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Determinants of adoption and adoption intensity of integrated soil fertility management technologies among sorghum farmers in Upper Eastern Kenya

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Abstract
Climate change manifestations and population pressure are some of the most critical challenges that affect agricultural productivity. Integrated soil fertility management (ISFM) technologies are among the agricultural innovations that have been developed to address declining crop productivity. These technologies have been promoted across diverse areas including marginal agro-ecological zones. Despite the nobility and versatility of ISFM technologies, their adoption is still low particularly across Kenya landscapes. Consequently, there is limited knowledge explaining the adoption of these technologies especially in the dry areas. This study therefore, applied Cragg's Double Hurdle model to determine the factors affecting adoption and adoption intensity of ISFM technologies among farmers in Upper Eastern Kenya, who mainly grow sorghum both as a food and a cash crop. The results revealed that gender, dependants, farming goal for subsistence purpose ($p < .01$), decision on information use, farm size, extension services, research awareness, ISFM awareness and ISFM access, significantly affected household decision on adoption of ISFM technologies. On the other hand, gender of household head, farm size, main source of agricultural information and formal agricultural training had significant influence on adoption intensity of ISFM technologies. There is a thus a crucial need for integration of determinants surrounding adoption and adoption intensity of ISFM technologies in policy making and planning processes to enhance sorghum crop productivity in marginal Upper Eastern areas of the country.

KEYWORDS
adoption, adoption intensity, ISFM, productivity and technology, sorghum

1 | INTRODUCTION

Agriculture is one of the key sectors that plays an important role in economic growth and development of most economies worldwide (Khan et al., 2020). About 80% of the total population depend on the sector for survival and it contributes up to 25% on gross domestic product (GDP) globally (WorldBank, 2021). Despite its economic significance, the sector faces a number of drawbacks on resource utilization because of population pressure and climate change (Ghosh, 2019; Njenga, Mugwe, Mogaka, et al., 2021; Njenga, Mugwe, Nyabuga, et al., 2021).

Because of increased land use to meet needs like settlement, industrialization and infrastructural growth, an increase in population affects the amount of arable land used for food production (Coulibaly & Li, 2020). On the other hand, climate change impacts on the sustainability of food systems threatens the state of food and nutrition security across the globe (Yazar & Ali, 2017). The stress of growing population which is largely disenfranchised and climate variation is more pronounced in sub-Saharan Africa (SSA) and especially in the dry areas (Mugwe & Otieno, 2021; Ndeke et al., 2021). Vulnerability to climate change variation in SSA has worsened because of high dependence on agriculture, high-poverty levels, inadequate and poor infrastructure, poor implementation of existing policies and limited access to improved agricultural inputs (Phiiri et al., 2016). This creates a hindrance to food production that is expected to feed SSA population which is projected to hit 2.7 billion by 2060 (Barbier & Hochard, 2018; Mugwe et al., 2020; Mugwe & Otieno, 2021).

Kenyan population is expected to rise to 95 million by 2050 thus prompting high demand for food (Waaswa et al., 2022). However, there are a number of factors that make it difficult to meet this demand, such include land degradation, high levels of farming inefficiency, climate shocks that manifest as severe floods which have a negative impact on agricultural productivity (Chepng'etich et al., 2014; Chimai, 2011; Marie et al., 2020; Wollie, 2018). Declining productivity has been exacerbated by rapidly declining soil fertility which is directly linked to severe nutrient mining without sufficient replenishment through quality external inputs (Souri et al., 2019; Tekulu et al., 2020). Similarly, heavy reliance on inorganic fertilizers contributes to unfavourable soil health lowering the realization of full potential of the land among the smallholder farmers (Stewart et al., 2020).

The use of ISFM is one of the currently considered intervention measure that is effective in mitigating soil productivity problems (Adolwa et al., 2012; Hörner & Wollni, 2021; Nkonya & Mirzabaev, 2016). Because of its novelty, ISFM's multifaceted contribution to improved crop yield has sparked widespread government promotion in Kenya, alongside farmers' engagement and assistance from foreign development partners (Adolwa et al., 2019). The combined ISFM technologies focus on the application of diverse options of inputs and practices of soil conservation that a farmer can choose from to address soil fertility issues common in marginal areas. Vanlauwe et al. (2010) defined ISFM as the soil fertility management approach that combines the use of mineral fertilizer, organic components, improved crop varieties and knowledge on how to adapt such technologies. Relatively, combined practices and inputs recommended should at least comprise of mineral fertilizer, improved seeds, herbicides, no-tillage, crop residues, mulching, cover crops, intercropping and crop rotation including knowledge on farm management (Kwadzo & Quayson, 2021). The practices of ISFM package reflects the best use of inherent soil nutrients which is intricately linked to trifold benefit of improved soil fertility, increased crop yields and improved household incomes (Agegnehu & Amede, 2017).

The dry regions of Upper Eastern Kenya have appreciated the application of ISFM in enhancing household crop productivity (Kimaru, 2017). This is evident through projects that have been launched in these areas in partnership with development partners latest being Kenya Climate Smart Agriculture Project (KCSAP) (Aila et al., 2021). However, investment in these technologies for the production of crops such as sorghum has not been able to yield its full potential because the registered crop yield still remains low (Chimoita et al., 2019). Productivity of grain has remained below 1 ton/ha as compared to the potential of 2.5 tons/ha (Mwangi et al., 2020).

Previous studies have asserted that ISFM technologies have great potential to improve agricultural productivity especially in arid and semi-arid areas but their adoption is still low (Kalele et al., 2021; Mutua-Mutuku et al., 2017; Sommer et al., 2018). Stagnating adoption levels have been attributed to limited resources within the farming households (Adimassu & Abera, 2017; Mponela et al., 2016; Wawire et al., 2021). Others indicate that household use of a technology is influenced by both biophysical attributes and the variation of farmer characteristics which generate diverse farming patterns (Kanyamuka et al., 2020). The adoption of soil fertility improving technologies is further constrained by high fragmentation of land that limits the potential of farming households to apply the techniques in the required proportion (Lindizgani & Chinangwa, 2006; Mponela et al., 2016). There is thus a need to address the persistent challenge of low adoption if the potential yield of crops such as sorghum is to be realized.

