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Effects of Integrated Soil Fertility Management Technologies on the Productivity of Sorghum in the Drier Parts of Upper Eastern Kenya

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Declining soil fertility amid the devastating effects of climate change is a threat to the state of food security in developing countries like Kenya. Enhancing production intervention through sustainable farming practices like integrated soil fertility management (ISFM) technologies has been promoted. However, there is a dearth of knowledge revealing the efficacy of such technologies, especially in dry regions of the country. Therefore, this study evaluated the effect of integrated soil fertility management technologies on sorghum productivity in the drier parts of Upper Eastern Kenya. Data was collected from 370 sorghum farmers using a semi-structured questionnaire. The data was analyzed using descriptive statistics (percentages) and Propensity Score Matching (PSM). The initial PSM stage revealed that various socioeconomic and institutional aspects (subsistence farming, access to extension services, perception of innovations, road infrastructure, ISFM awareness and ISFM costs) influence the adoption decision of ISFM. Further, the findings reveal that farmers who adopted ISFM technologies recorded increased sorghum productivity. Hence, the productivity of adopters was better than that of non-adopters. Improving adoption, therefore requires the facilitation of agricultural institutions and service providers who are key in imparting vital knowledge and creating awareness of productive technologies such as ISFM. Similarly, the results have wider policy effects for agriculture, especially in places where ISFM may be very important for long-term food security and agricultural productivity.

Keywords: Adoption, productivity. soil fertility, sorghum, technologies, matching.

INTRODUCTION

Sorghum (*Sorghum bicolor*) is the fourth most important cereal crop after maize, rice and wheat in Sub-Saharan Africa (SSA) and in Kenya(Ochieng *et al.*, 2020). It's a staple food crop for over a billion people in developing countries (Abreh *et al.*,2021). The crop exhibits drought-tolerant characteristics. Thus, its economic importance is more pronounced in arid and semi-arid regions across the country. It is an alternative source of food security and livelihood for most households in dry areas with limited amounts of rainfall (Okeyo *et al.*, 2020). Sorghum is rich in fibre, and it's used in a variety of ways, including porridge, flour, and industrial and local brewing industry and also as a livestock feed. Despite the significant economic value of sorghum in drylands, its productivity has been declining due to changing climatic conditions (Akinseye *et al.*, 2020). Although sorghum thrives well in dry areas with minimal nutrient requirements, its productivity is constrained by poor and obsolete agronomic practices that lead to soil nutrient depletion (Kagwiria *et al.*, 2019). Therefore, sustainable soil fertility management practices are crucial for ensuring high crop productivity, especially in regions with poor soils, like drier parts of Upper Eastern Kenya. Sorghum production is estimated to be 60 million metric tons globally. A third of its production originates in Africa. However, Kenya barely contributes 0.6% of the entire 20 million metric tons generated in Africa (Okeyo *et al.*, 2020). Sorghum is grown mostly in the country's semi-arid eastern, western, and coastal regions (Njagi *et al.*, 2019). Sorghum output in Eastern Kenya currently ranges from two to four bags per acre, which is less than the real yield of five bags per acre. In comparison, optimal nutrient administration during sorghum cultivation yields 3 bags per acre when conditions are unsuitable and up to 18 bags per acre under favorable conditions (Karanja *et al.*, 2014). Deteriorating soil fertility is one of the triggers of declining sorghum productivity. Similarly, crop yield in promising areas is dropping due to subsistence production

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(Esilaba *et al.*, 2021; Okeyo *et al.*, 2020). Low productivity in sorghum fields is also caused by the use of inappropriate agronomic techniques and a lack of soil nutrients (Kagwiria *et al.*, 2019). However, interventions through agricultural technologies such as Integrated Soil Fertility Management (ISFM) have been promoted to rehabilitate soils and improve productivity. The approach is hence more important for resource-constrained smallholder farmers in Sub-Saharan Africa and Kenya, especially those in the semi-arid and arid zones, providing answers to their problems.

