

**ADOPTION, PRODUCTIVITY AND RETURN ON INVESTMENT  
OF INTEGRATED SOIL FERTILITY MANAGEMENT  
TECHNOLOGIES AMONG SORGHUM FARMERS IN THARAKA-  
NITHI COUNTY, KENYA**

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MASTER OF SCIENCE IN AGRICULTURAL ECONOMICS OF  
THE UNIVERSITY OF EMBU**

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## DECLARATION

This thesis is my original work and has not been presented elsewhere for a degree or any other award.

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## **DEDICATION**

This work is dedicated to my beloved mother Eunice Chepkirui and my two well-wishers Mary Rotich and Elizabeth Macharia. Your support and prayers impacted me positively.

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## TABLE OF CONTENTS

<b>DECLARATION</b> .....	<b>ii</b>
<b>DEDICATION</b> .....	<b>iii</b>
<b>ACKNOWLEDGEMENT</b> .....	<b>iv</b>
<b>LIST OF TABLES</b> .....	<b>viii</b>
<b>LIST OF FIGURES</b> .....	<b>ix</b>
<b>LIST OF APPENDICES</b> .....	<b>x</b>
<b>LIST OF ABBREVIATIONS</b> .....	<b>xi</b>
<b>DEFINITION OF TERMS</b> .....	<b>xii</b>
<b>ABSTRACT</b> .....	<b>xiii</b>
<b>CHAPTER ONE</b> .....	<b>1</b>
<b>INTRODUCTION</b> .....	<b>1</b>
1.1 Background of the study.....	1
1.2 Statement of the problem .....	3
1.3 Research objectives .....	4
1.3.1 General objective.....	4
1.3.2 Specific objectives.....	4
1.3.3 Research questions .....	4
1.5 Justification .....	5
1.6 Scope of the study .....	5
1.7 Limitations of the study.....	5
<b>CHAPTER TWO</b> .....	<b>7</b>
<b>LITERATURE REVIEW</b> .....	<b>7</b>
2.1 Overview of sorghum production and productivity in Kenya.....	7
2.2 Factors influencing adoption of integrated soil fertility management technologies	8
2.3 Effect of integrated soil fertility management on sorghum productivity .....	9
2.4 Effect of integrated soil fertility management on returns on sorghum farming .....	10
2.5 Research gap.....	11
2.6 Theoretical framework .....	12
2.6.1 Random utility theory.....	12
2.6.2 Profit maximization theory.....	13
2.7 Conceptual framework .....	13

2.8 Operationalization of variables .....	15
<b>CHAPTER THREE .....</b>	<b>21</b>
<b>METHODOLOGY .....</b>	<b>21</b>
3.1 Study area .....	21
3.2 Research design .....	21
3.3 Target population and sample size .....	21
3.4 Sampling procedure.....	22
3.5 Data collection.....	23
3.6 Reliability and validity of instrument.....	23
3.7 Data analysis.....	24
3.7.1 Analytical test.....	24
3.7.1.1 Testing the explanatory variables for multicollinearity.....	24
3.7.2 Socioeconomic and institutional factors affecting adoption of integrated soil fertility management (ISFM).....	24
3.7.4 Effect of adopted ISFM technologies on sorghum productivity .....	25
3.7.5 Effect of adopted ISFM technologies on return on investment in sorghum farming .....	27
<b>CHAPTER FOUR.....</b>	<b>30</b>
<b>RESULTS AND INTERPRETATION .....</b>	<b>30</b>
4.1 Overview .....	30
4.2 Reliability and validity results.....	30
4.3 Descriptive results .....	31
4.3.1 Socioeconomic characteristics of adopters and non-adopters .....	31
4.3.2 Institutional factors of adopters and non-adopters.....	32
4.3.3 Continuous and discrete variables of adopters and non-adopters.....	36
4.3.4 Perception of integrated soil fertility management technologies (ISFM) among adopters.....	37
4.3.5 Combination of ISFM technologies.....	38
4.4 Multicollinearity .....	41
4.5 Factors affecting adoption of integrated soil fertility management technologies ..	41
4.5. 1 First hurdle.....	41
4.5.2 Second hurdle .....	44
4.6 Effect of ISFM technologies on sorghum productivity.....	45

4.7 Results of inverse probability-weighting with regression adjustment .....	47
4.8 Effect of ISFM technologies on return on investment of sorghum production.....	48
<b>CHAPTER FIVE.....</b>	<b>52</b>
<b>DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS .....</b>	<b>52</b>
5.1 Summary of the findings .....	52
5.2 Factors affecting adoption and adoption intensity of ISFM technologies.....	52
5.2.1 Adoption of ISFM .....	52
5.2.2 Adoption intensity .....	53
5.3 Effect of ISFM on productivity of sorghum.....	53
5.4 Effect of ISFM technologies on return on investment of sorghum.....	54
5.5.1 Factors affecting adoption and adoption intensity of integrated soil fertility management technologies.....	55
5.5.2 Effect of ISFM technologies on sorghum productivity .....	60
5.6 Conclusions and recommendations .....	62
<b>REFERENCES.....</b>	<b>64</b>

## LIST OF TABLES

Table 1: Operationalization of variables .....	15
Table 2: Distribution of the sampled households.....	22
Table 3: Spearman-Brown Coefficient of reliability results .....	30
Table 4: Categorical statistics of socioeconomic characteristics of Adopters and Non-Adopters .....	32
Table 5: Categorical statistics of institutional characteristics of Adopters and Non-Adopters .....	35
Table 6: Descriptive statistics of continuous and discrete variables of Adopters (N=286) and Non-adopters (N=84) .....	37
Table 7: Adopters` perception of technological factors affecting adoption of ISFM technologies.....	38
Table 8: Mean yields and returns of adopted combinations of ISFM technologies in sorghum production .....	40
Table 9: MANOVA test on observed differences in yields and returns .....	40
Table 10: Multicollinearity test.....	41
Table 11: Estimates from Double Hurdle Model.....	43
Table 12: Truncated .....	45
Table 13: Estimation results of ISFM adoption .....	46
Table 14: Effect of adoption of ISFM technologies on sorghum productivity (PSM) ....	47
Table 15: Effect of ISFM technologies on sorghum productivity (IPWRA).....	48
Table 16: Movestay estimates on adoption of ISFM technologies .....	50
Table 17: Effect of ISFM technologies on return to investment.....	51

## LIST OF FIGURES

Figure 2. 1 Conceptual framework.....	14
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## **LIST OF APPENDICES**

Appendix 1: Map of Tharaka-Nithi County, Kenya .....	78
Appendix 2: Questionnaire .....	79

## **LIST OF ABBREVIATIONS**

<b>ANOVA</b>	Analysis of Variance
<b>EOR</b>	Economic Optimal Rate
<b>ESR</b>	Endogenous Switching Regression
<b>FAO</b>	Food and Agriculture Organization
<b>GM</b>	Gross Margin
<b>ROK</b>	Republic of Kenya
<b>HA</b>	Hectares
<b>ICT</b>	Information Communication Technology
<b>IPWRA</b>	Inverse Probability Weighting Regression Adjustment
<b>ISFM</b>	Integrated Soil Fertility Management
<b>KES</b>	Kenyan Shillings
<b>KG</b>	Kilograms
<b>MANOVA</b>	Multivariate Analysis of Variance
<b>MC</b>	Marginal Cost
<b>MR</b>	Marginal Revenue
<b>PSM</b>	Propensity Score Matching
<b>ROI</b>	Return On Investment
<b>SSA</b>	Sub-Sahara Africa
<b>TR</b>	Total Revenue
<b>TVC</b>	Total Variable Cost
<b>UN</b>	United Nation
<b>VIF</b>	Variance Inflation Factor

## **DEFINITION OF TERMS**

- ISFM:** Integrated Soil Fertility Management (ISFM) is defined a set of soil fertility management practices comprising the use of mineral fertilizer, organic inputs, agronomic techniques and improved germplasm that aim at balancing soil nutrition (Vanlauwe et al. 2010).
- Adoption intensity:** The size of the farm that has been allocated for the practice of integrated soil fertility management (ISFM) technologies.
- Productivity:** It is defined as the ratio of quantity of output to the quantity of input used during the process of production (FAO, 2017). Therefore, it examines the relationship between input and output in a given production process.
- Return on investment:** The measure of benefit relative to the cost in an investment (Schueler et al., 2017). In this study, return on investment refers to the measure of benefits from ISFM investments relative to the cost of investment in the selected technologies.
- Profitability:** The ability of the farm to use available resources to generate returns that are higher than the cost incurred during the process of production.

## ABSTRACT

Declining soil fertility poses a serious threat to food production and food security to most farming households. Integrated Soil Fertility Management (ISFM) comprising the combination of organic and mineral fertilizer and other practices such as cereal-legume intercropping, diversified crop rotation and farmers' knowledge has been promoted in various countries in Sub-Saharan Africa (SSA) including Kenya. This study aimed at evaluating adoption, productivity and return to investment of ISFM technologies among sorghum farmers in Tharaka-Nithi County, Kenya. Cross-sectional data was obtained from a sample of 370 sorghum farmers through multistage stratified random sampling technique. The study employed a semi-structured questionnaire that was administered to the respondents to obtain relevant data. The SPSS and STATA softwares were used to analyze data and results presented using descriptive and inferential statistics. Cragg's Double Hurdle model was used to assess the influence of socioeconomic and institutional factors on the adoption intensity of ISFM technologies among sorghum farmers. Propensity Score Matching (PSM) and (Inverse Probability Weighting Regression) IPWRA models were applied in determining the effect of selected ISFM technologies on sorghum productivity among farmers. Budgetary technique was used to evaluate return on investment while Endogenous switching regression (ESR) model was used in determining the effect of selected ISFM technologies on return on investment (ROI) of sorghum. The results revealed that gender, dependents, farming goal for subsistence purpose, 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. The first stage results of PSM shows that extension services and ISFM awareness was significant in influencing adoption of the ISFM technologies positively while farming goal for subsistence, decision on information use and cost of ISFM affected adoption negatively. The second stage determined average treatment effect on adopters of ISFM and the results was 1.268, 1.120 and 1.192 bags of sorghum for nearest neighbor, kernel based and radius matches respectively. The results reveal that farmers who use ISFM technologies would produce 4.696 bags of sorghum compared to 1.424 bags obtained from not using the technologies. The expected ROI of farmers growing sorghum under ISFM technologies was reported to be 1.945 while that of non-adopters was 0.783. Based on the counterfactual outcomes ROI would have been 2.409 for adopters and 0.734 for non-adopters. It was therefore concluded that socio-economic and institutional characteristics continue to influence the choice to adopt ISFM technologies. The performance of adopted technologies on productivity and returns on investment as well remains high compared to non-adoption. 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 decision on pro-adoption, which will improve sorghum productivity and returns in Tharaka-Nithi County.