It has been observed that there is limited evidence on factors hindering the efficacy of the ISFM technologies on crops such as sorghum in dry zones of Kenya. Extant studies have focused on the use and economic contribution of improved sorghum varieties (Mucioki et al., 2016; Mwangi et al., 2020). Pertaining ISFM, studies have concentrated on the study of selected set of technologies that fails to give a full picture on the level of adoption and the intensity of such adoption (Njenga, Mugwe, Mogaka, et al., 2021; Njenga, Mugwe, Nyabuga, et al., 2021; Okeyo et al., 2014; Wawire et al., 2021). Additionally, studies on the uptake of the technologies were done on the adoption level of the few selected ISFM technologies while a few have focused on its adoption intensity (Mairura et al., 2022; Mwaura, Kiboi, Mugwe, et al., 2021; Ndeke et al., 2021; Otieno, Kiboi, et al., 2021; Otieno, Kipchirchir, et al., 2021). The factors influencing double approach of adoption and adoption intensity on all the available set of ISFM technologies under sorghum is hardly given due regard as a front for improving crop productivity using these appropriately combined technologies. The study therefore, seeks to determine the extent to which the selected factors affect adoption and adoption intensity of ISFM technologies among sorghum farmers in dry zones of Upper Eastern Kenya.

2 | MATERIALS AND METHODS

2.1 | Study area

The study was conducted in Tharaka-Nithi county located in eastern parts of Kenya. The region has a typical annual temperature range of 22–36°C with an annual rainfall of 200–800 mm. The area lies at an altitude of 250 and 1500 m above seas level (MoALF, 2017). It has a population of 393,177 with overly weathered and low fertile ferrasols as the dominant soils (KNBS, 2019; Mugi-Ngenga et al., 2016). The main economic activity of the area is agriculture consisting of both crop and livestock production (KFSSG & CSG, 2021).

2.2 | Study design and data collection

The data used was obtained from a survey conducted in March 2022 in Tharaka-Nithi county. A multistage sampling technique was applied in selecting the respondents. The first stage involved a purposive selection of eastern Kenyan region where use of ISFM technologies has been promoted. The second stage involved a purposive selection of sorghum farmers in Tharak-Nithi county, because sorghum is widely planted and best suited to the ecological conditions of the area. The third stage was also a purposive selection of sorghum farming zones in Igamba-Ngombe sub-county. The next stage was a random sampling of sorghum farming households in two Wards of Maara and Igamba-Ngombe. The total sample size used in the study was 370, proportionately comprising of 123 farmers in Maara and 247 farmers in Igamba-Ngombe Wards. The questionnaire applied sought to capture selected factors that included socioeconomic, technological, institutional and cultural attributes which ultimately yielded beneficial data used in the study. The descriptive and empirical results were analysed using SPSS version 25 and Stata version 13.

2.3 | Empirical framework

Enhanced productivity in agriculture requires transition in technologies applied in any production enterprise (Gebru et al., 2021). In the sector, this change is simply a transformation from the use of traditional to modern agricultural practices. Prior to the introduction of such technologies, sorghum farmers only used conventional farming practices. New agricultural technology has opened up a wide range of farming options. Several countries are now paying attention to these technologies as they work to combat acute food insecurity, catastrophic climate change variability and rising poverty rates. The ISFM technologies have been promoted especially in dry areas in order to manage soil fertility issues for better yields and productive soils (Hörner & Wollni, 2022). However, the application of these technologies normally faces dichotomous decisions, for instance, a choice to either adopt or not. This study assumed that a farmer will adopt ISFM technologies based on the expected benefits. A farmer normally adopts technologies that yield optimum outputs. Nevertheless, there are two outcomes that are presented in technology adoption (Yigezu et al., 2018). The first outcome involves dedicating technologies for enhanced sorghum productivity and adoption intensity that is represented by the size of land cultivated under ISFM technologies. Secondly, the decision of the farmer is affected by several factors. This study will therefore use empirical model in order to determine the effect of selected factors on adoption of ISFM technologies.

Most of the extant studies have majorly focused on adoption of ISFM technologies using models such as multivariate analysis and regression, Fisher's exact test, Welch's t test and ordered logistic regression, binary logistic (Mairura et al., 2022; Mwaura, Kiboi, Mugwe, et al., 2021; Njenga, Mugwe, Mogaka, et al., 2021; Njenga, Mugwe, Nyabuga, et al., 2021; Wawire et al., 2021). This prompts the study to apply a model that facilitate double approach of adoption and adoption intensity of ISFM technologies.

Tobit regression model, Cragg's Double Hurdle model and Heckman model are among the common econometric models that have been used to analyse adoption and adoption intensity by various studies. Tobit regression was proposed by Tobin (1958) to serve as a convectional technique that handles data with zero observation. The model ignores the sources of zero information as a result of random events within the existing factors (Haile et al., 2022; Martinez-Espin˜eira, 2006). Additionally, the model is associated with drawback of joint estimation of probability and intensity of adoption which can be misleading since decisions might not be necessarily joint (Wiredu et al., 2015). On the other hand, Heckman model permits two-stage estimation by desegregating the decision to adopt and adoption intensity. It also allows the use of different independent variables in each stage. Unique mechanism projected in the model is the fact that it assumes that there is no zero observation in the next stage once the first hurdle is passed. Therefore, for enhanced results Cragg's Double Hurdle model is applied. This model was modelled by Cragg (1971) to modify Tobit regression model. While Heckman model ignores zero observation in the second stage, Double hurdle model recognizes the possibility of zero observation in the second stage based on the deliberate choices made by individuals. Therefore, the model suits the study in determining the effect of selected factors on adoption and adoption intensity.

