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Original Article

Duration Analysis of ISFM Technology Adoption Among Smallholder Green Gram Farmers in Kenya

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Abstract: *Despite the well-documented benefits of Integrated Soil Fertility Management (ISFM) technologies, adoption among green gram farmers in Tharaka Nithi County, Kenya, remains limited and delayed. This study addresses a critical gap by examining not only the incidence but also the timing of adoption for three key ISFM practices: improved seeds, intercropping, and agroforestry. Using a multistage sampling approach, data were collected from 330 smallholder farmers in Chiakariga and Igambang'ombe sub-counties through structured household surveys. The study employed Kaplan-Meier survival estimates and the Cox Proportional Hazards model to examine adoption timing. The Kaplan-Meier results indicate that most adoptions occur within the first ten years of awareness, followed by a plateau. The Cox model highlights variation in adoption speed across practices but consistently identifies green gram acreage, access to credit, education, and farming experience as significant determinants. The study concludes that timely ISFM adoption is shaped by access to affordable credit, exposure to extension and training services, and farmers' understanding of ISFM practices. Policy recommendations include expanding access to affordable, input-specific credit (e.g., for improved seeds, fertilizers, and tree seedlings), strengthening extension systems, and promoting targeted interventions for resource-constrained farmers. This methodological approach offers a basis for designing more adaptive and effective ISFM promotion strategies in semi-arid smallholder systems.*

Keywords: *Adoption, Cox Model, Duration, ISFM Technologies, Kaplan-Meier, Smallholder Farmers, Green Grams.*

I. INTRODUCTION

Smallholder agriculture remains central to sustainable development in low and middle-income countries, serving as a foundation for rural livelihoods, economic growth, and food security (FAO, 2020; World Bank, 2008). Smallholders produce a substantial share of the world's food and support the livelihoods of an estimated 2 billion people (Lowder et al., 2016). Recognizing its potential, global development agendas such as the Millennium Development Goals (MDGs) and Sustainable Development Goals (SDGs) have prioritized smallholder-led agricultural transformation as a pathway to poverty reduction.

But the sector still has problems with productivity, especially in sub-Saharan Africa. Smallholders have a hard time moving from subsistence to market-oriented production because they don't have easy access to inputs, their extension systems aren't very good, their soils are getting worse, and the climate is changing more often (AGRA, 2021). ISFM has been marketed as a resource-efficient way to improve soil health and crop yields in specific situations to deal with these problems. ISFM combines organic and inorganic inputs that are suited to the local conditions. It has been shown to improve productivity, profitability, and ecological sustainability (Vanlauwe et al., 2015; Belay et al., 2023).

In Kenya, green gram (*Vigna radiata*) holds growing importance within smallholder farming systems, especially in arid and semi-arid regions. As a legume, green gram enhances food and nutrition security, contributes to soil fertility through nitrogen fixation, and fits well within mixed cropping systems. Its relatively short growing cycle and drought tolerance make it a strategic crop under increasing climate pressures (Mugo et al., 2023). Eastern Kenya accounts for the majority of national green gram production, where farmers alternate between improved and local varieties and commonly integrate the crop in intercropping or rotational systems with cereals and other legumes. Despite increased interest and government support, yields remain far below potential due to declining soil fertility, low input use, and limited adoption of ISFM practices (KNBS, 2018).

While existing research has explored the drivers of ISFM adoption, most studies treat adoption as a static, binary decision. However, agricultural innovation is a dynamic process in which farmers make decisions over time, influenced by evolving awareness, resources, institutional interactions, and risk preferences (Batz et al., 2003). Understanding not just whether but when farmers adopt ISFM technologies is crucial, especially for time-sensitive interventions. Duration analysis offers a more nuanced lens by examining the timing of adoption events and the factors that accelerate or delay uptake (Marechera et al., 2019).

This study enhances the literature by employing a Cox Proportional Hazards model to examine the timing of Integrated Soil Fertility Management (ISFM) adoption between smallholder green gram farmers in Tharaka Nithi County, Kenya. It concentrates on three ISFM practices: enhanced seed utilization, intercropping, and agroforestry, analyzing the impact of household, farm, and institutional variables on the rate of their adoption. Green gram offers a particularly pertinent context owing to its ecological and economic significance, alongside the consistently low uptake of soil fertility technologies despite national prioritization. This study incorporates a temporal dimension into the adoption framework, yielding insights that can inform the formulation of more effective and targeted policies to facilitate sustainable intensification in resource-limited agricultural systems.