Integrated Soil Fertility Management (ISFM) is a holistic approach that integrates multiple practices to improve soil and crop productivity. It involves the application of organic and inorganic materials such as crop residues, animal manure, compost, and mineral fertilizer. It also constitutes agronomic practices such as crop rotation, intercropping, and conservation tillage (Jabbar *et al.*, 2022; Kwadzo and Quayson, 2021). By applying this materials at the recommended rates, ISFM can improve soil health by enhancing water holding capacity and improving the soil structure thus increasing crop yields, and promoting long-term agricultural sustainability (Emongor *et al.*, 2022). The approach also aims to optimize nutrient utilization while minimizing environmental degradation and dependency on external inputs by integrating different soil fertility management practices (Jabbar *et al.*, 2022). Therefore, ISFM has been shown to significantly impact sorghum productivity especially in dry areas. The government of Kenya and other private partners have been working in collaboration to upscale and promote the use of ISFM practices in order to improve sorghum productivity and address the challenge of declining soil fertility in the drier parts of Eastern Kenya. According to the Kenya Plant Health Inspectorate Service (KEPHIS), forty-three sorghum cultivars with improved tolerant characteristics were certified, registered, and given to farmers by 2018 (Mwangi *et al.*, 2020). Despite the efforts to promote the adoption of ISFM, its potential effects on sorghum productivity especially in the drier parts of Eastern Kenya have not been assessed.

Extant studies reveal that adoption of ISFM technologies was highly influenced by the education level of the household head, participation in social groups, age of the households' head, off-farm revenues, and the amount of land owned (Aura, 2016). Similarly, Integrated Soil Fertility Management (ISFM) techniques is greatly affected by factors such as the purpose of growing crops, ownership of land, the proximity of the house to the nearest input market, access to loans, and the agro-ecological zone (Kwadzo and Quayson, 2021). Further, legume seed availability, land tenure security, group affiliation, and landholding size are all crucial determinants of the adoption and sustained utilization of Integrated Soil Fertility Management (ISFM) strategies. It is interesting that the same considerations discourage acceptance of ISFM techniques. For instance, the practice of not using maize-legume intercropping and rotation is discouraged due to limited availability of legume seed and extension services. On the other hand, the adoption of legume-maize rotation is promoted when there are greater landholding sizes. The study also found that female producers were more likely to continue the practice of maize-legume intercropping (Kanyamuka *et al.*, 2020). It is also evident that most studies have focused on factors affecting adoption of ISFM technologies using probit, multivariate probit, Wald's hierarchical clustering tecniques; with limited attention to drought tolerant crop such as sorghum (Aura, 2016; Kanyamuka *et al.*, 2020; Kwadzo and Quayson, 2021; Otieno *et al.*, 2021). Additionally, no study has explicitly examined the twofold approach of identifying the factors that influence the adoption of ISFM and its impact on sorghum productivity in semi-arid regions of Upper Eastern Kenya. Therefore, this research was designed to evaluate the effects of ISFM technologies on sorghum productivity and provide valuable insights on the potential benefits of ISFM for sustainable agriculture using a case study from the drier parts of Upper Eastern Kenya. The study employed propensity score matching, which facilitates the evaluation of both the adoption and the effect of ISFM technologies.

