

Influence of Climate Change Knowledge on Adoption of Agroforestry Practices in Machakos County, Kenya

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DOI: 10.29322/IJSRP.16.10.2026.p17818

<https://dx.doi.org/10.29322/IJSRP.16.10.2026.p17818>

Paper Received Date: 27th August 2026

Paper Acceptance Date: 16th October 2026

Paper Publication Date: 28th October 2026

Abstract: Climate change continues to threaten agricultural productivity and household livelihoods across semi-arid regions in Kenya. Small-scale farmers remain highly vulnerable to erratic rainfall patterns, prolonged droughts, declining soil fertility, and increasing food insecurity because agricultural production in these regions largely depends on rainfall. Agroforestry has increasingly been promoted as an important climate adaptation strategy because it improves soil conservation, enhances food security, strengthens environmental sustainability, and increases household resilience. Despite these benefits, adoption of agroforestry practices among farmers remains inconsistent. This study, guided by Rogers' Diffusion of Innovation Theory, examined how knowledge about climate change influences adoption of agroforestry practices among small-scale farmers in Machakos County, Kenya. The study adopted a cross-sectional descriptive research design targeting 245 small-scale farming households from selected sub-counties in Machakos County. Data were collected using structured questionnaires. Quantitative data were analyzed using descriptive and inferential statistics, including chi-square analysis and mean score analysis, while qualitative findings were analyzed thematically. The findings revealed that agroforestry adoption was generally high across respondents, with adoption rates ranging between 70% and 85% across most household categories. Home gardens emerged as the most common agroforestry practice, particularly among female respondents (53.5%). The study further established high levels of climate change awareness among farmers, with respondents strongly agreeing that climate change affects food production ($M = 4.58$), that farmers require climate change knowledge ($M = 4.62$), and that climate knowledge empowers women farmers ($M = 4.79$). Significant relationships were observed between farming experience ($p = 0.015$), land tenure system ($p = 0.008$), and the types of agroforestry practices adopted. The study concludes that climate change knowledge is associated with stronger adoption of agroforestry practices among small-scale farmers, although the cross-sectional design precludes causal interpretation, and socio-economic and institutional factors, particularly land tenure, shape the specific type of practice adopted. The study recommends strengthening farmer education, climate information dissemination, agricultural extension services, and land tenure support to improve sustainable agricultural adaptation in semi-arid regions.

Index Terms: Climate change knowledge; Agroforestry adoption; Climate adaptation; Small-scale farmers; Diffusion of Innovation Theory

I. Introduction

Climate change has emerged as one of the greatest threats to agricultural production and rural livelihoods across the world [1]. As the planet warms up, changing rainfall patterns, extended dry spells, flooding and more extreme weather events are further disrupting food systems and threatening food productivity in both developed and developing nations [2]. Agriculture is an inherently climate-sensitive activity and when climate variations and disturbances happen, farmers are especially vulnerable. The Intergovernmental Panel on Climate Change (IPCC) reports that climate variability has led to lower crop productivity, lower soil fertility, water shortages, and increased food insecurity in various parts of the world [3]. Climate change effects are amplified in developing countries where most rural households are directly dependent on rain-fed agriculture, with limited adaptive capacity, weak institutional support, and prevailing poverty, which is a vicious circle of vulnerability and food systems fragility [4].

Sub-Saharan Africa is still one of the regions most at risk from climate change due to its strong dependence on agriculture, poverty and weak ecosystems. Small-scale farming plays a key role in the livelihoods of many families in the region, but agriculture output has been diminishing due to the irregular rainfall, land degradation, pests and long dry seasons. According to Food and Agriculture Organization [3], climate change-related threats persist on Africa, particularly in the semi-arid and arid zones where droughts and rainfall failure is common, which impact agricultural productivity and household livelihood. Climate change has therefore made sustainable agriculture practices more relevant than ever, to build up resilience and protect the environment while enhancing food production.

In recent years agroforestry has become more and more in focus as one of the most promising climate-smart agriculture technologies to help meet the challenges of climate change in agriculture and support rural livelihoods. Agroforestry is the application of trees in conjunction with crop and livestock production systems to enhance productivity and environmental sustainability. Trees play an important role in conserving soil moisture, improving soil fertility, reducing erosion, enhancing biodiversity, and increasing carbon sequestration [4], while also providing shade and reducing the effects of strong winds and high temperatures on crops. Beyond these environmental benefits, agroforestry contributes to household food security by diversifying food sources, providing fruits, fodder, fuelwood, and timber, increasing farm income, and improving resilience during periods of climatic stress [5] [6] [7] [8].

Climate change in Kenya continues to negatively impact agricultural output, especially in the semi-arid and arid areas where rainfall is becoming unpredictable and droughts are becoming more frequent [9]. The semi-arid counties are facing reduced yields, chronic water scarcity, worsening land degradation and worsening food insecurity all of which is putting household livelihoods and economies at risk. These climate-related challenges in Agriculture have been addressed in Kenya through agroforestry, which has been touted as a strategic solution to address both environmental and agricultural vulnerabilities including household resilience [10]. Despite its potential, however, availability of reliable climate information for many small-scale farmers is limited, and technical training and extension support are also weak, all of which reduce the ability of these farmers to effectively implement sustainable agricultural practices. In semi-arid regions of Kenya, studies have indicated that farmers with better awareness of climate change and extension support are found to have adopted substantially higher rates of agroforestry practices as opposed to the less informed farmers [11]. Educating and informing farmers are therefore key levers for supporting sustainable farmers' adaptation to climate change; the effectiveness of agroforestry programmes depends on farmers' understanding of climate change processes and their openness to incorporating these into their ongoing activities.

