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Impact of farmer field schools on adoption of banana production technologies among smallholder farmers in Webuye East Sub-County, Bungoma County, Kenya

Lenis Nanjala Marani[1*]
Mary Goretti Kariaga[2]
Rose Onamu[3]
John Caleb Dimo[4]

[1*]lenimarani87@gmail.com

[1,2,3,4]Masinde Muliro University of Science and Technology, Kenya

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ABSTRACT

This study examined the impact of Farmer Field Schools (FFS) on the adoption of banana production technologies among smallholder farmers in Webuye East Sub-County, Bungoma County, Kenya. The study was guided by the diffusion of innovations theory, which explains how knowledge dissemination and social learning influence technology uptake among farmers. An evaluation research design was employed to facilitate comparison between FFS participants and non-participants within the same socio-economic context. The target population comprised smallholder banana farmers in the sub-county, from which a sample of 384 respondents was drawn, consisting of 192 FFS participants and 192 non-participants. A multistage sampling procedure was applied, incorporating purposive, stratified, cluster, and systematic random sampling techniques to ensure representativeness. Primary data were collected using structured questionnaires administered through face-to-face interviews. Data analysis involved both descriptive and inferential statistics, including means, independent sample t-tests, and Pearson correlation analysis to determine differences in adoption levels and relationships between variables. The findings revealed that participation in FFS had a statistically significant positive effect on the adoption of banana production technologies, with FFS farmers demonstrating higher adoption levels across all practices compared to non-participants ($p < 0.001$). The most pronounced differences were observed in the adoption of certified seedlings, pest and disease control, spacing, and integrated pest management practices, indicating the effectiveness of FFS in promoting knowledge-intensive technologies. The study concludes that FFS is a highly effective participatory extension approach that enhances farmers' technical capacity, decision-making skills, and overall technology uptake. It is recommended that policymakers and development agencies scale up FFS programs, integrate them into national agricultural extension systems, and complement them with input access and market support mechanisms to maximize adoption outcomes and improve smallholder livelihoods.

Keywords: Banana Production Technologies, Farmer Field Schools (FFS), Smallholder Banana Farmers, Technology Adoption

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I. INTRODUCTION

Agricultural transformation in developing economies is fundamentally driven by the adoption of improved technologies and effective extension systems(Justine *et al*., 2025). Globally, smallholder farmers produce over 30% of the world's food, yet their productivity remains constrained by limited access to knowledge, inputs, and advisory services (Tetti *et al.*, 2026). Technology adoption particularly improved seed varieties, soil fertility management, and integrated pest management has been widely recognized as a critical pathway for enhancing agricultural productivity, food security, and rural incomes (Frimpong *et al.*, 2026a). However, conventional top-down extension approaches have often failed to achieve sustained adoption due to weak farmer engagement, limited contextualization, and inadequate knowledge transfer mechanisms. In response, participatory extension models such as Farmer Field Schools (FFS) have gained global prominence. The FFS approach emphasizes experiential learning, group-based problem-solving, and farmer-led experimentation, enabling farmers to acquire practical knowledge and skills in real production environments (Van den Berg *et a*l., 2020). Evidence from Asia and Latin America indicates that FFS significantly improves farmers' technical knowledge and adoption of complex agricultural practices, particularly those requiring continuous management and decision-making (Shammout *et al*., 2025). Despite these successes, the magnitude and consistency of FFS impacts vary across regions and technologies, necessitating context-specific evaluations.

In Africa, agricultural productivity remains below global averages, largely due to low adoption of improved technologies among smallholder farmers (Wang & Zhou, 2026). Studies across Sub-Saharan Africa show that while awareness of innovations is relatively high, actual adoption remains limited due to institutional, socio-economic, and informational constraints(Jimaima *et al*., 2026). Participatory approaches such as FFS have been promoted to address these challenges by enhancing farmer capacity and facilitating peer learning. Empirical evidence suggests that FFS contributes to increased adoption of sustainable land management practices, improved crop yields, and enhanced resilience among smallholder farmers (Wang & Zhou, 2026; Tesfahun et *al*., 2026). However, some studies indicate that adoption outcomes may be uneven, particularly for capital-intensive technologies, highlighting the need for localized impact assessments.

In Kenya, agriculture contributes significantly to GDP and rural livelihoods, with smallholder farmers accounting for the majority of agricultural production (Nyamamba *et al*., 2020). Banana farming, in particular, plays a crucial role in food security and income generation in high-potential regions. Despite this importance, banana productivity remains suboptimal due to low uptake of improved agronomic practices such as use of certified seedlings, proper spacing, pest and disease management, and soil fertility practices (Chukwu *et al*., 2025). The Kenyan government and development partners have increasingly adopted FFS as a key extension strategy under programs such as the National Agricultural and Rural Inclusive Growth Project (NARIGP) (Mokaya, 2025). While these interventions aim to enhance farmer knowledge and technology uptake, empirical evidence on their effectiveness in specific value chains, including banana production, remains limited. Bungoma County is a major banana-producing region characterized by favorable agro-ecological conditions, including fertile soils and adequate rainfall (Akala, 2021). Despite this potential, smallholder banana farmers in the county continue to experience low productivity and income levels. This is largely attributed to poor adoption of improved production technologies and limited access to effective extension services (Mdoda & Mudhara, 2025). Although FFS programs have been implemented in the county, particularly in Webuye East Sub-County, there is insufficient empirical evidence quantifying their impact on farmers' adoption behavior.