## CHAPTER ONE

### INTRODUCTION

#### 1.1 Background of the study

Agriculture is one of the key sectors that play an important role in economic growth and development of most economies across the globe (Khan et al., 2020). Close to 80% of the total population depend on agriculture 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 due to population pressure and climate change (Ghosh, 2019; Njenga et al., 2021). Increased population reduces the capacity of arable land used for food production through increased land use for settlement, industrialization and expansion of infrastructure Coulibaly & Li, (2020); while variation in climate impacts on the sustainability of food production threatening the state of food security across the globe (Yazar & Ali, 2017). The stress of growing population and climate variation is more prominent in Sub-Saharan Africa (SSA) especially the dry areas (Mugwe & Otieno, 2021; Ndeke et al., 2021). This creates a hindrance to food production 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).

Some of the effects posed by climate change include; erratic rainfall, prolonged droughts, high temperature and unproductive lands determined by exhausted organic matter and low biological activities, which will ultimately bring negative impact on soil productivity for farmers (Mugwe et al., 2020; Ndeke et al., 2021). Attempt to curb this climate change is constrained by challenges like limited institutional support, low public investment on rain fed agriculture, under irrigation and gender differences which aggravate further the poor productivity of soil (Shimeles et al., 2018). Therefore, great effort is required to safe guard the underlying problem of intense soil degradation.

Low agricultural productivity in SSA is attributed to decreasing soil fertility that results from insufficient and improper techniques of fertilizer application, monoculture and improper management of crop residues (Vanlauwe et al., 2015). Interestingly, Africa accounts for 58 percent of arable land, which is approximately 873 million hectares globally. Eighty three percent of this portion is seriously affected by problems of soil

fertility while 75 percent experience severe deterioration of soil fertility (Wawire et al., 2021). Declining soil fertility is often contributed by severe nutrient mining without sufficient nutrient replenishment by external inputs (Souri et al., 2019; Tekulu et al., 2020). Similarly, heavy reliance on inorganic fertilizers contributes to unfavorable soil health lowering the realization of full potential of the land especially among the smallholder farmers (Stewart et al., 2020). However, to mitigate unproductive soils both donors and various governments have promoted the use of Integrated soil fertility management (ISFM) in various regions of SSA (Hörner & Wollni, 2021).

The Integrated Soil Fertility Management (ISFM) constitutes the application of diverse options of inputs and practices of soil conservation that a farmer can choose to use. The practices and inputs recommended 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 reflects the best use of inherent soil nutrients to improve soil fertility (Hörner & Wollni, 2021). The synergistic combination of ISFM technologies is believed to bear a trifold benefit that include; improved soil fertility, increased crop yields and improve household incomes (Agegnehu & Amede, 2017).

In Kenya, the ISFM has been promoted and tested in sorghum production in Tharaka-Nithi County (Kimaru, 2017). The previous studies have strongly asserted that ISFM technologies have great potential to improve agricultural productivity especially in arid and semi-arid areas but its adoption is still low. Stagnating and declining adoption levels have been attributed to limited resources within the farming households (Adimassu & Biratu Assefa Abera, 2017; Mponela et al., 2016; Wawire et al., 2021). Others posits that the use of a technology by an household is influenced by both biophysical attributes and the variation of farmer characteristics which generate diverse farming patterns (Yengoh, 2012). The adoption of soil fertility improving technologies is further constrained by high fragmentation of land that limits the potential of the farming household 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.

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 to 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 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 et al., 2021; Ndeke et al., 2021; Otieno et al., 2021; Otieno et al., 2021). The factors influencing double approach of adoption and adoption intensity on the recent set of ISFM technologies under sorghum is hardly given due regard as a front for improving crop productivity using these appropriately combined technologies. Similarly, there is inadequate information on how the technologies affect the economic returns of crops such as sorghum in dry zones. In this regard, the study seeks to determine the extent to which the selected socioeconomic and institutional factors affect adoption and adoption intensity of ISFM technologies, and determine the effect of ISFM on productivity and return on investment of sorghum among farmers in Tharaka-Nithi County.

## **1.2 Statement of the problem**

Globally, deteriorating soil fertility is a very critical challenge towards attainment of the envisaged sustainable agricultural productivity. Sub-Saharan Africa (SSA) experiences this challenge largely due continuous cropping, limited soil amendments and its susceptibility upon the impact of climate change. Current climate change results to extreme weather conditions that includes heavy rains and prolonged drought, posing a serious risk especially to farmers' dependent on rain-fed farming. The risk results to poor growth of crops, which increases food insecurities. The problem can be rectified by the adoption of ISFM technologies. These technologies are progressively being promoted in Kenya especially in the semi-arid areas. Despite the efforts by both the government and other developmental organization to disseminate technologies, adoption by the farmers is still low. Additionally, the role of such strategies to address poor soil fertility in order to improve agricultural productivity have not been fully investigated in Kenya, especially

for drought tolerant crops like sorghum in drier areas around Mt. Kenya. There is also little information pertaining to the best combination of ISFM technologies and its returns on sorghum in such areas. This necessitated the need for the study to address adoption, productivity and return on investment of ISFM technologies in dry parts of Tharaka-Nithi County.

### **1.3 Research objectives**

#### **1.3.1 General objective**

To evaluate the adoption, productivity and return on investment of integrated soil fertility management technologies among sorghum farmers in Tharaka-Nithi County, Kenya

#### **1.3.2 Specific objectives**

- i. To assess the socio-economic and institutional factors influencing adoption intensity of ISFM technologies among sorghum farmers in Tharaka-Nithi County, Kenya.
- ii. To determine the effect of adoption of integrated soil fertility management technologies on sorghum productivity among farmers in Tharaka-Nithi county, Kenya.
- iii. To evaluate the return on investment of adoption of selected integrated soil fertility management technologies among sorghum farmers in Tharaka-Nithi County, Kenya.

#### **1.3.3 Research questions**

- i. Which socio-economic and institutional factors affect adoption intensity of integrated soil fertility management technologies among sorghum farmers in Tharaka-Nithi County, Kenya?
- ii. What is the effect of integrated soil fertility management technologies adoption on productivity among sorghum farmers in Tharaka-Nithi County, Kenya?
- iii. What are the returns on investment from the adoption of selected integrated soil fertility management technologies among sorghum farmers in Tharaka-Nithi County, Kenya?

### **1.5 Justification**

Food insecurity is a problem that remains to be sorted by the government of Kenya. Through the government program of Vision 2030 and the Bottom-Up Economic Transformation Agenda, food security is among the key aspects of development in the country. Similarly, achievement of food security has been one of the major objective of Sustainable Development Goals of the United Nations (UN). This is also in line with the Africa Agenda 2063 and African Union summit geared towards reinforcing pillars to reduce poverty and hunger through development of sustainable agriculture. Therefore, there is need to regenerate and establish proven farming practices such as ISFM to enhance resilient food system. Additionally, agriculture sector needs to refurbish measures that have been curtailed by natural conditions prevailing in the arid and semi-arid areas so as to improve on productivity. Ultimately, the findings of the study will aid in guiding the policy makers in designing appropriate agricultural development strategies for the ASALs such as Tharaka-Nithi County. Farmers will benefit from the study through in-depth understanding of ISFM practices and also obtain information on the best combination of the technologies that generate more yields. Researches from the related field will also benefit from the knowledge contributed by this study.

### **1.6 Scope of the study**

This study was conducted in the dry eastern region of Kenya specifically the dry zones of Tharaka-Nithi County. The area was selected because most projects related to ISFM technologies have been promoted in the area and the fact that the area is one of the leading producers of sorghum in the country yet the productivity of the crop is still low. All the data collected for this study was within the sorghum farming zones in Chuka/Igamba-Ngombe Sub-county. The study focused on attaining the information that pertains its main objective intended to be achieved. It also aimed at determining features affecting adoption and adoption intensity of ISFM technologies and the effect of ISFM technologies on sorghum productivity and return on investment.

### **1.7 Limitations of the study**

This study was narrowed to determining socio-economic and institutional factors yet there are myriad aspects that could affect adoption and adoption intensity. This might generate

limited data, therefore, future studies should focus on incorporating technological, environmental and behavioral factors in relation to adoption and adoption intensity of agricultural technologies. Due to financial constraints and other factors, the study findings was limited to only one sub-county. The study also sorted to establish findings only in the upper eastern regions yet the country has a large cover of ASALs. It is evident that weak policy implementation has degenerated the efficacy of the ISFM technologies. This problem resulted to poor maintenance of ISFM technologies therefore limiting its potential resulting to attainment of poor data. The responses to the questions of this study was limited to the indebt understanding and ability to recall previous performance of ISFM technologies.

## CHAPTER TWO

### LITERATURE REVIEW

#### 2.1 Overview of sorghum production and productivity in Kenya

Sorghum is ranked fourth substantial cereal after maize, wheat and rice (Ochieng et al., 2020). Its importance is more advantageous in arid and semi-arid zones across the country. The crop is drought tolerant and is the most preferred alternative for food security and source of livelihood to many farmers in ASAL zones (Okeyo et al., 2020). Sorghum has a variety of uses that include porridge, flour, and local brew among others. However, arid and semi-arid regions register low productivity as a result of poor agronomic practices and deficient soil nutrients (Kagwiria et al., 2019). To mitigate this challenge, the Republic of Kenya (RoK) has put up strategies to raise food security and reduce poverty levels in these areas and as well promote sorghum production as a major source of livelihood (Mwangi et al., 2021). The Kenya Plant Health Inspectorate Service (KEPHIS) informs that by 2018, forty three sorghum varieties had been certified, registered and released to the farmers implying that the government is at the fore front of technology advancement (Mwangi et al., 2021).

Worldwide, production of sorghum stands at 60 million metric tons. A third of this production comes from entire Africa. However, Kenya contributes 0.6% only from the total 20 million metric tons produced in Africa (Okeyo et al., 2020). Sorghum is majorly produced in semi-arid areas of eastern, western and coastal regions of the country (Njagi et al., 2019). Current sorghum production in eastern is at two to four bags in one acre which is below the actual yield of five bags in one acre. In contrast to this, optimal application of required nutrients during production of sorghum yields 3 bags per acre when conditions are poor and up to 18 bags per acre at favorable conditions (Karanja et al., n.d.). Consequently, productivity of crop in the potential areas is declining owing to production for subsistence purposes (Esilaba et al., 2021; Okeyo et al., 2020). Low productivity also results from poor agronomic practices and the deficiency of soil nutrients in sorghum farms (Kagwiria et al., 2019).