Machakos County is among the semi-arid regions in Kenya that are highly vulnerable to climate variability and food insecurity. The county experiences irregular rainfall patterns, recurrent droughts, and declining agricultural productivity, which continue to affect the livelihoods of small-scale farmers who depend on agriculture as their primary source of food and income. Farmers in Machakos County have increasingly adopted strategies such as crop diversification, water conservation, and agroforestry to improve resilience and sustain agricultural production [11].

Although agroforestry has been widely promoted in the county as a sustainable agricultural practice capable of improving soil fertility, enhancing water conservation, increasing biodiversity, and strengthening climate resilience, adoption among farmers remains inconsistent, and differences in knowledge levels regarding climate change may influence the extent to which farmers adopt agroforestry practices. In the context of Kenya and other surrounding East African contexts, there is an emerging body of research that assesses farmer knowledge and awareness of the adoption

of climate-smart practices such as agroforestry (e.g. [11] [14] [37]). A relationship that has received little attention, however, is this relationship within Machakos County in particular, and how it operates alongside the socio-demographic and institutional variables that have been investigated in this study (such as farming experience and land tenure, among others). Farmers who are less knowledgeable about climate change may not be so enthusiastic on adopting agroforestry because of the uncertainties in its benefits, management and long-term effects. The study therefore provides empirical evidence at the county level on the relationship between knowledge and uptake of agroforestry by smallholder farmers in Machakos County that can guide policy makers, agricultural extension officers and development agencies in designing programmes to address the information and awareness needs of farmers in the county.

Climate change knowledge was chosen as the main explanatory variable in this study because it is upstream of socio-economic factors that have been garnering a lot of research interest for their role in influencing farmers' adoption of agroforestry: farmers need to first be aware of the risks caused by climate change and their understanding of agroforestry as a viable solution before any of these socio-economic factors can affect their intentions. Isolating the role of knowledge therefore helps clarify which barriers to agroforestry adoption are informational in nature, and can be addressed through education and extension, as distinct from those that are structural or resource-based and require policy or institutional intervention.

Understanding how climate change knowledge shapes adoption decisions is therefore important for strengthening climate adaptation strategies, improving agricultural sustainability, and enhancing household resilience among small-scale farmers. Therefore, this study sought to evaluate how knowledge about climate change influences adoption of agroforestry practices among small-scale farmers in Machakos County, Kenya.

Literature also has been subject to methodological critique relevant to the interpretation of this type of adoption study. In a systematic review of the contribution of agro-forestry to livelihoods and carbon sequestration in East Africa, [8] note that many studies on adoption of agroforestry are cross sectional and rely on self-reported data, thus not establishing temporal precedence, meaning that knowledge does not predate adoption, and that adoption studies used a wide range of definitions and measures of agroforestry adoption, from awareness to multi-year practice. The present study shares the problem of measurement inconsistencies that make it difficult to make comparisons over time and across studies and counties. Even [15], who looked at agroforestry adaptation in West Pokot County, warn of differing levels of knowledge versus land tenure and farm size according to the agro-ecological zones and caution that this cannot be simply extrapolated across to another semi-arid county.

Literature on barriers specifically pertaining to semi-arid regions has also been given continued attention. In agroforestry's impact on soil quality, [16] reported that one of the constraints in translating the awareness of farmers into regular practice was the lack of access to quality planting material that was also poorly followed up by extension. Similar challenges reported in the studies within the Machakos area [14] were also found in the present study. The lack of security in land and tree tenure, especially affecting women and youth, has been cited as a long-standing constraint to the scaling of agroforestry throughout Sub-Saharan Africa [17] [18]. However, knowing about the benefits of agroforestry is not enough to unlock these structural constraints; insecure land ownership and limited extension access were also found to be strong constraints to the adoption of agroforestry among the smallholders in Kenya [19].

Theoretical framework

This study is anchored on Rogers' (2003) Diffusion of Innovation Theory, which explains how an innovation is communicated over time among members of a social system, and how awareness, knowledge, and the perceived attributes of an innovation shape the decision to adopt or reject it. According to the theory, adoption is a five-stage process, which includes the knowledge, persuasion, decision, implementation, and confirmation stages, and access to information and communication is key in all of the five stages. In this study, the theory implies that farmers need to be made aware of the phenomenon of climate change and its associated risks (the knowledge stage) before they can be convinced that agroforestry represents a relative advantage as a means of adaptation (the attitude stage) and before socio-economic and institutional factors such as land tenure, household headship, and farming experience determine whether

that persuasion is translated into sustained implementation (the action stage). This framework helped to decide upon the inclusion of climate change knowledge as the main explanatory variable while at the same time taking care in examining the socio-demographic and institutional factors as moderating variables on the pathway of climate change adaptation.

Barriers to agroforestry adoption and debates in the literature

While there is a considerable amount of research that has documented the environmental and livelihood benefits of agroforestry, the results on the determinants of adoption in semi-arid Kenya are not always consistent, and in fact a closer examination of the literature seems to show that there remains a certain controversy. Even though knowledge is regarded as a prerequisite for adoption, recent studies in a number of counties adjacent and ecologically similar to Machakos have demonstrated that factors beyond knowledge such as socio-economic and institutional are also important in influencing the adoption of climate-smart practices like agroforestry. Similarly, [14] reported that few socio-demographic characteristics were significant predictors of adaptation with only 47.4% of the smallholder farmers reporting that they had adopted some form of adaptation practice, including agroforestry, intercropping or crop rotation, which broadly mirrors the present study where most socio-demographic variables explained relatively little variation in adoption. In the same way, in Western Kenya, [21] found that socioeconomic, institutional and biophysical factors were all interlinked and not separately significant in understanding farmer decisions of adopting climate-smart practices. However, alongside structural constraints, knowledge plays a significant role in driving adoption as was also reported by [22] in neighbouring Makueni County.

