a collection of contributions that will be presented as a panel session. The collection includes a forward-looking intersectional gender analysis of FLWS to 2050 and four agenda-setting pieces proposing evidence-based strategies to address structural barriers to equality and inclusion in relation to resilience to climate change and shocks, access to and governance of resources, digital inclusion, and young women's potential as drivers of change. In this presentation, we outline the conceptual foundation of the collection, building on the Gendered Food Systems Framework and feminist perspectives on power and structural inequalities. We situate the contributions within these frameworks and highlight that lasting transformative change towards more equitable and inclusive FLWS by 2050 requires addressing power imbalances at multiple levels, alongside shifts toward more equitable norms, agency, control over resources, governance, and voice in mutually reinforcing ways.

Keywords: 2050, climate change, food systems, gender equality, inclusion, polycrisis

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Equitable governance and resource rights: Pathways to inclusive and resilient agrifood system-based livelihoods

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[7]*International Water Management Institute, South Africa*

Agrifood systems are central to the livelihoods of marginalised women and men in low- and middle-income countries, yet gender and social inequalities in the governance, rights, and use of critical agrifood resources limit the benefits women derive from these systems. Gender gaps in tenure over land, water, and natural resources constrain women's productivity and undermine economic, food, and nutrition security outcomes. These inequalities are compounded by factors such as ethnicity, age, and marital status, resulting in multiple and intersecting forms of disadvantage for some groups of women.

This study, submitted as part of the proposed hybrid panel session Gender equality and inclusion in food, land, and water systems by 2050: Projections and solutions, organised by the CGIAR Gender Equality and Inclusion Accelerator and co-organised by the CGIAR Science Program on Multifunctional Landscapes, examines which strategies, interventions, and initiatives (i.e., 'solutions') effectively promote equality and inclusion in the governance of, and rights and access to land, water, and natural resources. We also ask under what conditions these solutions are effective, and identify actions needed from agricultural research for development and policy actors to support contextual adaptation and scaling.

Drawing on a review of peer-reviewed literature, we present solutions with robust evidence of effectiveness, organised using Njuki et al.'s (2022) Gender in Food Systems framework. This framework highlights the need to address both formal barriers (policies, regulations) and informal barriers (norms, beliefs, agency) to equality, across individual to systemic levels.

We show that system-level reforms, including gender-responsive land titling and quotas in resource user committees, can strengthen women's rights and

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influence in governance. However, these approaches are insufficient without addressing discriminatory norms. Behaviour change communication, community dialogues, and engagement with male champions and traditional leaders can support attitudinal change and acceptance of women's rights to resources. At the individual level, rights-awareness initiatives, governance training, and leadership development can strengthen women's agency to claim rights. Critically, collective action and feminist social movements are key for advancing resource rights. We conclude that solutions catalyzing change across multiple levels and domains – driven by diverse actors, especially women themselves – are essential for sustained progress toward equality.

Keywords: And water systems, collective action, food, gender, inclusion, land, rights

Building equitable resilience capacities under polycrisis: Gendered pathways and solutions

Ranjitha Puskur, Prama Mukhopadhyay, Aayushi Malhotra
International Rice Research Institute (IRRI), Sustainable Impact, India

Food, land, and water systems (FLWS) are increasingly shaped by intersecting crises including climate change, demographic transitions, and geopolitical instability that amplify existing inequalities and disproportionately undermine women's resilience capacities. This paper examines how these overlapping polycrises dynamics interact with structural gender constraints and reshape resilience across livelihoods, time use, health, and agency in low- and middle-income countries.

The analysis draws on a synthesis of peer-reviewed literature, global reports, and development interventions over the past two decades, applying a gendered food systems framework to identify solutions that are evidence-based, scalable, and capable of addressing multiple, interacting stressors. Findings show that women's resilience is constrained not only by unequal access to productive resources such as land, finance, climate information, and technologies, but also by entrenched social norms, rising unpaid care burdens, and limited representation in decision-making. These factors operate through reinforcing feedback loops, where reduced assets, time poverty, and institutional exclusion collectively limit women's ability to anticipate, absorb, and adapt to shocks.

The paper identifies three interdependent pathways for advancing equitable resilience. First, strengthening women's agency through collective action, leadership, and inclusive market engagement enables greater voice and decision-making power. Second, improving access to and control over bundled resources combining climate services, finance, and technologies enhances adaptive capacity when aligned with local contexts. Third, transforming gender norms, particularly around unpaid care and mobility, is critical to sustaining gains in both agency and resource use.

Evidence consistently highlights that integrated, multi-component interventions especially those delivered through women's collectives and supported by enabling policies such as gender-responsive budgeting, inclusive recognition systems, and shock-responsive social protection are most effective in addressing structural barriers.

The paper concludes by outlining actionable pathways for research, policy, and practice to design and scale gender-transformative resilience strategies, emphasising alignment between immediate adaptation needs and long-term systemic change toward equitable and sustainable FLWS by 2050.