## **2.2 Factors influencing adoption of integrated soil fertility management technologies**

Various components of ISFM have great potential of improving soil fertility and output (Kamau et al., 2014). Most farmers have not been able to leverage these crucial aspects of ISFM technologies to the required level due to the constraints arising from various institutional and socio-economic characteristics (Mucheru-Muna et al., 2021).

In Malawi, a study on predictors of ISFM technologies adoption and non-adoption among small-scale maize farmers using bivariate and multivariate probit model to analyze data found that access to legume seeds and extension services negatively influenced the practice of maize-legume intercropping and crop rotation. On the other hand, farm size had a positive influence as it encouraged the adoption of the two practices (Kanyamuka et al., 2020). This study however, focused only on intercropping and crop rotation practices and hence it did not capture the other practices such as fertilizer application.

When introducing a new technology, a study in Kenya on socioeconomic determinants, knowledge on ISFM and strategies of maize intensification discovered that there was the need to consider farmer`s knowledge, age, availability of labor, level of education, experience in farming, distribution of land, training, household income and gender of the households head (Mucheru-Muna et al., 2021). However, this study did not consider other determinants such as technological factors and institutional factors that play a major role in adoption of technology. The study of assessing soil fertility management among smallholder farmers of Mt Kenya East used a correlation matrix in data analysis. It revealed that adoption of the selected practices was affected by age, gender, education, occupation, level of experience, information on credit, number of livestock, household income, family size, type of labor and tropical livestock units. The size of the household and on farm labor influenced the adoption of ISFM technology while the size of livestock boosted manure utilization (Wawire et al., 2021). Notably, this study did not consider the use of other techniques such as liming and used of improved varieties by the smallholder farmers as part of ISFM practices.

The study of Kwadzo & Quayson (2021) used logit and multivariate model in examining the determinants of ISFM technologies among smallholder farmers in Ghana. They found out that factors such as ownership of land, proximity to the shop, agro-ecological

conditions, credit access and purpose of farming was significant in influencing adoption of ISFM technologies. However, this study focused on four technologies that included mineral fertilizer, minimum tillage, intercrops of legume and crop rotation. Hence, it has limited findings since it does not provide the factors affecting other technologies, for instance, organic farming and improved germplasm. Similarly, characteristics such as education level, extension services, region, food security status and ready market affected the adoption of ISFM technologies in bean production. This study was conducted in Machakos and Bungoma, and logistic regression model was applied in determining the factors affecting adoption (Emongor et al., 2022). Its findings are only limited to adoption hence it does not show the determinants on aspects of adoption intensity of ISFM technologies.

### **2.3 Effect of integrated soil fertility management on sorghum productivity**

Productivity in agriculture is raising a great concern over the increasing population that puts pressure on the available food systems (Clercq et al., 2018). Popp et al., (2014) indicates that to meet the current global food demand, there is need to improve agricultural productivity with a quest of minimizing ecosystem interaction. Integrated soil fertility management is therefore, considered to be one of the best approaches in breaking the nexus between high food demand and climate variations. A study in Burkina Faso confirms that the ISFM components which is cattle manure (5t/ha) and use of mineral fertilizer in the proportion of 60 kg-N/ha and 7.5 kg-P/ha produced the highest yields of sorghum (Serme et al., 2018). Similarly, the work in Ethiopia reported high productivity of sorghum with intercrop of haricot bean than cow pea (Hailu & Geremu, 2021) albeit the study does not reveal the variation of productivity between the two legumes. Increased cereal productivity by 200% was reported by the study related to managing soil fertility integration and crop nutrition in Ethiopia (Agegnehu & Amede, 2017). This study, however, did not reveal the performance in different treatments of integrated soil fertility and plant nutrient management.

A station experiment in Benin sought to establish whether the combination of a mix of hill-placed manure and mineral fertilizer technologies enhances maize productivity and profitability (Tovihoudji et al., 2017). The findings showed that there was gradual increase

in maize productivity in the subsequent 4 years of the experiment. This study majorly focused on maize hence there is no evidence on the performance of the practices on other cereal crops. The study reviewing the integration of organic and mineral fertilizer in Ethiopia reports that this approach improves crop productivity in spite of the fact that there is still low adoption of this ISFM technologies (Biramo, 2018). In Zimbabwe, the study on evaluation of integrated soil fertility management technologies and inoculation on soya bean growth and final yield using ANOVA; the data analysis reports indicated that the yields were higher in the treatment of inoculated soya bean, farmyard manure and mineral fertilizer (Kupurai et al., 2020). This study was limited to only technologies of inoculation, farmyard manure and mineral fertilizer. A study by Mango et al., (2020) reveals that integration of land, water and soil conservation technologies enhanced soil fertility and it has a capacity to markedly improve cereal productivity. In Philippines, research on the effect of community based farming and technology on productivity clearly reveals that Mango production was improved from approximately three to seven kilograms per hectare through the crop integrated management (Paguia et al., 2019). It is clear from the extant studies that ISFM technologies contributes in a large extent the yield of various crops and there is need to fully exploit the performance of these technologies in order to improve on food production.

#### **2.4 Effect of integrated soil fertility management on returns on sorghum farming**

It is imperative to note that countries like China and Japan reap considerable returns as a result of technology transfer in the agriculture sector (Mgendi et al., 2019). Therefore, technology adoption in agriculture is pertinent in ensuring that farmers obtain favorable returns across the whole value chain. A study assessing the economics of soil fertility management approaches in Nigeria using gross margin and multinomial logit model in data analysis showed that use of ISFM in maize production was the most profitable method with a ratio of 2.29 (Ogwu et al., 2018). In Ghana, the study on analyzing optimal fertilizer use in the context of ISFM found that farmers applying the technology in Economic Optimal Rate (EOR) gains a lot of returns compared with the application rate that was existing (Tetteh et al., 2017). However, these studies have applied gross margins in analyzing profitability and little focus is given to other methods such as budgetary techniques.

In Benin, the study on the use of farmyard manure and mineral fertilizer revealed that the gradual combination of the two fertilizers were able to increase the gross margins of maize revealed by value cost ratios and benefit-cost ratios greater than two (Tovihoudji et al., 2017). The study on the effect of ISFM on household in Ethiopia using inverse probability weighting regression adjustment method, and propensity score matching in data analysis found that ISFM had the potential of increasing income (by 32% for partial adoption and 33% for full adoption ) from investing the technology in wheat, teff and maize production (Hörner & Wollni, 2020). Similarly, the same findings also show that ISFM contributed to reduced income in other crops. This is therefore a clear indication that when ISFM technologies are appropriately applied under various agro ecological zones in farm production, benefits are realized (Adamtey et al., 2016). However, it is not clear whether the application of ISFM technologies in sorghum production yields better returns in the study area.

## **2.5 Research gap**

Based on the reviewed literature, it is clear that there are minimal studies on evaluation of adoption, perception, productivity and return on investment of ISFM technologies among growers of sorghum in Tharaka-Nithi in particular. Most studies have not considered social economic factors such as farm objectives, economic objectives, cognitive elements and even institutional factors such as market promotion, affordability of credit, willingness to take credit, past experience on credit, existing research institution among others. Most behavioral factors that affect decision-making have not been considered conclusively especially in the study area. Most studies of ISFM such as Kanyamuka et al., (2020); Mucheru-Muna et al., (2021); and Wawire et al., (2021) focused on socioeconomic and institutional factors such as age, education, access to agricultural credit, market access, farm size and extension services. Similarly, the benefits of ISFM package have not been fully exploited especially in crops such as sorghum. Conducting this study therefore was valuable in providing better understanding on the influence of institutional and socioeconomic factors on adoption and adoption intensity of ISFM technologies, effect of selected ISFM technologies on productivity and returns of Sorghum among farmers.

## 2.6 Theoretical framework

This study was anchored in two theories, random utility theory and profit maximization theory.

### 2.6.1 Random utility theory

This theory stipulates that the decision to adopt is regarded as a behavior expressed by a household towards a technology or innovation. This decision is normally triggered by the perceived benefit in choosing to adopt or not. In this study, sorghum farmers who are the consumers of integrated soil fertility management (ISFM) technologies are assumed to be rational with the goal of maximizing the utility derived in the use of the technologies they have adopted. Therefore, a farmer will adopt integrated soil fertility management (ISFM) technologies if he or she will perceive to earn higher returns than the non-adopters (Llewellyn et al., 2007). In essence, expected utility that is derived from technologies is considered random since it is neither observable nor known (Fernandez-cornejo, 2018). For this study, the utility associated with adoption of the integrated soil fertility management (ISFM) technologies is a function of the possible outcome.

$$U_0 = f \left( \frac{b}{X_0} \right) \dots\dots\dots 2.1$$

$$U_1 = f \left( \frac{b}{X_1} \right) \dots\dots\dots 2.2$$

$U_0$  and  $U_1$  are utilities derived from not adopting and adopting integrated soil fertility management (ISFM) technologies respectively,  $X_0$  and  $X_1$  are the socioeconomic and institutional factors affecting sorghum farmers and the  $b$ s are the parameters that explain the effect of farmers' characteristics on the utility derived.

Therefore, sorghum farmer will adopt integrated soil fertility management package or part of its components if ( $U_1 > U_0$ ), if the expected utility of adoption exceeds that of non-adoption. The utility derived from applying a given technology, adoption or non-adoption, cannot be observed. What is observable is the choice of soil fertility improvement strategies and subsequent adoption if its utility is high. The farmers who have adopted ISFM technologies will take a yes response and a 'no' response will be assigned to farmers

who are non-adopters of the ISFM technologies. The utility derived by adopters is assumed to be high and low for the non-adopters.