Webuye East has been a focal area for FFS implementation under NARIGP, targeting banana value chain development. While the program has trained farmer groups and promoted improved technologies, the extent to which participation in FFS translates into measurable differences in adoption compared to non-participants remains unclear. Existing studies in Kenya have largely focused on general extension outcomes or other crop systems, with limited focus on banana production technologies and localized comparative analysis between FFS and non-FFS farmers. Despite the increasing adoption of Farmer Field Schools as a participatory extension approach, there is a lack of rigorous, localized empirical evidence assessing their effectiveness in promoting adoption of banana production technologies among smallholder farmers. Specifically, few studies have systematically compared adoption levels between FFS participants and non-participants within the same socio-economic and agro-ecological context. This study addresses this gap by providing a comparative analysis of technology adoption among smallholder banana farmers in Webuye East Sub-County, Bungoma County, Kenya, thereby contributing to evidence-based policy and extension programming.

1.1 Statement of the Problem

Smallholder banana farmers in Kenya face persistent challenges related to low productivity, poor agronomic practices, and limited access to extension services. Conventional top-down extension approaches have proven insufficient in addressing these challenges due to weak farmer engagement and limited knowledge transfer. While FFS has been promoted as an alternative extension model, there is inadequate empirical evidence quantifying its impact on technology adoption at the local level. Specifically, limited studies have compared adoption levels between FFS participants and non-participants in banana value chains. This study addresses this gap by providing rigorous empirical analysis of FFS effectiveness in Webuye East Sub-County.

1.2 Research Objectives

i. Identify most influential technologies among smallholder banana farmers in Webuye East Sub-county, Bungoma County, Kenya.
ii. To evaluate the extent to which Farmer Field School (FFS) participation influences the adoption of both basic and advanced banana production technologies among banana farmers in Webuye East Sub-county, Bungoma County, Kenya.

II. LITERATURE REVIEW

2.1 Theoretical Review

The study is anchored on the diffusion of innovation theoretical frameworks that explain the adoption of innovations and the role of communication.

2.1.1 Diffusion of Innovations (DOI) Theory

The Diffusion of Innovations (DOI) Theory, developed by Everett M. Rogers, provides a robust framework for understanding how new ideas, technologies, and practices spread within a social system over time. According to

Rogers (2003), diffusion is the process through which an innovation is communicated via certain channels among members of a social system. The theory identifies four key elements influencing adoption: the innovation itself, communication channels, time, and the social system. It further categorizes adopters into five groups innovators, early adopters, early majority, late majority, and laggards based on their readiness to adopt innovations. A central premise of DOI theory is that the rate and extent of adoption are influenced by farmers' perceptions of the innovation's attributes, namely relative advantage, compatibility, complexity, trialability, and observability (Rogers, 2003). Innovations perceived as beneficial, easy to use, compatible with existing practices, and observable in outcomes are more likely to be adopted. Additionally, interpersonal communication and peer learning are critical in reducing uncertainty and facilitating informed decision-making among potential adopters.

The relevance of DOI theory to this study lies in its ability to explain how Farmer Field Schools (FFS) facilitate the diffusion and adoption of banana production technologies among smallholder farmers. The FFS approach is inherently aligned with the principles of DOI theory, as it emphasizes experiential learning, group interaction, and knowledge sharing. Through FFS, farmers are exposed to new technologies in a practical setting, allowing them to observe results (observability), test innovations on a small scale (trialability), and evaluate their benefits (relative advantage). This process reduces perceived risks and enhances farmers' confidence in adopting new practices. Furthermore, FFS promotes strong social networks and peer-to-peer learning, which serve as effective communication channels for innovation diffusion. Farmers within FFS groups act as both learners and disseminators of knowledge, accelerating the spread of innovations beyond the immediate participants. This aligns with the DOI concept that interpersonal networks are more influential than mass communication in shaping adoption decisions, particularly in rural agricultural contexts (Rogers, 2003).

In the context of this study, DOI theory provides a theoretical basis for analyzing differences in adoption levels between FFS participants and non-participants. It helps explain why FFS farmers are more likely to adopt improved banana production technologies due to enhanced access to information, practical exposure, and social reinforcement. The theory also supports the expectation that participatory extension approaches, such as FFS, are more effective in promoting sustained adoption compared to conventional top-down methods. The Diffusion of Innovations Theory underpins this study by linking the mechanisms of Farmer Field Schools to observed adoption outcomes, thereby offering a conceptual explanation for the role of experiential learning and social interaction in agricultural technology uptake.

