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"Towards multi-functional agro-ecosystems
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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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Abstract

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 agro-ecosystems.

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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