### 2.6.2 Profit maximization theory

Profit maximization theory assumes that farmers are efficient producers considered as the agents who maximize profit in economics. In comparison with risk averse, this kind of producers are just concerned with family welfare and not profit maximization (Masuku, 2014). Many firms take profit maximization as the only feasible goal coupled with the desire to fight rivals in the business environment. In essence profit is obtained from the difference of farm`s total revenue and total cost. This can be given as;

$$\pi = TR - TC \dots\dots\dots 2.3$$

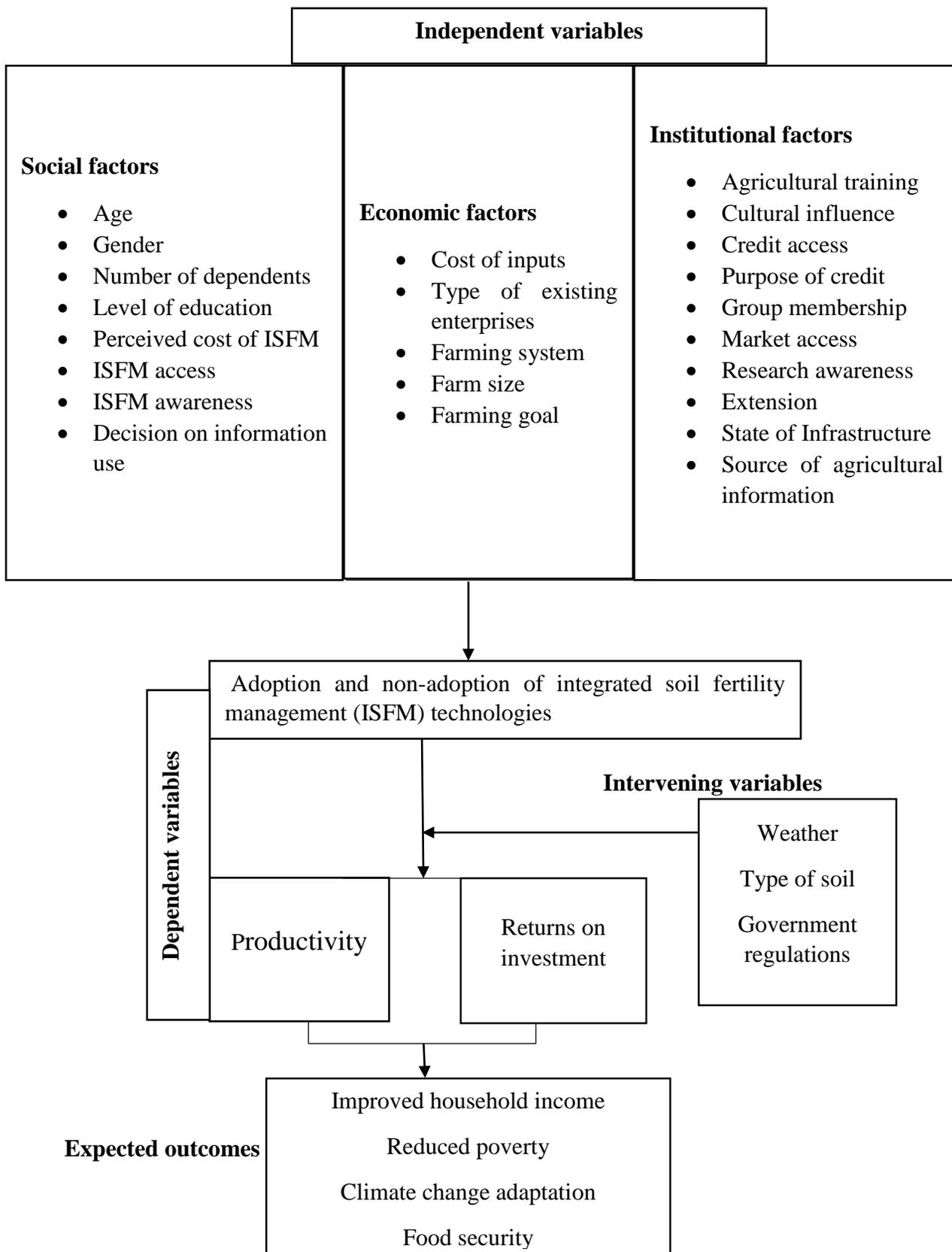
Where:  $\pi$  is the Profit, TR is the Total Revenue and TC is the Total Cost.

For this study therefore, TR will be the overall value of sales while TC is the total cost incurred during the process of production of sorghum under ISFM technologies. However, the household would consider increasing sorghum output when marginal revenue obtained from additional units of production under ISFM technologies will be higher than the marginal cost. For this case MR will be the additional revenue earned by the sale of one more unit of sorghum yields. On the other hand, MC will be the additional cost incurred in production of one more unit of sorghum. Hence, sorghum yields can be increased up to a point where MR=MC, which is normally referred as the point of profit maximization.

### 2.7 Conceptual framework

This Figure (2.1) indicates the conceptual framework for the study. It demonstrates the interaction of the dependent and independent variables. Socioeconomic and institutional factors are the independent variables while adoption intensity, productivity and returns on investment are the dependent variables. It is conceptualized that prevailing institutional factors, socioeconomic factors, productivity and profitability influences the choice of ISFM technologies. Therefore, this framework aid in developing understanding of how variables interact simultaneously.

**Figure 2. 1 Conceptual framework**



## 2.8 Operationalization of variables

The literature anchoring this study elucidate that technology adoption is affected by several factors. These factors may include socioeconomic and institutional factors considered in this study which determines the choice of adopting and intensity of adopting ISFM technologies. Explanatory variables selected to model the study include; age, gender, dependents, education, farm size, extension, group membership, cultural influence agricultural training, decision on information use, farming goal, research awareness, source of agricultural information, credit access, market access, ISFM awareness, ISFM access and cost of ISFM.

Table 1: Operationalization of variables

Variable	Description	Type	Expected sign
Independent variable			
Age	Farmer`s age in years	Continuous	+/-
Gender	Sex identity of the farmer (1 if male and 2=female)	Categorical	+/-
Dependents	Number of family members supported by the main income earners of the household	Discrete	+/-
Education	Education attained by the household respondent (1=None,2=Primary, 3=secondary, 4=Tertiary)	Categorical	+
Farm size	Total size of land owned by the farming household in acres	Continuous	+
Extension	Whether the household farmer has access to extension services(1 if yes, 0 otherwise)	Dummy	+
Group membership	Household participation in existing agricultural groups (1 if a member, 0 otherwise).	Dummy	+
Cultural influence	Perception on how culture influence technology use (1 if positive, 0 otherwise).	Dummy	+/-
Farm goal	Key farming decisions (for subsistence and commercial) of a household (1 if yes, 0 otherwise).	Dummy	+
Research awareness	Farmer`s awareness on the existing research (1 if yes, 0 otherwise).	Dummy	+
Agricultural training	Access to formal agricultural training by a household (1 if yes, 0 otherwise).	Dummy	+

Table 1 Cnt.

Source of agricultural information	Main source of agricultural information used by a household (1= farmers group, 2= Extension officers, 3=Radio, 4=Television, 5= Neighbors and 6= Internet).	Categorical	+
Decision on info. Use	Household decision on the use of new information (1 if yes, 0 otherwise).	Dummy	+
Credit	Access to credit by a household (1 if yes, 0 otherwise).	Dummy	+
Market access	Household access to market (1 if yes, 0 otherwise)	Dummy	+
ISFM awareness	Whether the household farmer is aware of ISFM technologies (1 if yes and 0 otherwise).	Dummy	+
ISFM access	Farmers who are proximal to ISFM technologies (1 if yes, 0 otherwise)	Dummy	+
Cost of ISFM	Perception on the cost of ISFM technologies (1=Expensive, 2=moderate, 3=Affordable, 4=Cheap).	Categorical	-
Dependent variable			
Adoption	Household farmer decision to adopt ISFM technologies or not (1 if Yes and 0 otherwise).	Binary	+
Adoption intensity	The size of land under ISFM technologies in a household in acres.	Continuous	+

### Age

Age is hypothesized to cause a mixed effect on adoption of ISFM. Young farmers have higher interest of venturing into the new technologies and they are risk takers hence they are likely to adopt the technologies (Saadun et al., 2018). Albeit older farmers being considered to be experienced and knowledgeable in farming, they tend to possess weak potential of adoption due to low interest of learning new technologies (Draife et al., 2018).

### Gender

In this study the gender of the farmer is hypothesized to influence adoption of ISFM technologies in a positive and negative extent. Positive rational is derived due to the ability of male in Africa to access greater control of resources compared to their counterparts.

Households headed males was pointed by Ernah et al. (2016) that they have the potential of adopting agricultural technologies.

### **Education**

Education is predicted to positively impact the choice of whether or not to adopt ISFM technologies. In farming, education is associated with the value of initiating better understanding of utilization of agricultural technologies. Education was positively significant in adoption of natural resource management (NRM) technologies (Ruzzante et al., 2021). However, less educated farmers affected adoption of organic cotton positively in Benin (Sodjinou et al., 2015).

### **Farm size**

The size of the farm owned by the farmer tend to affect adoption. It was measured in acres. In this study, it was hypothesized to have a negative and positive impact on adoption. Households possessing small sizes are potential adopters of the technologies which will transform their land performance. Large farm size discourage adoption where use of costly technologies is applied. Farm size had a significant influence in the decision to adopt ISFM technologies (Khonje et al., 2022).

### **Farming goal**

The major driving factor in farming is the underlying goal. Farming is either subsistence based or commercial based and many a times both. The farming goal is thus predicted to affect the decision to adopt the technologies positively. New farming technologies are likely to be adopted by a household to ensure more is produced for food security or stable income.

### **Group membership**

Group membership is predicted to affect decision of adopting ISFM technologies positively. Existing farmer groups are normally organized by farmers or a company or even by the government. Among the activities taking place in the group is sharing agricultural information. This will therefore reinforce understanding of issues related to agriculture. In this regard better understanding on the use of new agricultural technologies

is achieved hence encouraging adoption. Adoption of improved maize varieties was significantly affected by group membership (Khonje et al., 2015).

### **Agricultural training**

Access to formal agricultural technologies is hypothesized to positively influence adoption of ISFM technologies. Training imparts skills on the application of new technologies. More exposure to training encourage adoption. Farmers who had access to field demonstrations were found to ease adoption intensity of modern cultivars of wheat in Ethiopia (Siyum et al., 2022).

### **Extension**

Access to extension services is expected to positively affect adoption of ISFM technologies. Extension services are provided by various agricultural experts of diverse areas. Following the report of Kassie et al. (2015) contact with the providers of extension services was significant in influencing the choice of adopting the sustainable intensification practices.

### **Cultural influence**

Cultural norms are among the aspects highlighted to manipulate technology adoption decisions (Ruzzante et al., 2021). Influence of culture is hypothesized to have a mixed effect on adoption and adoption intensity of ISFM technologies. Cultures that promote the use of new agricultural technologies in crop production are likely to improve adoption. Contrastingly, cultures that have standards that cannot accommodate learning of new technologies affect adoption negatively.

### **Credit access**

In essence access to credit is associated with access to productive resources needed for farming. Hence, farmers who are capable of acquiring credit can easily adopt ISFM technologies since they can even access external ISFM inputs for instance, mineral fertilizer. Access to credit had positive effect in adoption of fertilizer in Kenya (Wainaina et al., 2016).