II. LITERATURE REVIEW

A) Overview of ISFM Technologies

Integrated soil fertility management (ISFM) technologies are very important for encouraging sustainable agriculture, especially in smallholder systems that do not have a lot of resources. ISFM combines organic and inorganic inputs, better germplasm, and agronomic practices that are specific to the area to make the soil more fertile, the crops more productive, and the land more sustainable in the long term (Vanlauwe & Zingore, 2011). These technologies deal with the many problems that African farming systems face, such as soil fertility loss, low input use, and climate change, by making better use of nutrients and improving soil structure. Consequently, ISFM embodies a comprehensive strategy customized to the ecological and socio-economic contexts of smallholder farmers (Vanlauwe et al., 2010; Kihara et al., 2016).

Empirical research has validated the advantages of ISFM technologies in augmenting crop yields, preserving soil health, and mitigating environmental degradation (Sanginga & Woomer, 2009; Tittonell et al., 2008). However, even with these benefits, smallholders still do not utilise them as extensively as they could, and when they do, it is often too late. It is essential to understand not only whether farmers use ISFM, but also when and why they do so, in order to develop effective extension strategies and support systems.

B) Duration Models in Technology Adoption

Duration (survival) analysis has become a useful econometric tool for figuring out when and in what order people adopt things. Binary adoption models, like probit or logit, only look at whether adoption happens. Duration models, on the other hand, examine the time it takes for adoption to occur and the factors that influence this timing. This methodology is particularly pertinent in agricultural systems, where adoption constitutes a process influenced by evolving household circumstances, institutional factors, and seasonal or climatic variations (Greene, 2003; Feder et al., 1985).

Gao et al. (2019) utilized duration models to analyze the implementation of green technological controls in the Huang-Huai-Hai Plain, China. Their findings indicated that elevated educational attainment, diminished risk aversion, and robust extension support substantially expedited the adoption process. Beyene and Kassie (2015) employed duration analysis to examine the adoption of enhanced maize varieties in Tanzania, pinpointing social networks and governmental interventions as significant catalysts.

Despite these advances, significant gaps persist in the literature. First, most studies do not disaggregate technologies, treating adoption as a singular event. In reality, different ISFM technologies may be adopted at different times based on perceived benefits, resource requirements, and institutional support. Second, few studies analyze adoption patterns over extended periods to determine whether adoption peaked early, slowed, or ceased entirely. These omissions obscure critical temporal dynamics that could inform the design of more effective extension strategies.

C) Contribution of this Study

This study addresses the aforementioned gaps by applying both non-parametric (Kaplan-Meier) and parametric (Cox Proportional Hazards) duration models to examine the *speed and determinants* of ISFM technology adoption among green gram farmers in Tharaka Nithi County, Kenya. Specifically, it investigates the timing of adoption for three core ISFM practices: improved seeds, intercropping, and agroforestry.

By disaggregating the technologies and considering diverse socio-economic, demographic, and institutional variables, the study captures the nuanced dynamics of technology uptake. This enables a better understanding of who adopts, how quickly they do so, and why. The analysis also highlights the importance of critical enablers such as land access, education, gender, and credit availability, providing a richer foundation for targeted agricultural interventions in semi-arid, smallholder contexts.

III. RESEARCH METHODOLOGY

A) Study Area and Sampling Design

This study took place in Tharaka Nithi County, which is on the eastern slopes of Mount Kenya in eastern Kenya (0°17′60.00″N, 38°00′0.00″E). The county has a population of 393,177, comprising six sub-counties and 15 administrative wards (KNBS, 2019). The research concentrated on the Chiakariga and Igambang'ombe sub-counties, deliberately chosen for their vigorous promotion and adoption of ISFM technologies (Mucheru-Muna et al., 2014). These areas are part of Kenya's arid and semi-arid lands (ASALs) and show how difficult it is to grow crops in places with little rain.

A cross-sectional research design incorporating a retrospective recall element was utilized to obtain both contemporary and historical data regarding the adoption of ISFM technology. A multi-stage sampling procedure guaranteed approximate coverage of small-scale farmers: The first step was to choose Chiakariga and Igambang'ombe on purpose because they have a lot of smallholder mixed farming systems, especially cereal-legume cropping (like green grams, sorghum, and cowpeas) along with raising livestock (like goats, cattle, and poultry) (KIPPRA, 2024; Jaetzold et al., 2007). The second step was to choose one ward from each sub-county based on the presence of ISFM-related programs and the advice of agricultural officers. In the third stage, two sub-locations were randomly chosen per ward, followed by the random selection of two villages per sub-location.