In application of double hurdle model, the effects will be separated by first using a Probit model to estimate the probability of adoption. Consequently, the second stage will use the truncated regression to analyse the intensity of adoption.

For the first hurdle the farmer's decision to adopt ISFM technology is a binary variable (D_i) such that:

$$D_i^* = X_\beta^i + \varepsilon_i \quad (1)$$

$$D_i = \begin{cases} 1 \; if \; D_i^* > 0 \\ 0 \; if \; D_i^* \leq 0 \end{cases} \quad (2)$$

Equation (1) assumes that ith farmer has an unobserved preference denoted byD_i^*. This preference is influenced by both observed (X_i) and unobserved factors $\mathcal{E}_i$. The relationship between the predicting and predicted variables is explained by β. X_i is the observed variable.

The second hurdle (truncated regression model) takes continuous dependent variable. Thus, the household decision on adoption intensity is a continuous variable (Y_i) such that:

$$Y_i^* = X_i^* \beta + \varepsilon_i \quad (3)$$

$$Y_i = \begin{cases} Y_i^* & if \; Y_i^* > 0 \\ 0 & if \; Y^* h Y_i^* \leq 0 \end{cases} \quad (4)$$

where Y_i^* is the observed response showing famer's intensity of adopting ISFM technologies which is measured by the proportion of land allocated to sorghum under ISFM. Here, the X_i is a vector of observed characteristics that explains the intensity of adopting ISFM.

3 | RESULTS AND DISCUSSION

3.1 | Descriptive results

The data set profiled 370 observations of sorghum farmers where 286 (77.3%) were adopters of ISFM technologies and 84 (22.7%) were non-adopters (Tables 1–3) The results in Tables 1 and 2 present proportions and chi square results of categorical variables while Table 3 present means and t tests for continuous variables. Chi-square and *t*-tests were used to determine the significance association between adopters and non-adopters.

3.2 | Socio-economic factors

The results in Table 1 showed that adoption of ISFM technologies was at 50.7% and 49.3% for male and female-headed households, respectively. On the other hand, female headed households (53.6%) were more among the non-adopters of ISFM technologies. This disparity among the gender household heads may be attributed to the cultural norms where men have an upper hand in making decisions for the family (Mukoni et al., 2018). The highest level of education for both household respondents was tertiary albeit who had attained partial primary level (31.4%) being generally more. Generally, the distribution of education level was 16.8%, 31.4%, 17.0%, 9.2%, 14.0%, 1.9% and 9.7% for none, partially primary, completed primary, partially secondary, completed secondary, partially tertiary and completed tertiary levels, respectively. In total, the educated farming population constituted 83.2% of the farmers in this area. Further the results show that a majority of the farmer respondents (48.4%) had some level of primary education which is critical in understanding the use of new agricultural technologies such as ISFM (Ruzzante et al., 2021a). It was observed that a majority of the respondents practiced mixed farming (77.8%) and it is favoured as a crucial aid for mitigating risks associated with climate change and the unpredictable market for farm produce (Ochieng et al., 2020). Among the sources of information used by the household to obtain agricultural information, radio dominated as the main source used by adopters with 54.5% and 53.6% for non-adopters in the respective responses. The use of radio as a main source of information among the resource poor farmers has been reported (Freeman & Mubichi, 2017). Efficient access to agricultural information is one the critical aspects in households' decision making process. Clear information on the use of a technology have been observed

TABLE 1 Categorical statistics of socioeconomic variables on adoption of ISFM technologies.

Variable	Categories	Frequencies (percentages) Adopters ($n = 286$)	Non-adopters ($n = 84$)	Total	χ^2
Gender	Male	145 (50.7)	39 (46.4)	184 (49.7)	0.4737
	Female	141 (49.3)	45 (53.6)	186 (50.3)	
Education	None	50 (17.5)	12 (14.3)	62 (16.8)	7.1128
	Partially primary	86 (30.1)	30 (35.7)	116 (31.4)	
	Completed primary	45 (15.7)	18 (21.4)	63 (17.0)	
	Partially secondary	27 (9.4)	7 (8.3)	34 (9.2)	
	Completed secondary	42 (14.7)	10 (11.9)	52 (14.0)	
	Partially tertiary	4 (1.4)	3 (3.6)	7 (1.9)	
	Completed tertiary	32 (11.2)	4 (4.8)	36 (9.7)	
Dependence on farming	Yes	239 (83.6)	73 (86.9)	312 (84.3)	0.5474
	No	47 (16.4)	11 (13.1)	58 (15.7)	
Farming system	Mixed	222 (77.62)	66 (78.6)	288 (77.8)	0.0339
	Crop	64 (22.38)	18 (21.4)	82 (22.2)	
Farming objective	Food	24 (8.4)	12 (14.3)	36 (9.7)	4.3947
	Income	24 (8.4)	3 (3.6)	27 (83.0)	
	Food and income	238 (83.2)	69 (82.1)	307 (7.3)	
Research awareness	Yes	87 (30.4)	18 (21.4)	105 (28.4)	2.5824
	No	199 (69.6)	66 (78.6)	265 (71.6)	
Decision on information use	Implement	4 (1.4)	1 (1.2)	5 (1.4)	44.7446***
	Wait for others	222 (77.6)	47 (56.0)	269 (72.7)	
	Do nothing	54 (18.9)	17 (20.2)	71 (19.2)	
	Other	6 (2.1)	19 (22.6)	25 (6.7)	

Note: *, ** and *** represents significance at 10%, 5% and 1%, respectively.

Source: author's computation from the conducted survey.

to encourage the households to adopt suitable technologies during production (Pivoto et al., 2019).