### **Market access**

Market access is hypothesized to have mixed effect in choice of either adopting or intensity of adopting ISFM technologies. Markets that are contract based can encourage adoption since their prices are rarely altered. Availability of ready and stable markets for a product dissipate fear over produce going to waste or fetching low prices. Easier penetration to the market promoted adoption of mineral fertilizer and improved maize variety technologies (Ogada et al., 2014).

### **Research awareness**

Research awareness is expected to trigger decision to adopt and intensity of adoption positively. Experimental sites provide farmers with assurance on the performance of the technologies in respective crops. Farmers who access such demonstrations sites have the potential of adopting the technologies. Conclusion made by Pivoto et al. (2019) informs that adoption requires farmers to be aware of how technology performs.

### **Decision on information use**

The decision to use the new information about a technology is expected to positively and negatively affect adoption. Farmers who always make the choices of immediate implementation are likely to adopt the technologies. On the other hand, farmers who wait to learn from others and those who rely on incentives can affect adoption negatively due to their indecisiveness.

### **Source of agricultural information**

Sources of agricultural information used by a household is expected to alter chances of adopting and intensity of adopting ISFM technologies positively. If important agricultural information is disseminated through formal sources of communication, most farmers may not have access in the case where they rely mostly on informal sources.

### **Technology awareness, access and perception on its cost**

Awareness of ISFM is expected to affect decision to adopt the technologies positively. Farmers who have received information about the technology are likely to adopt it. Access to ISFM is expected to affect adoption and adoption intensity positively. Availability of the resources attached to the new technologies will always encourage adoption. Similarly,

adoption may be high if the new technologies are contributed by resources obtained within the farm. Cost of ISFM is also expected to affect adoption and adoption intensity of the ISFM technologies negatively. Low adoption may occur if more of the new technologies are sourced externally.

## **CHAPTER THREE**

### **METHODOLOGY**

#### **3.1 Study area**

The study was carried out in Igamba-N`gombe subcounty in Tharaka-Nithi County. The county is situated in Upper Eastern Kenya. Further, the region is bordered by Embu County to the South West, Meru County to the North East, Kirinyaga and Nyeri Counties to the West and Kitui County to the South East. Dominating economic activity of the area is agriculture consisting of both crop and livestock production (KFSSG & CSG, 2021). It has two ecological zones namely the Highlands (upper midland), which is dominant in Maara and Chuka Sub-Counties. These areas receive adequate rainfall suitable for agricultural activities. The other ecological zone is Semi-Arid Zone (lower midland) dominating in Tharaka North, Tharaka South and Igamba Ng'ombe sub counties. These three areas receive less rainfall of 700 mm per annum which favors livestock production compared to crop production. Generally, Tharaka-Nithi is a low land zone depicted by its altitude ranging between 250 and 1500 m above the sea level (MoALF, 2017). This study area is preferred with respect to that soil fertility improvement and water conserving technologies have been promoted and the fact that the larger part of the area is arid and semi- arid.

#### **3.2 Research design**

The study adopted cross sectional survey design. The design was selected considering that it has an advantage of saving time and bears favorable level of accuracy (Hoffmann et al., 2018). Similarly, it facilitates data collection at a specific time without alteration of the prevailing conditions in the area of interest. This design enables the researchers to draw conclusions of the population with respect to the findings and as well measure its extent within a given population. Moreover, qualitative and quantitative data can be analyzed through this design (MacKay & Schluger, 2015).

#### **3.3 Target population and sample size**

The study targets farmers growing sorghum in Tharaka-Nithi County. The sample frame was determined from the list of households who practice sorghum farming. Households was treated as the sampling unit. Since the population of sorghum farmers was finite this

study adopted Yamane (1973) formula in determining the sample size as applied by (Amahalu et al., 2022). The formula is expressed as in equation 3.1:

$$n = \frac{N}{1 + Ne^2} \dots\dots\dots 3.1$$

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:

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

### 3.4 Sampling procedure

A multistage stratified random sampling technique was applied in obtaining the information of the study area. The method is logical and gives preferred target population (Masunga, 2014). Chuka/Igamba-Ngombe subcounty in Tharaka-Nithi County was purposively selected due to sorghum production and the fact that the larger part of the sub county is an ASAL. Additionally, the area has received support to promote various technologies on soil and water conservation. The first step was selecting two wards within the sub-county. In the second step, the locations in the two wards was established and two sub-locations randomly selected in each. The third step was selecting the villages to be considered randomly. Lastly, the records of sorghum farmers were obtained from extension officers. Thereafter, a sample frame was established and the number of respondents to be interviewed per village was then calculated.

Table 2: Distribution of the sampled households

Ward	No. of sorghum farmers	No. of respondents	Adopters	Non-adopters
Igamba-Ngombe	3050	246	189	57
Mariani	1520	124	97	27

### 3.5 Data collection

Primary data was obtained through a structured questionnaire tool that was administered to the sampled sorghum farmers who were adopters and non-adopters of ISFM technologies. The researcher used the Kobocollect tool to collect the data and digitize all points of data collection. The questions focused on issues related to ISFM adopters and non-adopters, performance of technology in sorghum productivity and returns on investment to sorghum farmers.

### 3.6 Reliability and validity of instrument

In this study, a pilot study constituting a sample of 30 respondents was conducted in the study to ascertain reliability of the research tool. This sample was selected following the suggestion of Israel, (2012) ,that a sample size survey equivalent or more than 20 offers representative results. Split-half method aided in testing reliability of the research tool (Israel, 2012). Split half method is a technique dividing the questionnaires into two and administering them to two different groups of respondents to estimate the reliability. Correlation coefficient between the two halves was calculated using the Split half method as shown in the Equation 3.2.

$$r = \frac{N\Sigma Y - [\Sigma(X)(\Sigma(Y))]}{\sqrt{[N\Sigma X^2 - (\Sigma(X)^2)][N\Sigma Y^2 - (\Sigma(Y)^2)]}} \dots\dots\dots 3.2$$

where: X is the odd scores, Y is the even scores,  $\Sigma(X)$  represent sum of X scores,  $\Sigma(Y)$  represent sum of Y scores,  $\Sigma(X^2)$  is sum of squared X scores,  $\Sigma(Y^2)$  is sum of squared Y scores,  $\Sigma(XY)$  represent sum of the product of paired X and Y scores, N = number of paired scores and r is coefficient correlation between halves. Since r represents one-half of the instrument, Spearman-Brown coefficient will be used to determine reliability of the full instrument as follows:

$$\text{Reliability} = \frac{2r}{2+r} = \frac{2 \times \text{reliability for } \frac{1}{2} \text{ tests}}{1+\text{reliability for } \frac{1}{2} \text{ tests}} \dots\dots\dots 3.3$$

On the other hand, to test validity of the research tool, conclusions were drawn and compared with recommendations from the content analysis. Content analysis was done by taking a sample of the questions from every part of the research tool and comparing it with existing recommendations.

### **3.7 Data analysis**

Analysis of the data collected proceeded through descriptive and inferential methods. Each variable of the study as provided in the questionnaire was coded in order to minimize margin of error and assure accuracy during analysis. Data was analyzed using statistical package for social sciences (SPSS) and STATA. The Cragg's Double Hurdle model, PSM, INPWR and ESR were used to answer the research questions of the study. The results were presented using tables and percentages to demonstrate a graphic view of the research findings.

#### **3.7.1 Analytical test**

##### **3.7.1.1 Testing the explanatory variables for multicollinearity**

Multicollinearity is the linear relationship existing among the independent variables considered in a given study (Gujarati, 2004). The estimated coefficients normally become vague and standard error become inflated when variables are highly correlated. Hence, to test the potential multicollinearity, Variance Inflation Factor (VIF) method was used. The VIF bears a decision rule stating that if the VIF of the independent variable is more than 10 then the variables are said to have high collinearity.

##### **3.7.2 Socioeconomic and institutional factors affecting adoption of integrated soil fertility management (ISFM)**

In most cases, Probit and Logit regression models are used to study the factors influencing technology adoption (Mugwe et al., 2009). These models are functional when the explained variable that is adoption is evaluated as a discrete variable. However, when measuring adoption intensity Probit and Logit models are not appropriate since they use categorical variables to measure adoption (Jingchao et al., 2019). Similarly, Tobit regression model and Heckman has been used to measure adoption intensity, but Tobit model ignores the sources of zero information as a result of random events within the existing factors (Martinez-Espin~eira, 2006; Newman *et al.*, 2003). Additionally, the model is associated with drawback of joint estimation of probability and intensity of adoption that can purely misinform since decisions might not be obviously joint (Wiredu *et al.*, 2015). On the other hand, Heckman model ignores zero observation in the second stage. Therefore, to account for all the deviation tendered by the above models this study

adopted the Cragg`s Double Hurdle model in determining the effect of selected factors on the will of adopting and intensity of adopting ISFM technologies.

In application of double hurdle model, the effects are separated by first using a Probit model to estimate the probability of adoption. Consequently, the second stage apply the truncated regression to analyze the intensity of adoption.

For the first hurdle the farmer decision of adopting ISFM technologies is a binary variable ( $D_i$ ) such that:

$$D_i^* = X_i^i \beta + \varepsilon_i \dots \dots \dots 3.4$$

$$D_i = \begin{cases} 1 & \text{if } D_i^* > 0 \\ 0 & \text{if } D_i^* \leq 0 \end{cases} \dots \dots \dots 3.5$$

equation (i) assumes that  $i^{\text{th}}$  farmer has an unobserved preference denoted by  $D_i^*$ . This preference is influenced by both observed ( $X_i$ ) and unobserved factors  $\varepsilon_i$ . The relationship between the predicting and predicted variables is explained by  $\beta$ .  $X_i$  is the observed variable.

For 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:

$$Y_i^* = X_i^* \beta + \varepsilon_i \dots \dots \dots 3.6$$

$$Y_i = \begin{cases} Y_i^* & \text{if } Y_i^* > 0 \\ 0 & \text{if } Y_i^* \leq 0 \end{cases} \dots \dots \dots 3.7$$

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.

**3.7.4 Effect of adopted ISFM technologies on sorghum productivity**

In estimating the effect of ISFM technologies on productivity this study used Propensity Score Matching (PSM) model and inverse probability weighting with regression

adjustment (IPWRA). PSM produces a variable called propensity score which is the probability that a sorghum farmer will use ISFM technologies based on certain observed characteristics of the farmer. PSM involves two steps of which the first is a set of obtaining propensity scores.

The propensity score is given as:

$$P(x) = \Pr(T = 1 | X = x) \dots \dots \dots 3.8$$

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, decision on new information, cultural influence, road infrastructure, ISFM awareness and ISFM cost.

