Integrated Technology Adoption and Agricultural Productivity: Evidence from M&E- Supported Interventions

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Abstract:

Agricultural technology adoption is widely promoted to enhance smallholder productivity, yet evidence on how the intensity of adoption influences outcomes remains limited. This study investigates the cumulative effects of multiple technologies disseminated through Monitoring and Evaluation (M&E) supported interventions on crop yields. A cross-sectional survey of 120 household heads, selected using multistage random sampling was complemented by key informant interviews. One-way ANOVA compared crop yields across adoption levels, while multiple linear regression examined the effects of adoption intensity and selected farmer and project-related factors on productivity. Results show that farmers implementing multiple technologies per crop achieved significantly higher yields than those adopting fewer innovations. Yield gains were particularly notable for maize and sunflower when two or more technologies were adopted, and for sorghum when three technologies were adopted. Regression analysis confirmed that adoption intensity positively influenced productivity ($\beta = 0.168$, $p = 0.036$), whereas greater farming experience was negatively associated with yield ($\beta = -0.269$, $p = 0.008$), suggesting that entrenched routines may limit responsiveness to new innovations. Participation in training had a positive but non-significant effect, underscoring the importance of training quality and relevance. The study highlights that synergistic adoption of complementary technologies drives productivity while accumulated experience may constrain adaptive change. These findings underscore the need for interventions that promote integrated technology packages, context-sensitive training and targeted engagement with experienced farmers to support sustainable productivity growth and effective innovation uptake among smallholders.

Keywords— *Agricultural Technology Adoption, Adoption Intensity, Smallholder Productivity*

I. Introduction

Adoption of agricultural technologies is widely recognized as a key strategy for improving smallholder productivity and promoting sustainable rural development. Persistent constraints such as pests, diseases, soil infertility and reliance on low-yielding crop varieties continue to suppress productivity in sub-Saharan Africa (Kaliba *et al.,* 2018; Muzari *et al.*, 2019). While many studies focus on whether farmers adopt technologies, the intensity of adoption the cumulative number and combination of technologies employed remains an under-theorized determinant of productivity outcomes (Montes de Oca Munguia *et al.,* 2021; Zulu-Mbata *et al.,* 2016). Understanding the role of adoption intensity is critical for designing interventions that optimize smallholder productivity.

In Tanzania, agriculture remains central to rural livelihoods and national food security. Staple crops such as maize and rice are widely cultivated, alongside sorghum, cassava and bananas (FAO, 2018). Despite sectoral growth, low adoption rates, weak extension systems and environmental degradation such as soil infertility, erosion and climate variability constrain productivity (Kaliba *et al.*, 2018; Mwaseba, 2018). Scholars have highlighted that technology adoption is influenced not only by the availability of innovations but also by institutional structures, access to knowledge, social networks and socio-cultural norms (Ayim *et al.,* 2022; Genius *et al.*, 2013; Krishnan & Patnam, 2013).

Monitoring and Evaluation (M&E) based participatory interventions including the Rural Initiatives for Participatory Agricultural Transformation (RIPAT), and broader agricultural transformation programs such as Building a Better Tomorrow (BBT) and the Agricultural Growth Corridors of Tanzania (AGCOT) have sought to facilitate adoption through structured learning, farmer engagement and knowledge dissemination (Vesterager *et al.,* 2017; Mfugale, 2025). Mfugale (2025) demonstrates that these initiatives have not only increased the uptake of complementary technologies but have also enabled semi-commercial farming, strengthened youth participation and enhanced rural livelihoods. These findings underscore the importance of coordinated, multi-level interventions that integrate technology dissemination with capacity-building, training and participatory learning.