2.2 Empirical Review

2.2.1 The Most Influential Banana Production Technologies Among Smallholder Farmers

Empirical literature on agricultural technology adoption globally indicates that the influence of specific technologies varies depending on their complexity, perceived benefits, and knowledge requirements (Frimpong *et al*., 2026b). Studies show that knowledge-intensive and management-based technologies, such as integrated pest management, improved planting materials, and soil fertility practices tend to have the greatest influence on farmer adoption due to their direct impact on productivity and sustainability (Bashiru et *al*., 2024).These technologies often require training and technical understanding, making them more responsive to structured learning approaches. In Sub-Saharan Africa, similar patterns have been observed, where technologies related to soil management, pest control, and crop husbandry practices are more influential compared to capital-intensive innovations. Empirical findings suggest that farmers are more likely to adopt technologies that are cost-effective, compatible with existing farming systems, and demonstrate clear yield benefits (Lindow *et al*., 2026; Frimpong *et a*l., 2026). For instance, practices such as crop rotation, mulching, and pest management have consistently shown higher adoption levels due to their relatively low cost and immediate agronomic benefits (Pokharel *et al*., 2026). However, technologies requiring higher financial investment, such as irrigation systems, tend to have lower influence despite their potential productivity gains.

In the Kenyan context, studies have shown that the most influential agricultural technologies among smallholder farmers are those that directly enhance productivity and resilience, including improved seed varieties, soil fertility management practices, and pest and disease control methods (Aynalem *et al*., 2026); Awoke & Brück, 2026). These technologies are often prioritized due to their immediate impact on food security and income generation. Furthermore, research highlights that farmer awareness, access to extension services, and perceived economic returns play a critical role in determining which technologies become dominant within farming communities (Prajapati *et al*., 2025). Despite this body of evidence, there is limited empirical research specifically focusing on banana production systems, particularly in Western Kenya. Existing studies tend to generalize across crops, thereby overlooking crop-specific dynamics that influence technology adoption. Additionally, there is a lack of localized evidence at the sub-county level, such as Webuye East, on which banana production technologies are most influential among smallholder farmers. This gap limits the ability to design targeted interventions that prioritize the most impactful technologies within specific contexts.

2.2.2 Influence of Farmer Field School Participation on Adoption of Banana Production Technologies

Globally, Farmer Field Schools (FFS) have been widely recognized as effective participatory extension approaches that enhance farmers' knowledge and promote the adoption of improved agricultural technologies (Prajapati *et al*., 2025) . Empirical studies demonstrate that FFS participation significantly increases adoption rates by facilitating experiential learning, peer interaction, and practical problem-solving (Pant *et al*., 2026). These approaches are particularly effective for complex and knowledge-intensive technologies, as they enable farmers to observe, experiment, and internalize new practices (Pokharel *et al*., 2026). Consequently, FFS has been associated with improved uptake of integrated pest management, improved planting materials, and sustainable land management practices. In Africa, evidence further supports the positive impact of FFS on technology adoption, although the magnitude of impact varies across technologies and contexts. Studies in countries such as Tanzania and Uganda indicate that FFS participation enhances farmers' capacity to adopt improved practices by strengthening knowledge, skills, and social learning networks (Justine *et al*., 2025; Tufan et *al*., 2025). However, adoption outcomes are often constrained by external factors such as limited access to inputs, financial resources, and market opportunities. As a result, while FFS improves knowledge and willingness to adopt, the actual uptake of certain technologies, particularly capital-intensive ones remain moderate.

In Kenya, empirical studies reveal that extension services and farmer training programs, including FFS, play a significant role in improving agricultural technology adoption. Research shows that farmers who participate in training programs are more likely to adopt both basic and advanced agricultural practices compared to those who do not receive such training (Pokharel *et al*., 2026). Additionally, evidence suggests that the effectiveness of FFS is particularly pronounced for knowledge-intensive technologies, where experiential learning helps reduce uncertainty and build farmer confidence (Tetti *et al*., 2026). However, despite the documented benefits of FFS, there remains limited empirical evidence comparing adoption levels between FFS and non-FFS farmers across a wide range of technologies within specific crop systems. Most studies focus on general adoption outcomes rather than examining the extent to which FFS influences both basic and advanced technologies simultaneously (Tesfahun *et al*., 2026; Wang *et al*., 2025). Furthermore, there is a scarcity of micro-level studies conducted at sub-county levels, such as Webuye East in Bungoma County, which limits understanding of localized impacts of FFS interventions. The reviewed literature demonstrates that while significant progress has been made in understanding agricultural technology adoption and the role of Farmer Field Schools, several critical gaps remain.

First, there is limited crop-specific evidence focusing on banana production technologies, particularly in the Kenyan context. Second, most studies are conducted at broader regional or national levels, with insufficient attention to sub-county dynamics where contextual factors strongly influence adoption behavior. Third, there is a lack of empirical studies that simultaneously identify the most influential technologies while also evaluating the differential impact of FFS participation across both basic and advanced practices. This study addresses these gaps by providing localized, crop-specific evidence from Webuye East Sub-county, explicitly identifying the most influential banana production technologies and empirically evaluating the impact of FFS participation on their adoption.