The second step comprise 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:

$$ATT = E(Y^1 - Y^0 | P(X)) = E(Y^1 | T = 1, P(X)) - E(Y^0 | T = 0, P(X)) \dots \dots \dots 3.9$$

Where,  $E(Y^1 | T = 1, P(X))$  is the yield of sorghum for the ISFM adopters and  $E(Y^0 | T = 0, P(X))$  is the sorghum yield for the ISFM 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.

To offset the bias arising from unobserved variables, inverse probability weighting with regression adjustment (IPWRA) was employed. The IPWRA was preferred for its double-

robust ability implying that the outcome of the treatment effect remains consistent under correct specification. The model is expressed as given in equation (3.10).

$$ATE_{IPWRA} = \frac{1}{N} \sum_{i=1}^N (\alpha_1 - \alpha_0) + (\beta_1 - \beta_0) X_i \dots \dots \dots 3.10$$

where,  $(\alpha_1, \beta_1)$  are estimated inverse probability weighting parameters of the outcome function represented by a linear regression model for the farmers who adopted ISFM technologies during production of sorghum, while  $(\alpha_0, \beta_0)$  represents farmers who were non-adopters of ISFM technologies in sorghum production estimated by inverse probability weighted least squares,  $X_i$  is a vector of independent variables affecting productivity of sorghum. N is the total sample size of farmers.

### 3.7.5 Effect of adopted ISFM technologies on return on investment in sorghum farming

It is evident that adopting technologies brings significant impact on profitability and returns in agricultural enterprises. This study considers returns on investment of sorghum production under ISFM technologies. Returns on investment was measured using budgetary technique. This method captures both costs and the returns (Adewale et al., 2020). Therefore, it makes it possible to obtain costs and returns on investment in integrated soil fertility management (ISFM) technology by sorghum farmers in Tharaka-Nithi County. Total cost (TC) comprise of both fixed cost and variable cost. Total fixed cost (TFC) is the sum of all costs incurred by the farmer on fixed inputs. Total variable cost (TVC) on the other hand is the sum of costs incurred on variable inputs during the process of production.

This budgetary analysis can be stated as:

$$TR = P \times Q$$

$$TC = TFC + TVC$$

$$\text{Profit} = TR - TC$$

Therefore, return on investment will be expressed:

$$\text{Return on investment (ROI)} = \left( \frac{\text{Profit}}{\text{Total cost}} \right) \dots \dots \dots 3.11$$

Where; TR is the Total revenue, P is the Price (KES) and Q is the Quantity of sorghum (in Kg). Endogenous switching regression model was applied in determining the effect of ISFM technologies on returns on investment of sorghum among farmers in Tharaka-Nithi County. ERS proceeds in two stages following (Di Falco et al., 2011; Gorst et al., 2018). Basing on this study the first stage involves the estimation of probability of adopting ISFM technologies using probit model. The second stage evaluates factors affecting return on investment of sorghum under ISFM technologies. However, stage two has a tendency of experiencing heteroskedastic residuals which can be averted by conducting maximum likelihood following (Lokshin & Sajaia, 2004). Consequently, theoretical framework charge that adoption always occur in relation to the benefits relished by the technology concerned. Therefore, a farmer will choose to adopt ISFM technologies if its returns accounted as  $R_1^*$  exceeds the outcome ( $R_0^*$ ) when the technology is not adopted. The resulting difference in this two outcomes is defined as  $R_i^*$ , that is,  $R_i^* = R_1^* - R_0^*$ . If then  $R_i^* > 0$  in this sense ISFM technologies will be adopted in sorghum production.  $R_i^*$  can be expressed as a function of observable characteristics as in equation 3.12.

$$R_i^* = X_i\beta + \mu_i \text{ with } R_i = \begin{cases} 1 & \text{if } R_i^* > 0 \\ 0 & \text{otherwise} \end{cases} \dots\dots\dots 3.12$$

where,  $R_i$  is a binary feature that takes the value of 1 and 0 if ISFM is adopted or not-adopted respectively.  $X_i$  is a vector of representing the factors influencing adoption of ISFM technologies,  $\beta$  is an unknown element that is being determined and  $\mu_i$  is an error term assumed to be normally distributed with zero means.

Since there is two outcome expected, separate functions of sorghum returns can be generated as expressed in equation 3.13 and 3.14.

$$R_1 = X_i\beta_1 + \varepsilon_1 \text{ if } R_i = 1 \dots\dots\dots 3.13$$

$$R_0 = X_i\beta_0 + \varepsilon_0 \text{ if } R_i = 0 \dots\dots\dots 3.14$$

where,  $R_1$  and  $R_0$  are returns of sorghum for adopters and non-adopters respectively,  $X_i$  is a vector of exogenous variables,  $\varepsilon_1$  and  $\varepsilon_0$  are random error terms linked to outcome variables.

Additionally, the coefficients obtained from the ESR is used to evaluate the treatment effects where the average treatment effects on the treated (ATT) is calculated for sorghum returns as expressed in equation 3.15 and 3.16.

The different expected yields is given as:

$$E(R_1 | P_i = 1) = X_i\beta_1 + \delta_{\varepsilon_1\varepsilon}\lambda_i \dots\dots\dots 3.15$$

$$E(R_0 | P_i = 0) = X_i\beta_0 + \delta_{0\varepsilon}\lambda_i \dots\dots\dots 3.16$$

where eqn is the expected sorghum returns of adopters who applied ISFM technologies in growing sorghum while eqn is the expected sorghum returns of farmers had they not use ISFM technologies. Following Di Falco et al. (2011) and Heckman et al. (2001) above outcomes are used to derive unbiased treatment effects (ATT). The function of ATT is expressed as in equation 3.17.

$$ATT = E(R_1 | P_i = 1) - E(R_0 | P_i = 0) = X_i(\beta_1 - \beta_0) + \lambda(\delta_1 - \delta_0) \dots\dots\dots 3.17$$

## CHAPTER FOUR

### RESULTS AND INTERPRETATION

#### 4.1 Overview

This section provides an outline of study results and interpretation. The results are based on the findings on reliability and validity of research instruments and descriptive results of the study predictors. Similarly, the section also constitutes the outcome of double hurdle model, propensity score matching (PSM), Inverse probability weighting regression model (IPWRA) and Endogenous switching regression model (ESR).

#### 4.2 Reliability and validity results

In order to test the reliability and validity of the research instrument that facilitated this study, split half technique was applied. Table 3 shows the Spearman-Brown coefficient results of the model. The results obtained implied that there was a correlation coefficient of 0.636 between the two halves. The equal and unequal lengths of the Spearman-Brown coefficient showed a strong correlation of 0.778. The internal consistency was determined by the Guttman Split-Half coefficient which was 0.718. This shows that there was high internal consistency of scores on the administered questionnaire tools among the set of the responses.

Table 3: Spearman-Brown Coefficient of reliability results

<b>Results</b>	<b>No of items</b>	<b>Values</b>
<b>Cronbach`s Alpha</b>		
Part 1	70	0.000
Part 2	74	0.597
Total No. of items	144	
<b>Correlation between forms</b>		0.636
<b>Spearman-Brown Coefficient</b>		
Equal Length		0.778
Unequal Length		0.778
<b>Guttman Split-Half Coefficient</b>		0.718

### **4.3 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 (Table 4). The results in Table 4 and Table 5 present proportions and chi square results of socio-economic variables and institutional variables respectively. The results in Table 6 present means and t tests for continuous variables. Parametric tests were introduced to determine the significant relationship between adopters and non-adopters. On the other hand, results in Table 7 present the perceptions of ISFM technologies among adopters, Table 8 presents the means of yields and returns of selected combination of ISFM technologies and Table 10 shows the multivariate test from MANOVA for the combined technologies.

#### **4.3.1 Socioeconomic characteristics of adopters and non-adopters**

The results in Table 4 showed that adoption of ISFM technologies was 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. However, the difference in the proportions of gender was not statistically significant. The highest level of education for the farmers who had adopted and those who had not was tertiary albeit who had attained primary level (48.4%) being generally more. Generally, the distribution of education level was 16.8%, 48.4%, 23.2%, and 11.6% for none, primary, secondary, and tertiary levels respectively. In total, the educated farming population constituted 83.2% of the farmers in this area even though the difference among who adopted and those that did not was statistically significant in influencing adoption. Most of the participants of this research practiced mixed farming (77.8%). Specifically, about 77.6% of the adopters and 78.6% of non-adopters practiced mixed farming. Even though the difference was not significant, mixed farming is favored as a crucial aid for mitigating risks associated with climate change and the unpredictable market for farm produce.

Two important farming objectives among the respondents which include farming for subsistence and commercial purposes was also reported in the study (Table 4). Majority of the adopters (83.2%) and non-adopters (82.1) preferred farming for both food and income but the deviation in the two groups was insignificant. Furthermore, 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. This variation was significant implying that success of fellow farmers coupled with own experience augments the desire to try a new technology to improve farm performance.

Table 4: Categorical statistics of socioeconomic characteristics of Adopters and Non-Adopters

Variable	Categories	Frequencies(percentages)		Total	Chi <sup>2</sup>
		Adopters(n=286)	Non-adopters (n=84)		
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
	Primary	131(45.8)	48(57.2)	179(48.4)	
	Secondary	69(24.1)	17(20.2)	86(23.2)	
	Tertiary	36(12.6)	7 (8.3)	43(11.6)	
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(7.3)	
	Food and income	238(83.2)	69(82.1)	307(83.0)	
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)	
	Wait for incentive	6(2.1)	19(22.6)	25(6.7)	

\*\* and \*\*\* rep significance at 5% and 1% respectively.

#### 4.3.2 Institutional factors of adopters and non-adopters

The results in Table 5 reveal that source of agricultural information, extension, group membership, agricultural training and cultural influence had a significant difference among sorghum farmers who are adopters and non-adopters of ISFM technologies. 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 has been observed to encourage the households to adopt suitable technologies during production (Pivoto *et al.*, 2019).

Market access was pointed out by most respondents (81.1%) as an important tool in farming (Table 5). Difficulty in market access may not encourage the use of improved technologies since the excess yield go to waste after increased investment on the technology. However, there was no significant difference between adopters and non-adopters in relation to market access. Out of all the farmers surveyed, majority (83.5%) 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. Almost half of the farmers who participated in the study had been formally trained on the aspects of farming 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 due to the practical experience realized.

About three quarters (74.3%) of the respondents indicated that they were not members of any existing agricultural group (Table 5). 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 due to 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 5). This arose due to 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 due to the availability of requisite infrastructure that guarantees ease of business compared to the rural settings such as the study location herein.

Majority of adopters (69.6%) and non-adopters (78.6%) were not aware of research programs facilitated in the area (Table 5). The chi square results of research awareness reveal that there was no significant difference between the two groups. 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).