Two important farming objectives among the respondents were also captured (Table 1). These include farming for subsistence and commercial purposes. Majority of the respondents (83%) preferred farming for both food and income. This is because excess yields that may not be utilized for food can be traded for income by a household to cater for financial needs of the families (Holmelin, 2021). This diversification strategy helps to spread risks attributable to climate change and market dynamics of demand and supply (Ochieng et al., 2020). The strategy also promotes need for improved storage facilities and the potential for value addition to fetch better prices for the farm produce such as sorghum (Mgale & Yunxian, 2020). When this approach succeeds, the decision to adopt a technology or set of technologies such as ISFM becomes more feasible among the farmers (Norton & Alwang, 2020).

The results also show that, the decision on the use of agricultural information heavily relied on other farmers' experience as indicated by 77.6% for adopters and 56% for non-adopters. The success of fellow farmers coupled with own experience augments the desire to try a new technology to improved farm performance. Farmers tend to believe in the success of fellow farmers (usually the early adopters) who then become examples to emulate (Cai et al., 2019).

3.3 | Institutional factors

The results in Table 2 reveal that market access was pointed out by most respondents (81.1%) as an important tool in farming. Availability of and close proximity to the market by a household produce can encourage the use of technologies that increase yields for both subsistence and commercial purposes (Marie et al., 2020). Difficulty

TABLE 2 Categorical statistics of institutional variables on adoption of ISFM technologies.

Variable	Categories	Frequencies (percentages)			
		Adopters ($n = 286$)	Non-adopters ($n = 84$)	Total	χ^2
Main source of agricultural information	Radio	156 (54.55)	45 (53.6)	201 (54.3)	17.8200***
	Television	15 (5.24)	1 (1.2)	16 (4.3)	
	Farmers group	53 (18.53)	8 (9.5)	61 (16.5)	
	Neighbours	39 (13.64)	26 (30.9)	65 (17.6)	
	Extension agents	8 (2.80)	1 (1.2)	9 (2.4)	
	Internet	15 (5.24)	3 (3.6)	18 (4.9)	
Market access	Yes	232 (81.1)	68 (81.0)	300 (81.1)	0.0012
	No	54 (18.9)	16 (19.0)	70 (18.9)	
Extension services	Yes	55 (19.2)	6 (7.1)	61 (16.5)	6.8907***
	No	231 (80.8)	78 (92.9)	309 (83.5)	
Group membership	Yes	87 (30.4)	8 (9.5)	95 (25.7)	14.8562***
	No	199 (69.6)	76 (90.5)	275 (74.3)	
Agricultural training	Yes	140 (48.9)	22 (26.2)	162 (43.8)	13.6658***
	No	146 (51.1)	62 (73.8)	208 (56.2)	
Credit access	Yes	48 (16.8)	10 (11.9)	58 (15.7)	1.1690
	No	238 (83.2)	74 (88.1)	312 (84.3)	
Research awareness	Yes	87 (30.4)	18 (21.4)	105 (28.4)	2.5824
	No	199 (69.6)	66 (78.6)	265 (71.6)	
Cultural influence	Positive	93 (32.5)	18 (21.4)	111 (30.0)	3.8019*
	Negative	193 (67.5)	66 (78.6)	259 (70.0)	

Note: *, ** and *** represents significance at 10%, 5% and 1%, respectively.

Source: Author's computation from the conducted survey.

TABLE 3 Descriptive statistics of continuous variables of adopters ($n = 286$) and non-adopters ($n = 84$).

Variable	Mean	Std	Min	Max	T
Age	42.8 (45.7)	13.8 (12.7)	20 (22)	73 (75)	1.7391*
Farm size	3.3 (3.3)	2.5 (2.5)	0.5 (0.25)	52 (20)	−0.1937
Farm size under sorghum	1.5 (1.49)	0.93 (1.08)	0.25 (0.25)	6.0 (5.5)	−0.2160
Dependents	4.3 (4.1)	2.0 (1.9)	1 (1)	9 (8)	−0.7144
Sorghum yields	4.8 (2.4)	3.4 (1.7)	0.5 (0.4)	25 (7.5)	−6.3639

Note: * represents significance at 10%.

Source: Author's computation from the conducted survey: Adopters (non-adopters).

in market access may not encourage the use of improved technologies since the excess yield go to waste after increased investment on the technology. Majority (83.5%) of the surveyed households had no access to extension services, thereby limiting them on appropriate source of information on emerging agricultural technologies and their proper application for improved farming. Extension is an agent of technology dissemination, therefore, appropriate technology adoption may not be achieved in cases where extension services meant to inform the farmers is inactive or unavailable (Takahashi et al., 2019).

Almost half (48.9%) of the respondents had received formal agricultural training accounting of whom 48.9% were adopters and 26.2% were non-adopters. Agricultural training helps impart requisite farming skills for emerging technologies such as those of ISFM (Macharia et al., 2014). This is important as it adds impetus on deciding to adopt a given technology or set of technologies because of the practical experience realized (Siyum et al., 2022). About three quarters (74.3%) of the respondents indicated that they were not members of any existing agricultural group (Table 1). Group dynamics help enhance the conviction that new technologies have benefits leading to the decision to adopt them (Manda et al., 2020). However, most members reported that they were triggered to withdraw because of limitation on the shared group resources, for instance, amount of farm inputs are shared equally among the members without considering the size of land under cultivation. This would then lead to low adoption of agricultural technologies such as ISFM and seriously curtail the intensity of adoption of such technologies in sorghum production.

There was limited access to credit among the farmers accounting for 18.4% of the households (Table 1). This arose because of minimal formal credit sources and some reported to turning to the informal credit sources whenever there was opportunity and need to do so. Most financial institutions are located in urban or peri-urban areas because of the availability of requisite infrastructure that guarantees ease of business compared to the rural settings such as the study location herein (Agwu, 2020). Additionally, most respondents do not prefer intensive investments because of the dry conditions that promise limited returns from the farms coupled with weak policy implementation by the government. Adoption of new technology is thus tied to the associated gains (Jayashankar et al., 2018).