B) Theoretical Framework

a. Duration Model

The study is anchored in the Theory of Random Utility Maximization (RUM), which posits that a farmer will adopt a new agricultural technology if the expected utility from adoption exceeds that of non-adoption (Feder et al., 1985; Greene, 2003). In this context, adoption is not only a binary outcome but also a process shaped by the timing of decision-making. While the binary adoption decision reflects whether or not adoption occurs, the duration model extends this framework by examining *when* adoption takes place. Ignoring the temporal dimension risks overlooking structural and behavioural factors that shape adoption pathways.

Let U_1 denote the utility derived from adopting ISFM, and U_0 the utility from continuing with conventional practices. The adoption condition is formalized as:

$$\boldsymbol{U_1 > U_0} \qquad \text{........ (1)}$$

However, since utility is not directly observable, it is modeled as a function of observable characteristics, for example; farm size, education, input access, and unobservable elements, such as preferences or risk attitudes captured in a random error term. This framework acknowledges that the probability of adoption is influenced by both measurable household and farm attributes as well as unobserved heterogeneity (Greene, 2003; Feder et al., 1985).

To empirically analyze the timing of adoption, this study employs duration (survival) analysis, which models the time until an event, in this case, adoption, occurs. This approach is particularly suitable for analyzing data that includes right-censored observations, i.e., households that had not adopted ISFM by the time of the survey.

We begin with non-parametric methods using the Kaplan-Meier estimator, which describes the probability of non-adoption over time. This is represented by the survival function, $S(t)$, which indicates the probability that a household has not adopted by time t. To complement this, the hazard function, $h(t)$, estimates the conditional probability of adoption at time t, given that the household has not adopted up to that point. Formally:

$$\boldsymbol{S_t = P_r(T \geq t) = 1 - F(t)} \qquad \text{........(2)}$$

$$\boldsymbol{h(t) = \frac{f(t)}{S(t)}} \qquad \text{....................(3)}$$

Where, T, is the duration until adoption, $f(t)$ the probability density function, and $F(t)$ the cumulative distribution function. This modeling framework allows for a dynamic understanding of ISFM technology uptake behaviour, incorporating both static characteristics and time-varying influences.

Recent empirical applications demonstrate the efficacy of this approach. Mazungwi et al. (2024) utilized Kaplan-Meier and hazard models to examine the adoption of fruit tree-based agroforestry technologies in Malawi, whereas Beyene and Kassie (2015) employed analogous methodologies to assess the rapidity of improved maize range adoption in Tanzania.

To conduct a more nuanced analysis, we enhance the framework by incorporating parametric duration models, including the Cox Proportional Hazards model and Accelerated Failure Time (AFT) models, as well as the Weibull and Log-logistic models. These models assess the influence of covariates, such as extension access, credit availability, or soil characteristics, on the timing of ISFM adoption, while accommodating adaptable assumptions concerning the baseline hazard (Abdulai & Huffman, 2005; Beegle et al., 2012).

This dual approach, encompassing both non-parametric and parametric methods, establishes an effective analytical structure that elucidates the intricacies of adoption processes, especially in semi-arid, resource-limited settings like Tharaka Nithi County.

IV. RESULTS AND DISCUSSIONS

A) Empirical Variables

Duration analysis, on the other hand, looks at when adoption happens, which is called the adoption spell. Discrete choice models only look at binary adoption decisions. The duration spell is the number of years between when a farmer could use ISFM technologies and when they first used them. The beginning of this spell is based on either (a) the year in which the technology was first used in the area or (b) the year the household started taking care of its own farm work, whichever came last.

The selection of explanatory variables for the duration model was informed by established theoretical frameworks, previous empirical studies, and the contextual characteristics of ISFM technologies. These variables are expected to influence the speed of adoption through their impact on farmers' resource endowments, access to information, risk attitudes, and managerial capacity. '

Table 1 presents the variables included in the model, their coding, types, and units of measurement.