MATERIALS AND METHODS

***Study site description*:** This study was carried out in the drier parts of Upper Eastern Kenya specifically in Tharaka-Nithi County, Igamba Ng'ombe Subcounty. The area covers 324.6.4 km^2 with a population of 53,210 people (KNBS, 2019). It's located between an altitude of 250 and 1500 meters above sea level with mean annual temperature of 24 degrees Celsius. The rainfall received is bimodal with long rains occurring from March to June and short rains from October to February thus the area supports two cropping seasons annually (Oduor *et al.*, 2022). The annual rainfall received ranges from 500 to 750mm, which is insufficient to support cultivation of traditionally consumed crops. Therefore, the area is suitable for drought tolerant crops such as sorghum and millet. The soils in the area are heavily weathered ferrasols which support farming and cattle production (Kimaru-Muchai *et al.*, 2021). Small scale farmers in the area who are resource constrained depend on rainfed agriculture for food and livelihoods. The main crops grown in the area include millet, sorghum, cassava, maize and beans (Ndeke *et al.*, 2021). Drought and erratic rainfall patterns in the area periodically disrupt rain-fed agriculture, this necessitates sustainable soil management approaches that will improve soil and water conservation in order to improve farm productivity, increase incomes and boost food security in the region.

The anonymity and respect of the farmers who participated in this study were critical during its execution. Before any data was gathered, all participants were asked to express informed consent. The producers were given a detailed description of the study's aims, procedures, risks, and benefits in their local language. They were advised that their participation was entirely voluntary. To ensure anonymity, participants were identified using a unique code rather than personal identifiers. The data was only accessible to the research team. Moreover, the results of this inquiry will not contain any information that might be used to identify the participants.

***Target population and sample procedures*:** The study's target population was mostly Tharaka Nithi County's rural sorghum growers who are approximately 4,050 in number as outlined by the Ministry of Agriculture. Because there was a finite number of sorghum farmers in the study area, the sample size was determined using the Yamane (1973) formula as applied by (Amahalu *et al*., 2022).

The formula is expressed as shown below:

$$n = \frac{N}{1 + Ne^2}$$

Where n = sample size; N= Population size = 4050; e = Margin of error (0.05) at 95% level of significance

The sample size was calculated as:

$$n = \frac{4050}{1 + 4050(0.05)^2} = 370$$

A multistage stratified sampling approach was applied in the sampling process. In the first step, Tharaka-Nithi County was selected by purposive sampling due to its potential for sorghum production. Similarly, the majority of ISFM technologies have been promoted in this region, hence it was picked. Furthermore, the Igamba-Ngombe sub-county, where the ISFM experiments were laid, was deliberately chosen. The second phase involved randomly selecting four subcounty locations with a high concentration of sorghum growing. Using the resulting sample frame, 370 sorghum farmers were chosen at random from the four regions for the third step. A semi-structured questionnaire was used to collect data.

***Propensity Score Matching (PSM) model specification*:** Propensity Score Matching (PSM) model was used in this study to estimate the impact of ISFM technologies on productivity. Based on specific observed traits of a farmer, PSM generates a variable called propensity score, which is the likelihood that a sorghum farmer will employ ISFM technologies. Propensity score acquisition is the first of two processes in PSM. The following is the propensity score:

$$P\,(x) = \Pr(T = 1)/\,X = x)$$

Where, T= (0, 1) represents a subject of treatment and X is a multidimensional vector of pretreatment features that include age, gender, education level, number of household dependents, total farm size, subsistence farming, commercial farming, credit access, group membership, extension services, agricultural training, source of agricultural information, the decision on new information, cultural influence, road infrastructure, ISFM awareness and ISFM cost.

The second step comprises of a set of matches between adopters and non-adopters. Matching technique is a design that evaluates the average treatment effect on the treated (ATT) which represents the difference on the result of applying ISFM technologies and counterfactual results that would have been realized if ISFM were not used in production. ATT is formulated as shown below:

$$ATT = E\left(Y^1 - Y^0/P(X)\right) = E\left(Y^1\,T = 1, P(X)\right) - E(Y^O/T = 0, P(X))$$

Where, $E\left(Y^1\,T = 1, P(X)\right)$ is the yield of sorghum for the ISFM adopters and $E(Y^O/T = 0, P(X))$ is the sorghum yield for the ISFM non-adopters had it not been adopted. Most of the PMS techniques that have been considered in the extant studies include nearest-neighbour matching (NNM), kernel-based matching (KBM), radius matching and stratification matching. This study applied nearest-neighbour matching (NNM), kernel-based matching (KBM) and radius matching methods to evaluate the effect of ISFM technologies on productivity.

