



Influences of Independent Variables on the Adoption of Recommended Coffee Production Practices in Siha District, Kilimanjaro Region

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The adoption of recommended coffee agricultural practices is critical for enhancing the productivity and sustainability of smallholder coffee farmers. This study explores the influences of independent variables on the adoption of these practices.

Study Design: A quantitative method was employed, utilizing structured questionnaires administered to the sample size of 198 smallholder farmers.

Methodology: Data were analysed using SPSS version 20 with descriptive statistics (frequencies and percentages) to assess adoption levels. The Probit regression model was applied to evaluate the likelihood that a farmer adopts a given practice based on a set of explanatory variables. The regression examined the association between adoption decision and independent variables,

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including access to loan, annual income, gender, access to training, number of coffee plants, farm size and educational level.

Results: The findings revealed that adoption rate varied across different coffee practices, while some practices like shade adoption and weeding are widely adopted, others like Integrated pest management (IPM) and pesticides use need more support to be widely implemented. Income, land size and access to training were found to significantly affect the adoption of many practices. Income and access to training were associated with the adoption of more advanced practices suggesting farmers with greater financial resources and knowledge are more likely to implement these practices. On the other hand, marital status and gender has no significant influence on adoption of most practices.

Conclusion: The study concludes that addressing access to credits and education challenges among smallholder farmers can significantly improve the adoption of these practices, thereby increasing productivity and farmers income. Based on these finding practical training program to improve farmers knowledge, financial support to farmers and targeted interventions for younger farmers should be emphasized.

Keywords: Adoption; smallholder farmers; coffee agricultural practices; independent variables.

1. INTRODUCTION

Coffee rank among top valuable traded commodities in international trade with 100 million bags produced annually in 50 countries (Adugna BG, 2021). The income of the coffee sector is estimated to exceeds 200 billion US dollar annually. It supports more than 100 million people globally (Adugna BG, 2021). Countries leading in coffee production globally include Brazil which account for 39% of the total (66.3 million 60kg bags), followed by Vietnam with 16% (27.5 million bags) while Colombia which rank third in global production and contribute 8% (12.76million bags) (USDA Global Coffee Production Report, 2024). Africa contribution is only 12% of the total global coffee production (USDA Global Coffee Production Report, 2024). Leading African countries include Ethiopia which produce about 5% of the world total coffee supply, followed by Uganda with 4% (Wossen *et al.*, 2015; ICO, 2023). Tanzania accounts for approximately 6% of African coffee production, and globally rank 14th producing 1,350,000 60kg bags representing 0.8% of the global coffee supply (USDA Global Coffee Production Report, 2024). In comparison, Tanzania coffee yield has declined over the years particularly compared to 1990s and early 2000s (TaCRI,2005). Addressing the decline interventions to enhance productivity and quality are required TaCRI, 2005).

Globally, demand for coffee has increased by 65% as the coffee sector has continued evolving in major coffee growing regions in the past two decades (Bozzola *et al.*, 2021). Likewise coffee consumption has continued to rise with the demand expected to be 300 million bags by 2050

(Bozzola *et al.*, 2021). This is driven by advancement in technology, expansion of production capacities and shifting in consumer preferences (Bozzola *et al.*, 2021). For instance, global leading counties such as Brazil, Vietnam and Colombia have solidified their position through consistent investment in research, market expansion and innovation to ensure constant supply of high-quality coffee to meet the growing global demand (Bozzola *et al.*, 2021; ICO, 2023). In countries such as Colombia, Latin American and Caribbean various national and international initiatives supporting farmers through policy representation, market access, sustainability, and skill development have been laid out at the producer level (Bozzola *et al.*, 2021). At the buyer level, various initiatives focusing on sustainability through corporate guidelines, ethical sourcing programs, agronomic support, financial services, and digital sustainability platforms have been well established. As international trade pattern shifts, Emerging countries, particularly in South-East Asia and the Middle East, are reshaping global coffee market dynamics with rising domestic consumption and a growing preference for coffee over traditional beverages like tea. Countries such as India, Indonesia, Philippines, and Vietnam are not only major producers but also increasing consumers, while regions like Saudi Arabia, Turkey, and United Arab Emirates (UAE) show rapid growth in coffee imports driven by young, affluent populations (Bozzola *et al.*, 2021).

Africa has retained its position in global coffee production not only as an origin of arabica coffee but also as a key supplier in international trade (Amamo AA, 2014). Despite Africans small

coffee contribution to global supply in comparison to Asia and Latin America, still its unique coffee varieties, rich biodiversity and expanding specialty coffee market position it as an important region in the industry (Bozzola *et al.*, 2021). Strengthening production and processing systems across African coffee-growing nations can enhance the continent's competitiveness and ensure long-term sustainability in the global coffee trade (Behar, 2023).

Several studies conducted in regions growing coffee in Tanzania have identified poor farming practices as the main constraint to coffee productivity (Otieno *et al.*, 2019). The majority of coffee growers are small holder farmers accounting for 90% of the total producer often struggle with low yields due to inadequate agronomic knowledge (Otieno *et al.*, 2019). These persistent challenges have drawn attention for national and international agricultural agencies which have led to the development of recommended agronomic practices as among initiatives aiming at improving yield and ultimately promoting coffee sustainability (Wintgens, 2012). The successful adoption and integration of these practices by farmers are not only important for improving farmers incomes but also for maintaining Tanzania position in the global coffee business.