The literature has also been critiqued on methodological grounds in ways that are relevant to interpreting adoption studies of this kind. [8] in a systematic review of agroforestry's contribution to livelihoods and carbon sequestration in East Africa, note that many adoption studies rely on cross-sectional, self-reported data that cannot establish whether knowledge precedes adoption or is acquired in the course of adopting, and that studies vary widely in how they define and measure 'adoption', ranging from mere awareness to sustained multi-year practice. This measurement inconsistency makes it difficult to compare adoption rates across studies and counties, and is a limitation that the present study also shares. [15], analyzing agroforestry adaptation in West Pokot County, further caution that the relative importance of knowledge versus land tenure and farm size varies by agro-ecological zone, suggesting that findings from one semi-arid county cannot automatically be generalised to another.

Barriers specific to semi-arid regions have also received attention in the literature. [16], studying agroforestry's effects on soil quality in Western Kenya, observed that limited access to quality planting material and inconsistent extension follow-up constrain the translation of farmer awareness into sustained practice, echoing barriers reported in Machakos-area studies [14]. Land and tree tenure insecurity, which disproportionately affects women and youth, has also been identified as a generic barrier to agroforestry scaling across Sub-Saharan Africa [17] [18]; a concern that resonates with the significant land tenure effect on practice type observed in the present study (Section 3.5). [19] similarly found that insecure land ownership and limited extension contact were among the strongest constraints to agroforestry adoption among Kenyan smallholders, regardless of farmers' awareness of its benefits.

Methodologically, most of the studies reviewed here, including [14] and [21] relied on cross-sectional survey designs combined with chi-square tests and logistic or probit regression, an approach consistent with the present study's design and one that is well suited to establishing statistical association, though not causal pathways, between knowledge, socio-economic status, and adoption behaviour. This methodological consistency across studies strengthens comparability of findings across counties, but also means the causality limitation identified above is common to this body of literature rather than unique to the present study.

III. Research Elaborations

Description of the study area

The study was conducted in Machakos County, which borders Nairobi and Kiambu counties to the west, Embu to the north, Kitui to the east, Makueni to the south, Kajiado to the south-west, and Murang'a and Kirinyaga to the north-west, and lies at an altitude of approximately 1,000 to 1,600 metres above sea level. The county experiences semi-arid climatic

conditions characterized by unreliable rainfall patterns, recurrent droughts, high temperatures, and soils that are susceptible to both water and wind erosion. Machakos County is divided into eight sub-counties namely; Kangundo, Kathiani, Matungulu, Mwala, Machakos Town, Mavoko, Mwangwe, and Yatta, all of which have administrative headquarters. The agriculture sector continues to be the main economic activity in the county, with majority of households relying on small-scale farming activities for food and income. The farmers in the area practice farming, animal husbandry and agroforestry as adaptation measures for enhancing climate variability resilience [12].

Study design and sampling procedure

The research design for this study was cross sectional descriptive research design which was used to find out the effect of climate change knowledge on agroforestry uptake by small scale farmers in Machakos County, Kenya. Descriptive research design is suitable for studies which aim to describe the existing situation and explore the relationship between the variables in a particular population [23]. The design allowed for the collection of data from the respondents at a single time point, and the generation of descriptive and analytical data about climate change knowledge, and the adoption of agroforestry.

Target population for the study were small-scale farmers from Kathiani and Kangundo sub-counties in Machakos Town. These areas were selected because agroforestry practices are commonly practiced and the communities continue to experience significant climate-related agricultural challenges; specifically, the agroforestry promotion areas were chosen since agroforestry is practiced in all of these areas and the communities still face major challenges related to agriculture climate change. These sub-counties were targeted for variation in agroforestry promotion activities and accessibility of farmers. The more peri-urban context of Machakos Town has better accessibility to markets and agricultural extension and is the administrative and commercial hub of the county. By contrast, Kathiani and Kangundo are more rural, and the adoption of agroforestry and climate adaptation programmes have taken place in these areas before, and thus they are good study sites to investigate various adoption experiences in different institutional and market settings.

The study employed stratified random sampling to ensure adequate representation of respondents from the selected sub-counties. Stratified sampling improves representational by dividing the target population into homogeneous groups before selecting respondents randomly from each group [24]. A target sample size of 245 households was used in the study.

The sample size of 245 households was determined using Cochran's formula for sample size estimation at a 95% confidence level, assuming a conservative population proportion of 0.5 to maximise variance, and was proportionately allocated to the respective sub-counties (Machakos Town, Kathiani and Kangundo) depending on their respective number of farming households, resulting in $n = 82$ for Machakos Town, $n = 82$ for Kathiani and $n = 81$ for Kangundo, respectively. The data were collected during November and December 2024.

Complete and usable responses were obtained from 236 households, a response rate of 96.3%, consistent with the respondent totals reported in the cross-tabulations in Tables 1 and 2 of this manuscript.

For the purposes of this study, a household was classified as an agroforestry adopter if it reported actively practising at least one form of agroforestry, such as alley cropping, a shamba system, windbreaks, home gardens, or another form of integrating trees or shrubs into its farming system, at the time of the survey; households reporting no such integration of woody perennials into their farming system were classified as non-adopters. This operational definition is consistent with standard definitions of agroforestry adoption used elsewhere in the literature [5] [32].

Data collection

Data for the study were collected using structured questionnaires administered to farmers. The questionnaires contained both closed- and open-ended questions designed to gather information on demographic characteristics, climate change knowledge, and adoption of agroforestry practices, with items developed from constructs identified in the Diffusion of Innovation Theory and the reviewed literature on climate change knowledge and agroforestry adoption. In addition,

qualitative information was obtained from key informants, including agricultural extension officers and community leaders, to support interpretation of the findings.

