

ICT Adoption and Adoption Intensity among Tomato Farmers in Kenya

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Access to timely, accurate, and relevant agricultural information is essential for improving productivity and decision-making among smallholder farmers. However, conventional extension systems in Kenya continue to face challenges related to limited coverage, inadequate staffing, and resource constraints. Information and Communication Technologies (ICTs), including mobile phones, internet-based platforms, social media applications, and SMS-based advisory services, offer alternative channels for delivering agricultural information and advisory services to farmers. Despite their potential, the adoption and effective utilization of ICT-based agricultural advisory services remain uneven among smallholder farmers. This study examined the socio-economic and institutional factors influencing both the adoption and adoption intensity of ICT-based agricultural advisory services among 384 smallholder tomato farmers in Kirinyaga County, Kenya. A cross-sectional survey design was employed, and respondents were selected through a multistage sampling procedure to ensure representative coverage of major tomato-producing wards in the county. A sequential modelling approach was adopted, using a Probit model to analyse the binary decision to adopt ICT-based advisory services and a Poisson regression model to examine adoption intensity, measured as the number of ICT-based agricultural advisory functions utilized by a farmer. The findings indicate that extension contact frequency and access to agricultural credit were positively associated with both ICT adoption and adoption intensity. Farmer group membership significantly increased the likelihood of ICT adoption, while household education positively influenced the intensity of ICT use. Conversely, larger tomato farm sizes were associated with lower adoption intensity. The results underscore the importance of human capital, institutional support, and financial inclusion in promoting meaningful engagement with digital agricultural advisory services. The study recommends strengthening farmer education and digital literacy initiatives, integrating ICTs into existing extension systems, improving access to agricultural credit, and promoting farmer group participation to enhance both the adoption and effective utilization of ICT-based agricultural advisory services. By jointly examining adoption and adoption intensity, the study contributes to the growing body of literature on digital agricultural extension and provides evidence to inform the design of inclusive and sustainable ICT-enabled advisory systems for smallholder horticultural farmers.

Keywords: Smallholder tomato farmers, ICT adoption, ICT adoption intensity, Agricultural extension, probit model, poisson model.

INTRODUCTION

Smallholder agriculture plays a vital role in the provision of food security, rural livelihoods and income generation in Sub-Saharan Africa (Moyo & Assan, 2025; Kapari et al., 2023). Nonetheless, the rate at which productivity in smallholder agriculture in SSA can grow still faces challenges in terms of limited access to relevant and timely information in agriculture. Extension services have been at the forefront in providing the link between available information and smallholder farmers (Abiri et al., 2023). In developing

countries like Kenya, the traditional public extension service model has been overstretched to the extent that it can no longer reach smallholder farmers, despite the pivotal role they played traditionally in bridging information gaps. However, conventional public extension systems in many developing countries, including Kenya, are increasingly overstretched, under-resourced and unable to reach dispersed farming populations consistently (Venter, 2022). As a result, there is shift of attention toward information and communication technologies (ICTs) as alternative and synergistic channels

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for delivering agricultural knowledge at cost-effective, scalable and responsive ways (Mulungu et al., 2025).

In Kenya, the ratio of extension officers to farmers remains far below recommended levels, limiting effective dissemination of agricultural information and advisory services (Violet et al., 2022). ICT-mediated agricultural extension delivered through mobile phones, internet-based platforms, and digital advisory services, has gained prominence as a mechanism for enhancing farmers' access to production advice, market information, weather forecasts and pest and disease alerts (Peng et al., 2024; Lahiri et al., 2024). Empirical evidence suggests that ICTs can reduce information asymmetries, improve decision-making and strengthen farmers integration into markets (Mapiye et al., 2023). This contributes to productivity growth and income stability. Despite this potential, adoption and effective use of ICT-based extension services among smallholder farmers remain uneven, particularly in horticultural systems that are information-intensive and highly sensitive to management decisions (Mbaya, 2023). Tomato production is one such system. Tomatoes are among the most commercially important horticultural crops in Kenya, providing income and employment for thousands of smallholder farmers while supplying urban and peri-urban markets (Violet et al., 2022). Tomato production is highly information-intensive due to frequent pest and disease outbreaks, price fluctuations and high input requirements, making timely digital advisory services particularly relevant compared to many staple crop. However, tomato production is characterized by high production risks, frequent pest and disease outbreaks, volatile prices and substantial post-harvest losses (Maurya et al., 2025; Reséndiz-Castro et al., 2025). These challenges heighten the value of timely extension information and make tomato farmers an important group for examining digital extension adoption.