In response to production constraints, for example, the Tanzania Coffee research Institute (TaCRI) have recommended key practices for improving coffee production (Mbunduki, 2024). The practices include, adoption of improved coffee varieties that are resistant to diseases and are of high productivity (Maro *et al.*, 2014) Proper plant spacing, integrated soil fertility management with the use of both organic and inorganic amendments (Maro *et al.*, 2024). These practices are crucial for improving overall farm productivity and soil, as they contribute to long term sustainability. Furthermore, integrated pest management (IPM) which include range of practices from mechanical, cultural, biological to chemical has been strongly advocated to control major coffee pests. Other essential agronomic recommended measures for coffee includes shade tree management, mulching and efficient water use through irrigation and rain water harvest.

Despite the proven benefits of these recommended practices, their adoption among small holder farmers remains inconsistent (Mhando, 2019). Substantial efforts have been

made to promote improved coffee techniques yet adoption has remained inadequate (Otieno *et al.*, 2019). Such efforts include, initiative by TaCRI and the coffee body to distribute and disseminate improved seeds and seedlings to farmers in all coffee growing regions. Farmers receive these seedlings at no cost. These limited adoption among farmers undermines the potential for increased agricultural productivity and social economic benefits. For instance, if the recommended practices could be best adopted, production could increase by 4 to 15 folds from current standing of 200-750kg/ha to 3t/ha with the same land (Bongers *et al.*, 2015) The persistent challenge of inadequate adoption of these practices highlights the need to investigate the factors that influences their adoption among small holder farmers.

Adoption of recommended practices is influenced by independent factors (Teklewold *et al.*, 2013: Kassie *et al.*, 2013: Abegunde *et al.*, 2019: Msuya, 2021: Wambua *et al.*, 2021) and intervening factors (Dessart *et al.*, 2021) However, the influence of these factors varies significantly across different farming system and social cultural settings (Mwinuka and Hyera, 2022: Nnanna *et al.*, 2025: Mahindaratne & Min, 2018). Therefore, this study aims at analysing how the independent factors shape adoption decisions in the context of coffee production in Siha, Kilimanjaro. By examining these factors, the study seeks to offer actionable insight that can guide the development of targeted interventions to increase adoption rate, improve productivity and enhance farmers livelihood, ultimately contributing to the region's economic growth.

The study is crucial as the coffee sector is the key driver of Tanzania economy contributing approximately 4% of the nation's GDP and providing livelihood to around 2.4 million smallholder farmers (Food and Agriculture Organization, 2020). The study also contributes to the broader discourse on sustainable coffee production sub-Saharan Africa, where many producers face challenges related to climate change, pests and low adoption of modern farming techniques.

1.1 Theoretical Framework

This study is anchored on two interrelated theoretical frameworks, The Technology Adoption Theory (Davis, 1989) and Diffusion of Innovation Theory (2003). These theories provide a comprehensive lens for understanding the

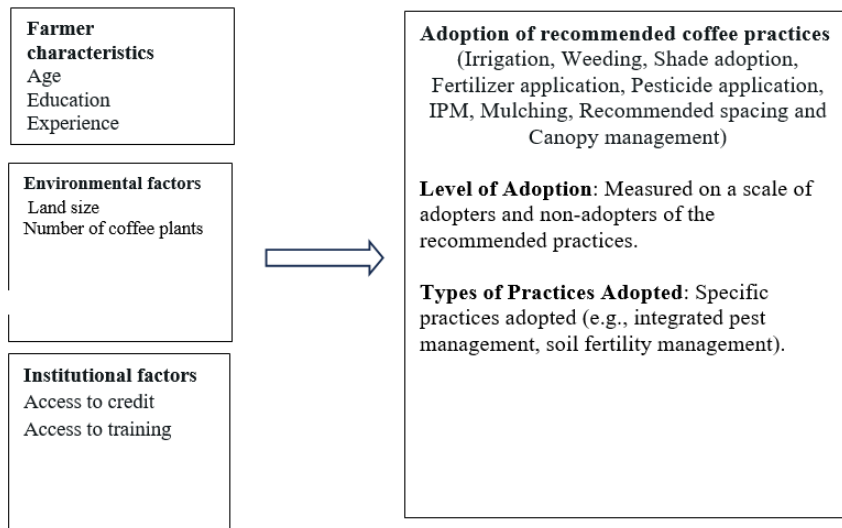


Fig. 1. Conceptual framework independent variables adoption

complex factors that influence the adoption of recommended practices in coffee production.

According to the Rogers' Diffusion of Innovation theory, five key factors influencing the adoption of the recommended practices; compatibility, relative advantage, observability, complexity and trialability. Farmers are more likely to implement these practices if they observe them as better than the existing practices, line up with their believe and values, are easy to implement and understand, can be tried up in small scale and yield visible results.

Complementing to these factors, Davis' Technology Adoption theory emphasizes two main perceptions that directly influence adoption decision: Perceived usefulness and perceived ease of use. Perceived usefulness is defined as the degree to which a farmer believes that adopting a certain practice will improve their productivity, income, or overall farm performance. Perceived ease of use refers to the degree to which the practices are seen as simple, understandable and requiring minimal effort to apply.