III. METHODOLOGY

3.1 Study Location and Context

The study was conducted in Bungoma County, Webuye East Sub-county (Figure 1) where national agricultural and rural inclusive Growth program (NARIGP) implemented a banana value chain using the FFS approach (GoK, 2017). The activity was implemented during the 2018/2019, 2019/2020, 2020/2021, 2021/2022 and 2022/2023 banana years. Bungoma County is situated on the slopes and foothills of Mt. Elgon, and its natural potential is partly related to the natural potential of the districts in Central and East Kenya, characterized by fertile volcanic soils and enough water. The average annual rainfall in the County ranges from 1000 to 1800 mm (KNBS, 2019).

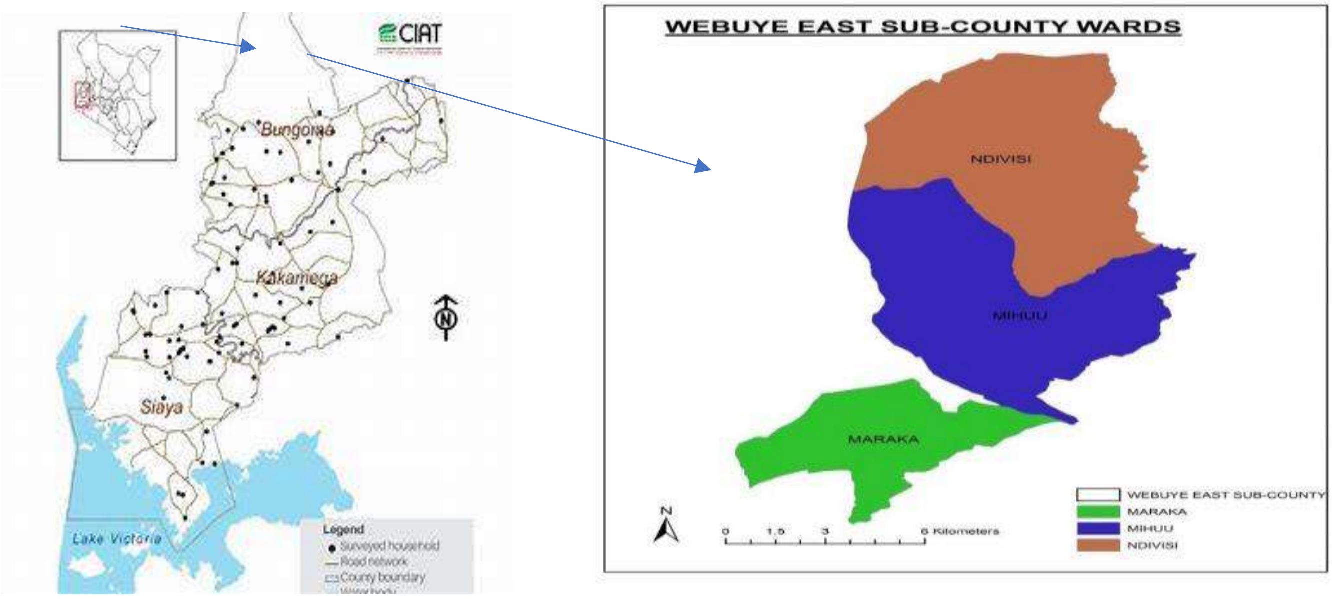

Figure 1
Map of study area for Banana farmers in Webuye East Sub-County, Bungoma County, Kenya

3.2 Research Design

The study employed the evaluation research design to compare adoption between FFS participants and non-participants. The design was appropriate since it allowed collection of information and description of population from a sample. The design was helpful in making accurate assessment of inferences and relationship of phenomenon (Design *et al.*, 2021).

3.3 Target Population

Data was elicited from small holder banana farmers. Sample size for banana farmers was determined based on the formula proposed by (Cochran & Taiwan, 1977), as indicated below;

$$n = \frac{z^2 pq}{e^2}$$

Where n is the sample size, z is the confidence level with a standard value of 1.96, p is the proportion of farmers that produce banana. A value of 50% representing 0.5 will be used due to unavailability of information on the proportion. Q is 1-p and e are the precision level of 0.05 representing 5%. When substituted,

$n = \frac{1.96\text{x}1.96\text{x}0.5\text{x}0.5}{.05^2}$ = 384 farmers.

Therefore 384 smallholder banana farmers were selected for the study. This constituted 192 banana farmers involved in FFS program and 192 banana farmers not involved in the FFS.

3.4 Sampling Procedure and Sample Size

The first stage involved purposive selection of Webuye East Sub County in Bungoma County since it was among the sub counties that implemented NARIGP-FFS program and was among the key banana producing sub counties in Bungoma County. Stratified sampling was used to categorize each of the three wards (Mihuu, Ndivisi and Maraka) into strata. Simple random sampling was used to select four FFS groups of banana farmers from each of the ward making a total of twelve (12) groups. Each group has membership of between 25-30 farmers. Systematic random sampling was used to select 16 farmers from each group to make a sample size of 192 farmers from the treatment group (FFS). Similarly, for the control group (non-FFS participants), four groups were selected from each ward with 16 farmers per group to make a total of 192 farmers. A multistage sampling approach was used as summarized below in table 1.