Table 5: Categorical statistics of institutional characteristics of Adopters and Non-Adopters

Variable	Categories	Frequencies (percentages)		Total	Chi <sup>2</sup>
		Adopters (n=286)	Non-adopters (n=84)		
Main source of agricultural information	Radio	156(54.55)	45(53.6)	201(54.3)	17.820***
	Television	15(5.24)	1(1.2)	16(4.3)	
	Farmers group	53(18.53)	8(9.5)	61(16.5)	
	Neighbors	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)	
Extension services	Yes	55(19.2)	6(7.1)	61(16.5)	6.891***
	No	231(80.8)	78(92.9)	309(83.5)	
Group membership	Yes	87(30.4)	8(9.5)	95(25.7)	14.856***
	No	199(69.6)	76(90.5)	275(74.3)	
Agricultural training	Yes	140(48.9)	22(26.2)	162(43.8)	13.666***
	No	146(51.1)	62(73.8)	208(56.2)	
Credit access	Yes	48(16.8)	10(11.9)	58(15.7)	1.169
	No	238(83.2)	74(88.1)	312(84.3)	
Research awareness	Yes	87(30.4)	18(21.4)	105(28.4)	2.582
	No	199(69.6)	66(78.6)	265(71.6)	
Cultural influence	Positive	93(32.5)	18(21.4)	111(30.0)	3.802*
	Negative	193(67.5)	66(78.6)	259(70.0)	

\*, \*\* and \*\*\* rep significance at 10%, 5% and 1% respectively

### **4.3.3 Continuous and discrete variables of adopters and non-adopters**

The mean age of the majority of adopters 286 (77.3%) was 42.8 years and was lower than that of non-adopters (22.7%) with the mean of 45.7 (Table 6). 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 enthusiastic about learning new ideas, productive and energetic (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 adopting ISFM technologies.

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.

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 6) 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 those who had chosen to adopt

ISFM were young compared to non-adopters owing to the fact that adoption of new technologies is more flexible to farmers within the active age of production. For the yield, the difference is credited to role of ISFM technologies in augmenting crop productivity (Atere *et al.*, 2022).

Table 6: Descriptive statistics of continuous and discrete variables of Adopters (N=286) and Non-adopters (N=84)

Variable	Unit	Mean Adopters	Mean Non-adopters	Mean Combined	t
Age	Years	42.8	45.7	43.5	1.7391*
Farm size	Number	3.3	3.3	3.3	-0.1937
Farm size under sorghum	Acres	1.5	1.5	1.5	-0.2160
Dependents	Number	4.3	4.1	3.6	-0.7144
Sorghum yields	Bags(90kg)/Acre	4.8	2.4	3.3	6.3639***

\* and \*\*\* rep significance at 10% and 1% respectively

#### 4.3.4 Perception of integrated soil fertility management technologies (ISFM) among adopters

The statistic results in Table 7 shows that 86% of the respondents perceived ISFM technologies to be inaccessible. The rest were either not sure (11%) or generally disagreed (3%) to the inaccessibility of the technologies. This shows that the adopted technologies were largely acceptable among the sorghum farmers in the area due to its accessibility. Based on technology benefits, respondents (94%) perceived that ISFM has potential to augment yields while 70% were of the view that technologies improved their soil fertility, 27% and 34% had perception that the technologies helped in efficient control of pest and diseases 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. These yields were greatly influenced by improved soil fertility and the potential to control pests and diseases.

Challenges on technology adoption were also reported by the respondents (Table 7). Most respondents (96%) cited weather variation as a serious challenge in technology adoption while 73% felt that they incurred high cost during application of the ISFM technologies.

The issues relating to cost of adoption and unpredictable weather patterns that confound the expected gains tend to impact on the choice of adopting modern techniques of farming. This may lead to reduced adoption of otherwise beneficial farming technologies meant to enhance response to effects of climate change (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 rates and adoption intensity of technologies such as of ISFM.

Table 7: Adopters` perception of technological factors affecting adoption of ISFM technologies

Variable	Yes (%)	No (%)	Not Sure (%)
ISFM technologies are not easy to access	247(86)	9(3)	30(11)
ISFM technologies improve soil fertility	200(70)	71(25)	15(5)
ISFM technologies can control pest	78(27)	158(55)	50(18)
ISFM technologies efficiently control diseases	96(34)	125(43)	65(23)
ISFM technologies increase yields	268(94)	8(2)	10(4)
ISFM technologies are costly	207(73)	50(17)	29(10)
Weather variation affects performance of adopted ISFM technologies	275(96)	6(2)	5(2)

#### 4.3.5 Combination of ISFM technologies

This study evaluated the yields and returns of the combinations of ISFM technologies currently utilized by adopters in growing sorghum. The results presented in Table 8 displays the frequency, means of yields and returns 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 fertilizer in sorghum growing.

Similarly, combinations of ISFM technologies that incorporated organic fertilizers was adopted by respondents in proportions of 16%, 17% and 32%. This suggests that substantial use of organic fertilizers which was probably influenced by knowledge on preparation of organic fertilizers and the practice of keeping livestock which provide manure. Approximately 25% of the respondents had adopted combinations of ISFM technologies that excluded fertilizers in sorghum cultivation. The absence of fertilizer in this combinations may be attributed to high cost of fertilizers and being not involved in livestock keeping or maintaining a number that is insufficient for accumulating manure for sorghum production.

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 refrained from using any fertilizers obtained yields of 3.8 bags. This underscores that adopting the complete set of ISFM technologies leads to higher yields, possibly due to each technology contributing to achieving balanced nutrition. Consequently, higher yields contribute to increased produce for commercialization resulting in favorable returns as indicated by returns of up to 2.4 times for complete set of selected ISFM technologies.

Table 8: Mean yields and returns of adopted combinations of ISFM technologies in sorghum production

Adopted combination of selected ISFM technologies	Frequency (Percentage)	Yields (bags/acre)	Returns (ratio)
Inorganic fertilizer + improved germplasm + organic fertilizer + legume intercrop + crop rotation + crop residue + zero tillage	5(2)	5.7	2.40
Organic fertilizer + Improved germplasm + legume intercrop + crop rotation + crop residue	46(16)	4.6	1.94
Improved germplasm + organic fertilizer + legume intercrop + Zero tillage	48(17)	4.9	2.06
Inorganic fertilizer + improved germplasm + organic fertilizer + legume intercrop + crop rotation	23(8)	5.4	2.27
Organic fertilizer + legume intercrop + crop rotation + zero tillage	93(32)	4.4	1.72
Improved germplasm + legume intercrop + crop rotation + crop residue + zero tillage	71(25)	3.8	1.56

MANOVA test was used to test the significance of the observed differences in yield and returns among the adopted combinations of ISFM technologies. The findings are presented in Table 9. The test statistics for Wilk`s Lambda and Lawley Hotelling had values of 0.6936 and 0.3956 respectively which revealed significant differences at 5% level of significance.

Table 9: MANOVA test on observed differences in yields and returns

Multivariate test	Value	F	P-Value
Wilk`s Lambda	0.6936	77.0	0.0360
Lawley Hotelling trace	0.3956	77.0	0.0202

#### **4.4 Multicollinearity**

The results in Table 10 show the VIF values of the predictors that was used. All the VIF values were below 10 meaning that the multicollinearity among the variables was not significant.

Table 10: Multicollinearity test

<b>Variable</b>	<b>VIF</b>
Gender	1.18
Age	1.58
Education	1.61
Dependents	1.25
Subsistence farming	1.29
Commercial farming	1.49
Decision on information use	1.25
Farm size	1.85
Farming system	1.75
Research	1.81
Culture	1.41
Group membership	1.54
Purpose of credit	1.28
Source of agricultural information	1.33
Agricultural Training	1.54
Extension	1.53
Market access	1.08
ISFM awareness	1.31
Perception on cost	1.47
ISFM access	2.36

#### **4.5 Factors affecting adoption of integrated soil fertility management technologies**

##### **4.5. 1 First hurdle**

Double hurdle model was applied in order to estimate the effect of socio-economic and institutional characteristics on adoption and adoption intensity of ISFM technologies. The

results in Table 11 were run separately using 20 variables that were selected for use in explaining the dependent variable. The first three columns present the results of the probit model and out of the 20 variables only 8 factors were significant in explaining adoption of ISFM technologies. These factors comprise of gender, dependents, farming goal for subsistence, farm size, research awareness, extension and ISFM awareness. The gender of the household head had negative significance of 1.012 at  $P < 0.05$ . The number of dependents in a household had positive significance of 0.218 at  $P < 0.05$ . Size of the total farm owned by a household had negative significance of 0.215 at  $P < 0.05$ . Farming goal of subsistence was negatively associated with adoption and it was significant by 0.99 at  $P < 0.01$ . Research awareness on the performance of ISFM had positive significance of 0.99 at  $P < 0.05$ . Access to extension services by a household was also significant in influencing adoption with 2.796 at  $P < 0.05$ . Similarly, ISFM awareness affected adoption positively and it was significant by 4.149 at  $P < 0.001$ .

Table 11: Estimates from Double Hurdle Model

Variable	Coef	SE	ME
Constant	9.356***	3.091	-
Gender	-1.012**	.464	-.058
Age	.015	.017	.001
Education	-.100	.120	-.006
Dependents	.218**	.108	.012
Farming(subs	-4.278***	1.269	-.244
Farming(comm)	-.885	.548	-.051
Decision on inf.	-.073	.275	-.004
Farm size	-.215**	.085	-.012
Farming system	-.162	.520	-.009
Research	.990**	.481	.057
Culture	.253	.449	.014
Group mshp	1.131	.598	.065
Purpose of crdt	.205	.547	.012
Source of agric.inf	-.149	.141	-.009
Agric. Training	-.276	.424	-.016
Extension	2.796**	.906	.160
Market access	-.707	.540	-.040
ISFM awareness	4.149***	.968	.237
Perception on cost	-.288	.264	-.016
ISFM access	-1.879***	.293	-.107
Wald X <sup>2</sup> ***(20)	321.29		
<b>Log-L</b>	37.55		
Pseudo R <sup>2</sup>	0.8105		
<b>No.of observations</b>	370		

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

#### **4.5.2 Second hurdle**

The second hurdle involved the use of truncated regression. In this stage the signs of some independent variables varied with the ones on the first hurdle which confirms the likelihood of the variation in the two steps (Asfaw et al., 2011). The variables that were significant in explaining adoption intensity of ISFM technologies include gender, farm size, main source of agricultural information and agricultural technologies. According to the results in Table 12 gender of the household head was negatively significant by 0.346 at  $P < 0.01$ . Contrary to the first stage, farm size positively affected adoption intensity and it was significant by 0.247 at  $P < 0.01$ . The source of agricultural information used by a household had negative effect on adoption intensity and it was significant by 0.17 at  $P < 0.01$ . Access to formal agricultural training by sorghum farmers affected adoption intensity positively with significance of 0.424 at  $P < 0.01$ .