Key informants, including agricultural extension officers and community leaders, were purposively selected on the basis of their professional role and familiarity with agroforestry programmes in the study area. Interviews continued across the three sub-counties until responses became repetitive and no substantially new themes emerged, a thematic saturation criterion commonly used to guide sample size in small-scale qualitative components of mixed-methods studies [25]. The length of each interview was about 30-45 minutes for the pilot interviews and 15-30 minutes for the key informant interviews.

Reliability and validity

A pilot study was conducted before the main data collection exercise to assess the validity of the research instruments. Farmers included in the pilot were not included in the final sample, and their feedback was used to improve the clarity, consistency, and suitability of the questionnaire items.

Pilot testing was conducted with a small number of farmers in the study area who were not included in the final sample, sufficient to identify and correct ambiguous or poorly performing items before full deployment.

Instrument validity was established through this pilot testing and review process rather than through a computed internal-consistency coefficient.

Data analysis

Quantitative data were analyzed using the Statistical Package for Social Sciences (SPSS) version 27. Descriptive statistics such as frequencies, percentages, means, and standard deviations were used to summarize the findings. Chi-square tests of independence were selected to examine relationships between categorical socio-demographic variables and agroforestry adoption because the dependent variables (adoption status and type of practice adopted) were measured on a nominal scale, for which chi-square analysis is the appropriate test of association [26]; continuous variables such as age and farming experience were categorized for cross-tabulation to allow comparison across ordinal groupings consistent with prior studies in the region [11] [14]. Regression and Pearson correlation analyses were additionally used to determine the relationship between climate change knowledge and adoption of agroforestry practices.

Ethical considerations

Ethical considerations were observed throughout the research process. All respondents were given an opportunity to sign informed consent forms before data collection, and participation was voluntary. Confidentiality and anonymity was ensured by not sharing any personal information. All the information collected was applied only for academic purposes, according to the principles of research ethics [27].

IV. Findings

Agroforestry adoption by household characteristics

The results reveal that the level of adoption of agroforestry was high in most of the household categories, with a range from 70% to 85% as shown in Table 1. The adoption rate of male respondents was 80.2% and 79.6% for female respondents, indicating that there was hardly any gender difference in the adoption rate. The adoption rates were also relatively higher in the cases of married respondents (82.8%) than in those of divorced or widowed respondents (65.7%), and male-headed households (82.5%) also showed higher adoption rates than female-headed households (70.2%). There was slight variation in the rates of adoption across household sizes, with smaller households (1-3 members: 83.3%) having slightly higher rates of adoption than larger households (above 8 members: 70.8%). But, no statistically significant association was found between household gender, household size and agroforestry adoption with only marital status and household headship having weak significance at 10% level ($p = 0.065$ and $p = 0.058$ respectively). The low correlation between household headship and adoption could be attributed to structural inequalities faced by female

headed households such as lack of land, credit, extension services and labour, which have been observed in other parts of Eastern Africa [28];[29].

Table 1. Agroforestry adoption by household characteristics in Machakos County, Kenya.

Independent variable	Category	Adopters n (%)	Non-adopters n (%)	p-value
Household gender	Male	146 (80.2)	36 (19.8)	NS
	Female	43 (79.6)	11 (20.4)	
Marital status	Married	159 (82.8)	33 (17.2)	0.065*
	Single	7 (77.8)	2 (22.2)	
	Divorced or widowed	23 (65.7)	12 (34.3)	
Household headship	Male headed	156 (82.5)	33 (17.5)	0.058*
	Female headed	33 (70.2)	14 (29.8)	
Household size	1 to 3	20 (83.3)	4 (16.7)	NS
	4 to 6	98 (83.1)	20 (16.9)	
	6 to 8	54 (77.1)	16 (22.9)	
	Above 8	17 (70.8)	7 (29.2)	

Values in parenthesis are row percentages.

Agroforestry adoption by socio-economic characteristics

The results show that agroforestry adoption was relatively high in all socio-economic categories with all the groups maintaining a high adoption percentage (above 70%) as presented in Table 2. Respondents aged between 25 and 45 years recorded higher adoption rates (85.1% and 85.2%, respectively) compared to older respondents (45–55 years: 78.3%; above 55 years: 80.1%). Farmers with primary and secondary school education also demonstrated higher adoption levels (84.5% and 81.4%, respectively) compared to respondents with university education (65.7%), a counterintuitive finding that may reflect competing off-farm livelihood opportunities among more educated households. Adoption rates declined slightly with increasing farming experience—from 85.1% (1–5 years) to 75.6% (more than 10 years)—and with farm size—from 85.1% (less than 1 hectare) to 70.8% (2–5 hectares)—although these differences were not statistically significant. Farmers operating on leased land recorded the highest adoption rates (91.7%), while rented land recorded relatively lower levels (70.2%). Household income levels showed minimal variation in agroforestry adoption, ranging from 83.3% (lowest income bracket) to 79.3% (Ksh 20,000–30,000).

Table 2. Agroforestry adoption by socio-economic characteristics.

Independent variable	Category	Adopters n (%)	Non-adopters n (%)	p-value
Age (years)	18 to 25	8 (80.0)	2 (20.0)	NS
	25 to 35	40 (85.1)	7 (14.9)	
	35 to 45	46 (85.2)	8 (14.8)	
	45 to 55	36 (78.3)	10 (21.7)	
	Above 55	47 (80.1)	12 (19.9)	
Educational background	No education	10 (83.3)	2 (16.7)	NS
	Primary school	60 (84.5)	11 (15.5)	
	Secondary school	96 (81.4)	22 (18.6)	
	University	23 (65.7)	12 (34.3)	
Years of farming experience	Less than 1 year	20 (83.3)	4 (16.7)	NS
	1 to 5 years	40 (85.1)	7 (14.9)	
	6 to 10 years	67 (80.7)	16 (19.3)	
	More than 10 years	62 (75.6)	20 (24.4)	
Farm size	Less than 1 hectare	80 (85.1)	14 (14.9)	NS
	1 to 2 hectares	65 (78.3)	18 (21.7)	
	2 to 5 hectares	17 (70.8)	7 (29.2)	
Land tenure system	Owned	145 (81.9)	32 (18.1)	NS