RESULTS AND DISCUSSION

***Farm and farmer characteristics*:** The results in Table 1 present the descriptive statistics of farm and farmer characteristics. Most of the adopters of ISFM technologies were male (51%) while majority of the non-adopters were female (54%). This implies that male farmers have better chances of adopting technologies. The study by (Hörner and Wollni, 2022) reported that male farmers were likely to adopt ISFM technologies and their combinations. Both adopters and non-adopters exhibited access to education, with the majority of the two groups being primary level in the proportion of 46% and 58%, respectively. The dominant farming system for adopters was mixed farming (78%), similar to non-adopters, who accounted for 79%. The two groups (adopters (84%) and non-adopters (82%)) preferred farming for both food and income. The mean age of non-adopters (45.7) was higher than that of adopters 42.8. This suggests that adoption tends to decrease as farmers become older. This is in line with the report that young farmers who are in the productive age have a higher potential for adoption (Funmilayo and Olumide , 2022). The means of farm sizes (3.3) and farm sizes under sorghum (1.5) were equal in the two groups. Compared to non-adopters (4.1), adopters had a little higher mean number of dependents per household (4.3). Additionally, adopters' mean sorghum yields were 4.8, whereas non-adopters yields were 2.4. Thus, crop yields are increased by ISFM technology adoption. This is consistent with the finding (Jabbar *et al*., 2022) that wheat produced by users of ISFM technologies was superior.

Table 1. Farm and farmer characteristics.

Variable	Categories	Percentages	
		Adopters (n=286)	**Non-adopters (n=84)**
Gender	Male	51	46
	Female	49	54
Education	None	17	14
	Primary	46	58
	Secondary	24	20
	Tertiary	13	8
Farming system	Mixed	78	79
	Crop	22	21
Farming objective	Food	8	14
	Income	8	4
	Food and income	84	82
	Unit	**Mean**	**Mean**
Age	Years	42.8	45.7
Farm size	Number	3.3	3.3
Farm size under sorghum	Acres	1.5	1.5
Dependents	Number	4.3	4.1
Sorghum yields	Bags(90kg)/Acre	4.8	2.4

Adopters' perception on ISFM technologies**:** Adopters of ISFM technologies had varied perceptions as displayed in Table 2. Across different variables, respondents were asked to indicate whether they agreed (Yes), disagreed (No), or were unsure (Not Sure) about each perception. Overall, a high percentage of adopters perceived ISFM positively, with the majority (70%) agreeing that ISFM technologies improve soil fertility and 94% agreeing that application of the technologies increases yields. However, only 27% of the respondents perceived that ISFM technologies can control pests while 34% believed that the technologies help in controlling crop diseases.

Table 2. Adopters` perception of technological factors affecting adoption of ISFM technologies.

Perception	Yes (%)	No (%)	Not Sure (%) (n=370)
ISFM technologies are not easy to access	86	3	11
ISFM technologies improve soil fertility	70	25	5
ISFM technologies can control pest	27	55	18
ISFM technologies efficiently control diseases	34	43	23
ISFM technologies increase yields	94	2	4
ISFM technologies are costly	73	17	10
Weather variation affects the performance of adopted ISFM technologies	96	2	2

Source: Author`s computation from the conducted survey

A negative perception was observed regarding technologies` cost, access and weather influence, as agreed by 73%, 86% and 96%, respectively. It is, therefore, clear that adopters had varied perceptions of ISFM technologies. The perception of soil fertility management was reported to be significant in affecting the adoption of technology patterns (Mairura *et al.*, 2022).