Keywords: Agency, collective action, gender, norms, pathways, policy, polycrises, resilience capacities

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Looking ahead – gender and inclusion in food, land and water systems in 2050

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This presentation is part of a proposed hybrid panel session entitled "Gender equality and inclusion in food, land, and water systems by 2050: Projections and solutions" by the CGIAR Gender Equality and Inclusion Accelerator, co-organised by CGIAR Science Program on Multifunctional Landscapes. Foresight research has not fully explored gender equality as an outcome of food system change over time. Only marginal progress is being made to address gender inequalities in food systems in some areas, such as closing the gender digital divide. Moreover, intensifying climate change, proliferating conflicts, and declines in official development assistance, are eroding progress or even exacerbating inequalities. If women remain marginalised in food systems in terms of economic opportunities, participation in governance and decision-making, and capacity to adapt to change, achieving global development goals is unlikely. Addressing gender inequality is not only a moral imperative; it is also a catalyst for food system transformation. FAO (2023) estimates that closing gender gaps in farm productivity and wages would increase global GDP by 1 percent and reduce global food insecurity by 2 percentage points. Additional evidence shows that investing in women's empowerment can boost incomes, reduce poverty, and strengthen resilience. This chapter extends existing analyses by projecting changes in gender equality and opportunities for youth in food system-based livelihoods under three alternative scenarios: an optimistic future, a pessimistic future, and business as usual. Each scenario draws on historical data over the past 20 years and assumes alternative futures based on climate change trends, demographic shifts, technological development, and economic growth. The model produces linear projections for indicators of gender equality and engagement in agrifood systems to 2050, disaggregated by region and, where possible, by age group. Given limited data availability for key issues that influence gender equality outcomes, we treat three areas as special cases: 1) access to and ownership of natural resources, 2) migration, and 3) digital inclusion. The results highlight key drivers of gender (in)equality and point to promising areas for intervention.

Keywords: Food systems, foresight, gender equality, youth

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Solutions for digital inclusion and digital innovations for inclusion by 2050

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This presentation is part of a proposed hybrid panel session entitled "Gender equality and inclusion in food, land, and water systems by 2050: Projections and solutions" by the CGIAR Gender Equality and Inclusion Accelerator, co-organised by the CGIAR Science Program on Multifunctional Landscapes.

Digital technologies are rapidly transforming food, land, and water systems (FLWS), yet their benefits remain uneven and risk reinforcing existing gender inequalities. This paper argues that digital inclusion will only advance gender equality by 2050 if it goes beyond expanding access to ensure that women and socially excluded groups can use, shape, and act on digital technologies.

Drawing on global evidence and CGIAR research, the analysis shows that digital exclusion is not driven by a single constraint, but by the interaction of infrastructure, affordability, skills, institutional delivery, and social norms. As a result, closing digital gender gaps requires moving beyond "access-focused" approaches toward strengthening agency – defined as the ability to interpret information, make decisions, and translate digital engagement into meaningful outcomes.

The paper highlights three key findings. First, expanding connectivity alone has limited impact where women lack control over resources, time, and decision-making power. Second, standalone digital solutions often fail to reach or benefit women due to low relevance, literacy barriers, and restrictive norms. Third, bundled and context-responsive approaches – combining digital tools with training, finance, extension services, and community-based support – are more effective in enabling sustained and equitable outcomes.

The paper concludes that achieving inclusive digital transformation requires coordinated action across multiple actors. Governments must invest in inclusive infrastructure and policies; the private sector must design affordable and user-centered technologies; and research and development actors must address bias in data and AI systems while supporting co-design with users. Strengthening intermediary systems and community networks is critical to ensure that digital technologies translate into real opportunities.

Advancing digital inclusion is therefore not only a technological challenge, but a systemic one – central to achieving equitable, resilient, and sustainable agrifood systems by 2050.

Keywords: Agri-food systems, digital inclusion, digital transformation, gender equality, social inclusion

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Supporting young women to thrive and drive transformation in food, land and water systems

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This presentation is part of a proposed hybrid panel session entitled "Gender equality and inclusion in food, land, and water systems by 2050: Projections and solutions" by the CGIAR Gender Equality and Inclusion Accelerator, co-organised by CGIAR Science Program on Multifunctional Landscapes.

Youth livelihoods and unemployment are receiving increased attention from by policy makers, and food, land, and water systems (FLWS) are positioned to meet the need for jobs. Additionally, the unique experiences of young women are often overlooked, while those who reside in rural agrarian communities are further marginalised. We identify promising solutions to support young women in FLWS. Given that young women often experience lack of capital and land, we focus on three areas with i) low start-up costs, ii) existing evidence on young women, and iii) potential for expanding young women's engagement. These include agricultural processing and marketing, livestock and fisheries, and multifunctional landscapes. To address the lack of capital, we also examine financial inclusion approaches that target young women in FLWS.

Across these themes, despite strong evidence on barriers, there is limited evidence on robust solutions for supporting young women. Most interventions focus on reaching young women but not benefiting or empowering them. Within the gender at work framework, gender norms present a substantial barrier, with few gender transformative approaches designed for young women in FLWS. A promising approach is to bundle technical and skills-based interventions with gender transformative approaches to address root constraints.

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Limited assets confine young women to activities with low start-up costs, and limited profits, appropriately designed financial services that simultaneously address access, knowledge, and agency are key. Moreover, the voices of young women are often excluded from key decisions; collectives designed for and led by young women may amplifying their voices and support livelihoods. Overall, solutions for young women need to simultaneously build transferable skills and continue to make FLWS livelihoods safe and appealing for young women. Co-designing interventions can identify and leverage existing opportunities where young women exercise agency and gain benefits in ways that support sustainable FLWs.

Keywords: Agriculture, employment, gender, youth

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