Independent variable	Category	Adopters n (%)	Non-adopters n (%)	p-value
Household monthly income (Ksh)	Leased	11 (91.7)	1 (8.3)	NS
	Rented	33 (70.2)	14 (29.8)	
	Less than 5,000	10 (83.3)	2 (16.7)	
	5,000 to 10,000	20 (83.3)	4 (16.7)	
	10,000 to 20,000	30 (85.7)	5 (14.3)	
	20,000 to 30,000	111 (79.3)	29 (20.7)	
	30,000 to 40,000	8 (66.7)	4 (33.3)	
	40,000 to 50,000	5 (83.3)	1 (16.7)	
	Above 50,000	5 (71.4)	2 (28.6)	

Values in parenthesis are row percentages.

Socio-demographic factors influencing agroforestry adoption

The binary logistic regression results in Table 3 show that none of the socioeconomic and farm-level characteristics significantly predicted agroforestry adoption once considered jointly, in contrast to the bivariate chi-square results in Table 1, where marital status and household headship were each weakly associated with adoption at the 10% level. This attenuation is consistent with the two variables sharing overlapping variance in the multivariate model, and with the general caution that a small number of bivariate associations significant only at the 10% level, out of the ten socio-demographic and farm-level variables tested across Tables 1 and 2, are also compatible with chance findings arising from multiple comparisons rather than genuine associations; neither Table 1 nor Table 3 was corrected for multiple testing (e.g., via a Bonferroni adjustment), and this is noted as a limitation in Section 5.2. Similar findings have been reported elsewhere in sub-Saharan Africa: [30] found that gender, age, marital status, farming experience, and income did not significantly predict agroforestry adoption in Rwanda, while [31] similarly observed that age and education did not distinguish adopters from non-adopters in The Gambia. The fact that these results indicate that demographic characteristics may lose their power as a predictor where agroforestry is already common among various socio-economic groups suggests a normalization of the practice, which extends beyond individual socio-economic profiles. However, the results were counterintuitive to research that found household/farm resources played a major role in the adoption process, suggesting that the relative importance of socio-demographic factors may vary depending on the context and the stage of diffusion in a particular farming community.

Table 3. Socio-demographic factors influencing agroforestry adoption

	B	S.E.	Wald	Sig.
Gender	0.08	0.40	0.04	0.85
Age	0.32	0.45	0.48	0.49
Educational background	0.01	0.72	0.00	0.99
Marital status	1.24	0.97	1.63	0.20
Household Headship	1.20	2.65	0.21	0.65
Household size	-0.19	0.57	0.11	0.74
Farming experience	0.10	0.63	0.02	0.88
Farm size	0.24	0.61	0.15	0.70
Land tenure system	-1.57	1.29	1.48	0.22
Household monthly income	-0.32	0.32	0.98	0.32

Constant	-2.66	1.59	2.80	0.09
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Statistical significance was assessed at $\alpha = 0.05$.

Types of agroforestry practices by household characteristics

Table 4 shows that home gardens were found to be the most prevalent agroforestry practice in all the categories of households. The involvement of the female respondents in home gardens was more as compared to male respondents. The second most prevalent was windbreaks and shamba system and alley cropping were less common.

The household size also affected the distribution of agroforestry practices. The home garden involvement was higher in smaller households, and the involvement in windbreak and shamba involvement was slightly higher in larger households. There were however no statistically significant relationship between the type of agroforestry practice adopted and gender, household headship or household size.

Table 4. Types of agroforestry practices by household characteristics in Machakos County, Kenya.

Variable	Category	Alley cropping n (%)	Shamba system n (%)	Windbreaks n (%)	Home gardens n (%)	Other n (%)	p-value
Gender	Male	26 (17.8)	17 (11.6)	40 (27.4)	57 (39.0)	6 (4.1)	NS
	Female	4 (9.3)	3 (7.0)	10 (23.3)	23 (53.5)	3 (7.0)	
Household headship	Male headed	28 (17.9)	13 (8.3)	42 (26.9)	65 (41.7)	8 (5.1)	NS
	Female headed	2 (6.1)	7 (21.2)	8 (24.2)	15 (45.5)	1 (3.0)	
Household size	1 to 3	2 (10.0)	0 (0.0)	6 (30.0)	12 (60.0)	0 (0.0)	NS
	4 to 6	22 (22.4)	8 (8.2)	25 (25.5)	36 (36.7)	7 (7.1)	
	6 to 8	5 (9.3)	9 (16.7)	13 (24.1)	25 (46.3)	2 (3.7)	
	Above 8	1 (5.9)	3 (17.6)	6 (35.3)	7 (41.2)	0 (0.0)	

Values in parenthesis are row percentages.

Types of agroforestry practices by socio-economic characteristics

The findings indicate that home gardens remained the most dominant agroforestry practice across all socio-economic categories (Table 5). Younger and older farmers demonstrated a strong preference for home gardens, while respondents with moderate farming experience showed greater involvement in technically complex practices such as alley cropping and windbreaks.

Significant associations were observed between years of farming experience, farm size, and land tenure system with the type of agroforestry practice adopted. Farmers with six to ten years of farming experience demonstrated higher involvement in alley cropping and windbreaks compared to highly experienced farmers, who preferred home gardens and shamba systems. Land tenure system demonstrated the strongest significant relationship with agroforestry practice type: farmers operating on leased land relied almost entirely on home gardens

Table 5. Types of agroforestry practices by socio-economic characteristics.