Table 1: Description of variables used in econometric models

Variable	Code	Type	Measurement
Mean age of household head	AGE	Continuous	Years
Gender of household head	GENDER	Dummy	Female = 1, male = 0
Years in school	YSCH	Number	Number of years in school
Farm size	FRMSIZ	Continuous	Ha
Years of farming experience	YREXP	Continuous	Years
Land ownership	LANDOWN	Dummy	Yes = 1, No = 0
Acres under green gram cultivation	ACRES	Number	Number in Acres
Occupation of the household head	OCCUPTN	Dummy	Yes = 1, No = 0
Household income	INCOM	Continuous	Kshs
Livestock ownership	LVSCK	Dummy	Yes = 1, No = 0
Source of information on ISFM	SRCEINFO	Continuous	Number of distinct information sources
Access to credit	ACCCREDT	Dummy	Yes = 1, No = 0
Training on ISFM	TRNNG	Dummy	Yes = 1, No = 0
Farmer association	FMASSN	Dummy	Yes = 1, No = 0
Accessibility of ISFM	ACCESS	Dummy	Yes = Easily accessible No = Otherwise
Soil fertility perceptions	SFERTILITY	Dummy	1, if it is highly fertile, 0, if otherwise

Age of Household Head: It is believed that age affects adoption by changing how people feel about risk and how easy it is for them to get resources. Older farmers may have more experience and connections, but younger farmers are often more open to new ideas and technologies because they have greater planning horizons and better access to information (Odendo et al., 2011).

Gender of Household Head: Gender roles in agricultural decision-making influence access to land, credit, and services for extension. Female-headed households frequently encounter systemic obstacles that hinder adoption; however, certain studies indicate that when women are empowered, they embrace sustainable practices at elevated rates (Ndiritu et al., 2014).

Years in School: Education improves cognitive capacity and the ability to retrieve, analyze, and implement information regarding ISFM practices. Consequently, more educated farmers are anticipated to embrace technologies more swiftly (Wossen et al., 2017; Khonje et al., 2015).

Farm Size: Larger estates allow for the testing of new technologies and lessen the risks that come with trial and error. Research indicates a positive correlation between farm size and the early adoption of sustainable practices (Kassie et al., 2011; Ragasa et al., 2018).

Years of Farming Experience: Having experience in farming may help people adopt new practices because they have learned a lot and feel confident judging them. But in some situations, farmers who have been doing it for a long time may be more conservative and less likely to change the way things are done (Odendo et al., 2011).

Land Ownership: Secure land tenure gives people the peace of mind they need to make permanent investments in ISFM technologies like composting or agroforestry. Tenure security has consistently correlated with elevated adoption rates (Kiptot & Franzel, 2011).

Green Gram Acreage: A larger area of land used to grow green gram may mean that farmers are more focused on the market and have more specialized skills, both of which can encourage them to adopt technologies that improve productivity early on.

Off-Farm Occupation: Households with off-farm income may adopt ISFM technologies more quickly because they have fewer money problems. But not being on the farm very often might also make it less important to adopt (Khonje et al., 2015).

Household Income: A higher household income allows for more investment in ISFM-related inputs, equipment, and training, which could speed up adoption (Ragasa et al., 2018).

Livestock Ownership: Owning the livestock can help you build wealth and make it easier to do things like apply manure (Nganga et al., 2020). Integrated farming systems may make it easier for households with livestock to adopt.

Sources of ISFM Information: Having more than one source of information makes things less confusing and makes people more likely to trust technology. The variety of sources increases awareness and knowledge, which makes it easier to adopt (Mekonnen et al., 2021).

Access to Credit: Getting credit makes it easier to get ISFM inputs on time by easing liquidity problems. A lot of people agree that it is a key factor in adoption (Wossen et al., 2017).

Training in ISFM Received: Training enhances technical proficiency and self-assurance, thereby diminishing the perceived risks associated with adoption. It frequently functions as a prerequisite for the adoption of intricate or knowledge-intensive practices (Mekonnen et al., 2021).

Joining a Farmer Association: Being part of a group helps people learn from each other and gives them access to shared resources like marketing channels and buying inputs. It also makes it easier to see demonstrations and get training (Kiptot & Franzel, 2011).

Accessibility of ISFM Technologies: Making it easy to get to ISFM tools and inputs lowers transaction costs and delays in logistics, which speeds up adoption.