If a practice is perceived as too complicated, even if it is potentially beneficial, farmers may be reluctant to adopt it. Therefore, innovations and practices that are both effective and easy to implement are more likely to be adopted.

2. METHODOLOGY

2.1 Research Design

This study adopted cross-sectional design. The design has been recommended by several

scholars including (Omair, 2015; Setia, 2016). Quantitative methods were employed to analyse the adoption of recommended coffee production practices among smallholder farmers.

2.2 Description of the Study Area

The selection of Siha District as a study area was due to its low coffee productivity despite having all the favourable conditions for Arabica coffee production. The district is located in the Kilimanjaro region of Tanzania, with population of approximately 139,019 as of the 2022 census (Tanzania National Bureau of Statistics, 2022) most of them being smallholder farmers. While coffee remains the primary cash crop, they also cultivate other crops sch as bananas, beans and maize for both subsistence and income generation. Its fertile soil, diverse microclimates and varying altitudes create perfect condition for coffee farming. Nevertheless, due to low productivity it has prompted efforts to promote high yielding, disease-resistant hybrid coffee varieties as a part of the recommended agricultural practices. This transition presents an opportunity to examine the factors influencing level of adoption and the factors influencing farmers decisions.

2.3 Data Collection

The method used for data collection was Structured questionnaire administered to a sample of 198 smallholder farmers from Kandashi, Karansi, Mendai and Ashengai villages in Siha district. The questionnaire enclosed social-economic characteristics, adoption behaviour and knowledge of

recommended coffee practices. Key informant interview was held with extension officers and cooperative leaders to complement data from farmers.

Information on the package of the recommended coffee production practices was collected from the Tanzania Coffee Research Institute (TaCRI). This valuable information provided by secondary sources presented a comprehensive view of the study area.

2.4 Data Collection and Measurement

The baseline for the recommended practices in this study, was defined by established agricultural standards for coffee production, as delineated by experts. These standards consist of guidelines for key practices such as mulching, pest control, water management, pruning, plant spacing, shade management and fertilizer application (Avelino *et al.*, 2015). For the application of fertilizer, depending on soil pH, farmers are recommended to apply 180-200 grams per tree per season of NPK or CAN fertilizers, or 90-100 grams of Urea for tree over three years old (Otieno *et al.*, 2019; Kassie *et al.*, 2011; Hamadi, 2016). Spacing is recommended to be 1.5x2 meters or 2mx2m, 2.5x2.5 meters, 2.74x2.74 meters or 3x3 meters while shade cover is recommended at 25-30%, to promote healthy growth of the plant (Bosselmann *et al.*, 2009). Pruning is recommended at least three times per year, upholding 30-37 branches per tree, with a 6–7year rejuvenation cycle (Winston *et al.*, 2005). Moreover, Pest control should follow Integrated Pest Management (IPM) techniques, and organic mulching is endorsed to retain soil moisture and prevent erosion. Irrigation should be done at least once a week during dry periods, and farmers are encouraged to adopt rainwater harvesting of drip irrigation.

2.5 Sampling and Sample Size Determination

In this study villages in Siha district were selected using a simple random sampling technique. The list of all coffee-producing villages was obtained from coffee boards and the associated farmers cooperatives. A unique identification number was assigned to every village, and a random number generator was used to randomly hand-picked a predetermined number of villages. To determine the appropriate sample size the Yamane formula was used (Umar & Wachiko 2021). The formula was considered fitting for this study as it provides an

accurate sample size calculation for predetermined population guaranteeing statistical accuracy. Due to its simplicity and effectiveness this formula is commonly used in many studies. The required number of 198 farmers from the identified villages were selected using a systematic random sampling approach.

Sample size calculation; using Tara Yamane method (1967) (Umar & Wachiko 2021) To get a representative sample

Formula: $n = N / 1 + N(e)^2$

Whereby; n=Sample size

N= Population size

e= Level of precision 5%

The total population of farmers with improved coffee varieties in the selected villages for this study was 400.

$n = 400 / 1 + 400(0.05)^2$

$n = 400 / 1 + 400(0.0025)$

n=198

2.6 Data Analysis

The data were entered and cleaned on Excel then transferred to Statistical Package for Social Sciences (SPSS) version 20. SPSS was used to code and analyse the collected quantitative data. Descriptive statistics including, percentages and frequencies were used in the assessment of the level of adoption of recommended coffee production practices

In examining factors influencing adoption, the Probit regression model was applied to evaluate the likelihood that a farmer adopts a given practice based on a set of explanatory variables. The model is well suited for binary outcomes, where the dependent variable takes the value of 0 for non-adoption and 1 for adoption.

The regression examined the association between adoption decision and key independent variables, including access to loan, annual income, gender, access to training, number of coffee plants, farm size and educational level. The approach provided a comprehensive valuation of how institutional, environmental and social-economic factors shape the probability of adopting the recommended practices.

The Probit model was selected over Binary Regression due to its strong theoretical foundation in modeling decision making processes, particularly in adoption studies. The Probit model assumes a normally distributed error term, unlike the logistic model, making it more appropriate when adoption decisions are influenced by latent continuous factors which is realistic for social behavior. It also employs the cumulative normal distribution function (Φ), guaranteeing even probability estimates and avoiding extreme distortions in marginal effects.