Despite these efforts, the productivity implications of adoption intensity remain underexplored, and emerging evidence suggests that farmer experience may negatively moderate adoption outcomes. Experienced farmers often adhere to entrenched routines, reflecting path dependency or traditionalism which can limit responsiveness to new innovations (Muzari *et al.,* 2019; Zulu- Mbata *et al.*, 2016). This observation aligns with the Diffusion of Innovations framework, which emphasizes stages of awareness, decision and implementation in adoption and Institutional Learning theory, which highlights the importance of social learning and structured training in shaping effective uptake (Anderson & Feder, 2007; Rogers, 2003). In line with this conceptualization, the study addresses two key research questions: RQ1: Does

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adoption intensity (number of technologies adopted) influence crop productivity more than individual adoption? RQ2: Why might farmer experience negatively moderate the relationship between technology adoption and productivity? By examining these questions, the study contributes to theory on cumulative adoption effects, institutional learning and constraints imposed by traditional farming practices. The findings offer practical implications for designing interventions that move beyond single-technology promotion toward integrated technology packages, context-sensitive training and targeted engagement with experienced farmers to enhance adaptive capacity and sustainable productivity growth (Mfugale, 2025; Ayim *et al*., 2022; Montes de Oca Munguia *et al.,* 2021).

II. Conceptual Framework

This study is guided by a conceptual framework grounded in the RIPAT (Rural Initiative for Participatory Agricultural Transformation) Theory of Change, which emphasizes participatory learning, experimentation and the integrated adoption of context-specific agricultural technologies as pathways to improved smallholder productivity. The framework ***Error! Reference source not found.*** translates this theory into analytically testable relationships that explain how institutional facilitation and farmer attributes shape technology adoption and agricultural productivity among smallholder farmers in Ikungi District, Tanzania.

Consistent with the RIPAT Theory of Change, the framework is organized around three core constructs: institutional support, adoption intensity, and farmer characteristics. These constructs reflect the sequential logic of RIPAT interventions, whereby institutional inputs stimulate learning and experimentation, leading to cumulative technology adoption and, ultimately, productivity gains (Mfugale, 2025; Montes de Oca Munguia et al., 2021; Rogers, 2003).

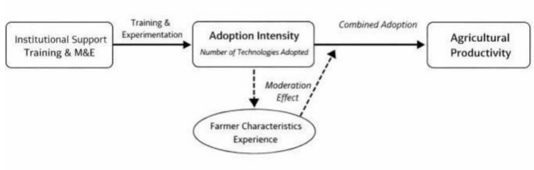

Figure 1:Conceptual Framework

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Institutional support represents the primary enabling mechanism within the framework and corresponds to the input and process stages of the RIPAT model. It is operationalized through participation in RIPAT training sessions, exposure to field demonstrations, engagement with Monitoring and Evaluation (M&E) activities, and access to extension-based agricultural information. Rather than exerting a direct effect on productivity, institutional support is conceptualized as a catalytic factor that enhances farmers' capacity to experiment, learn, and integrate multiple innovations.

Adoption intensity captures the central behavioral outcome of the RIPAT process and serves as the main mediating construct in the framework. It is defined as the cumulative number of RIPAT promoted technologies actively implemented by a farmer, including improved seeds, conservation agriculture practices, irrigation innovations and home gardening systems. The framework hypothesizes that higher adoption intensity directly increases agricultural productivity through the synergistic effects of complementary technologies, reflecting the RIPAT emphasis on integrated rather than single-technology adoption.

Farmer characteristics, particularly farming experience, are incorporated as moderating factors that condition the effectiveness of RIPAT-supported adoption pathways. Experience, measured by years of engagement in crop production, may enhance decision-making and technical competence, but it may also constrain adoption through path dependency and adherence to established practices. As such, farmer experience is expected to shape the strength and direction of the relationships between institutional support, adoption intensity, and productivity (Zulu-Mbata *et al.*, 2016; Muzari *et al.*, 2019).

The causal structure embedded in the framework mirrors the RIPAT Theory of Change: institutional support promotes training and social learning, which fosters experimentation and combined technology adoption (Training → Experimentation → Combined Adoption). Adoption intensity then exerts a direct effect on agricultural productivity, while farmer experience moderates these pathways. Overall, this conceptual framework informed the study's variable selection, data collection design, and analytical strategy. By explicitly grounding the framework in the RIPAT Theory of Change while maintaining conceptual clarity and empirical focus, the study provides a robust basis for testing how participatory, institutionally supported technology adoption influences smallholder agricultural productivity.