Soil Fertility Perception: The perceived soil fertility affects how much people think they need to intervene. Farmers who think their soils are already fertile may not be as eager to use ISFM, whereas those who see soil degradation may act more quickly (Ndiritu et al., 2014).

B) Descriptive Statistics of Explanatory Variables

Table 2 shows the most important social and economic traits of the 330 green gram farming households that were sampled in Tharaka Nithi County. These variables are not only essential for comprehending the context of green gram production but also serve as potential determinants for the adoption of ISFM technologies by farmers, including enhanced seeds, intercropping, and agroforestry.

The results show that 31.8% of household heads are men, but 61.8% of respondents are women. This means that women are likely to be the ones making most of the decisions about farming on a daily basis. This has significant ramifications for gender-sensitive extension strategies, especially in customizing ISFM training and communication for female farmers, who may be the actual executors despite male-headed households.

Farming is the principal livelihood for 88.2% of household heads, underscoring the area's heavy reliance on agriculture. This high dependence may increase responsiveness to soil fertility innovations, particularly if these improvements enhance productivity. However, the low rates of off-farm employment (7.5% combined) reflect limited income diversification, potentially constraining the financial flexibility needed to adopt new technologies in a timely manner.

Secure land tenure is evident, with 75.5% owning land with title deeds. Tenure security is an important factor in ISFM adoption because it motivates people to invest in long-term practices like agroforestry. The fact that so many people own livestock (94.5%) also indicates integrated farming systems. These systems can support ISFM practices such as manure use and fodder trees, potentially accelerating adoption for farmers who already manage diverse systems.

Extension access remains a key barrier: only 37.3% of households reported receiving any agricultural training. This suggests a significant gap in knowledge transfer that could delay awareness and uptake of ISFM technologies. Strengthening extension services, particularly participatory or peer-to-peer models, could hasten adoption by improving farmer exposure.

Perceptions of soil fertility were mixed: while 86.4% described their soils as highly fertile, 83% also classified them as lowly fertile, suggesting confusion or plot-level variation. Such perceptions can influence technology adoption decisions, especially when ISFM is viewed as unnecessary on "fertile" plots. Promoting soil testing and farmer education can help align perceptions with actual soil health, leading to more targeted adoption behaviour.

Lastly, access to credit is critically low, with only 6.4% of households reporting successful credit acquisition. Given that ISFM practices, especially improved seeds and agroforestry, require upfront investment, the lack of access to credit may delay or deter adoption. This finding highlights the need for inclusive rural finance schemes and bundled input-credit-extension programs.

Table 2: Descriptive Statistics Used In Analysis For Sample Households (n=330)

Variable	Category	Frequency	Percentage (%)
Gender of Household Head	Female	10	3.0
	Male	105	31.8
Gender of Respondent	Female	204	61.8
	Male	126	38.2
Occupation of HHH	Employed (Private)	11	3.3
	Employed (Public)	14	4.2
	Farming	291	88.2
	Self-employed	14	4.2
Land Ownership	With Title Deed	249	75.5
	Without Title Deed	81	24.5
Livestock Ownership	Yes	312	94.5
	No	18	5.5
Training (any agricultural)	Yes	135	37.3
	No	227	62.7
Soil Fertility Perception	Lowly Fertile	274	83.0
	Moderately Fertile	219	66.4
	Highly Fertile	285	86.4
Access to Credit	Yes	21	6.4
	No	309	93.6

C) Duration Model of the Timing of ISFM Adoption

While the Probit Model reveals which factors influence the decision to adopt ISFM, it does not explain when this adoption occurs. To explore the timing and speed of uptake among adopters, the next section applies duration analysis, utilizing both non-parametric (Kaplan-Meier) and parametric (Cox Proportional Hazards) methods.

a. Results of non-parametric Duration Analysis

Figures 1, 2, and 3 present the Kaplan-Meier survival estimates for the adoption of improved seeds, intercropping, and agroforestry, respectively. The survival curves illustrate the proportion of households that had not yet adopted each ISFM technology over time, with each step in the curve representing the occurrence of an adoption event. For all three technologies, the survival functions exhibit a steep decline in the initial years, indicating rapid early adoption among households. Specifically, the curve for improved seeds shows a sharp drop between 0 and 10 years, while the survival functions for intercropping and agroforestry decline rapidly within the first year. These patterns suggest that a significant proportion of households adopted the respective technologies soon after they were introduced, reflecting strong initial uptake likely driven by awareness campaigns, extension efforts, or perceived benefits.