Table 1

Summary of Sampling Procedures in the Study Area

Level	Sampling Method	Sample Description	Sample Size
Sub-county	Purposive	Webuye East	1
Wards	Stratified	Mihuu, Maraka, Ndivisi	3
Farmer Groups	Cluster	FFS (12) + Non-FFS (12)	24
Individual Farmers	Systematic random	16 farmers per group	384

3.5 Instrumentation

The primary data was gathered by a semi-structured, researcher-administered questionnaire by the researcher in Webuye East, Mihuu, Maraka and Ndivisi wards. The questionnaire was straightforward to conduct, facilitating realistic scoring and data analysis. Moreover, the replies to the items in the questionnaire exhibit consistency among the respondents (Qing, 2025). The questionnaire items were created in accordance with the study goals.

3.7.1 Validity

The validity of a questionnaire refers to its capacity to accurately assess the intended construct (Krase *et al*., 2026). Before data collection, the instrument was presented to experts in the School of Agricultural Veterinary Science and Technology to assess its validity. The experts' feedback was utilized to enhance the tool.

3.7.2 Reliability

Reliability assesses the instrument's consistency (Krase *et al*., 2026). The questionnaire's dependability was established through a pilot study involving 30 smallholder farmers in Kabula Ward, Kanduyi sub-county, Bungoma County. Consequently, smallholder farmers in Kabula exhibiting socioeconomic characteristics similar to those of the target demographic were selected for the pilot study. Kabula was selected due of its vulnerability to climate change and the involvement of its young in agriculture. The reliability coefficient of 0.805 was calculated using the Cronbach Alpha Scale (Edelsbrunner *et al*., 2025). The questionnaire was deemed reliable as its reliability coefficient above 0.70. Modifications to the instrument questions were implemented based on the findings of the pilot study.

3.6 Data Collection Procedure

Data collection was conducted using a structured and systematic approach to ensure accuracy, consistency, and reliability of the information gathered from smallholder banana farmers in Webuye East Sub-county. Prior to the commencement of fieldwork, official authorization was obtained from relevant institutional bodies, including the university and local administrative authorities within Bungoma County. Permission was also sought from ward agricultural officers and Farmer Field School (FFS) group leaders to facilitate access to respondents. A pilot study had earlier been conducted in Kabula Ward to test the reliability and clarity of the questionnaire, and necessary adjustments were made prior to the main data collection exercise. During the actual data collection, the researcher administered the semi-structured questionnaires through face-to-face interviews with selected farmers. This approach was preferred to enhance response rates and ensure accurate capturing of responses, particularly among respondents with varying literacy levels.

The data collection process followed the multistage sampling framework outlined in the study. Farmers were first identified from selected FFS and non-FFS groups within Mihuu, Ndivisi, and Maraka wards. Systematic random sampling was then applied within each group to select individual respondents. A total of 384 farmers were interviewed, comprising 192 FFS participants (treatment group) and 192 non-FFS farmers (control group). Ethical considerations were strictly observed throughout the process. Respondents were informed about the purpose of the study, and their participation was voluntary. Informed consent was obtained prior to the interviews, and confidentiality of the information provided was assured. Data collected were securely stored and used strictly for academic and research purposes.

3.7 Data Analysis

Data analysis was conducted using both descriptive and inferential statistical techniques in line with the study objectives. Data were first coded, cleaned, and entered into statistical software for analysis. Descriptive statistics such as means and standard deviations were used to summarize adoption levels of different banana production technologies. Inferential statistics, particularly independent sample t-tests and effect size analysis, were used to compare adoption levels between FFS and non-FFS farmers and determine the statistical significance of observed differences.

IV. FINDINGS & DISCUSSION

4.1 Most Influential Banana Production Technologies Promoted through FFS

The findings indicate that Farmer Field Schools (FFS) significantly influence the adoption of banana production technologies, with the greatest effects observed in knowledge-intensive and management-sensitive practices. Specifically, the use of certified seedlings (M = 1.4312), pest and disease control (M = 1.222), and proper spacing and holing (M = 1.1682) ranked as the most influential technologies, demonstrating the largest adoption differences between FFS and non-FFS farmers. Other moderately adopted practices include timely land preparation, integrated pest management, and de-suckering, while relatively lower adoption gains were observed for practices such as solarization (M = 0.3419) and herbicide application (M = 0.2123). Overall, the pattern suggests that FFS interventions are more effective in promoting agronomic practices requiring technical knowledge and farmer training compared to input-based or less knowledge-intensive technologies (Table 2).

Table 2

Ranked Technologies Based on the Magnitude of Adoption Differences between FFS and non-FFS Farmers

Technology	Mean Difference	Rank
Use of certified seedlings	1.4312	1
Pest and Disease control	1.222	2
Spacing and Holing	1.1682	3
Timely land preparation	1.1518	4
Integrated pest management	1.1184	5
De-suckering	1.0841	6
Hot water treatment	0.9998	7
Use of inorganic fertilizers	0.9736	8
Root trimming	0.9103	9
Pruning	0.8534	10
Mulch and windbreak	0.7844	11
Organic fertilizers	0.6582	12
Solarization	0.3419	13
Herbicide application	0.2123	14

The results highlight a clear trend. The FFS approaches are particularly effective in facilitating the adoption of complex, skill-based agricultural practices. The highest-ranked technologies are certified seedlings, pest and disease control, and spacing are all practices that require not only awareness but also practical understanding and continuous management. This supports the core pedagogical model of FFS, which emphasizes experiential learning, peer-to-peer knowledge exchange, and field-based demonstrations. Certified seedlings ranking highest suggest that FFS successfully enhances farmers' awareness of quality planting materials and their long-term benefits, such as improved yields and disease resistance. Similarly, the strong adoption of pest and disease control measures reflects the effectiveness of participatory training in diagnosing and managing crop health challenges. Practices like spacing and timely land preparation further indicate that FFS strengthens farmers' agronomic decision-making skills, which are critical for optimizing productivity.