Kirinyaga County is one of the leading tomato-producer in Kenya (Horticultural Crops Directorate, report of 2024). Kirinyaga County provides a suitable case because it combines intensive tomato production, high market orientation, diverse agroecological conditions and expanding mobile connectivity. Thus, it creates an appropriate setting for examining both adoption and intensity of ICT use. Farmers operate under small landholdings and variable institutional support, creating heterogeneous conditions for ICT engagement (Fredrick et al., 2022). Existing studies in Kenya have largely focused on binary adoption decisions and have rarely examined the intensity with which farmers utilize multiple ICT-based advisory functions after adoption, particularly within horticultural value chains such as tomato production. Studies consistently highlight the role of socio-economic characteristics such as education, farming experience, household size and gender in shaping farmers' capacity to engage with digital tools (Nguyen & Hoang, 2025; Onyango et al., 2025; Saghir et al., 2025; Ntsoane et al.,

2025). Institutional factors including access to extension services, credit availability and farmer group participation have also been shown to influence ICT adoption by lowering information and financial barriers (Idu et al., 2025; Shitaye et al., 2025; Effiong et al., 2025). Empirical analyses in East Africa and beyond frequently employ binary choice models such as probit or logit to examine adoption decisions, finding education, extension contact and perceived usefulness of ICTs to be among the most robust predictors (Mwonge et al., 2025). More recent research has extended the scope beyond binary adoption to investigate the intensity of ICT adoption, acknowledging the limitation of the binary approach in capturing the extent to which ICTs are utilized and the potential welfare impacts of ICTs in agriculture (Xu et al., 2022; Wang & Zhao, 2023). Researchers have utilized count data models like Poisson or negative binomial regression to investigate the frequency or extent to which farmers utilize ICT-based services after they have adopted them. The consensus emerging from recent research indicates that the determinants of initial ICT adoption might not be the same as those influencing the intensity of ICT adoption, emphasizing the need to model these decisions independently. However, there is limited empirical research on ICT intensity, especially in horticultural value chains in Kenya at the sub-national level. Although tomato farming in Kirinyaga has high potential for production, the practice in the region is hampered by pest and disease attacks, price variability and limited access to timely information on agriculture (Wafula, 2022). This situation in Kirinyaga County justifies the suitability of the study area for the analysis of ICT-mediated agriculture extension services.

In view of the above, the purpose of the present study was to examine the socio-economic and institutional determinants of the adoption and intensity of adoption of ICT-based agricultural extension services by smallholder tomato farmers in Kirinyaga County in Kenya. This study is grounded in Random Utility Theory (RUT), which posits that farmers adopt technologies when the expected utility from adoption exceeds that from non-adoption. Conceptually, the study viewed the engagement of ICTs by farmers as a two-step process in which the farmer makes a binary choice in the first step to adopt ICT-based extension services, followed by the intensity of adoption in the second step. Using a probit model for the analysis of adoption and a Poisson regression for the analysis of the intensity of adoption, the study sought to match the analytical methodology with the actual decision-making behavior of the farmers. This study contributes to the growing literature on digital agricultural extension by simultaneously examining both adoption and adoption intensity among smallholder tomato farmers in Kenya. The specific objectives of this study therefore were: (i) To determine factors influencing adoption of ICT-based agricultural advisory services among smallholder tomato farmers and (ii) To



examine factors influencing the intensity of ICT-based agricultural advisory service use among adopters.