Variable	Category	Alley cropping n (%)	Shamba system n (%)	Windbreaks n (%)	Home gardens n (%)	Other n (%)	p-value
Age (years)	18 to 25	1 (12.5)	0 (0.0)	2 (25.0)	5 (62.5)	0 (0.0)	NS
	25 to 35	9 (22.5)	3 (7.5)	10 (25.0)	16 (40.0)	2 (5.0)	
	35 to 45	10 (21.7)	3 (6.5)	13 (28.3)	17 (37.0)	3 (6.5)	
	45 to 55	7 (19.4)	3 (8.3)	13 (36.1)	11 (30.6)	2 (5.6)	
	Above 55	3 (5.1)	11 (18.6)	12 (20.3)	31 (52.5)	2 (3.4)	
Educational background	No education	1 (10.0)	0 (0.0)	3 (30.0)	6 (60.0)	0 (0.0)	NS
	Primary school	13 (21.7)	4 (6.7)	13 (21.7)	27 (45.0)	3 (5.0)	
	Secondary school	14 (14.6)	11 (11.5)	27 (28.1)	39 (40.6)	5 (5.2)	
	University	2 (8.7)	5 (21.7)	7 (30.4)	8 (34.8)	1 (4.3)	

Variable	Category	Alley cropping n (%)	Shamba system n (%)	Windbreaks n (%)	Home gardens n (%)	Other n (%)	p-value
Years of farming experience	Less than 1 year	2 (10.0)	0 (0.0)	6 (30.0)	12 (60.0)	0 (0.0)	0.015**
	1 to 5 years	9 (22.5)	4 (10.0)	8 (20.0)	17 (42.5)	2 (5.0)	
	6 to 10 years	16 (23.9)	5 (7.5)	22 (32.8)	19 (28.4)	5 (7.5)	
	More than 10 years	3 (4.8)	11 (17.7)	14 (22.6)	32 (51.6)	2 (3.2)	
Farm size	Less than 1 hectare	16 (20.0)	5 (6.3)	20 (25.0)	35 (43.8)	4 (5.0)	0.062*
	1 to 2 hectares	12 (18.5)	8 (12.3)	22 (33.8)	20 (30.8)	3 (4.6)	
	2 to 5 hectares	1 (3.7)	4 (14.8)	2 (7.4)	18 (66.7)	2 (7.4)	
	5 to 20 hectares	1 (5.9)	3 (17.6)	6 (35.3)	7 (41.2)	0 (0.0)	
Land tenure system	Owned	28 (19.3)	13 (9.0)	42 (29.0)	55 (37.9)	7 (4.8)	0.008***
	Leased	0 (0.0)	0 (0.0)	0 (0.0)	10 (90.9)	1 (9.1)	
	Rented	2 (6.1)	7 (21.2)	8 (24.2)	15 (45.5)	1 (3.0)	

Values in parenthesis are row percentages. *Significant at the 10% level; **significant at the 5% level; ***significant at the 1% level.

Perception of climate change and agroforestry adoption

The findings demonstrate high levels of perception of climate change among respondents (Figure 1). Farmers strongly agreed that climate change has altered local weather patterns and negatively affected food production. Respondents also recognized the importance of climate change knowledge in supporting agricultural decision-making and agroforestry adoption, and perceived agroforestry as an effective climate adaptation strategy capable of improving food security, soil conservation, and resilience against climatic stress. Respondents also acknowledged that climate knowledge empowers women farmers and strengthens household adaptation capacity.

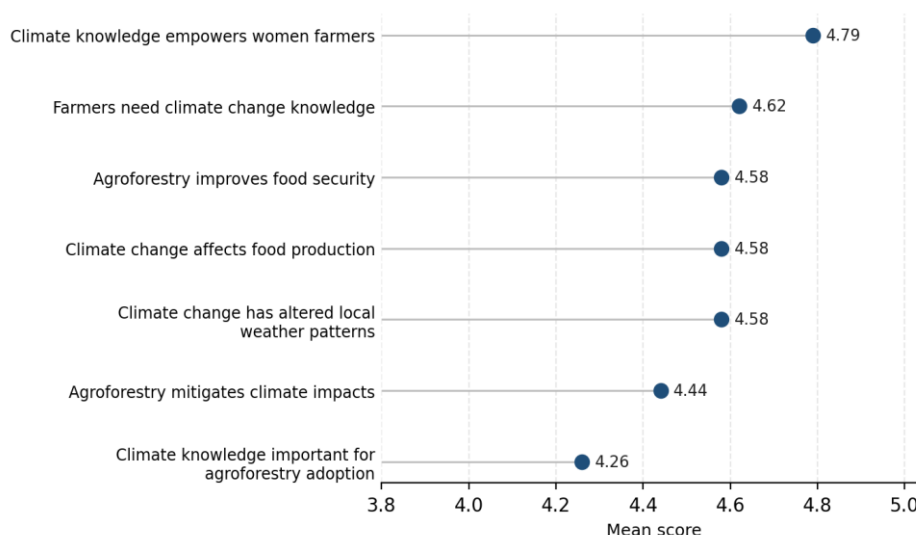


Figure 1. Mean scores showing farmers' knowledge and perceptions of climate change and agroforestry as an adaptation strategy.

Mean scores in Figure 1 are presented without confidence intervals, as item-level standard deviations were not retained in the summary dataset used for this analysis; this is noted as a limitation in Section 5.2.

The findings demonstrate high levels of perception of climate change among respondents (Figure 1). Farmers strongly agreed that climate change has altered local weather patterns and negatively affected food production. Respondents also recognized the importance of climate change knowledge in supporting agricultural decision-making and agroforestry adoption, and perceived agroforestry as an effective climate adaptation strategy capable of improving food security, soil conservation, and resilience against climatic stress. Respondents also acknowledged that climate knowledge empowers women farmers and strengthens household adaptation capacity.

V. Conclusions

Household and socio-economic influences on agroforestry adoption

Consistent with the descriptive findings in Sections 3.1 to 3.3, agroforestry adoption was high and relatively uniform across household and socio-economic categories, with only marital status and household headship showing weak statistical significance. This is consistent with what [32] found as part of their research: stable household structures are linked to long-term investment in agriculture and adaptation to climate change, and with [33] who found that once the practical value of climate-smart practices is recognised, regardless of individual socio-economic status, the practice becomes normalised within a farming population. The findings also imply that agroforestry is not only adopted by a particular social or economic group, but has become more common among farmers, suggesting that agroforestry is being perceived as an adaptation tool of great importance to farmers rather than an early adopter specialization tool.

Only two of the eight socio-demographic variables studied in this paper (Table 3) were even weakly statistically significant, and both refer to the structure of the household and not to the individual, e.g. age, gender, or education. This pattern closely parallels a considerably larger study of smallholder agroforestry adoption in Tanzania ($n = 697$), in which [34] similarly found that none of the eight individual and household-level variables tested, including age, gender, health, and ability to read and write, were statistically significant predictors of adoption, while socio-economic and institutional variables, specifically project participation and source of seedlings, and farmer perception variables were among the few significant predictors. Read together, these findings from two distinct East African smallholder contexts suggest that individual demographic profile is a comparatively weak predictor of agroforestry adoption, and that institutional access and resource-related factors warrant greater emphasis in adoption research and policy design than individual targeting.

One finding that runs against the expectation that more education should be associated with greater adoption of a knowledge-intensive innovation such as agroforestry is that university-educated respondents recorded the lowest adoption rate (65.7%) of any education category, lower than farmers with only primary or secondary education (Table 2). A plausible explanation is that more educated household heads in Machakos County are more likely to hold formal or off-farm employment, treating farming as a secondary rather than primary livelihood activity and reducing the time and long-term horizon needed to establish tree-based systems. [14], studying the neighbouring Machakos, Makueni, and Kitui counties, likewise found that education level had only a modest influence on climate adaptation uptake, suggesting that formal education does not automatically translate into agroforestry adoption in this setting.

The low level of association between household headship and adoption could be due to structural constraints that exist for female-headed households, such as poor access to land, credit, extension services and labour. Similar findings were reported by [28], who observed that women farmers in Eastern Africa often face institutional barriers that reduce their capacity to invest in long-term agricultural practices. These findings support Rogers' Diffusion of Innovation Theory, which argues that innovations become normalized once communities widely perceive their benefits, while also indicating that the theory's classical emphasis on individual socio-economic predictors of adoption is only weakly borne out in this setting.

Types of agroforestry practices adopted

The widespread adoption of home gardens observed in Sections 3.4 and 3.5 may be attributed to their low establishment costs, immediate food production benefits, and lower technical and knowledge requirements relative to alley cropping or windbreaks, which involve more deliberate spatial planning, longer investment horizons, and greater agronomic knowledge. Because this study's operational definition of agroforestry adoption (Section 2.2) counts home gardens alongside these more technically demanding practices, the high overall adoption rates reported in Table 1 and Table 2 are likely driven substantially by this low-barrier practice, and should not be read as evidence of equally widespread uptake of the more complex, higher-investment forms of agroforestry. Similar findings were reported by [35], who observed that home gardens improve food availability and dietary diversity among small-scale farmers in Machakos County.

Land tenure system demonstrated a strong significant relationship with agroforestry practice type, with farmers operating on leased land relying mainly on home gardens because of limited incentives to invest in longer-term tree-

based systems. Similar findings were reported by [36], who established that insecure land tenure reduces farmers' willingness to invest in long-term agroforestry practices, and this pattern is consistent with broader evidence that land and tree tenure insecurity constrains agroforestry scaling across Sub-Saharan Africa, particularly for women and youth ([17]; [18] [19]. By contrast, [34], studying Tanzania, found that farmers renting land, rather than those who owned it outright, were significantly more likely to adopt agroforestry, and that a reliable source of seedlings was among the strongest predictors of adoption; taken together with the present study's finding that land tenure arrangement was the strongest institutional predictor of practice type (Table 5), this suggests that the specific terms under which land and planting inputs are held and accessed, rather than simple ownership status, may be what matters most for agroforestry decisions across East African smallholder settings. The findings further support Rogers' Diffusion of Innovation Theory, which suggests that adoption behaviour varies depending on farmers' experience, perceived benefits, and resource security, and extend it by showing that resource security, specifically secure land tenure, can shape not only whether farmers adopt an innovation but which variant of it they adopt.

Perception of climate change and agroforestry adoption

Farmers' high scores on the climate change perception scale (Figure 1) are consistent with the view that awareness of climate variability is positively associated with adoption of climate-smart agricultural technologies. It should be noted that the items underlying Figure 1 capture farmers' self-reported perceptions of, and agreement with, statements about climate change and agroforestry, rather than an objectively tested measure of cognitive knowledge (e.g., correct identification of causes of climate change or climate-smart practices); this conceptual distinction is discussed further as a study limitation in Section 5.2. With this caveat in mind, the pattern observed here is similar to that reported by [37], who found that awareness of climate variability was positively associated with adoption of climate-smart agricultural technologies in Eastern Africa. The results are also broadly consistent with Rogers' Diffusion of Innovation Theory, which holds that access to information and awareness of an innovation's attributes shape movement through the knowledge and persuasion stages of the adoption process, although the present cross-sectional data cannot establish whether awareness precedes or follows adoption.

The study aimed at studying the effect of awareness of climate change on the adoption of agroforestry by smallholder farmers in Machakos County, Kenya. The results show that agroforestry is a climate change adaptation technology that has been embraced by farming households in the county. The majority of respondents recognized that climate change has impacted rainfall on the land, productivity of agricultural crops and the susceptibility to food insecurity. Farmers also showed a high level of awareness of the importance of agroforestry and other agriculture adaptation practices for their farms.

The study showed that knowledge of climate change is correlated with the adoption of agroforestry practices, but due to its cross sectional design could not be interpreted as causal. Farmers were more likely to report understanding of the benefits and impacts of climate variability, and more likely to have implemented agroforestry farming systems for improving soil fertility, conserving moisture, boosting food security, and improving household resilience. The results also reveal that agroforestry, including home gardens and windbreaks, have emerged as important adaptation strategies as they fit into the small-scale agricultural production system.

The study further revealed that most socio-demographic variables were not significantly affecting agroforestry adoption. This indicates that agroforestry is already gaining acceptance across all gender groups, age, level of educational attainment, household size and income groups in farming communities in Machakos County. But marital status and headship of households showed low effects on adoption, suggesting that household structure and decision making processes might influence long term investments in agriculture.

When viewed from the perspective of the type of agroforestry practices adopted, there were significant relationships between farming experience, farm size and land tenure system. Diverse and technically demanding agroforestry systems were more likely to be implemented by farmers who had secure land rights and had experienced moderate farming practices, than by farmers who farmed on leased or rented land. The findings further indicate that agroforestry practices such as home gardens and windbreaks have become important adaptation approaches because of their suitability within small-scale farming systems.

The study also found that most socio-demographic characteristics did not significantly influence agroforestry adoption. This suggests that agroforestry has already achieved widespread acceptance among farming communities in Machakos County regardless of differences in gender, age, education level, household size, or income. However, marital status and household headship demonstrated weak influence on adoption, indicating that household structure and decision-making dynamics may still shape long-term agricultural investments.

In relation to the types of agroforestry practices adopted, significant relationships were observed between farming experience, farm size, and land tenure system. Farmers with secure land ownership and moderate farming experience were more likely to adopt diverse and technically demanding agroforestry systems compared to farmers operating on leased or rented land. The findings therefore demonstrate that while climate knowledge is important in promoting agroforestry adoption, institutional and resource-related factors also shape the type and extent of adoption among farmers.

Overall, the study concludes that strengthening climate change awareness and farmer education remains essential in promoting sustainable agricultural adaptation and improving resilience among small-scale farmers in semi-arid regions such as Machakos County, but that this must be paired with attention to land tenure security if more technically demanding agroforestry systems are to be adopted at scale.

Declarations

Credit authorship contribution statement

Merveille Sanginga Arlette: Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Writing – original draft.

Ezekiel Ndunda: Conceptualization, Methodology, Supervision, Validation, Writing – review & editing.

Monicah Mucheru-Muna: Conceptualization, Methodology, Supervision, Validation – review & editing.

Funding statement

The work received no specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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Appendices

Appendix A. Summary of hypothesised relationships between independent variables and agroforestry adoption

Table A1. Expected relationships between independent variables and agroforestry adoption, based on reviewed literature, and the relationship observed in this study.

Variable	Hypothesised direction	Rationale	Supporting reference(s)	Observed in this study
Household gender	Positive (male)	In patriarchal rural settings, male household heads typically control land and resource-allocation decisions, which may translate into greater capacity to adopt agroforestry.	[28]	Not significant
Marital status	Positive (married)	Married households benefit from more stable labour and resource pooling, supporting long-term agricultural investment.	[32]	Weak significant association
Household headship	Positive (male-headed)	Male-headed households often have greater access to land, credit, and extension services.	[6]	Weak significant association
Household size	Positive	Larger households may provide more available labour for establishing and maintaining tree-based systems.	[34]	Not significant
Age	Mixed	Older farmers may have accumulated more land and resources, though younger farmers may be more receptive to new practices.	[14]	Not significant
Education level	Positive	More educated farmers are expected to better understand the benefits and management requirements of agroforestry.	[14] [11]	Not significant
Farming experience	Positive	Farmers with more years of experience are expected to have accumulated the resources and knowledge needed for adoption.	[11]	Not significant
Farm size	Positive	Larger farms provide more physical space to integrate trees without displacing food or cash crops.	[34]	Not significant
Land tenure system	Positive (secure/owned)	Secure land tenure is expected to encourage long-term investment in tree-based systems.	[17]; [18]; [19]	Significant for practice type ($p = 0.008$)
Household monthly income	Positive	Households with greater income are expected to have more resources available for the initial investment agroforestry requires.	[21]; [22]	Not significant

This table synthesises the directional hypotheses implied by the literature discussed in Sections 1.2 and 4, alongside the corresponding results reported in Tables 1–5 of this manuscript.

Appendix B. Variable definitions

Table B1. Definitions and categories of the dependent and independent variables used in this study.

Variable	Categories used in this study	Variable type
Agroforestry adoption (dependent variable)	Adopter / Non-adopter	Binary
Type of agroforestry practice (dependent variable, Tables 4–5)	Alley cropping / Shamba system / Windbreaks / Home gardens / Other	Categorical
Household gender	Male / Female	Binary
Marital status	Married / Single / Divorced or widowed	Categorical
Household headship	Male headed / Female headed	Binary
Household size	1 to 3 / 4 to 6 / 6 to 8 / Above 8	Ordinal
Age (years)	18 to 25 / 25 to 35 / 35 to 45 / 45 to 55 / Above 55	Ordinal
Educational background	No education / Primary school / Secondary school / University	Ordinal
Years of farming experience	Less than 1 year / 1 to 5 years / 6 to 10 years / More than 10 years	Ordinal
Farm size	Less than 1 hectare / 1 to 2 hectares / 2 to 5 hectares	Ordinal
Land tenure system	Owned / Leased / Rented	Categorical
Household monthly income (Ksh)	Less than 5,000 / 5,000–10,000 / 10,000–20,000 / 20,000–30,000 / 30,000–40,000 / 40,000–50,000 / Above 50,000	Ordinal