Majority of adopters (69.6%) and non-adopters (78.6%) were not aware of research programs facilitated in the area. This would be associated with low availability of extension services that usually provides such information by linking the farming community to the research institutions (Takahashi et al., 2019). The importance of available extension services in providing and promoting relevant technologies to farmers has been emphasized in other works (Dhraief et al., 2018; Ugochukwu & Phillips, 2018). Research institutions generate knowledge on improved agricultural technologies and often work with farmers through field demonstrations to show case the superiority these technologies (Ibrahim, 2017). Where this is not possible, the information is packaged and passed over through extension providers who become the link between the farmers and the research institutions. Equipped with such knowledge, farmers are then able to adopt or enhance the adoption intensity of the technologies they deem relevant and beneficial (Norton & Alwang, 2020). Farming activities among the respondents were influenced positively (30%) and negatively (70%) by the cultural standards. For the farmers, culture provides the unwritten law that governs a community's social and economic disposition, and is the first line of reference in accepting new ideas into one's life (Sharan et al., 2019). This may, however, be moderated by other factors such as a farmer's exposure through, school, travel and own experience in understanding farming business dynamics (Kimathi et al., 2021). In this study, the chi square results shows that there was significant difference in cultural influence among other factors such as decision on information use, agricultural training, group membership, extension services, source of agricultural information and farm size among adopters and non-adopters (Tables 1 and 2) similar observations were made by (Abdul-Rahaman et al., 2021).

3.4 | Continuous variables

The mean age of the majority of adopters (77.3%) was 42.8 years and was lower than that of non-adopters (22.7%) with the mean of 45.7 (Table 3). This is an indication that adoption decreases with an increase in age among the sorghum farmers in the area. Old farmers are not in a position to appreciate the learning of new technologies compared to young people who are productive, energetic and enthusiastic about learning new ideas (Xie & Huang, 2021). There is thus need to promote the new ISFM technologies among the young farmers to enhance both adoption and adoption intensity for increased sorghum production. The mean size of the total farm size owned and leased by the household were equal in both cases with an average of 3.3 acres. This means that adopters and non-adopters had equal chance of allocating land for various technology options and that farmers in the area had relatively the same size of farmland. The deviation may occur in priorities on important enterprises and farming objectives of a household and the ease of adoption of the ISFM technologies (Mohammed et al., 2021). The mean sizes of the land allocated to sorghum production by the farmers were also equal among both the adopters and non-adopters with a mean of 1.5 acres. This could be explained by the fact that the crop is appreciated for its suitability to the conditions of the area, taking on average half of the farm land. Sorghum is a drought resistant crop Kagwiria et al. (2019), that, it can significantly perform well in the area. That adaptation of the sorghum assures farmers of yields even in bad weather (Abreha et al., 2022). There was minimal variation in the means of household dependents with adopters (4.3) and non-adopters (4.1). This reveals that households among adopters and non-adopters is the same across the two categories and play an important role in offering support to the family members. This emphasizes the common family bride and ties that are evident in African societies (Quan-Baffour, 2014).

The yield of sorghum was higher among the adopters with 4.8 bags of 90 kilograms per acre compared to 2.4 bags per acre obtained by non-adopters. This is a clear indication that application of improved technologies with better management can improve or double yields of crops such as sorghum (Atere et al., 2022). However, the *t*-test results (Table 3) reveals that the difference in means for adopters and non-adopters were only statistically significant for age at 10% and yield at 1%. This means that adopters were younger than non-adopters owing to the fact that adoption of new technologies is more flexible to farmers in the productive age. On the other hand, difference in yield is credited to role of ISFM technologies in augmenting crop productivity (Atere et al., 2022).

3.5 | Technological factors

The statistic results on the ISFM technologies in Table 4 shows that about two thirds (67.1%) of the respondents perceived that access to the technologies was efficient, with a combined approval rate being 86.3%. The rest were either not sure (10.5%) or generally disagreed (3.28%). This shows that the adopted technologies were acceptable among the sorghum farmers in the area because of the realized and perceived benefits (Sawadogo et al., 2020).

Based on technology benefits, respondents (93.7%) perceived that ISFM has potential to augment yields while 75.2% were of the view that technologies improved their soil fertility, and 33.6% had perception that the technologies helped in efficient control of pest and disease, respectively. Such benefits noted by the farmers enhances their decision to pick up and adopt the technologies that guarantee a net gain (Brookes & Barfoot, 2020). The findings also imply that technology adoption is based on benefit priority starting with increased yields then improved soil fertility followed by potential to control pests and diseases, the latter two indirectly contributing to the first. Challenges on technology adoption were also noted from the respondents. Most respondents (97.9%) cited weather variation as a serious challenge in technology adoption while 72.4% felt that they incurred high cost during application of the ISFM technologies. Issues relating to cost of adoption and unpredictable weather patterns that confound the expected gains have been reported to influence the decision to adopt new technologies (Getare et al., 2021). This may lead to reduced adoption of otherwise beneficial farming technologies meant to promote resilience to climate change effects (Nezomba et al., 2018). In the current study, the adoption of the technologies was generally high, implying the sorghum is adapted to the area conditions and the farmers are able to manage agricultural activities with relative ease. This in effect enhances the adoption and adoption intensity of technologies such as of ISFM.

3.6 | Inferential results

Double hurdle model was applied in order to estimate the effect of socio-economic, institutional and technological characteristics on adoption and adoption intensity of ISFM technologies (Figure 1). The results in Table 5 were run separately using 20 variables that were selected for use in explaining the dependent variable.

In the first and second stages, gender of the household respondent had a negative significance in adoption and adoption intensity of ISFM technologies at $p<.05$ and $p<.01$, respectively. From the marginal results (Table 5),

TABLE 4 Descriptive statistics of adopters perception on ISFM technologies ($n=286$).