The Probit model is specified as follows:

$$P(Y=1/X) = \Phi (\beta_0 + \beta_1 \times 1 + \beta_2 \times 2 + \dots + \beta_k \times k)$$

Whereby,

$P (Y=1/X)$ Is the probability of adoption (dependent variable).

Φ is the cumulative normal distribution function.

X_1, X_2, X_k are the independent variables

$\beta_0, \beta_1, \beta_k$ are the coefficients of the independent variables, which quantify the influence of each variable on the adoption probability

3. RESULTS AND DISCUSSION

3.1 Socio-Economic Characteristics of Respondents

The finding in Table 1, revealed that the average age of smallholder farmers adopting recommended coffee production practices was 59 years, majority of them (50.5%) falling within the age group of above 61 years), this specifies that coffee production is mainly dominated by old aged individuals, who are generally more experienced in agricultural activities. This indicates limited youth participation in coffee farming, which may affect long-term sector sustainability. The youngest farmers were 30 years while the oldest farmers were 92 years. The findings also revealed that 33% of surveyed farmers were female-headed households compared to 67% male-headed households. Concerning marital status, 74% of farmers were married. Five family members were the average household size of the interviewed families, with a minimum of 1 and maximum of 9 suggesting that larger households provide the necessary labour for effectively implementing the recommended practices. Education also appeared as a significant factor, with 78% of farmers having attained at least primary education. This finding highlights the role of literacy in facilitating the application and understanding of recommended

coffee practices. On average the farmers cultivate 0.82acre of coffee, the minimum being 0.2 acres and maximum 4 acres. Furthermore, on average each farmer has 432 coffee plant suggesting that they are below the recommended amount of at least 500coffee plants 67(Hella et al., 2005: Njoroge et al., 1992). Farming experience averaged 13 years, ranging from 2 to 44 years. Income from coffee ranged from 80,000 TZS to 2,900,000 TZS, with an average of 200,383 TZS.

3.2 Adoption of Recommended Practices

Results in Table 2 revealed varied adoption rates, with some practices being extensively implemented while others lagged. Shade adoption was a highly practiced practice with an adoption rate of 18.2%, demonstrating that nearly one in five farmers have implemented some form of shade technique. This is followed by weeding at 16.2%, where a considerable number of farmers have integrated weeding practices into their routine. In disparity, pesticide application (8.6%) and integrated pest management (IPM) (3.5%) have notably lower adoption rates, signifying these practices are still not extensively practiced among farmers.

The highest adoption rate can be clarified by the relatively lower perceived complexity and perhaps a quicker implementation phase for farmers as highlighted in Rogers (2003) diffusion of innovation theory. Weeding (16.2%) correspondingly has a reasonable adoption rate because it's a basic practice that fits into farmers existing routines and farming systems supported as well by Rogers, (2003) theory. The lower adoption rates of practices like pesticide application (8.6%) and IPM (3.5%) can be described by the risk associated with the practice. These practices are perceived as risky by farmers due to uncertainties related to pest control methods, lack of technical knowledge and cost.

On the other hand, practices like IPM (3.5%) and pesticide application (8.6%) likely face higher barriers related to trialability and complexity. According to Rogers, innovations characterized by higher complexity or perceived risk are less expected to be adopted quickly, which may explain why farmers are less inclined to adopt these practices without prolonged experience or external support. Additionally, Uncertainty about the performance of these practices, as emphasized in the technology adoption theory, further contributes to the low adoption rates.

Table 1. Demographic information of participants

Category	Item	Frequency	Percentage
Sex of respondents	Male	181	67.9
	Female	17	32.1
	Total	198	100.0
Age of respondents	30-45	18	9.1
	46-60	78	39.4
	>61	102	50.5
	Total	198	100.0
Land size under coffee	0.5-1 acre	93	47.0
	1-2 acre	87	43.9
	>2 acres	18	9.1
	Total	198	100.0
Level of education	Primary	155	78.3
	Secondary	38	19.2
	Collage	5	2.5
	Total	198	100.0
Level of income	<100,000 TZS	10	5.1
	100,000-300,000 TZS	116	58.6
	>300,000 TZS	72	36.4
	Total	198	100.0
Marital status	Single	51	25.8
	Married	147	74.2
	Total	198	100.0

Table 2. Adoption index of the recommended practices

Practice	Total Responses	Frequency	Adoption Index (%)
Irrigation	198	12	6.1
Weeding	198	32	16.2
Shade adoption	198	36	18.2
Fertilizer application	198	25	12.6
Pesticides application	198	17	8.6
IPM	198	7	3.5
Mulching	198	8	4.0
Recommended Spacing	198	34	17.2
Canopy management	198	27	13.6

3.3 Independent Factors Influencing Adoption of Recommended Practices

To ensure the Probit model fit the data appropriately several model diagnostic tests were conducted. These included pseudo-R-squared values for goodness-of-fit, a Likelihood Ratio Test to assess the overall significance of the model, and the calculation of Variance Inflation Factors (VIF) to detect multicollinearity among the independent variables. Furthermore, randomness was examined using model residuals and to confirm the appropriateness of the normal cumulative distribution function link function validation was executed. After the suitability of the model was verified, it was considered well-fitted and the analysis proceeded with the examination of

environmental, institutional and social-economic factors influencing adoption.

The finding on the independent factors were categorized in to social-economic factors environmental and institutional factors to comprehensively analyse their impact on the adoption of the recommended practices for coffee production. The independent factors were each examined separately, with the corresponding standard error, coefficients, p-value, z-value and 95% confidence interval.