Table 12: Truncated

Variable	Truncated		
	Coef	SE	ME
Constant	-.860	.809	-
Gender	-.346***	.122	-.346
Age	.008	.005	.008
Education	.059	.039	.059
Dependents	.023	.032	.023
Farming(subs	.190	.232	.190
Farming(comm)	.392	.235	.392
Decision on inf.	.065	.105	.065
Farm size	.247***	.022	.247
Farming system	-.003	.171	-.003
Research	-.095	.133	-.095
Culture	.046	.144	.046
Group mshp	-.225	.159	-.225
Purpose of crdt	.086	.112	.086
Source of agric.inf	-.170***	.049	-.170
Agric. Training	.424***	.136	.424
Extension	.096	.170	.096
Market access	.033	.151	.033
ISFM awareness	.319	.213	.319
Perception on cost	.078	.072	.078
ISFM access	.079	.074	.079
<b>Wald X<sup>2</sup> ***(20)</b>	204.84		
<b>Log-L</b>	-336.90		
<b>No. of observations</b>	361		

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

#### 4.6 Effect of ISFM technologies on sorghum productivity

Probit model was used to estimate the propensity scores of ISFM technologies adoption for each observation. The model took into consideration all the observed covariates

affecting adoption of ISFM technologies. Generally, the model was significant in explaining the existence of difference associated with covariates among adopters and non-adopters of ISFM technologies. The results in Table 13 show that extension services and ISFM awareness influence the choice of adopting ISFM technologies positively while farming goal for subsistence, decision on information use and cost of ISFM affected adoption negatively.

Table 13: Estimation results of ISFM adoption

<b>Variables</b>	<b>Coeff.</b>	<b>Standard error</b>
_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) $X^2(17)$	204.63	
Prob> $X^2$	0.000	
Pseudo $R^2$	0.5162	

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

The effect of ISFM technologies on productivity were determined through nearest neighbor matching, kernel based matching and radius matching. The overall matching estimates showed that ISFM technologies impacts positively the production of sorghum. The average treatment effect on adopters of ISFM was 1.268, 1.120 and 1.192 for nearest neighbor, kernel based and radius matches respectively (Table 14). This means that farmers growing sorghum were better in production by an average of 1.193 bags through adoption of ISFM technologies.

Table 14: 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

ATT= Average treatment on the treated; \*\*\* represents significance at 1%

#### 4.7 Results of inverse probability-weighting with regression adjustment

The results in Table 15 present estimates from IPWRA estimator purposely for comparison. Following the argument of (Wossen et al, 2017) the results of PSM model may encounter misspecification that renders the estimated results to be biased. Ideally, the results of the PSM are consistent and unbiased only in cases where the model is correctly specified. In this regard IPWRA was used to establish the effect of ISFM adoption on sorghum productivity. The results reveal that farmers who use ISFM technologies would produce 4.696 bags of sorghum compared to 1.424 bags obtained from not using the technologies. The ATE shows that adopters of ISFM would be better in production by 3.272 bags of sorghum. Notably, there is a difference on these results with PSM results confirming there might be bias arising from misspecification.

Table 15: Effect of ISFM technologies on sorghum productivity (IPWRA)

Outcome variable	Adoption status		ATT
	Adopters	Non-adopters	
Sorghum productivity	4.696(0.097)***	1.424(0.088)***	3.272

ATT= Average treatment on the treated; \*\*\* represents significance at 1%.

#### 4.8 Effect of ISFM technologies on return on investment of sorghum production.

Table 16 display the results which were obtained by endogenous switching regression model through maximum likelihood estimation procedure with the use of *movestay* command in STATA.

The results reveal that the correlation coefficient from both selection equation and the outcome variables in the two groups sorghum farmers are significant at 1% (p-value= 0.000). This is an indication that sufficient evidence justifying existence of observed and unobserved covariates that affect adoption of ISFM technologies, hence it renders the adoption equation endogenous to the resultant variable which is return on investment of sorghum.

The significance of correlation coefficient relating to the application of ISFM technologies suggest that farmers who choose the technology are advantaged in realizing better sorghum returns than if they had decided otherwise. In contrast, it is a proof that non-users of the technologies are worse off on the choice of not adopting the technology. Therefore, users of the ISFM technologies with average returns are likely to apply the technologies and in return sustain improved sorghum returns than a random farmer. In contrast, farmers who did not apply the technology in production obtained lower returns of sorghum compared to the returns that would have been realized by a random farmer.

The results also reveal that age of the household head was negatively correlated to the returns of ISFM technologies, and it was only significant among adopters. The results show that an increase age by an adopter reduce returns of sorghum by 1%. This means that the returns based on ISFM technologies applied significantly decrease as adopters become older. The results of education were also significant for both adopters and non-

adopters. This display a positive correlation of returns and the use of ISFM technologies among adopters. The results show that education could increase returns by 4.7% among adopters of ISFM while contributing up to 10.9% of the returns among non-adopters. This means that education is important in imparting knowledge that can be used to generate more returns.

The results of land allocated to sorghum showed positive correlation on returns of ISFM and were significant among adopters. This means that adopters had allocated at least more land for sorghum production, which enable them increase their returns by 19.4%. This could be because adopters might have enjoyed benefits of the technologies that triggered them to increase the size of land allocated to sorghum in order to gunner more returns. The results also reveal that research awareness had a positive significance on sorghum returns among farmers who were adopters of ISFM technologies. It was evident that research awareness could increase the returns by 16.4%. This means that farmers who are aware of technology research outcomes will choose technologies that credit them maximum returns. Further, the results indicate that market access had a positive correlation on returns and it was significant for adopters only. With market access, returns could increase by 17.8% meaning that assurance of market encourages use of technologies that has the potential of increasing production, such that excess can be taken to the market.

The results show that cost of ISFM had negative correlation on the returns of sorghum for both adopters and non-adopters though it was only significant for non-adopters. This indicates that an increase in cost of ISFM by one-unit decrease returns by 87.5%. This means that returns will decrease for non-adopters who rely on external sources of ISFM technologies. The results also show that prioritizing farming activities had a positive correlation among adopters and negative correlation for non-adopters. However, it was only significant for non-adopters and it showed that if more priority is given to farming activities decrease returns by 44.8%. This suggests that if non-adopters prioritize farming activities, they are likely to experience a decrease in returns due to that they may fail to apply appropriate techniques which fructify the soils hence better production.

Table 16: Movestay estimates on adoption of ISFM technologies

Variable	Adoption	Non-adoption	Selection
Const.	1.242	2.922	-0.668
Gender	-0.073	-0.159	-0.728
Age	-0.010***	-0.006	0.004
Education	0.047**	0.109**	
Dependents	0.032	0.025	
Farming activities	0.112	-0.448**	-0.718
Land under sorghum	0.194***	-0.036	
Decision on info. use	0.012	0.164	-0.212
Source of agric. Info.	0.023	-0.038	0.030
Market access	0.178**	-0.023	-0.520
Agricultural training	-0.010	-0.160	0.590
Extension services	-0.028	-0.504	0.797
Group membership	0.041	-0.115	1.350***
ISFM awareness	-0.462	-0.001	2.933***
Influence of culture	-0.090	-0.053	0.175
Research awareness	0.164**	0.026	1.137***
Cost of ISFM	-0.502	-0.875**	-0.478**
ISFM access			2.913***
Sigma1	0.531		
	0.022		
Sigma 0		0.612	
		0.053	
Rho 1	0.042***		
	-0.321		
Rho 0		0.086***	
		0.551	
Log likelihood	-349.010		
No. of observation	370		
Wald Chi <sup>2</sup>	33.480		

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

Table 17 presents the estimates of the expected ROI scores given the actual and counterfactual scenarios. Both adopters and non-adopters of ISFM are faced with two possible decisions; to adopt and not adopt. The expected ROI of farmers growing sorghum under ISFM technologies was reported to be 1.945 while that of non-adopters was 0.783. Based on the counterfactual outcomes ROI would have been 2.409 units for adopters and 0.734 for non-adopters.

Table 17: Effect of ISFM technologies on return to investment

Outcome variable	Subsample	ISFM Decision		Treatment effects
		Use	Not to use	
ROI	Adopter	1.945	0.783	1.162 <sup>ATET ***</sup>
ROI	Non-adopter	2.409	0.734	1.675 <sup>ATU ***</sup>

**ATET**= The average treatment effect on the treated, **ATU** = The average treatment on the untreated \*\*\*significant at 1%

## CHAPTER FIVE

### DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

#### 5.1 Summary of the findings

The aim of this study was anchored in determining the factors affecting adoption and adoption intensity of ISFM technologies, and the effect of the technologies on sorghum productivity and return on investment. These objectives were achieved through the application of Craggs Double Hurdle, PSM, IPWRA and ESR models.

#### 5.2 Factors affecting adoption and adoption intensity of ISFM technologies

The chi-square results attested the existing deviation in features surrounding adoption and non-adoption. Table 4 results show that cultural influence (10%), decision on information use (1%), agricultural training (1%), group membership (1%), extension (1%) and main source of agricultural information (1%) were statistically significant in explaining the difference between adopters and non-adopters. This deviation is supported by the fact that farmers who are better exposed in farming and have access to knowledge on various farming techniques are likely to adopt ISFM technologies.

##### 5.2.1 Adoption of ISFM

The results of gender of the household head was significant but it affected adoption of ISFM technologies negatively. A rise in the involvement of female engaging in agriculture, adoption of ISFM technologies would decrease by 1.102 units. The number of dependents in a household was positively significant in influencing adoption of ISFM technologies. The results show that an increase in the number of dependents in a household increases adoption by a factor of 0.218. The farming for subsistence had negative significance in influencing adoption of ISFM technologies. With increase in the goal of farming for subsistence decreased adoption by 4.278. Similarly, the size of the farm owned by a household had negative significance in affecting adoption of ISFM technologies. An increase in the size of the farm owned by the household decreased adoption of the technologies by 0.215. The farmers' awareness on the research outcome of ISFM technologies significantly affected ISFM technologies. The results were positive and it revealed that, increase in farmer's awareness would increase adoption by 0.99 units. The results based on extension services was significant in adoption of ISFM technologies.

This shows that farmers who have frequent contact with extension service providers are likely to increase the probability of adoption by 2.796. The farmers' awareness on ISFM technologies had positive significant effect on adoption of ISFM technologies. