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Agroecological pathways for rainfed agricultural systems towards sustainable agroecosystems and land use productivity

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Abstract
A sustainable agroecosystems approach supports continuous land productivity and ecologically sound land management practices through closed nutrient cycles which is vital in rainfed agricultural systems, dominating over 90% of total croplands in sub-Saharan Africa. However, these agroecosystems face escalating challenges from land use change, climate variability, soil degradation, and water limitations, necessitating strategies, and practices that support a sustainable and equitable transformation of agri-food system through land use reconciliation and soil regeneration. This study identified and evaluated straw mulch as an agroecological farming practices in Uganda that are of non-mechanical tillage but offer promising pathways to enhance soil fertility, increase water use efficiency, and soil moisture while simultaneously advancing environmental conservation and food security. These practices also contribute to a transformative approach aligned with Sustainable Development Goals (SDG 2 of zero hunger and SDG 15 of Life on land), emphasizing soil regeneration, diversified cropping systems, and nature-based solutions. Farm based techniques such as mulching, and the use of straw mulch is an organic soil amendment which improves nutrient cycling, enhance on-farm biodiversity, and reduce reliance on synthetic inputs, while maintaining ecological integrity and supporting climate-resilient farming systems. Notably in this study, the application of organic mulch at thicknesses of 4 cm and 6 cm led to maize yield increase of up to 40%. These findings highlight the broader implications of agroecological practices on soil moisture retention and overall agroecosystem productivity towards a sustainable planetary health. Therefore, there is a need to underscore urgent need to scale agroecological innovations, strengthen indigenous knowledge systems, and inform policy frameworks that promote regenerative, biodiversity-based agriculture particularly in tropical rainfed agroecosystems, which are currently at the crossroads.

Keywords: Agroecology, Land Use and Climate resilience, Rainfed systems, Soil regeneration

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1. Introduction

Rainfed agricultural production systems form the backbone of food production in sub-Saharan Africa, accounting for over 90% of cultivated land (Zizinga et al., 2026; Biazin et a 2012; Wani et al., 2012). These systems are highly vulnerable to increasing climatic variability, land degradation, and water scarcity. The reliance on conventional practices such as intensive tillage and synthetic inputs has further depleted soil health and biodiversity, threatening long-term land productivity. In contrast, agroecological farming offers a sustainable alternative that integrates ecological principles with agricultural practices to support resilient agroecosystems. Agroecology promotes a holistic approach by emphasizing closed nutrient cycles, diversified cropping systems, conservation practices, and the enhancement of ecosystem services (Vikas, & Ranjan, 2024). These principles are particularly critical for rainfed production systems, which depend on efficient water and nutrient use to withstand climatic stressors. By aligning with global development targets such as Sustainable Development Goals like SDG 2 (Zero hunger), and SDG 15 (Life on Land), agroecological practices offer viable pathways to restore degraded lands, improve livelihoods, and ensure food security. This study therefore, evaluated selected non-mechanical agroecological practices in Uganda, focusing on their capacity to regenerate soils, enhance water use efficiency, and boost crop productivity under rainfed conditions. These are soil water based agroecological practices that impacts on soil fertility, water retention, crop yields, and they contribute to climate resilience and sustainable land use.

2. Material and Methods

2.1. Study Area

The study was conducted in mid-western Uganda, an area dominated by rainfed farming systems. It experiences a bimodal rainfall pattern with increasing inter-annual variability and is representative of smallholder, low-input agricultural systems.

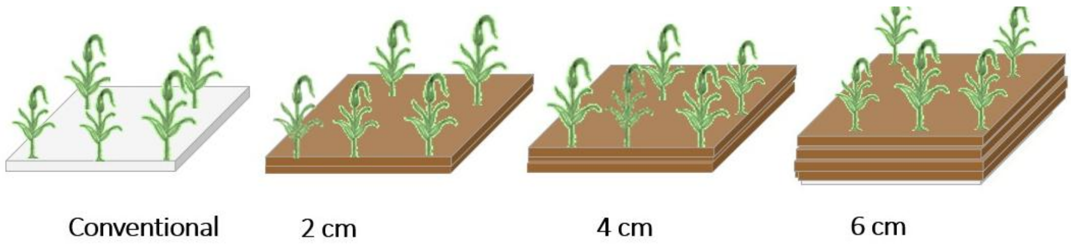

Figure 1. Mulch plots layout experiment (*Photo depicted from Zizinga et al., 2026*)

2.2. Data Collection

Field data were collected through participatory farmer engagements, field experiments, and structured observations from 2018 to 2020. The primary focus was on straw mulch as a non-mechanical agroecological intervention offering soil surface cover and insulation under maize rainfed cropping system. The study investigated mulch thickness (2 cm, 4 cm and 6 cm), together with conventional practice effects on maize yield.

Figure 2. Maize experiment under mulch helps conserve soil moisture, suppress weeds, and regulate soil temperature, promoting healthier maize growth and yield (*Photo: Author credits 2018*)

2.3. Experimental Design

Field trials involved randomized block experiment design on farmer fields, evaluating the effects of organic straw mulch application at 2 cm, 4 cm, and 6 cm thickness on maize yields. Soil samples were analyzed for organic matter content, moisture retention, and nutrient availability before and after application.