3.3.1 Social-economic factors

These factors examined individual characteristics such as marital status, gender, income, education and age which influences farmers

capacity and decision-making to implement recommended coffee practices.

i. Gender

The finding in Table 3 revealed that gender significantly influences the adoption of irrigation practices among coffee farmers ($P=0.010$). The positive coefficient of 1.321 proposes that male farmers are more probable to implement irrigation practices equated to farmers who are female. Specifically, the probability of adopting irrigation increases as gender changes from female to male. These findings are supported by previous study (Njoroge *et al.*, 2021) which found out that the male headed households are more expected to engage in small scale irrigation due to better access to extension, credit services and access to information. In contrast, female-headed households have additional home responsibilities they often lack the time to gather information. Likewise, the finding from study in Ethiopia on factors determine adoption of technology in coffee (Million *et al.*, 2020) revealed gender specifically farmers being female have negative correlation with adoption of mulching practices. However, for the other coffee practices including use of pesticides, spacing, weeding, mulching, fertilizer application, shade adoption, canopy management and Integrated pest management (IPM), gender influence was statistically insignificant, signifying both female and male adopt these practices irrespective of their gender. This aligns with findings from other research (Aboud *et al.*, 1996) which showed that gender was not a significant factor in predicting the adoption of coffee enhancing practices.

ii. Education

Education plays a crucial role in the adoption process as it influences the decision of an individual in processing, analyzing and utilizing various source. The finding in Table 4 displays that, there is a significant influence of education on the adoption of various recommended coffee production practices. Specifically, it has a positive impact on the adoption of weeding ($P=.049$), spacing ($P=.03$), pesticide application ($P=.02$), fertilizer application ($P=0.03$) and irrigation ($P=0.001$). The coefficient of .488 being positive for irrigation suggests that as the education level increases, the probability of adopting irrigation also increases. likewise, fertilizer application, pesticide application and spacing have positive coefficients (.322, .293 and .224 respectively) meaning that as education

increases, the underlying probability of adopting these practices also rises. This is consistent with the finding from (Bizimana *et al.*, 2002) who defined the education of the principal farm decision-maker as a decisive factor in adopting recommended farming practices in Rwanda. However, the non-significant results for canopy management ($P=.27$) and shade adoption ($P=.57$) suggests that factors beyond education such as extension support and resources availability, may play a bigger role in influencing these practices, in line with findings by (Urgessa Waktola & Fekadu, 2021) on adoption of coffee shade agroforestry technology.

iii. Marital Status

The probit regression analysis reveals that marital status significantly influences the adoption of canopy management ($P=.047$) and shade trees ($P=0.01$), showing that farmers who are married are more expected to adopt these long-term coffee management practices. The positive coefficient for canopy management (.530) and shade adoption (.467) suggesting an increased probability of adoption. In contrast, other coffee practices, including spacing, integrated pest management (IPM), pesticide application, mulching, irrigation, fertilizer application and weeding, show no statistically significant relationship with marital status. Though some of the practices, such as mulching (.300), weeding (.373) and pesticides application (.390) have positive coefficients, their p-value proposes weak evidence of their association. These results show most of farmers who prioritize structural and long-term investments such as canopy control and shade adoption in coffee management are married while short-term agronomic practices remain unaffected by marital status. These results are consistent with the study (Ngeywo *et al.*, 2015) by which also found that age, marital status and gender does practices significantly impact coffee production. Both studies suggest that while demographic factors may have limited effect on adoption, their influence varies across specific practice.

iv. Income

The result of the probit regression analysis specifies that income has a statistically significant influence on the adoption of certain coffee practices, particularly canopy management (coefficient = .573, $P= 0.034$) and shade adoption (coefficient = .512, $P= 0.006$). A positive coefficient suggests that as income

Table 3. Influence of gender on the adoption of coffee practices

Variable	Practice	coefficient	Std. Err	Z	P>z	95%	Interval
Gender	Irrigation	1.321	0.512	2.58	.010	0.345	2.978
	Weeding	.151	0.401	0.17	.50	-0.088	0.076
	Shade adoption	.161	0.276	0.58	.56	-1.079	0.357
	Fertilizer application	.200	0.350	0.57	.57	-0.904	0.704
	Pesticide application	.057	0.424	0.13	.89	-0.887	0.774
	IPM	.050	0.360	0.14	.89	-0.789	0.777
	Mulching	.100	0.400	0.25	.80	-0.689	0.992
	Spacing	.070	0.415	0.17	.87	-0.743	0.883
	Canopy management	.581	0.402	1.45	.148	-0.206	1.369

Table 4. Influence of education on the adoption of coffee practices

Practice	Coefficient	Std. Err	z	P>z	95% conf.	Interval
Irrigation	.488	0.152	3.21	.001	0.258	0.784
Weeding	.172	0.200	0.86	.049	0.704	0.904
Shade Adoption	.081	0.142	0.57	.57	0.045	0.505
Fertilizer Application	.322	0.178	1.81	.03	0.142	0.864
Pesticide Application	.293	0.175	1.67	.02	0.051	0.136
IPM	.307	0.173	1.77	.08	0.004	0.008
Mulching	.295	0.186	1.58	.12	0.043	0.459
Spacing	.224	0.186	1.2	.03	0.301	0.985
Canopy Management	.210	0.189	1.1	.27	0.356	0.631