MATERIALS AND METHODS

Study area: The study was conducted in Kirinyaga County, Kenya. It focuses on five major tomato-producing wards: Kanyekeni, Kariti, Kiine, Mutithi, and Nyangati. The County is characterized by favorable agro-ecological conditions for horticultural production including fertile soils, reliable bimodal rainfall and proximity to major urban markets such as Nairobi and Embu. Agriculture is the main economic activity with tomato farming constituting the dominant commercial enterprises among over 20,000 smallholder farmers in the County (Njeru et al., 2025).

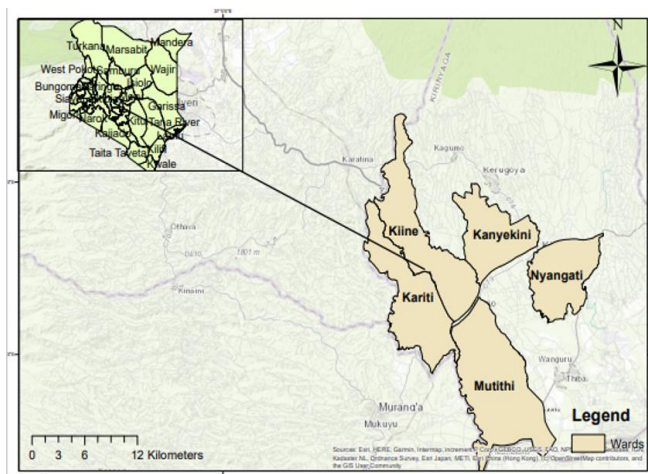


Figure 1. Map of the study area.

Research design: The study adopted a cross-sectional research design. This design is suitable for capturing variations in socio-economic characteristics, institutional access and ICT adoption patterns at a single point in time allowing for systematic analysis of factors influencing both ICT adoption and intensity of use.

Sampling technique and procedure: A multistage sampling procedure was employed. First, three tomato-producing sub-counties in Kirinyaga County were purposively selected based on production intensity. Second, five tomato-producing wards namely; Kanyekeni, Kariti, Kiine, Mutithi and Nyangati were randomly selected across the three sub-counties. Finally, smallholder tomato farmers were randomly selected from farmer lists obtained from local agricultural offices. To ensure representativeness, probability proportionate to size (PPS) sampling was used to determine the number of respondents selected from each ward. Only households actively engaged in tomato production during the reference season were included in the survey. Farmer lists used as sampling frames were obtained from ward agricultural extension offices and farmer groups. The lists

were reviewed and updated in consultation with agricultural officers before random selection to ensure accuracy and completeness.

Sample size determination: Using Cochran's formula for large populations yielded a minimum sample size of 384 households, which was considered adequate for statistical inference.

$$n = \frac{Z^2 p(1-p)}{e^2}$$

Where: $Z = 1.96$, $p = 0.5$ and $e = 0.05$. $n=384$

Since no prior estimate of ICT adoption among tomato farmers in the study area was available, p was set at 0.5. This value maximizes variability and yields the largest required sample size, thereby ensuring adequate statistical precision.

Data collection: Enumerators received training on questionnaire administration, ethical considerations and interview procedures. Field supervision and daily consistency checks were undertaken throughout data collection. Primary data were collected using structured questionnaire administered to the smallholder tomato farmers in the County between June 2025 and July 2025. The questionnaire was developed based on previous studies on ICT adoption and agricultural extension. Content validity was assessed through expert review by agricultural economists and extension specialists. Feedback was incorporated to improve clarity and relevance of questionnaire items. A pilot survey involving 30 tomato farmers was conducted prior to the main survey. The pilot results informed refinement of question wording, sequencing and response categories. The questionnaire captured information on household socio-economic characteristics, farm attributes, institutional factors and ICT-related variables, including adoption and intensity of ICT-mediated extension adoption. The instrument was pre-tested prior to the main survey to enhance clarity and reliability. Trained enumerators conducted interviews. Data was analysed using Stata software version 18.