Following this early surge, the rate of adoption slows down. For improved seeds, the survival function continues to decline gradually between years 10 and 40. For intercropping and agroforestry, the decline occurs between years 1 and 4. These slower rates of decline imply that while adoption continued, it did so at a more moderate pace, potentially due to heterogeneity in resource access, risk preferences, or levels of exposure to the technologies.

The flat segments of the survival curves indicate periods where no new adoptions occurred, suggesting phases of stagnation or consolidation in technology diffusion. By the end of the observation period, year 40 for improved seeds and year 4 for intercropping and agroforestry the survival functions approach zero. This implies that nearly all households in the sample had adopted the respective ISFM technologies by these points in time. Overall, the Kaplan-Meier curves highlight typical adoption dynamics: rapid early uptake followed by slower, incremental adoption.

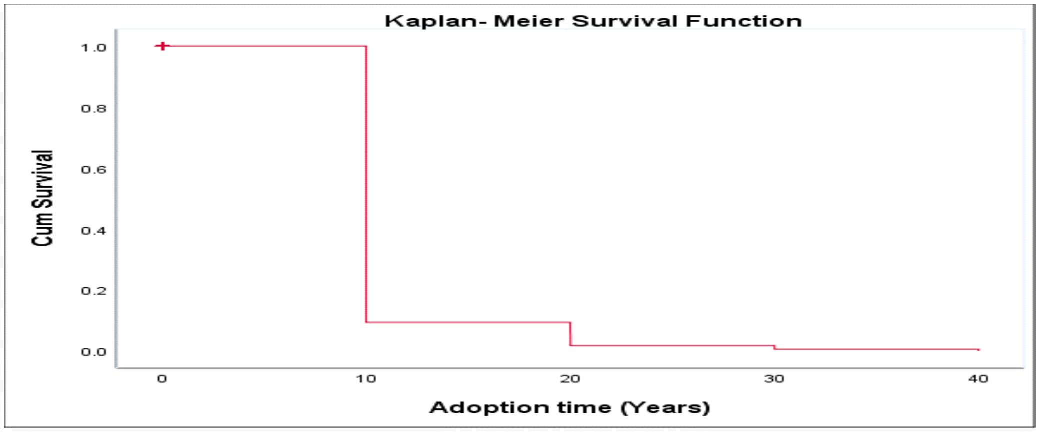

Figure 1: Improved seeds

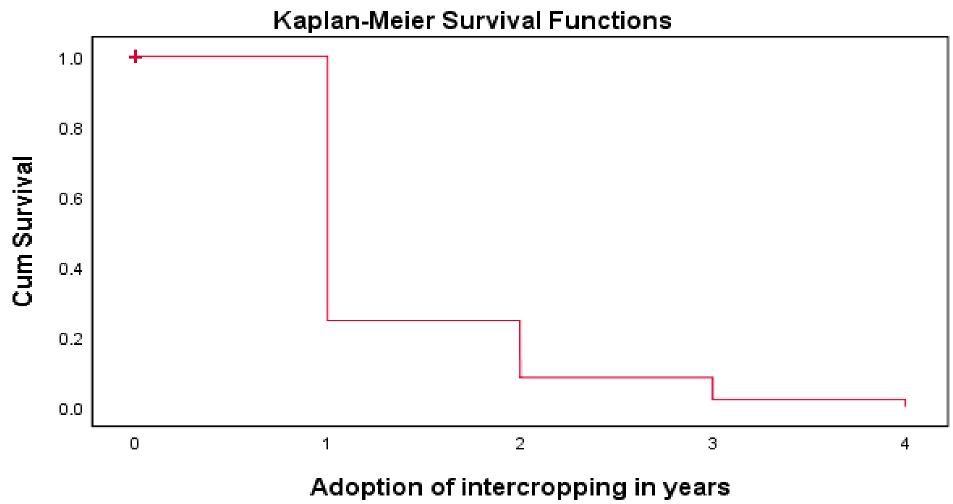

Figure 2: Intercropping

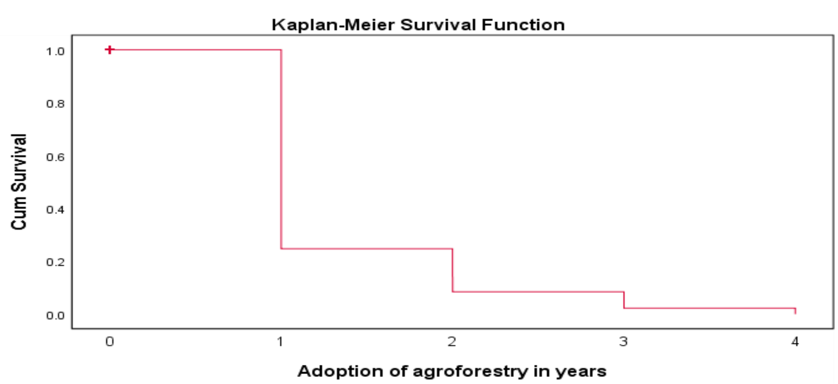

Figure 3: Agroforestry

b. Results of Parametric Duration Analysis

The Cox Proportional Hazards model identified several key factors influencing the timing of adoption of ISFM technologies, namely improved seeds, intercropping, and agroforestry among smallholder green gram farmers. The results highlight both socio-demographic and farm-specific variables that shape adoption behaviour across the three technologies.

The year of birth of the household head (HHH) had a statistically significant positive effect on the hazard of adopting improved seeds (HR = 1.115). This suggests that younger household heads are approximately 11.5% more likely to adopt improved seeds than older ones. Younger farmers may be more open to innovation, less risk-averse, and more likely to access or trust new information channels such as extension services and digital platforms. However, this finding contradicts Gao et al. (2019), who observed higher adoption rates among older farmers, attributing it to their farming experience and resource endowments. The divergence in findings may be due to regional differences in exposure to extension programs or generational attitudes toward the adoption of technology.

Total land size was another influential factor (HR = 2.787), indicating that households with larger landholdings were 178.7% more likely to adopt improved seeds. Larger farms afford greater flexibility to experiment with new technologies and absorb potential risks associated with adoption. This finding is consistent with studies by Kassie et al. (2011) and Teklewold et al. (2013), which underscore landholding size as a key enabler of agricultural innovation.