Table 5. Influence of marital status on the adoption of coffee practices

Practice	Coefficient	Std. Err	z	P>z	95% Conf. Interval
Irrigation	.055	0.190	-0.29	.77	0.258, 0.543
Weeding	.373	0.275	-1.35	.18	0.169, 0.913
Shade adoption	.467	0.199	2.35	.01	0.105, 0.305
Fertilizer application	.183	0.228	0.80	0.42	0.018, 0.402
Pesticides application	.390	0.272	-1.44	.15	0.004, 0.008
IPM	.244	0.237	-1.03	.30	0.404, 0.715
Mulching	.300	0.263	-1.14	.26	0.045, 0.505
Spacing	.224	0.186	1.20	.23	0.589, 0.975
Canopy management	.530	0.267	-1.99	.047	0.214, 0.611

Table 6. Influence of Income on the Adoption of Coffee Practices

Practice	Coefficient	Std. Err	z	P > z	95% conf. Interval
Irrigation	.112	0.178	0.63	.53	-0.236, 0.460
Weeding	.295	0.260	1.13	.26	0.098, 0.592
Shade Adoption	.512	0.185	2.77	.006	0.142, 0.882
Fertilizer Application	.208	0.219	0.95	.34	-0.103, 0.519
Pesticide Application	.354	0.258	1.37	.17	-0.089, 0.797
IPM	.267	0.229	1.17	.24	-0.118, 0.652
Mulching	.321	0.251	1.28	.20	-0.072, 0.714
Spacing	.249	0.175	1.42	.16	0.034, 0.647
Canopy Management	.573	0.255	2.10	.04	0.197, 0.949

increases, the likelihood of adopting these practices also increases. These results suggests that these recommended practices are more likely to be adopted by farmers with higher incomes, likely due to the capital requirements associated with managing the canopy structure

and maintaining shade trees. This is in line with findings from (Ronalds *et al.*, 2023) on the study on social economic factors in uptake of coffee recommended practices in Uganda. Other practices such as pesticide application (coefficient = .354, $P=.17$), mulching (coefficient

=.321, $P=.20$) and weeding (coefficient = .295 $P=.26$), coefficient being positive suggests a tendency for higher income farmers to adopt them, but the results are not statistically significant, suggesting that while income may inspire adoption, other factors like access to inputs, extension support and knowledge may play a more decisive role.

3.3.2 Environmental factors

Environmental factors assessed the role of the number of coffee plants and land size.

v. Land size

The results from probit regression shows that land size influences the adoption of several coffee practices including mulching (coefficient = .381, $P = .02$), Integrated Pest Management (IPM) (coefficient = .334, $P = .02$), pesticides application (coefficient = .278, $P=.05$), fertilizer application (coefficient = .393, $P = .01$) and irrigation (coefficient = .558, $P = .00$). This finding is well supported by diffusion of innovation theory (Rogers,2003), which identifies trialability and observability as critical attributes influencing the adoption of innovation. Bigger farm sizes would allow farmers to get to try new technologies without compromising the scale of the main crop hence it promotes adoption (Kassie *et al.*, 2011; Ghimire *et al.*, 2015). The positive coefficient suggests that an increase in land size increases the probability of adopting these practices. Larger land sizes encourage the adoption of labor-intensive and capital-intensive practices such as fertilizer application and irrigation, as farmers with larger plots tends to invest more in improving productivity. Shade adoption (coefficient = .190, $P = .048$), suggesting that shade trees in coffee production are more likely to be adopted by farmers with larger land size. Positive coefficient suggests that an increase in land size is related to a higher possibility of integrating shade trees, probably due to the availability of space and long-term investment perspectives. This is consistent with the results of the study from Rwanda (Bizimana *et al.*, 2002). which found that education of the principal farm decision-maker, availability of wealth and liquidity and land fragmentation as the most significant factors influencing the adoption of recommended and suitable farming practices on coffee farms. Weeding (coefficient = 0.245, $p = .070$) displays a positive relationship with land size, but it is not statistically significant at the 5% level. This depicts that while farmers with larger land sizes may be more motivated to adopt

weeding as a part of their farm management practices, other factors such as Labor availability or extension services might also influence this decision. Also, (Diro, 2024) found a positive effect of land size on the adoption of improved crop varieties Conversely, canopy management ($p = .074$) and Spacing ($p = .0801$) are not significantly influenced by land size, suggesting that these practices may be more dependent on extension services, traditional farming practices or technical knowledge rather than the availability of land.

vi. The number of coffee plants

Probit regression analysis revealed that the number of coffee plants significantly influences the adoption of various practices including shade adoption ($P=.008$), fertilizer application ($P=.00$), IPM ($P=.00$), Mulching ($P=.00$), spacing ($P=.00$) and canopy management ($P=.00$). This suggests that farmers with more plants are more likely to implement practices intended at improving sustainability and productivity. For instance, fertilizer application (coefficient = .007, $P=.00$), shade adoption (coefficient = .002, $P = .008$), mulching (coefficient = .007, $P = .00$) and IPM (coefficient = .006, $P = 0.00$) all display positive relationships with the number of plants, display that these practices are more expected to be used by farmers with larger plots. The findings align with studies by (Bravo-Monroy *et al.*, 2016) who found that among the main drivers influencing farmers decisions to organic or conventional coffee management practices, the number of coffee plant is one of them. On the other hand, irrigation (coefficient = .001, $P = .62$) displayed no statistically significant relationship with the number of plants, which proposes that irrigation is not strongly tied to farm size in this context.