III. Methodology

The study employed a quantitative cross-sectional research design to examine the relationships between institutional support, adoption intensity, farmer characteristics and agricultural productivity among smallholder farmers in Ikungi District, Tanzania. This design was selected to capture variation in technology adoption and productivity outcomes within the RIPAT program context at a single point in time, consistent with the study's objective of testing theoretically informed associations rather than causal effects. The approach aligns with the conceptual framework grounded in the RIPAT Theory of Change and allows for systematic multivariate analysis of key constructs.

The study population comprised smallholder farmers participating in the RIPAT intervention. A structured sampling procedure was used to ensure representation across program sites and levels of exposure to institutional support. Primary data were collected through a standardized household survey administered by trained enumerators using a pre-tested questionnaire. The instrument captured information on technology adoption, agricultural output, institutional support variables, and farmer characteristics. To enhance data reliability, survey responses related to training participation and program engagement were cross-checked with RIPAT administrative records where available. Ethical approval for the study was obtained from the relevant institutional review authority prior to data collection. Participation was voluntary, informed consent was obtained from all respondents, and confidentiality and anonymity were assured in accordance with established ethical standards for social science research.

Agricultural productivity was measured as output per hectare, while adoption intensity was operationalized as the cumulative number of RIPAT-promoted technologies actively implemented by each farmer. Institutional support indicators reflected participation in training, exposure to field activities, and access to extension information, consistent with the RIPAT Theory of Change. Data analysis employed regression-based estimation techniques to assess associations between adoption intensity and productivity, controlling for institutional support and farmer characteristics. Model specifications reflected the hypothesized mediating role of adoption intensity and the moderating influence of farmer experience. All results are interpreted as associational, and their credibility is assessed through internal consistency, theoretical coherence, and alignment with prior empirical evidence.

IV. Integrated Technology and Agricultural Productivity

A. Demographic Information

The results indicate that agriculture in the study area is predominantly male-headed, with nearly two-thirds (68.3%) of households headed by men. This reflects prevailing gender norms in rural Tanzania, where land ownership and major production decisions are largely controlled by men, potentially influencing technology adoption dynamics. The age distribution shows that the majority of respondents (55.0%) were between 41 and 60 years, suggesting a mature farming population. While this age group possesses substantial farming experience, previous literature suggests that older farmers may be more risk-averse and slower to adopt new technologies, a finding later confirmed by the negative effect of farming experience on productivity in the regression results. Education levels were generally low, with over half of respondents (50.8%) having only primary education, and 18.3% having no formal education. Limited education may constrain farmers' ability to interpret technical information and fully exploit complex agricultural innovations, underscoring the importance of participatory and hands-on extension approaches such as RIPAT.

Household sizes were relatively large, with 85.8% of households comprising four or more members, implying the availability of family labor for agricultural activities. Larger household sizes may enhance labor-intensive technology adoption but may also increase subsistence pressure on farm output. In terms of farming experience, more than half of the respondents (50.8%) had over 20 years of farming experience, indicating deep familiarity with local agro-ecological conditions. However, as demonstrated in subsequent analysis, long experience does not necessarily translate into higher productivity when it reinforces reliance on traditional practices rather than innovation.

Most respondents (79.1%) operated on small landholdings of two hectares or less, consistent with the smallholder nature of Tanzanian agriculture. Small farm sizes highlight the relevance of productivity-enhancing technologies that intensify production rather than expand cultivated area. Finally, a substantial proportion of farmers (69.2%) reported having participated in RIPAT training activities. This relatively high level of participation reflects the effectiveness of M&E-based participatory approaches in reaching farming communities, although later findings indicate that participation alone is insufficient unless accompanied by effective integration of multiple technologies.

B. RIPAT Technology and Crop Yields

A one-way Analysis of Variance (ANOVA) was conducted to examine differences in crop yields across households adopting varying numbers of RIPAT-disseminated technologies, including conservation agriculture, poultry mother units, rainwater harvesting, and raised home garden

Across all crop categories, households adopting multiple RIPAT technologies generally achieved higher yields than those adopting fewer practices. For maize and sunflower, yield differentials across adoption levels were statistically significant ($p < 0.05$), indicating that productivity gains are closely linked to the integration of complementary technologies. A one-way Analysis of Variance (ANOVA) was conducted to examine differences in crop yields across households adopting varying numbers of RIPAT-disseminated technologies, including conservation agriculture, poultry mother units, rainwater harvesting, and raised home garden