Theoretical framework: This study is anchored on Random Utility Theory (RUT). Under RUT, each farmer is assumed to choose the option that maximizes expected utility, subject to information constraints and resource endowments. The ICTs adoption decision arises when the expected utility from adopting ICTs exceeds that of non-adoption. This utility depends on observable characteristics (education, experience, institutional access, perceived usefulness) and unobservable factors captured by the error term. Random Utility Theory was selected because adoption of ICT-mediated advisory services involves a discrete choice in which farmers compare the expected utility derived from adoption with that of non-adoption. The theory provides a direct foundation for estimating binary adoption decisions using discrete choice models such as Probit regression.

Econometric framework

Overview of the empirical strategy: Farmers' adoption of ICT-mediated agricultural extension services (AES) is



conceptualized as a sequential decision-making process in which two distinct, but related decisions are made: the decision to adopt ICTs (at the extensive margin) and the decision concerning the intensity of adoption of ICTs among adopters (at the intensive margin). As farmers who did not adopt ICTs necessarily have an adoption level of zero, the decision concerning the intensity of adoption of ICTs would be confounded with the decision concerning adoption itself if the intensive adoption decision is not conditioned on adoption. To overcome this problem, the study adopts sequential modeling approach in which each decision is modeled using the most appropriate model given the nature of the dependent variable. The Probit-Poisson framework was adopted because adoption and adoption intensity represent two distinct decisions. The Probit model is appropriate for analysing binary adoption outcomes, while Poisson regression is suitable for modelling count outcomes such as the number of ICT-based advisory functions utilized.

First Part

ICTs Adoption: Probit Model: The first part models the probability that household i adopts ICTs using a probit specification:

Let Y_i be a binary outcome variable such that:

$$Y_i = \begin{cases} 1 & \text{if the event of interest occurs} \\ 0 & \text{otherwise} \end{cases}$$

The Probit model is derived from an unobserved (latent) variable Y_i^* :

$$Y_i^* = X_i'\beta + \varepsilon_i$$

where:

- X_i is a vector of explanatory variables
- β is a vector of parameters to be estimated
- $\varepsilon_i \sim N(0,1)$ (standard normal error term)

$$ICT_i^* = Z_i\gamma + \varepsilon_i$$

$$ICT_i = \begin{cases} 1 & \text{if } ICT_i^* > 0 \\ 0 & \text{otherwise} \end{cases}$$

where:

- ICT_i is a binary indicator of ICTs adoption,
- Z_i is a vector of household, farm, institutional, and information-related characteristics,
- $\varepsilon_i \sim N(0,1)$.

The robit model is appropriate given the dichotomous nature of the adoption decision and allows for nonlinear effects of explanatory variables on adoption probabilities. Average marginal effects are reported for ease of interpretation.

Second part

ICTs Adoption Intensity: Poisson Model: Poisson regression is used when the dependent variable is a count variable, taking non-negative integer values: ICT adoption intensity was measured as a count variable representing the number of ICT-based advisory functions utilized by a farmer. These included access to weather information, market information, pest and disease management information, input information and extension communication services.

$$Y_i = 0, 1, 2, 3, \dots$$

The Poisson model assumes that the conditional mean of Y_i given covariates X_i is:

$$E(Y_i | X_i) = \lambda_i = \exp(X_i'\beta)$$

where:

- $\lambda_i > 0$ is the expected count,
- X_i is a vector of explanatory variables,
- β is a vector of parameters.

The exponential form guarantees non-negative predicted values.

Conditional on adoption ($ICT_i = 1$), the intensity of ICT adoption is modeled using a Poisson regression:

$$E(ICT_Intensity_i | ICT_i = 1, X_i) = \exp(X_i'\beta)$$

where:

- $ICT_Intensity_i$ is a discrete variable measuring the number of ICT-based functions or services used,
- X_i is a vector of explanatory variables,
- β are parameters to be estimated.

The Poisson model is suitable because the dependent variable is non-negative, discrete and right-skewed. Robust standard errors are used to account for potential heteroskedasticity, and goodness-of-fit statistics indicate no evidence of overdispersion.

Diagnostic and robustness checks: Multicollinearity was assessed using Variance Inflation Factors (VIF), with all variables falling below the critical threshold of 10. Robustness checks comparing probit and logit specifications yielded qualitatively similar results.

RESULTS AND DISCUSSION

Descriptive statistics: Table 1 summarizes the findings obtained from descriptive statistics as well as the t-test and chi-square statistics on whether differences between adopters and non-adopters of ICT-based advisory services exist in terms of various characteristics among tomato growers in Kirinyaga County, Kenya.

From the results presented below, it can be inferred that the farmers sampled had relatively matured households, with average age of the household head being 54 years old. Nonetheless, age was statistically insignificant ($p=0.054$) in differentiating adopters from non-adopters. Household size was statistically insignificant ($p=0.441$), showing that the number of people within an adopted household was statistically similar to those in non-adopting households. On the other hand, tomato farming experience showed statistically significant difference between ICT adopters and non-adopters at the 1% significance level ($p=0.008$). This indicates that tomato farming experience plays a key role in determining whether farmers adopt or not. It can also be argued that the longer a tomato farmer stays within the farming industry, the better the farmer becomes familiar with



the production risks and uncertainties, thus the need to get timely and credible agricultural advice.

Tomato farm size also exhibits statistical significance at 5% ($p = 0.019$) while extension service contact is significant at 1% ($p = 0.002$). The findings imply that farm resource endowments affect ICT adoption decisions while regular contact with extension agents increases chances of adopting digital advisory services. The average ICT adoption intensity score among adopters was about four ICT-based functions or services. Therefore, moderate use of digital advisory services is witnessed among tomato farmers. The lower standard deviation indicates limited variance among the intensities.

The chi-square tests reveal some notable differences concerning the categorical variables. Specifically, the ICT adoption status is significant at the 5% level ($p = 0.048$). In other words, adoption decisions vary among sampled households. Membership in farmer groups was highly significant at the 1% level ($p = 0.001$), implying that social networks and collective participation are associated with greater ICT adoption. Similarly, access to agricultural credit was statistically significant at the 1% level ($p = 0.007$), suggesting that financially constrained households may face barriers in accessing ICT-enabled advisory services. Conversely, gender of the household head was statistically insignificant ($p = 0.591$), indicating no significant association between gender and ICT adoption in the study area.

Overall, the descriptive results suggest that institutional and resource-related factors, particularly farming experience, extension interaction, farmer group participation, and access to credit, are more important in differentiating ICT adopters from non-adopters than demographic characteristics such as age and household size.

Determinants of adoption of ICT-mediated extension services: This section presents a discussion on the socio-economic and institutional factors that influence the adoption of ICT-mediated extension services among smallholder tomato farmers in Kirinyaga County, based on marginal effects from a probit model. Only factors that are statistically

significant at 1% and 5% were discussed in this section. Experience in tomato farming has a positive and statistically significant influence on ICT adoption at a 1% level of significance. This implies that experienced farmers are more likely to adopt ICT-mediated extension services. Experienced farmers are more likely to recognize production risks, pest and disease threats and market volatility thereby valuing timely and targeted information delivered through ICT channels. This study corroborates with another study conducted in China where farmers with more experience in agricultural production were found to have stronger willingness and adoption of agricultural technologies (Zhao et al., 2024)

Extension contact frequency positively influences ICTs adoption at the 5% significance level, indicating that farmers with more frequent interactions with extension agents are more likely to use ICT-mediated advisory services. This result provides strong evidence of complementarity between conventional extension systems and digital platforms. Extension agents may act as important intermediaries by introducing farmers to ICT applications, demonstrating their use and advancing digital advisory content. Similarly, a study carried out in Zimbabwe aiming at unlocking the maize potential in the country assessed the drivers of ICTs among smallholders and established that extension contacts were significant drivers of ICTs adoption (Nyakudya et al., 2024). Access to agricultural credit is positive and statistically significant determinant of ICTs adoption at the 1% level. This underlines the role that financial capacity can play in facilitating ICT adoption. Access to credit is likely to alleviate any liquidity constraints that might arise when purchasing smartphones, maintaining mobile subscriptions and procuring data bundles that can facilitate ICT adoption. In addition to this, access to credit might also reflect better institutional integration and financial literacy, which are both beneficial for ICT adoption. In resource-constrained smallholder systems, even relatively inexpensive forms of technology can prove to be unaffordable without sufficient financial support.

Table 1. Descriptive statistics of smallholder tomato farmers.

Variable	Mean	Std. Dev.	Min.	Max.	T-test
Continuous variables					
Household head age (years)	54.27	7.23	24	78	0.054
Household size (number)	5.21	2.14	1	10	0.441
Tomato farming experience (years)	9.22	6.73	0	50	0.008***
Tomato land size (acres)	1.81	0.91	0	5	0.019**
Extension contact frequency	2.58	1.92	0	10	0.002***
ICTs adoption intensity (count index)	4.04	1.17			0.067
Categorical variables					
Gender (Male=1, 0 Female)	58.12%, 41.88%				0.591
ICT adoption (1=yes, 0=No)	43.64%, 56.36%				0.048**
Membership to groups (1=Member, 0=Non-member)	40.90%, 59.10%				0.001***
Access to credit (1=yes, 0=No)	49%, 51%				0.007***

Source: Field survey, 2025



A meta-analysis study in Ethiopia to evaluate the nexus between credit access and agricultural technology adoption found that access to credit is associated with agricultural technology adoption among smallholder farmers (Girma, 2022).

The perceived mobile usefulness is also a highly significant factor in ICT adoption at a 1% probability level. This underlines the role that perceived benefits can play in facilitating ICT adoption. Smallholder farmers who find mobile-based technologies to be useful are more likely to engage with ICT adoption. In rural agricultural systems, mobile phones might be the only viable ICTs interface that can facilitate access to information and real-time advisory services. This finding is consistent with the Technology Acceptance Model, which posits perceived usefulness as a primary driver of technology adoption (Salah & Ayyash, 2025).

Table 2. Determinants of ICT-Mediated agricultural extension adoption among smallholder tomato farmers.

Variable	Marginal effects	Std. Error
Household education	-0.0273	0.0334
Tomato farming experience	0.0391***	0.0650
Farmer group membership	0.0710**	0.0380
Extension contact frequency	0.0432**	0.1680
Land tenure	-0.0390	0.0314
Tomato land size (acres)	0.0557	0.0413
Gender of household head	0.0130	0.0110
Household size	0.0100	0.0090
Access to agricultural credit	0.2530***	0.1170
Mobile usefulness	0.0963***	0.0434
Internet usefulness	0.0141	0.0170
Distance to market	-0.0663	0.0748

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Source: Author field survey 2025.

Determinants of adoption intensity of icts-mediated extension services: ICT adoption intensity was measured as a count variable representing the number of ICT-based agricultural advisory functions utilized by a farmer. The variable captures the degree to which households integrate ICTs into their farming operations with higher values reflecting more frequent and diverse use of digital tools. Given the count nature of the dependent variable and the focus on adopters of ICTs technologies, a Poisson regression model with robust standard errors was employed to estimate the association between household and farm characteristics and ICTs adoption intensity. The model is appropriate because it accounts for the non-negative, distribution of intensity scores and adjusts for heteroskedasticity as confirmed by goodness-of-fit tests (Deviance and Pearson, $\text{Prob} > \chi^2 = 1.000$) in Table 3 indicating an excellent model fit.

The results indicate that household education is positively associated with ICTs adoption intensity ($\beta = 0.0398$, $p =$

0.048). This implies that farmers with higher levels of formal education are more likely use a greater number of ICT tools and services in their tomato production activities. Education would also be expected to improve farmers abilities to understand, access and use ICT resources which supports the findings in earlier literature on the importance of human capital in the use of technology in smallholder agriculture. Study by (Abdul-Wakeel Karakara & Osabuohien, 2022) found education to have a positive link with intensity of ICTs-mediated extension adoption in farming households in Ghana.