Combination of selected ISFM technologies**:** This study evaluated the yields of the combinations of ISFM technologies currently utilized by adopters in growing sorghum. The results presented in Table 3 display the percentages of yields across the various combinations of adopted ISFM technologies. The findings show that only 2% of the respondents had adopted a complete set of the selected ISFM technologies inclusive of inorganic fertilizers. Only 8% adopted combinations that included inorganic fertilizers, which implies limited use of mineral fertilizers in sorghum growing. Similarly, combinations of ISFM technologies that incorporated organic fertilizers were adopted by respondents in proportions of 16%, 17% and 32%. This suggests that the substantial use of organic fertilizers was probably influenced by knowledge of the preparation of organic fertilizers and the practice of keeping livestock that provide manure. Approximately 25% of the respondents had adopted combinations of ISFM technologies that excluded both organic and inorganic fertilizers in sorghum cultivation. The absence of fertilizer in these combinations may be attributed to the high cost of fertilizers, which is not involved in livestock keeping or maintaining a number that is insufficient for accumulating manure for sorghum production.

Table 3. Mean yields of adopted combinations of ISFM technologies in sorghum production.

Adopted combination of selected ISFM technologies	Percentage (%) (N=370)	Yields (bags/acre)
Inorganic fertilizer + improved germplasm + organic fertilizer + legume intercrop + crop rotation + crop residue + zero tillage	2	5.7
Organic fertilizer + Improved germplasm + legume intercrop + crop rotation + crop residue	16	4.6
Improved germplasm + organic fertilizer + legume intercrop + Zero tillage	17	4.9
Inorganic fertilizer + improved germplasm + organic fertilizer + legume intercrop + crop rotation	8	5.4
Organic fertilizer + legume intercrop + crop rotation + zero tillage	32	4.4
Improved germplasm + legume intercrop + crop rotation + crop residue + zero tillage	25	3.8

Source: Author`s computation from the conducted survey

Nevertheless, combinations of ISFM technologies that included inorganic fertilizers demonstrated higher yields of 5.4 and 5.7 bags of sorghum per acre. Adopters who included organic fertilizers in their combination achieved yields between 4.4 and 4.9 bags of sorghum per acre, while those who did not use any fertilizers obtained yields of 3.8 bags. This underscores the fact that adopting the complete set of ISFM technologies leads to higher yields, possibly due to each technology contributing to achieving balanced nutrition. Overall, the adoption of ISFM combination is significantly differentiated. Varied combinations were reported to be arising from an imbalance in access to resources. Hence, adoption is based on the available resources (Mponela *et al.*, 2016).

Productivity of integrated soil fertility management technologies: The Probit model was used to estimate the propensity scores of ISFM adoption of each observation, where adoption takes a value of 1 if a farmer adopts a package of at least three ISFM technologies and 0 otherwise. The model was fit in explaining the factors influencing adoption. This was indicated by the likelihood ratio test statistics indicating that the coefficients of the hypothesis are equal to 0 and are rejected at a 1% level of significance (Table 4). Additionally, the model shows that the estimates of adoption correctly predict 51.62% of all observations.

Table 4. Estimation results of ISFM adoption.

Variables	Coeff.	Standard error
cons	1.510	1.514
Gender	-0.288	0.227
Age	0.00135	0.00916
Education	-0.00796	0.0694
Dependents	0.127	0.0673
Total farm size	-0.0630	0.0509
Subsistence farming	-2.391**	0.781
Commercial farming	0.0397	0.334
Credit access	-0.111	0.353
Group membership	0.555	0.374
Extension services	1.487**	0.497
Agricultural training	0.146	0.258
Source of agricultural info.	-0.0996	0.0816
Decision on new info.	-0.522**	0.166
Cultural influence	0.399	0.264
Road infrastructure	0.534*	0.224
ISFM Awareness	3.946***	0.657
Cost of ISFM	-0.387**	0.138
Log Likelihood	-95.878	
Number of observations	370	
Likelihood Ratio (LR) $X^2(17)$	204.630	
Prob> X^2	0.000	
Pseudo R^2	0.5162	

The results show that extension services and ISFM awareness influence the choice of adopting ISFM technologies positively, while farming goals for subsistence, decision on information use and cost of ISFM affected adoption negatively. This implies that sorghum production under ISFM technologies was curtailed by factors in and outside the farm. Given the potentiality of ISFM technologies in augmenting yields, such factors tend to influence the decision made by the farmer on whether to use or not use the technologies. These findings relate to the study of Draife *et al.* (2018), who found that some social, economic and institutional factors such as extension, source of technology information, knowledge of farming and herd size affected farmers` choice of innovative technologies.