Variable	Category	Frequency	Percentage
Perception on access to ISFM	Strongly agree	55	19.2
	Agree	192	67.1
	Not sure	30	10.5
	Disagree	8	2.8
	Strongly disagree	1	0.4
Perceived benefits			
Improved soil fertility	Yes (No)	215 (71)	75.2 (24.8)
Better control of pest	Yes (No)	78 (208)	27.3 (72.7)
Efficient control of diseases	Yes (No)	96 (190)	33.6 (66.4)
Increase yields	Yes (No)	268 (18)	93.7 (6.3)
Perceived challenges			
High cost	Yes (No)	207 (79)	72.4 (27.6)
Unstable weather	Yes (No)	280 (6)	97.9 (2.1)

Source: author's computation from the conducted survey.

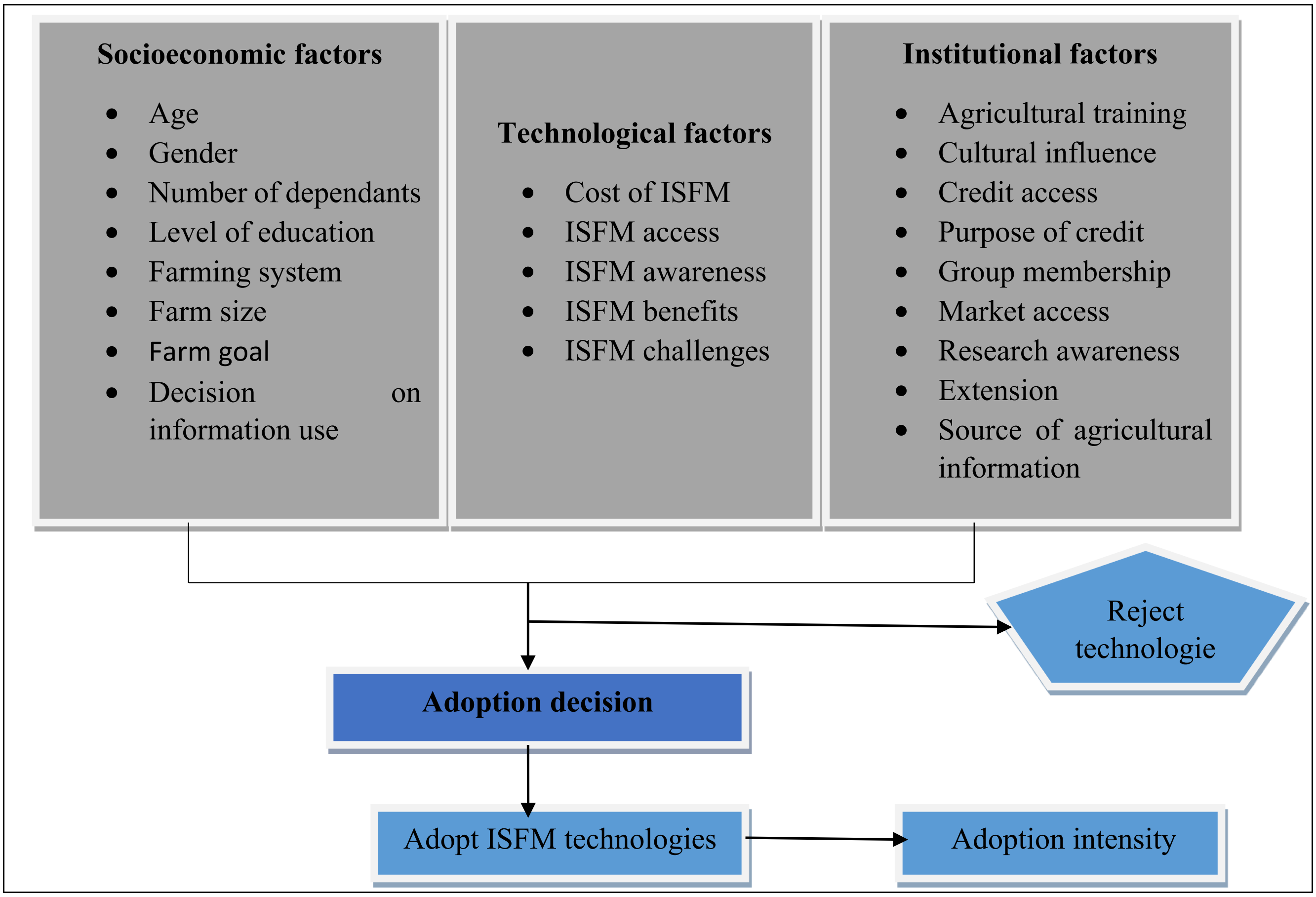

FIGURE 1 Conceptual framework. *Note*. The framework was produced by author to summarize how socioeconomic, technological and institutional factors influence adoption and adoption intensity of ISFM technologies.

gender could reduce adoption of ISFM technologies by 0.058 and adoption intensity by 0.346. This could be attributed to more female taking part in household farming activities who could otherwise be disadvantaged by limited share of resources and decision making. The finding differs with the findings of (Mponela et al., 2016; Wawire et al., 2021) who reported that gender had no relationship with ISFM adoption. The current study, however, corroborate the findings of Teklewold et al. (2013) and Kassie et al. (2015) that gender is one of the factors that significantly affect adoption of ISFM technologies. According to Kwadzo and Quayson (2021), ownership of family resources is a hindrance to female gender adopting ISFM technologies. In a patriarchal society households are headed by males who are accustomed to resource endowment and as a result gender disparities with respect to wealth management occur (Okuthe et al., 2013). Gender differences is highlighted as the core element that determines access to family resources and agricultural inputs, information as well as decision making which influence adoption and adoption intensity of useful farm technologies (Ndiritu et al., 2014; Peterman et al., 2014).