3.3.3 Institutional factors

Institutional factors evaluated the role of access to credit and training in enabling adoption through financial support, resource accessibility and knowledge dissemination.

vii. Access to training

The results from probit regression indicates that the probability of adopting several recommended practices is increased by training. The highly significant effect of training on shade adoption (coefficient = .891, $P = .00$) suggests that farmers with training have a greater possibility of integrating shade trees, likely due to increased

Table 7. Influence of land size on the adoption of coffee practices

Practice	Coefficient	Std. Err	z	P > z	95% Conf. Interval
Irrigation	.558	0.153	3.65	.00	[0.259, 0.857]
Weeding	.245	0.135	1.81	.07	[-0.019, 0.509]
Shade Adoption	.190	0.096	1.98	.048	[0.001, 0.379]
Fertilizer Application	.393	0.155	2.54	.01	[0.090, 0.696]
Pesticide Application	.278	0.142	1.96	.05	[0.000, 0.556]
IPM	.334	0.144	2.32	.02	[0.051, 0.617]
Mulching	.381	0.167	2.28	.02	[0.054, 0.708]
Spacing	.037	0.148	0.25	.80	[-0.253, 0.327]
Canopy Management	.305	0.170	1.79	.07	[-0.028, 0.638]

Table 8. Influence of number of plant on the adoption of coffee practices

Practices	Coefficient	Std. Err	z	P > z	95% Conf. Interval
Irrigation	.001	0.002	0.50	.62	[-0.003, 0.005]
Weeding	.003	0.002	1.50	.13	[0.000, 0.006]
Shade Adoption	.002	0.001	2.67	.008	[0.001, 0.003]
Fertilizer Application	.007	0.001	6.10	.00	[0.005, 0.009]
Pesticide Application	.004	0.002	2.00	.046	[0.000, 0.008]
IPM	.006	0.001	5.80	.00	[0.004, 0.008]
Mulching	.007	0.001	6.20	.00	[0.005, 0.009]
Spacing	.006	0.001	5.77	.00	[0.004, 0.008]
Canopy Management	.006	0.001	5.75	.00	[0.005, 0.008]

Table 9. Influence of training on the adoption of coffee practices

Variable	Coefficient	Std. Err	z	P>z	95% Conf. Interval
Irrigation	.678	0.298	2.27	.02	0.094, 1.262
Weeding	.410	0.185	2.22	.03	0.049, 0.771
Shade Adoption	.891	0.252	3.54	.00	0.397, 1.385
Fertilizer Application	.642	0.278	2.31	.02	0.097, 1.189
Pesticide Application	.536	0.215	2.49	.01	0.115, 0.957
IPM	.780	0.308	2.53	.01	0.176, 1.384
Mulching	.876	0.337	2.60	.009	0.216, 1.536
Spacing	.575	0.328	1.75	0.08	-0.073, 1.223
Canopy Management	.670	0.335	2.00	0.046	0.06, 1.334

Table 10. Influence of access to loans on the adoption of coffee practices

Variable	Coefficient	Std. Err	z	p>z	95% Conf. Interval
Irrigation	.417	0.160	2.60	.009	0.102, 0.732
Weeding	.315	0.146	2.16	.03	0.027, 0.603
Shade adoption	.217	0.189	1.15	.25	-0.153, 0.587
Fertilizer Application	.561	0.211	2.66	.008	0.145, 0.977
Pesticide Application	.198	0.154	1.29	.198	-0.104, 0.500
IPM	.431	0.193	2.24	.03	0.052, 0.811
Mulching	.101	0.228	0.44	.66	-0.345, 0.547
Spacing	-0.168	0.234	-0.72	.47	-0.0626, 0.290
Canopy Management	.360	0.201	1.83	.07	-0.022, 0.760

consciousness of their benefits in regulating temperature and improving soil health. Correspondingly, the possibility of adopting IPM (.780, $P = .01$) and Mulching (.876, $P = .009$) is

significantly higher among farmers with training, strengthening the knowledge transfer in promoting pest management practices and sustainable soil. Also, with the increase in

training, the adoption probability of fertilizer application (.642, $P = .02$) and irrigation (.678, $P = .02$) also increases, signifying that access to technical knowledge improves decision-making in nutrient and water management. This is also consistent with the technology adoption theory (feder *et al.*, 1985), farmers access to information significantly shaped their decisions to adopt the practices. Additionally, pesticide application (.536, $P = .013$) and weeding (.410, $P = .03$) show substantial positive effects, signifying that trained farmers are more likely to implement improved weed and pest control strategies. The amplified possibility of adopting canopy management (.670, $P = .046$) further highlights the impact of training on the uptake of proper pruning and shade regulation techniques. This is in line with the findings from (Luusa *et al.*, 2018) in Kenya where it described that coffee farmers fitting in farmer field schools were more engaged with frequently training hence, they adopted coffee recommended practices compared to farmers who were not member of farmer field school (FFS). Nevertheless, spacing (.575, $P = .08$) does not show a statistically significant effect, signifying that training alone may not strongly influence decision related to plant arrangement, possibly due to existing land limitation or traditional planting methods.