Across all crop categories, households adopting multiple RIPAT technologies generally achieved higher yields than those adopting fewer practices. For maize and sunflower, yield differentials across adoption levels were statistically significant ($p < 0.05$), indicating that productivity gains are closely linked to the integration of complementary technologies. In these cases, higher yields among farmers adopting four technologies suggest that combined soil, water, and management practices generate reinforcing effects that exceed those associated with isolated interventions. However, the relationship between adoption intensity and productivity is non-linear. For maize, yields declined among households adopting three technologies before increasing again at four technologies. This pattern suggests the presence of intermediate adjustment costs, likely arising from increased coordination demands, learning requirements, or short-term resource reallocation associated with managing multiple innovations concurrently. Productivity gains therefore appear contingent not only on the number of technologies adopted, but also on farmers' capacity to absorb and operationalize complexity over time.

For sorghum, the highest yields were observed among farmers adopting three technologies, although differences were not statistically significant. This outcome points to crop-specific adoption thresholds, beyond which additional technologies may yield diminishing or uncertain marginal returns. Similar trends were observed for millet and finger millet, where yield improvements at higher adoption levels did not reach statistical significance. These findings suggest that the productivity effects of technological integration are mediated by crop characteristics and agro-ecological conditions, rather than being uniformly transferable across farming systems.

Taken together, the results provide empirical support for the RIPAT model's emphasis on participatory learning and technological pluralism. Productivity gains are associated less with the adoption of individual technologies than with farmers' ability to combine and adapt multiple practices within their production systems. At the same time, the observed non-linear patterns underscore that technology integration is a learning-intensive and transitional process, in which short-term productivity fluctuations may precede longer-term gains. Consistent with earlier studies demonstrating the advantages of integrated agricultural technologies over single-practice adoption (Msuya *et al.,* 2018; Kassie *et al.,* 2020), this analysis extends the literature by highlighting the conditional and dynamic nature of productivity outcomes. The findings suggest that dissemination strategies should move beyond promoting uptake per se and instead provide sustained support that enables farmers to manage the coordination and learning challenges inherent in multi-technology integration.

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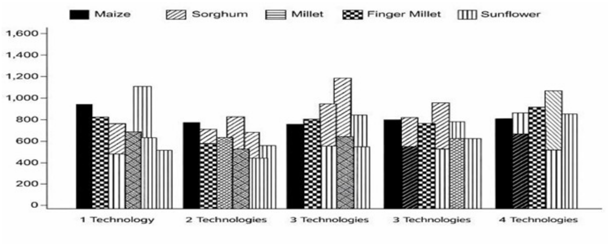

Figure 2: Technology and Agricultural Productivity

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C. Adoption Intensity and Productivity Determinants

The regression results corroborate and extend a growing body of empirical scholarship indicating that adoption intensity, rather than isolated technology uptake, is a key driver of smallholder agricultural productivity. Consistent with prior studies in sub-Saharan Africa (Zulu-Mbata *et al.,* 2016; Kassie *et al.*, 2020; Montes de Oca Munguia *et al.*, 2021), the number of RIPAT technologies adopted is positively and significantly associated with crop productivity ($\beta = 0.168$, $p = 0.036$). This underscores that productivity gains are maximized when farmers implement complementary technologies that collectively address multiple production constraints, including soil fertility, water management, and crop husbandry. Situating these effects within an M&E-supported participatory framework empirically validates the RIPAT Theory of Change, which emphasizes integrated experimentation and learning rather than simple technology transfer. Conversely, the negative and statistically significant effect of farmer experience on productivity ($\beta = -0.269$, $p = 0.008$) highlights the constraints of entrenched routines. Long-standing production practices while historically effective may become suboptimal under climatic variability and rapidly changing technological contexts. This finding refines diffusion theory by demonstrating that adopter characteristics influence not only adoption decisions but also the productivity returns to adoption, particularly when experience reinforces risk aversion and cognitive lock-in. The statistically non-significant effects of training participation and methods suggest that training functions primarily as an enabling mechanism for adaptive learning rather than as a direct determinant of yields, aligning with institutional learning theory (Anderson & Feder, 2007; Genius *et al.*, 2013). Similarly, the lack of association between mobile phone use and productivity reinforces the notion that technology access alone does not improve decision-making unless integrated within trusted, context-specific extension systems. Figure 3 visualizes these relationships and underscores that meaningful productivity

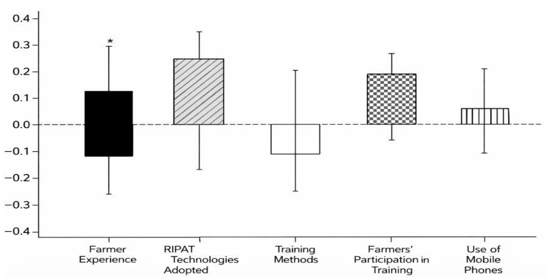

Figure 3: Adoption Intensity and Productivity Determinants

improvements require more than isolated technology adoption; they depend on cumulative adoption and active engagement in learning processes. Collectively, these findings contribute to the literature in three important ways. First, they provide empirical support for adoption intensity as a superior explanatory construct to binary adoption measures, demonstrating that integrated use of complementary technologies drives significant productivity gains. Second, the study highlights that farmer experience may constrain adaptive capacity and productivity when entrenched practices limit openness to innovation. Third, the results strengthen institutional learning theory by showing that training and information access function primarily as catalytic mechanisms whose productivity impact depends on their capacity to disrupt established routines and facilitate technology integration.

From a practical standpoint, the findings resonate strongly with national agricultural strategies, including Tanzania's Agricultural Sector Development Programme (ASDP II) and the National Agricultural Policy (2013), both of which prioritize sustainable productivity growth through integrated technology dissemination, capacity-building, and farmer-centered extension services. By demonstrating that systemic adoption of complementary technologies enhances yields while considering the moderating role of farmer experience, this study underscores the importance of designing interventions that align with policy goals, target behavioral and institutional barriers, and promote context-responsive training. In this way, RIPAT- style participatory M&E approaches not only support farm-level productivity but also contribute to national objectives of food security, climate resilience, and rural development.

V. CONCLUSION

This study advances understanding of agricultural technology adoption by demonstrating that productivity gains among smallholder farmers are driven less by the act of adopting individual innovations than by the depth and integration of adoption across complementary technologies. By empirically showing that adoption intensity exerts a stronger influence on productivity than isolated uptake, the findings challenge dominant binary adoption models and support a systemoriented interpretation of innovation diffusion. Adoption emerges not as a discrete decision but as an adaptive, cumulative process shaped by learning, experimentation, and the capacity to manage technological complexity within specific institutional and agro-ecological contexts.

Equally important, the study refines prevailing assumptions about the role of farmer experience. Rather than functioning as an unqualified asset, experience is shown to potentially constrain productivity when it reinforces path-dependent practices, risk aversion, and cognitive lock-in. This insight extends diffusion and institutional learning theories by illustrating that adopter characteristics influence not only the likelihood of innovation uptake but also the productivity returns to adoption. Experience enhances outcomes only when it is continuously reconfigured through structured learning and exposure to integrated innovation systems.

The findings carry important implications for scholarship and practice. For research, they underscore the need to move beyond single-technology and adoption–non-adoption frameworks toward analytical models that capture configurational adoption, learning dynamics, and heterogeneity among farmers. For policy and development practice, the results suggest that interventions should prioritize integrated technology packages supported by sustained facilitation, experiential learning, and differentiated engagement strategies that explicitly address behavioral and institutional constraints faced by experienced farmers. Training and information provision are most effective when they function as catalysts for adaptive learning rather than as standalone inputs, while digital tools yield limited impact unless embedded within trusted and context- responsive extension systems.

Overall, the study demonstrates that sustainable productivity growth in smallholder agriculture depends fundamentally on the capacity to foster adaptive learning and systemic integration of innovations, rather than on technology dissemination alone. By shifting analytical and practical attention toward adoption intensity and its interaction with farmer experience, the study offers a more nuanced and pragmatically grounded framework for designing agricultural interventions capable of generating durable productivity gains in sub-Saharan Africa and comparable smallholder contexts.

VI. ACKNOWLEDGEMENT

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