2.4. Data Analysis

Quantitative data were analyzed using analysis of variance (ANOVA) to determine significant differences in yield, and soil moisture. For quantitative analysis, the yield data was analyzed using ANOVA to assess statistical differences across the selected mulch thicknesses with R statistical tool version 4.4.3 (R Core Team, 2024). Additionally, other insights from farmers were thematically analyzed to understand socio-ecological drivers of adoption.

3. Results and Discussion

3.1. Agroecological Practices and Soil Health

Mulching significantly ($P < 0.05$) increased maize yields over conventional practice in both 2018 and 2019. In 2019, yields rose across all treatments, from about 4.5 t/ha under conventional management to 6.5 t/ha with 6 cm mulch. The 4 cm and 6 cm mulch treatments (thickness) produced the highest yields, outperforming both the 2 cm mulch and the conventional approach.

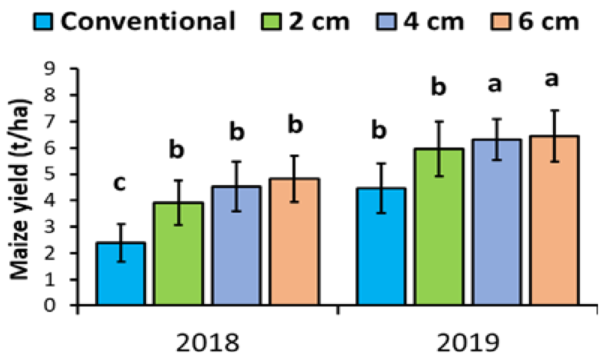

Figure 3. Maize grain yield with studies mulch treatments

The gradual increase in mulch thickness from 2 cm to 6 cm enhances key agroecological functions that directly support higher maize yields (Figure 3). Mulch improves soil moisture retention by reducing evaporation and buffering against rainfall variability, which is critical in predominantly rainfed systems. Thicker mulch layers (4 cm and 6 cm) also suppress weeds more effectively, lowering competition for nutrients and water. Additionally, mulch moderates soil temperature and promotes microbial activity, improving soil structure, organic matter turnover, and nutrient availability. The superior yields seen under 4 cm and 6 cm treatments reflect stronger ecosystem support functions compared to 2 cm and conventional practices, demonstrating mulch's role in climate-resilient productivity.

3.2. Maize yield response

The application of mulch showed a consistent positive effect on maize yields (Figure 3). Plots with 4 cm mulch recorded 28% increase in yield, while those with 6 cm achieved up to 40% increase compared to conventional plots. The increased yield is attributed to improved soil moisture retention, moderated soil temperatures, and reduced weed pressure on maize plants.

3.3. Mulch thickness increases soil moisture

The 6 cm mulch treatment consistently maintained the highest soil moisture across seasons, highlighting its effect to buffer against soil evaporation (Figure 4). In contrast, the conventional practice showed the lowest moisture content, reflecting rapid surface drying and poor water retention. Mulching clearly reduced evaporative losses at shallow soil depths by creating a protective barrier that limits direct exposure to heat and wind. Even in deeper layers of 30 cm and 40 cm, thicker mulch improved infiltration and minimized downward water loss, ensuring sustained moisture availability. These findings emphasize that greater straw mulch thickness enhances the soil's hydrological function, supporting resilience in rainfed agroecosystems under variable climatic conditions.

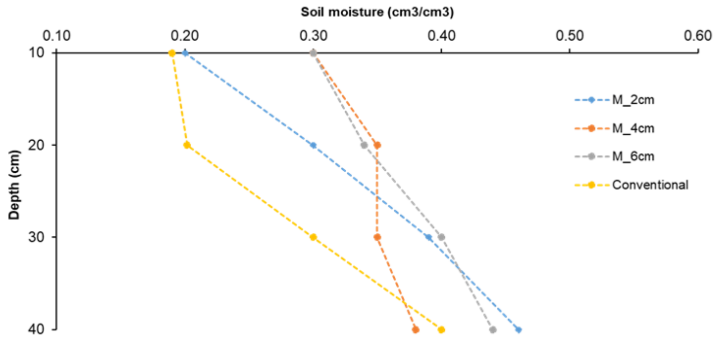

Figure 4. Soil moisture under mulch treatments

4.4. Policy and knowledge implications

Despite the positive outcomes, adoption is limited by inadequate technical support, weak policy incentives, and limited access to mulch inputs due to ever growing competition of resources. Strengthening local knowledge systems and aligning organic straw mulch as an agroecological practice with national agricultural extension services can enhance their reach, adoption, and impact. Policies need to shift towards enabling environments for regenerative agriculture, recognizing farmer-led innovations and ecosystem co-benefits.

5. Conclusions and Outlook

This study demonstrates that organic straw mulching, as an agroecological practice is rooted in low-external-input approaches, which can significantly contribute to the enhancement of rainfed agricultural productivity while strengthening ecosystem functions. By improving organic matter accumulation, conserving soil moisture, and supporting biodiversity, straw mulching offers a viable alternative for sustainable land management in tropical regions. To fully harness its potential, there is an urgent need to institutionalize agroecological trainings and farmer-extension support systems, promote participatory research and co-design of locally adapted innovations, and integrate agroecology into policies aligned with climate adaptation, biodiversity conservation, and food security.

Future research should prioritize on long-term impact assessments, economic feasibility, and scalable models through multi-stakeholder platforms on straw mulch practices. Investing in agroecology today is investing in a climate-resilient and equitable food future.

6. References

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