ABSTRACT

Agriculture remains a central pillar of rural livelihood in many developing countries, where smallholder farmers constitute the backbone of food production. In developing countries where agriculture is the mainstay of the economy, encouraging sustainable crop production can increase farmers' incomes, alleviate food insecurity, and contribute to economic development. Although agriculture is a leading contributor to economic growth worldwide, smallholder farmers in developing countries continue to grapple with a range of constraints: limited access to technology and infrastructure, insufficient extension services, and weather variability. In Tanzania, coffee is an important cash crop that contributes to foreign exchange earnings and rural livelihoods. However, productivity remains low due to old trees, the impacts of climate change, pests and diseases, and poor market linkages. Agricultural extension perceived as a crucial support for the diffusion of knowledge, the increased use of improved technologies, and the promotion of cost-saving production techniques. This study assesses how agricultural extension services promote the sustainability of smallholder coffee farming in Meru District, Tanzania. The research is rooted in two theoretical perspectives: the Agricultural Knowledge and Information System (AKIS) theory, which posits that knowledge production and dissemination are a dynamic, multi-actor process; and Collective Action theory, which emphasizes the role of group action and social capital in achieving sustainable outcomes. These serve as a basis for exploring how AES engages with local socio-ecological systems to affect sustainability across economic, environmental, and social domains.

Mixed-methods research used to combine quantitative and qualitative methods to obtain measurable sustainability outcomes and the experiences of those involved in coffee extension. Data collected from 240 coffee farmers through structured household surveys; 20 key informant interviews conducted with agricultural extension officers, co-operative officers' representatives, and private sector actors; and 08 focus group discussions comprising farmers and agricultural extension staff in selected villages. Secondary data gathered from policy papers, extension reports, and institutional records. Descriptive statistics and econometric models, including ordinary least squares (OLS) regression, two-stage least squares (2SLS) with instrumental variable analysis, and generalized method of moments (GMM), were used to develop and quantify a unified sustainability index with economic, environmental, and social dimensions. At the same time, qualitative data analyzed thematically to contextualize and interpret extension practices, institutional dynamics, and farmer perceptions.

The findings presented in relation to three overarching research objectives. First, it analyses the current situation of AES regarding the sustainability of coffee farming in Meru District. It elaborates on the roles of different stakeholders in imparting knowledge, skills, and sustainable practices to smallholder coffee farmers. The findings indicate that the delivery of AES accomplished through several actors, including extension officers from the government, co-operative officers, and research institutions like Tanzania Coffee Research Institute (TaCRI), Tanzania Coffee Association (TCA), non-governmental organizations such as Arusha Cooperative Union (ACU) and Rafiki Organization, Dorman Coffee Tanzania Ltd., Café Africa. Such agents use participative, digital , and linkage-facilitation modes to spread agronomic information and climate-resilient technologies, increase the availability of quality inputs and credit, and develop markets. The study confirms that successful AES results in higher coffee productivity, better bean quality, higher income for producers, and greater decision-makers' adoption of sustainable practices. The study underscores that a collaborative multi-stakeholder extension system is necessary to improve smallholders' economic, environmental, and social sustainability in coffee production. Moreover, the study examines the modalities employed by different actors in the provision of extension services. The study demonstrates that service providers employed different modalities, including participatory, group-based, Digital and ICT-enabled, linked facilitation, and individual farm visits, which accelerate the sustainability of coffee farming among coffee growers in the study area. Through these modalities, coffee farmers interacted with extension agents to improve farm yields and the sustainability of coffee farming.

Second, the research analyzes the impacts of AES on the coffee farm's sustainability. The study results indicate that agricultural extension services have a significant effect on the sustainability of smallholder coffee farming, with distinct differences across service types and delivery mechanisms. Direct, participatory, and farm-level extension approaches through on-farm demonstrations, individual farm visits and advisory services, input supply linkage with instruction to farmers, soil testing and nutrient management support, integrated pest management (IPM) advisory services, and participatory research programs had a significant positive impact on the sustainability index. On-farm demonstrations had the greatest impact by providing hands-on experience and reducing uncertainty about new methods, while individualized advisory visits improved the accuracy of farm management decisions. Participatory research and IPM services also contributed to sustainability by encouraging farmer innovation, ecologically based pest control, and locally suitable alternatives. Indirect

and informational modalities such as training workshops, print materials, radio programs, and SMS advisories had relatively small independent effects, predominantly on awareness rather than sustained behavioral change.

Third, the study examines the mechanisms of service delivery in agricultural extension and their implications for the sustainability of smallholder coffee production in Meru District. The study reveals four dominant mechanisms: knowledge transfer and capacity building, institutional and systematic mechanisms, motivational and behavioral influence mechanisms, and advisory and facilitation mechanisms, linkage-facilitation approaches that emphasized connecting farmers to resources- finance, input, and markets, and individual farm visits. The analysis shows that each mechanism contributes to different sustainability dimensions, environment, economy, and society with specific pathways. Knowledge transfer and capacity building enable experiential learning and joint actions to address soil health and efficient institutions, and systematic mechanisms facilitate decision-making. Timely decision-making for climate adaptation improved through ICT tools and facilitation of linkages, reducing transaction costs and expanding market accessibility. Visits to single farms enable disease-specific diagnostics and appropriate actions in heterogeneous farm situations. It found that farmers' use of these mechanisms motivated by perceptions of economic viability, social compliance, and risk management, especially in the context of climate variability. Cumulatively, these delivery mechanisms help to establish adaptive, productive, and sustainable coffee farming systems by promoting farmer learning and improving extension services.

In conclusion, the study has shown that agricultural extension services play a crucial role in promoting sustainable smallholder coffee farming in Meru District. However, they only work when participatory, digital, and linkage approaches integrated into coherent multi-actor systems. The study suggests improving coordination among extension providers, expanding investment in digital infrastructure and farmer digital literacy, delivering better-tailored, climate-adapted advisory services, encouraging inclusive advisory approaches with a focus on women and youth farmers, and deepening market linkages and value-chain development. Adopted policy measures can improve AES's contribution to sustainable coffee production and support the livelihoods of coffee-growing regions.

Keywords: Agricultural extension services, sustainability, smallholder, Coffee farming, Meru District.