The frequency of contacts with extension services also shows a significant positive effect on ICTs intensity ($\beta = 0.0205$, $p = 0.028$), implying that farmers with higher frequency of contacts with extension services are more likely to engage with digital tools. Extension services are likely to provide farmers with access to ICT-enabled services, which can enhance farmers learning about mobile or internet-enabled technologies. This links their engagement with digital tools in agriculture. On the other hand, visits from extension was found to reduce the likelihood of intensifying the use of digital agricultural solutions (Miine et al., 2023).

Tomato farm size measured in terms of acres shows a negative relationship with ICTs adoption intensity ($\beta = -0.0746$, $p = 0.005$). This could imply that perhaps farmers with large farm sizes either engage in traditional farming practices that are labor-intensive or are limited in their capacity to effectively utilize ICTs. This could also imply that perhaps smaller farm sizes are easier to manage and therefore can accommodate intensive ICTs usage. This is in support of Ntsoane et al. (2025) study that sought to find out whether farm size negatively influences agriculture mediated ICTs among smallholder farmers in the Mpumalanga region in South Africa.

The relationship between access to agricultural credit and ICTs adoption intensity is positively related ($\beta = 0.397$, $p = 0.013$). This is because perhaps farmers with access to credit can afford smartphones and other ICTs-related inputs that can facilitate intensive ICTs usage in agriculture. This is because access to credit positively and significantly influences the number of ICTs-mediated extension among farmers in Ghana (Miine et al., 2023).

Table 3. Drivers of intensity of icts-mediated extension among smallholder tomato farmers.

Variable	Marginal effects	Std. Error
Household education	0.0398**	0.0201
Tomato farming experience	0.0034	0.0033
Farmer group membership	-0.0046	0.0052
Extension contact frequency	0.0205**	0.0093
Tomato land size (acres)	-0.0746***	0.0263
Mobile usefulness	0.0570	0.0284
Internet usefulness	-0.0098	0.0108
Access to credit	0.3970**	0.1590
Constant	1.3416***	0.1284



*** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. Prob $> \chi^2 = 1.000$

Source: Author field survey 2025

Conclusion: This study aimed to investigate socio-economic and institutional factors influencing the adoption and usage intensity of ICT-mediated agricultural extension services among smallholder tomato farmers in Kirinyaga County. The results revealed that farmer group membership, frequency of contacts with extension services, usefulness of mobile phones and access to credit were significant in influencing the decision to adopt ICTs. The results also revealed that level of education, access to credit and extension services were statistically significant in influencing the intensity of ICTs adoption. The study also revealed that smallholder tomato farmers with larger farm sizes have lower intensity in using ICTs. This indicates that farm management complexities may impede effective engagement in ICT-mediated services. The findings of this study reveal that ICTs adoption and usage are not just dependent on access to ICTs but also on human capital, extension services and access to finance. Since extension contact significantly increased both ICT adoption and intensity, County governments should integrate digital advisory delivery within existing extension systems through hybrid extension models combining physical and mobile-based support. Given the positive role of credit access, financial institutions and agricultural programs should expand affordable digital financing products targeting smallholder horticultural farmers. Because education significantly enhances ICT use intensity, farmer digital literacy programs should be prioritized to strengthen effective utilization rather than mere access to ICT tools.

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Ethical statement: The study adhered to established ethical research standards. Participation was voluntary and informed consent was obtained from all respondents prior to data collection. Respondents were assured of confidentiality and anonymity.

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Consent to participate: N/A

Informed consent: N/A

Consent for publication: N/A

SDGs addressed: Zero Hunger, Quality Education, Decent Work and Economic Growth, Industry Innovation and Infrastructure.

Policy referred: Digital Agriculture and ICT Policy; Agricultural Extension and Advisory Services Policy; Agricultural Credit and Financial Inclusion Policy; Smallholder Farmer Development Policy.

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