Access to credit also played a significant role (HR = 1.023). While the effect size is modest, even slight improvements in access to credit appear to enhance the likelihood of adoption, likely by reducing financial barriers to purchasing certified seeds. Similarly, the number of acres under green gram farming showed a positive effect (HR = 1.191), suggesting that households that invest more in green gram production are 19.1% more likely to adopt improved seeds, potentially due to a greater orientation toward commercial farming and yield optimization.

The gender of the household head had a strong positive association with intercropping adoption (HR = 1.832), with female-headed households being 83.2% more likely to adopt this practice compared to male-headed ones. This finding suggests that female farmers may be more inclined to maximize land productivity and food security through crop diversification. It contrasts with the often-reported barriers faced by women in accessing productive resources, but aligns with findings by Ndiritu et al. (2014), who argued that when women are empowered, they adopt sustainable practices at higher rates.

Education (years in school) also contributed positively (HR = 1.022), indicating that better-educated farmers are more likely to adopt intercropping. Education likely enhances the ability to understand and implement knowledge-intensive practices like crop diversification, a conclusion supported by Abdulai and Huffman (2005). Furthermore, farming as the major occupation of the household head had a small but meaningful effect (HR = 1.028), suggesting that those engaged full-time in agriculture are more likely to explore intercropping as a strategy to improve land use efficiency and income.

Acres under green gram cultivation again showed a strong influence (HR = 1.743), pointing to a pattern where more commercially-oriented or specialized farmers are more open to adopting complementary practices such as intercropping. Access to credit (HR = 1.138) and training on soil fertility (HR = 1.074) were also important, reinforcing the notion that both financial capacity and knowledge enhancement are critical drivers of sustainable technology uptake.

For the adoption of agroforestry, several predictors were statistically significant. Male-headed households were more likely to adopt agroforestry than female-headed ones (HR = 1.087). This outcome may be linked to gendered disparities in land tenure and access to extension services, which often limit women’s ability to engage in long-term land-based investments such as agroforestry. This aligns with Odendo et al. (2011) but stands in contrast to some localized studies suggesting greater female responsiveness when programs specifically target them.

Education again emerged as a key factor (HR = 1.077), with each additional year of schooling increasing the likelihood of adoption by 7.7%. Educated farmers may be better equipped to understand the long-term environmental and economic benefits of tree-based systems. This finding is consistent with Yigezu et al. (2018), who highlight education as a catalyst for adopting resource-conserving technologies.

The household head’s occupation in farming also showed a positive effect (HR = 1.060), indicating that full-time farmers are more likely to invest in agroforestry. Most notably, acres under green gram farming had a very strong influence (HR = 2.659), suggesting that farmers who are more engaged in green gram production are 165.9% more likely to adopt agroforestry, perhaps due to a higher level of market integration and environmental awareness. Finally, access to credit had a substantial positive effect (HR = 1.534), underscoring the importance of liquidity in supporting long-term investments such as tree planting, a finding consistent with Kiptot and Franzel (2011).

Table 4: Results of Parametric Duration Analysis

ISFM Technologies	Improved Seeds		Intercropping		Agroforestry	
Variables	**Coeff**	**Hazard Ratio**	**Coeff**	**Hazard Ratio**	**Coeff**	**Hazard Ratio**
Year of birth of household head	0.109	**1.115**	-0.503	0.605	-0.072	0.930
Gender of household head	-0.160	0.852	0.605	**1.832**	0.084	**1.087**
Years in school	-0.027	0.973	0.022	**1.022**	0.074	**1.077**
Total land size	**1.025**	**2.787**	-1.320	0.267	0.096	**1.101**
Land ownership (Title deed)	-0.067	0.935	-0.139	0.870	-0.057	0.945
Farming experience (years)	-0.085	0.918	-0.430	0.650	-0.380	0.684
Acres under green gram	0.175	**1.191**	0.556	**1.743**	0.978	**2.659**
Access to credit	0.023	**1.023**	0.129	**1.138**	0.428	**1.534**
Training on soil fertility farming	-0.040	0.961	-0.040	0.961	-0.017	0.983
Farmer membership to agri. group	-0.085	0.919	-0.156	0.856	-0.118	0.889
Major occupation of household head	-0.015	0.985	0.028	**1.028**	0.058	**1.060**
Training on general agri. production	-0.025	0.975	-0.040	0.961	-0.060	0.941
Household size	-0.237	0.789	-0.537	0.585	-0.765	0.465
Livestock ownership	-0.062	0.940	-0.236	0.790	-0.141	0.869
Number of subjects	170		196		178	
-2log likelihood	1653.300		1822.231		1656.671	
Chi-square	5.008		35.405		22.198	

V. CONCLUSION AND POLICY RECOMMENDATION

This study contributes to a growing body of literature on agricultural technology adoption by unpacking the temporal dynamics of ISFM uptake among smallholder green gram farmers in Tharaka Nithi County. By applying a Cox Proportional Hazards model, the analysis moves beyond the binary framing of adoption to reveal how demographic, economic, and institutional factors shape when, not just whether, farmers adopt specific ISFM practices. The differential timing across technologies, with younger farmers adopting improved seeds sooner, and female-headed households more inclined toward intercropping, reflects not only access and awareness but also risk perceptions, gendered labour dynamics, and crop management strategies tailored to green gram systems.

Importantly, the finding that education and credit access consistently accelerate adoption across technologies underscores the need for interventions that enable informed and timely decision-making, rather than simply encouraging uptake. Similarly, the inverse relationship between household size or farming experience and adoption speed suggests that established routines and perceived risks may delay innovation, even among resource-endowed farmers. These insights challenge the assumption that resource availability alone drives adoption and point to the importance of behaviourally-informed extension strategies.

From a policy standpoint, this research underscores the importance of aligning ISFM promotion with farmers' decision-making timelines. Credit schemes must be not only accessible but also timed to match the agricultural calendar, while extension messages should differentiate between early adopters and those requiring sustained engagement. Gender-sensitive programming must move beyond inclusion to address structural barriers that shape adoption timing, particularly for land- and labour-intensive practices like agroforestry. Furthermore, embedding ISFM within the green gram value chain upgrades, including input systems, market linkages, and post-harvest support, can make adoption both more viable and more attractive.

VI. SCOPE FOR FUTURE RESEARCH

Future research should explore the evolving role of social networks, digital tools, and behavioural nudges in influencing adoption timing. Longitudinal studies tracking adoption trajectories and their impacts on productivity and resilience will be essential for designing adaptive, farmer-centric interventions. As agricultural systems face increasing climate and market pressures, understanding the tempo of technological change that is adopted, how fast, and why will be just as important as the technologies themselves.

VII. REFERENCES

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