In contrast, lower-ranked technologies such as herbicide application and solarization may require fewer technical skills or may be constrained by cost, accessibility, or perceived risk. The relatively low adoption of organic fertilizers compared to inorganic ones may also reflect economic and labor considerations, as organic inputs often require more effort to prepare and apply. These findings are consistent with recent studies on agricultural extension and participatory learning approaches. Similarly, a study by Pant *et a*l. (2026) reported that FFS interventions are more effective for knowledge-intensive technologies than for simple input adoption, aligning with the higher rankings observed for pest management and spacing practices in this study.

However, some contrasts emerge when compared to more recent evaluations. For instance, studies such as Van den Berg *et al*. (2020) suggest that while FFS improves knowledge, its impact on adoption may vary depending on socio-economic factors such as access to inputs and market incentives. This may explain the lower adoption of technologies like herbicide application and solarization in the present results, as these may depend more on financial capacity than on knowledge alone. Additionally, research by Tesfahun *et al*. (2026) emphasizes that gender dynamics and resource constraints can influence technology uptake, which may further explain variations in adoption across different practices. Unlike the current findings, some studies have reported higher adoption of input-based technologies when subsidies or market linkages are present, suggesting that FFS alone may not be sufficient to drive adoption of cost-intensive innovations.

4.2.1 Comparison of Technology Adoption Levels Between FFS and Non-FFS Farmers

The results reveal statistically significant differences in the adoption of banana production technologies between Farmer Field School (FFS) participants and non-participants across all practices examined. FFS farmers consistently reported higher adoption levels, with the largest mean differences observed in the use of certified seedlings (MD = 1.4312, $t = 16.3213$, $p < .001$), pest and disease control (MD = 1.222, $t = 16.4744$, $p < .001$), spacing and holing (MD = 1.1682, $t = 14.5987$, $p < .001$), and timely land preparation (MD = 1.1518, $t = 13.9661$, $p < .001$). Moderate gains were recorded for integrated pest management, de-suckering, and fertilizer use, while relatively smaller differences were observed for solarization (MD = 0.3419) and herbicide application (MD = 0.2123). Importantly, all differences were highly significant ($p = .000$), indicating a strong and consistent positive effect of FFS participation on technology adoption (Table 3).

Table 3

Comparison of Technology Adoption Levels Between FFS and Non-FFS Farmers

Technology	Control N	Control Mean	Treated N	Treated Mean	Mean Difference	t-value	p-value
Timely land preparation	192	2.3455	192	3.4974	1.1518	13.9661	0.0
Spacing and Holing	192	2.267	192	3.4352	1.1682	14.5987	0.0
Solarization	192	1.0052	192	1.3471	0.3419	7.8975	0.0
Herbicide application	192	1.0052	192	1.2176	0.2123	6.006	0.0
Use of certified seedlings	192	1.3874	192	2.8186	1.4312	16.3213	0.0
Use of organic fertilizers	192	2.979	192	3.6373	0.6582	7.2233	0.0
Use of inorganic fertilizers	192	1.0471	192	2.0207	0.9736	15.5103	0.0
Root trimming	192	1.1465	192	2.0569	0.9103	13.2828	0.0
Hot water treatment	192	1.0104	192	2.0103	0.9998	13.7487	0.0
De-suckering	192	2.3821	192	3.4663	1.0841	12.9975	0.0
Pruning	192	2.6387	192	3.4922	0.8534	10.4995	0.0
Pest and Disease control	192	1.5759	192	2.7979	1.222	16.4744	0.0
Use of Mulch and windbreak	192	2.3036	192	3.088	0.7844	9.9505	0.0
Integrated pest management strategies	192	1.5706	192	2.6891	1.1184	16.5171	0.0

The findings provide robust empirical evidence that FFS participation significantly enhances the uptake of improved agricultural technologies. The consistently higher mean scores among treated farmers across all technologies indicate that FFS is an effective extension approach for bridging knowledge and practice gaps in banana production. The largest adoption gains, certified seedlings, pest and disease control, spacing, and land preparation, highlight the strength of FFS in promoting agronomic practices that require technical knowledge, observation, and decision-making. These practices are central to improving productivity and are often difficult to adopt without hands-on training. The high *t*-values further reinforce that these differences are not due to chance but reflect substantial program impact. Technologies such as integrated pest management (IPM), de-suckering, and fertilizer application also show strong adoption gains, suggesting that FFS successfully integrates both ecological and input-based practices. This indicates a balanced learning outcome where farmers adopt both sustainable and productivity-enhancing technologies. Conversely, the relatively lower adoption differences for solarization and herbicide application suggest that these practices may be less influenced by knowledge transfer alone. Factors such as cost, labor requirements, or access to inputs may constrain their adoption. This underscores the limitation of FFS when structural or economic barriers are present, even when knowledge is improved.