In the first stage farm size was negatively significant ($p < .05$) in determining adoption of ISFM technologies (Table 5). Contrastingly, in the second stage it showed a positive significance ($p < .01$) on the effect of adoption intensity. On the other hand, the marginal results revealed that the size of land lowers adoption by 0.012 while increasing adoption intensity by 0.247. This implies that farmers with large junks of land have the option of maintaining their farming practices while those with small parcels of land will adopt technologies that will boost their farm production like in growing sorghum. Albeit farm size being significant in affecting adoption of agricultural technologies (Mwangi & Kariuki, 2015), negative significance may be an indication of time lag experienced in technology uptake linked to insufficient technology information or inadequate resources among other factors. Additionally, negative significance shows that, as the farm size increases more farmers would shun away from adopting the ISFM technologies as a result of obstruction by its high cost. This finding corresponds the report that total land size owned by a household was negatively significant in determining adoption of manure (Aura, 2016). It,

TABLE 5 Estimates from double hurdle model.

Variable	Probit Coef	Probit Std.err	Probit ME	Truncated Coef	Truncated Std.err	Truncated ME
Constant	9.356***	3.091	–	−0.860	0.809	-
Gender	−1.012**	0.464	−0.058	−0.346***	0.122	−0.346
Age	0.015	0.017	0.001	0.008	0.005	0.008
Education	−0.100	0.120	−0.006	0.059	0.039	0.059
Dependents	0.218**	0.108	0.012	0.023	0.032	0.023
Subsistence farming	−4.278***	1.269	−0.244	0.190	0.232	0.190
Commercial farming	−0.885	0.548	−0.051	0.392	0.235	0.392
Decision on Agric info.	−0.073	0.275	−0.004	0.065	0.105	0.065
Farm size	−0.215**	0.085	−0.012	0.247***	0.022	0.247
Farming system	−0.162	0.520	−0.009	−0.003	0.171	−0.003
Research	0.990**	0.481	0.057	−0.095	0.133	−0.095
Culture	0.253	0.449	0.014	0.046	0.144	0.046
Group membership	1.131	0.598	0.065	−0.225	0.159	−0.225
Purpose of credit	0.205	0.547	0.012	0.086	0.112	0.086
Source of agric.inf	−0.149	0.141	−0.009	−0.170***	0.049	−0.170
Agricultural Training	−0.276	0.424	−0.016	0.424***	0.136	0.424
Extension	2.796**	0.906	0.160	0.096	0.170	0.096
Market access	−0.707	0.540	−0.040	0.033	0.151	0.033
ISFM awareness	4.149***	0.968	0.237	0.319	0.213	0.319
Perception on cost	−0.288	0.264	−0.016	0.078	0.072	0.078
ISFM access	−1.879***	0.293	−0.107	0.079	0.074	0.079
			Probit			**Trunreg**
Wald X^2 ***(20)			321.29			204.84
Log-L			37.55			−336.90
Pseudo R^2			0.8105			361
No. of observations			370			

Note: ** and *** at 5% and 1%, respectively represents significance. Trunreg represents truncated regression. Agric info. stands for agricultural information.

however, differs with Martey et al. (2014) who concluded that farm size was the most influential factor among adopters of inorganic fertilizer. Similarly, adoption of FISP and ISFM technologies were positively promoted by the size of land (Adolwa et al., 2019; Khonje et al., 2022; Manda et al., 2016; Tesfaye et al., 2020). For adoption intensity, the study is consistent with the conclusion that total land size affected the choice and use intensity of Zai pits (Ndeke et al., 2021). However, the results contradicts the findings of Awuni et al. (2018) and Zakaria et al. (2020) who reported that farm size negatively influenced adoption of improved agricultural technologies. It is noted that the decision by farmers to adopt or intensify the adoption of a technology or set of technologies such as ISFM will be influenced by factors such as land size, type of technology, relevance of the technology and the farming enterprise.

Farming goal for subsistence was one of the variables that was significant ($p < .01$) in the study even though it negatively affected adoption of ISFM technologies (Table 5). However, the variable was not significant in stage two meaning that it was not among the determinants of adoption intensity. The marginal results revealed that farming for subsistence reduced adoption of ISFM technologies by 0.244. This could be the case because the farmers are not keen on surplus yields associated with new climate smart or precision agriculture technologies that might as well demand more spending, an averse requirement among the resource poor sorghum farmers (Schimmelpfennig, 2016). This study ascribes negative significance to limited farmers' interest in satisfying family interests only which is a common phenomenon among farmers who are economically disadvantaged. To them, there will not be any need for ISFM technologies that increases production if the available technique is able to produce capacity that meets the family consumption needs from one season to another. On the other hand, Vorley et al. (2012) and Giller et al. (2021) attributes farming goal for subsistence to limited access to productive resources by farmers, limiting their capacity to embrace change.

Dependants showed a positive significance ($p < .05$) in influencing adoption of ISFM technologies (Table 5). Arguably, this significance proofs that family dependants have the potential to alter the decision of farming. However, this attribute was not significant in influencing adoption of better agricultural technologies as reported by other studies (Muhaimin et al., 2020; Zulqarnain et al., 2020). Similarly, dependents of the family was significant but can negatively affected adoption of climate smart technologies (Asfaw et al., 2018). The positive results of the study agrees with the findings of Nyangena (2007) that the necessity of adoption of useful agricultural technologies can be encouraged by the dependants of the family who are within the productive age; on the other hand, low interest towards technology adoption may result from family dependants who require extra economic care, and thus puts pressure on consumption of the available resources.

Access to extension services was positive and significant ($p < .05$) in determining adoption of ISFM technologies among the farming households. The results revealed that, with access to extension services, adoption of ISFM by the farmer increases by 0.160 (Table 5), and in relation to adoption intensity, the variable was not significant implying that it was not a factor to be considered in intensity of adopting ISFM technologies. This study corroborates the findings that access to extension services was significant in adoption of ISFM and agricultural technologies generally (Diallo et al., 2019; Mutua-Mutuku et al., 2017; Ruzzante et al., 2021b). Extension services are thus a crucial tool in technology dissemination as a means of informal education and training (Takahashi et al., 2019). It enables farmers to be aware of diverse farming challenges and the response the technology avails in ameliorating soil fertility and increasing yields (Tesfay et al., 2016). Adoption of the agricultural technologies that includes ISFM will thus be efficient if farmers are frequently in touch with the extension providers who will provide the right information to serve particular farming needs like the growing of sorghum in the study location.