viii. Access to loans

Agricultural credit promotes agricultural modernization economic growth, as long as the capital is utilized efficiently (Mwonge & Naho, 2022). Results from probit regression shows that the possibilities of adopting several recommended coffee practices, are increased by the access to loans, mostly those requiring financial investment. The positive and significant effect of loans on fertilizer application (coefficient = .561, $P = .008$) suggests that farmers ability to purchase fertilizers, improving soil fertility and productivity is enhanced by financial support. Correspondingly, access to loans, significantly influences the adoption of irrigation (.417, $P = .009$) signifying that the investment in water management infrastructures is crucial for sustaining the production of coffee under variable climatic condition is enabled by financial access. The possibility of adoption of weeding (.315, $P = .031$) and IPM (.431, $P = .03$) also increases with access to loan, signifying that the availability of credit helps farmers affords essential inputs for weed management and pest control, which are essential for maintaining crop health. This aligns with study by (Mpirwa, 2022) in Kenya which

found that farmers who displayed higher technical efficiency are those who obtained credit with an additional 6% potential to increase coffee production under the same input levels while other factors remain constant. In contrast, those who showed lower technical efficiency were those without credit access compared to their counterparts who received financial support.

Nevertheless, pesticide application (0.198, $p = .198$) and shade adoption (0.217, $p = .250$) do not show significant effects, showing that financial access alone may not be the primary driver of decisions regarding chemical pest control and shade tree integration. Similarly, spacing (-0.168, $p = .472$) and mulching (0.101, $p = .660$) shows no substantial association with access to loan probably due to their lesser financial requirements related to other practices. Canopy management (0.369, $p = .067$) approaches significance, signifying that loans may slightly simplify investments in pruning activities, although other factors such as availability of labour and knowledge may also play a role

4. CONCLUSION AND RECOMMENDATION

The study findings shows that the adoption of the recommended practices for coffee production varies significantly across different practices, with some being more extensively executed than others. Weeding and shade adoption were among the most commonly adopted practices, suggesting that farmers recognize their importance in coffee sustainability and productivity. Conversely, pesticides and integrated pest management (IPM) use had relatively low adoption rates, likely due to limited awareness, perceived complexity or financial constraints in implementation.

The study further reveals that institutional factors and social-economic play a crucial role in inducing adoption decision. Key determinants such as land size, income, and access to training pointedly impacted the likelihood of farmers adopting various coffee management practices. Farmers with higher income levels were more likely to adopt capital-intensive practices such as IPM, Irrigation and Fertilizer application, indicating that financial capacity is a major enabler of improved coffee production. Likewise, access to training was positively linked with higher adoption rates, emphasizing the critical

role of knowledge distribution in enhancing the uptake of improved agricultural practices.

Another suggestion from the study is that farm size is a critical determinant of adoption, as larger landholders established a greater probability of implementing multiple recommended practices. This may be credited to their capacity to assign more resources, both financial and labour-related, toward enhanced coffee production techniques. Nevertheless, gender and marital status did not significantly influence the adoption of most practices, signifying that these demographic factors may not be primary drivers of adoption behaviour in the study area.

The study finding recommend the crucial role that training play in promoting the adoption of improved coffee production practices. To enhance the effectiveness and reach of these services, it is suggested that both the government and agricultural organizations increase their investments in practical, accessible farmer training program. These programs should not only focus on the dissemination of knowledge but also on fostering hands-on skills and confidence in implementing recommended practices. By prioritizing these initiatives farmers will be better equipped to adopt new technologies and methods, ultimately leading to increased productivity and sustainability in coffee farming.

Age-related differences in adoption rates suggest the need for targeted interventions for younger farmers. It is suggested that training programs precisely designed for this group be developed, highlighting modern agricultural practices and innovative technologies. Such programs could provide younger farmers with the tools and knowledge to become leaders in agricultural innovation in the coffee sector. This approach would also prepare them for the challenges and opportunities of the future, ensuring the long-term competitiveness and viability of the industry.

With the barriers in finance that farmers face, particularly smallholders, non-governmental organizations (NGOs) and the government should explore options for subsidizing agricultural inputs such as fertilizer. The establishment of a targeted subsidy program focusing on low-income farmers or those in high-potential yield areas would help reduce the financial burden associated with adopting full recommended input levels. Initiatives like that would make it easier for

farmers to invest in essential inputs, ultimately driving higher productivity, and improving their economic well-being.

Additionally, there is a necessity for credit facilities or financial support to assist farmers access the necessary resources to adopt improved practices. Starting partnerships between financial institutions and the government could facilitate affordable loans or credit facilities personalized to the needs of smallholder farmers. This would enable them to invest in agricultural inputs and technology, thereby improving productivity and ensuring that they remain competitive inputs and technology, thereby cultivating productivity and ensuring that they remain competitive in the coffee industry.

Lastly, embattled interventions for women and younger farmers should be prioritized in order to bridge age and gender disparities in adoption rate. These interventions should focus on presenting modern farming technologies and providing support that encourages the participation of younger generation and women in agricultural invention. By investing in these groups, the industry can nurture the next generation of farmers who will drive sustainability and innovation in coffee production.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

I, Shelta Hosea Mseja hereby declares that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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