These findings align closely with existing literature on the effectiveness of FFS. For instance, Tetti *et al*., (2026) demonstrated that FFS significantly improves farmers' knowledge and adoption of integrated pest management practices, particularly those requiring analytical skills and field-based learning. The strong performance of pest and disease control and IPM in the current study directly supports this conclusion. Similarly, Aynalem *et al*., (2026) in a comprehensive systematic review, found that FFS programs have a positive and statistically significant impact on technology adoption, especially for practices that involve learning-by-doing. The uniformly significant *p*-values across all technologies in the present results reinforce this broader evidence base. More recent work by Van den Berg *et al*. (2020) further confirms that FFS is particularly effective in enhancing farmers' ecological knowledge and decision-making capacity. The high adoption of practices such as spacing, de-suckering, and land preparation in this study reflects this enhanced capacity for farm management. However, some contrasts emerge when compared to recent studies that emphasize contextual limitations. Tesfahun *et al*. (2026) argue that socio-economic factors, including gender, access to resources, and market conditions, can mediate the effectiveness of extension programs. This perspective helps explain why technologies like herbicide application and solarization show smaller adoption gains despite being promoted through FFS. Additionally, emerging studies suggest that combining FFS with complementary interventions such as input subsidies or market linkages can significantly enhance adoption of cost-intensive technologies. Unlike such integrated approaches, the current findings suggest that FFS alone may not fully address financial or structural barriers to adoption.

4.3.2 Comparison of Additional Technology Adoption Levels Between FFS and Non-FFS Farmers

The results demonstrate significant differences in the adoption of additional agricultural technologies between Farmer Field School (FFS) participants and non-participants, with FFS farmers consistently exhibiting higher adoption levels across all practices. Notably, large and statistically significant effects ($p < .001$) were observed for most technologies, including minimum tillage (MD = 1.3314, d = 2.15), basin making (MD = 1.3177, d = 1.63), soil sampling and testing (MD = 1.015, d = 1.97), de-budding (MD = 1.1194, d = 1.47), and propping (MD = 1.1028, d = 1.46). Other practices such as crop rotation, cover cropping, and timely harvesting also recorded large effect sizes, indicating substantial practical significance. In contrast, relatively smaller (though still significant) effects were observed for drip irrigation (MD = 0.2901, d = 0.79) and timely weeding (MD = 0.6057, d = 0.72), suggesting moderate adoption differences. Overall, the findings confirm that FFS participation has a strong and practically meaningful impact on a wide range of agricultural technologies (Table 4).

Table 4

Comparison of Additional Technology Adoption Levels Between FFS and Non-FFS Farmers

Technology	Control Mean	Treated Mean	Mean Difference	t-value	p-value	Cohen's d	Effect Size	Interpretation
Use of nematicide	1.0052	1.3471	0.3419	8.85	0.0	0.91	Large	Practically meaningful difference
Soil sampling and testing	1.0471	2.0621	1.015	19.2626	0.0	1.97	Large	Practically meaningful difference
Liming	1.0	1.5388	0.5388	11.3983	0.0	1.17	Large	Practically meaningful difference
Contour ploughing	1.6544	2.3937	0.7393	8.7928	0.0	0.9	Large	Practically meaningful difference
Crop rotation	1.8167	2.7875	0.9708	12.6824	0.0	1.3	Large	Practically meaningful difference
Minimum tillage	1.0104	2.3419	1.3314	21.001	0.0	2.15	Large	Practically meaningful difference
Drip irrigation	1.0	1.2901	0.2901	7.7238	0.0	0.79	Medium	Moderate difference
De-budding	2.4712	3.5906	1.1194	14.3796	0.0	1.47	Large	Practically meaningful difference
Propping	2.5706	3.6735	1.1028	14.2641	0.0	1.46	Large	Practically meaningful difference
Timely weeding	2.5445	3.1502	0.6057	7.0334	0.0	0.72	Medium	Moderate difference
Use of cover crops	1.691	2.7668	1.0757	11.6759	0.0	1.19	Large	Practically meaningful difference
Basin making	1.3404	2.658	1.3177	15.8861	0.0	1.63	Large	Practically meaningful difference
Bagging	1.1989	1.9326	0.7336	11.6054	0.0	1.19	Large	Practically meaningful difference
Timely and proper harvesting	2.9109	3.8911	0.9801	13.8302	0.0	1.42	Large	Practically meaningful difference

The results provide compelling evidence that FFS significantly enhances the adoption of diverse agricultural technologies, particularly those requiring technical knowledge, planning, and sustained management. The consistently large effect sizes across most technologies indicate not only statistical significance but also strong practical relevance, suggesting that FFS has a transformative effect on farmers' practices. Technologies such as minimum tillage, basin making, and soil sampling and testing recorded the highest effect sizes, highlighting the effectiveness of FFS in promoting sustainable land management practices. These practices require a deeper understanding of soil health, conservation principles, and long-term productivity benefits, which are effectively conveyed through participatory and experiential learning approaches characteristic of FFS.