Research awareness by the sorghum farmer showed a positive significance ($p < .05$) in influencing adoption of ISFM technologies. In contrast to the findings of stage one, stage two results reveals that research awareness was not significant on the effect of adoption intensity. Marginal results showed that research can increase adoption of the technologies by 0.057 among the sorghum farmers. Notably, without research it can be difficult to convince farmers on how technologies are suitable and this could severely hinder adoption (Ibrahim, 2017). Essentially conducting research on different technologies provides proven findings important for improving agricultural production and adoption of technologies. The study attributes positive significance to the fact that the research related to ISFM technologies foster technical support on how the technologies are applied and also their end result. It is important to add that field based demonstrations augment the farmers' research capabilities at farm level, enabling positive decision making on adoption of new technologies they find relevant (Norton & Alwang, 2020). Therefore, farmers who are aware of the existing research in the area can be easily persuaded by the favourable performance of the technologies being promoted, and better still, in which they have participated.

Household awareness on ISFM technologies was significantly (0.01) positive in adoption of ISFM technologies but in the second stage it was not significant in influencing adoption intensity. According to the marginal outcomes, the variable was able to increase adoption by 0.237 (Table 5). The previous findings correspond to the study with the report that ISFM awareness was significant in influencing adoption of improved farming technologies (Baah et al., 2011; Gwandu et al., 2014). This could be an indication that the more farmers are knowledgeable about the technologies the more their adoption likelihood increases. In addition, knowledge about how the technology performs in the farm guarantees a greater chance of applying the technology as the farmers can easily relate with it.

Access to ISFM displayed a negative significance ($p < .01$) in adoption of ISFM technologies even though it was not significant in adoption intensity. In relation to the marginal results, access to ISFM could reduce adoption by 0.107 (Table 5). Negative significance is attributed to situation where a household relies on more external sources of ISFM technologies that are not within reach, for example the source of water for irrigation. Adoption therefore, becomes difficult in the case where such technologies require extra spending to implement and the farmer feels it is not worth the effort at that point in time. The findings of the current study corroborates with the results of Quaye et al. (2021) who found that access to ISFM technologies was significant in adoption of organic technologies tied to ISFM. The results also are in tandem with findings that full access to supporting resources of the agricultural technology promotes adoption by farmers (Macharia et al., 2014; Mugwe et al., 2009).

The main source of agricultural information was not significant in the first stage. In the second stage it was significant ($p < .01$) affecting the adoption intensity of ISFM negatively. The marginal effects of the dependence of a particular source of agricultural information lowered adoption by 0.170 (Table 5). Except for official sources of agricultural information, social media has penetrated the space but its reliability cannot be easily authenticated, leaving farmers in doubt on what to accept and adopt in the agricultural business (Mamgain et al., 2020). Essentially, emergence of information communication systems has rendered efficient access to agricultural information through devices such as mobile phones, personal computers and internet (Shanthy & Thiagarajan, 2011). Limitation to this information system is generated as a result of formal and informal sources which differ in efficiency among the rural households especially in Africa (Gwandu et al., 2014). Negative significance on the characteristic of agricultural information may thus be ascribed to reliance of formal sources in propagating information pertaining to ISFM technologies which then may limit farmers who depend on informal sources of information. Therefore, adoption will be lower where information sources used favours subjects of formal sources of information where known and trusted experts are involved in providing the agricultural technology information (Oliver et al., 2020).

Access to agricultural training by the respondents of this study was not significant in the first stage albeit being positively significant at ($p < .01$) in the second stage (Table 5). It is thus evidence that formal agricultural training play a crucial role in steering up adoption intensity of ISFM technologies. Training is one of the critical means of acquiring, developing and assimilating diverse agricultural techniques which ultimately impart positive behaviour and attitude on the impact of agricultural technologies (Lukuyu et al., 2012; Macharia et al., 2014). Additionally, training is vital in imparting knowledge and sensitizing farmers on productivity effects and environmental concerns of agricultural technologies (Njenga, Mugwe, Mogaka, et al., 2021; Njenga, Mugwe, Nyabuga, et al., 2021). The findings by Danquah et al. (2019) has shown that farmers who have frequent contact with training programs are likely to adopt agricultural technologies, attributing a similar aspect in adoption intensity. In relation to other findings, access to training was positively significant in influencing uptake of soil and water conservation (SWC) technologies (Kpadonou et al., 2017; Moges & Taye, 2017). Intensity of using organic based soil fertility management technologies was also shown to be influenced positively by agricultural training (Mwaura, Kiboi, Bett, et al., 2021). However, even in cases where only a few farmers have access to formal training, the high cost associated with its facilitation, high efficiencies of the technologies in small scale farms have been reported (Fischer & Qaim, 2012; Johansen et al., 2012).

4 | CONCLUSION AND RECOMMENDATION

The aim of this study was to identify the factors that affect adoption and adoption intensity of ISFM technologies among farmers in dry zones of upper eastern Kenya. From the econometric results obtained using Double Hurdle Model, out of the 20 variables used to determine their relationship on the explained variable shows that, gender, dependents, farming goal for subsistence purpose, decision on information use, farm size, extension services, research, ISFM awareness and ISFM access significantly affected decision on adopting ISFM technologies. On the other hand, gender, farm size, main source of agricultural information and formal agricultural training had a significant influence in ISFM technologies adoption intensity. This is an implication on the need to promote the uptake and use of ISFM technologies. This can be done through collaboration of the national government with other agricultural stakeholders by facilitating appropriate education to farmers, disseminating research findings through training and provide subsidies on external ISFM inputs so as to enhance adoption and adoption intensity among farmers in marginal areas.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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