The effect of ISFM technologies on productivity was determined through nearest-neighbour matching, kernel-based matching and radius matching (Table 5). The overall matching estimates showed that ISFM technologies positively impact the production of sorghum. The average treatment effect on adopters of ISFM was 1.268, 1.120 and 1.192 for the nearest neighbour, kernel-based and radius matches, respectively. This means that farmers growing sorghum were better in production by an average of 1.193 bags through the adoption of ISFM technologies. This is an indication that adopting ISFM technologies guarantees improved productivity of sorghum. The results correspond well with the findings that agricultural technologies play a crucial role in crop productivity (Kassie *et al.*, 2011). This is because technologies in themselves, especially ISFM, have the potential to improve crop productivity (Shah and Wu, 2019). The use of recommended standards of ISFM components, such as fertilizer, was found to increase sorghum output up to the range of 44-120% (Tabo *et al.*, 2007). Therefore, this is evident that the adoption of ISFM technologies has a positive and significant impact on sorghum yields per acre. This conclusion favours the findings that agricultural technologies positively influence crop yields if appropriate measures are put in place (Kassie *et al.*, 2011). Integrated soil fertility management methods, in particular, have played an important role in increasing crop yields, including maize (Kihara *et al.*, 2022). While ISFM is a definite means to boost agricultural yields, increased production is inextricably tied to the rate at which such technologies are adopted (Doldt *et al.*, 2023). The application of ISFM technologies has long-term benefits for soil, increasing crop yield Adams *et al.* (2020), which could greatly improve farmers' livelihoods.

Table 5. Effect of adoption of ISFM technologies on sorghum productivity (PSM).

Matching Algorithm	Outcome variable	ATT	Std
Nearest Neighbor	Sorghum yield in 90Kg bag / Acre	1.2682***	0.4873
Kernel-based	Sorghum yield in 90Kg bag / Acre	1.1200***	0.3319
Radius	Sorghum yield in 90Kg bag / Acre	1.1920***	0.2434

Conclusion: The results of this study highlight the significance of ISFM techniques in enhancing sorghum yields in the arid regions of Upper Eastern Kenya. It has a positive effect on yields. Hence, ISFM could be a strategy to increase food security in arid and semi-arid regions. However, there are social, economic, and institutional factors such as the cost of ISFM, awareness of ISFM, farming objectives for subsistence, and decisions on information use that influence the adoption of ISFM technologies. This emphasizes the importance of implementing focused interventions to enhance the uptake of beneficial agricultural technologies. These findings also highlight the critical need for increased funding of agricultural extension programs from a policy perspective. The government can facilitate the exchange of information between extension workers and farmers by constructing additional extension centres. This will aid in the effective dissemination of ISFM knowledge. In addition, initiating farmer-specific educational initiatives can help farmers fill up knowledge gaps and increase ISFM adoption, both of which mitigate the impact of climate change and ameliorate soils for better production. In addition, these findings extend beyond Kenya and have consequences for agricultural strategy. Notably, the deteriorating soil fertility and climate change variations cause significant challenges in crop production. However, ISFM technologies come in handy towards the maintenance of crop farming systems. Therefore, policymakers must consider incorporating ISFM into broader strategies for agricultural development and allocate resources to support its implementation on a community level. Facilitating this will aid in strengthening agricultural systems, which will improve farmers` livelihoods and sustain the productivity of soils.

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***SDGs Addressed*:** No Poverty, Zero Hunger.

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