Similarly, high adoption levels for de-budding, propping, and timely harvesting indicate that FFS strengthens farmers' crop management skills, particularly in banana production systems. These practices are labor-intensive and require precision and timing, further emphasizing the role of hands-on training and peer learning in facilitating their uptake. The strong performance of agroecological practices such as crop rotation, cover cropping, and contour ploughing suggests that FFS contributes to broader sustainability goals by promoting environmentally friendly farming techniques. This aligns with the holistic learning model of FFS, which integrates productivity, sustainability, and resilience.

However, the relatively lower effect sizes for drip irrigation and timely weeding indicate that not all technologies benefit equally from FFS interventions. Drip irrigation, for instance, may be constrained by high initial investment costs and infrastructure requirements, limiting adoption despite increased awareness. Similarly, timely weeding, while important, may already be widely practiced, resulting in smaller observable differences between FFS and non-FFS farmers. Synthesizing these findings, it is evident that FFS is particularly effective in promoting complex, knowledge-intensive, and sustainability-oriented technologies, while its impact on capital-intensive or already common practices is comparatively moderate.

The findings are strongly consistent with existing and recent literature on the effectiveness of FFS approaches. Justine *et al*. (2025) found that FFS significantly improves the adoption of sustainable agricultural practices, particularly those requiring critical thinking and field-based experimentation. The large effect sizes observed for soil management and conservation practices in the current study align closely with these findings. Chen *et al*. (2026) similarly reported that FFS has substantial impacts on farmer knowledge and practice adoption, especially for integrated and ecological farming methods. The strong adoption of crop rotation, cover cropping, and contour ploughing in this study reinforces the conclusion that FFS is highly effective in promoting agroecological practices. More recent research by (Wang & Zhou, 2026) highlights that FFS enhances farmers' capacity for adaptive management and innovation. The high adoption rates of practices such as minimum tillage and basin making in the present results reflect this increased capacity for informed decision-making and long-term planning.

However, the findings also reveal some contrasts with recent studies that emphasize structural constraints. Pokharel *et al*. (2026) argue that access to resources, including capital and inputs, plays a critical role in technology adoption. This perspective helps explain the moderate adoption of drip irrigation in the current study, as financial barriers may limit uptake despite improved knowledge. Additionally, emerging literature suggests that while FFS is effective in knowledge dissemination, its impact can be enhanced when combined with complementary interventions such as financial support, input subsidies, or market access programs (Tesfahun *et al*., 2026). The relatively lower adoption of certain technologies in this study supports this argument, indicating that knowledge alone may not be sufficient to drive adoption of resource-intensive innovations.

V. CONCLUSION & RECOMMENDATIONS

5.1 Conclusion

The study established that participation in Farmer Field Schools (FFS) has a significant and positive effect on the adoption of banana production technologies among smallholder farmers in Webuye East Sub-County. Farmers who participated in FFS consistently demonstrated higher adoption levels across all categories of technologies compared to non-participants, confirming the effectiveness of the approach as a participatory extension model. The findings further indicate that FFS is particularly effective in promoting knowledge-intensive and management-driven practices, including certified seedling use, pest and disease control, spacing, and sustainable land management techniques. These technologies typically require hands-on learning, critical thinking, and continuous decision-making, which are well facilitated through the experiential and group-based learning processes inherent in FFS.

However, the study also revealed that the impact of FFS on the adoption of input-dependent and capital-intensive technologies is comparatively lower. This suggests that while FFS effectively enhances farmers' knowledge, skills, and capacity to adopt improved practices, external constraints such as cost, limited access to inputs, and resource availability may hinder the adoption of certain technologies. Overall, the results demonstrate that FFS is a robust and practically significant approach for enhancing agricultural technology uptake, particularly for practices that depend on farmer knowledge and active engagement in farm management.

5.2 Recommendations

Based on the study findings, it is recommended that policymakers, extension agencies, and development partners scale up the implementation of Farmer Field Schools as an effective participatory extension approach for promoting agricultural technology adoption among smallholder farmers. Given its demonstrated strength in enhancing knowledge and facilitating the uptake of management-intensive practices, FFS should be institutionalized within national and county agricultural extension systems to ensure wider outreach and sustained impact. However, to maximize the overall effectiveness of FFS, it is essential to integrate the approach with complementary support mechanisms that address existing structural and economic constraints faced by farmers. Specifically, interventions such as improved access to affordable agricultural inputs, credit facilities, and market linkages should be incorporated alongside FFS programs to enhance the adoption of input-dependent and capital-intensive technologies. Such integrated approaches will ensure that gains in knowledge and skills acquired through FFS are effectively translated into practical adoption outcomes across all categories of technologies. Furthermore, strengthening linkages between extension services, research institutions, and value chain actors is necessary to provide holistic support to farmers. This will enhance the sustainability of technology adoption and contribute to improved agricultural productivity, income generation, and livelihoods among smallholder banana farmers.

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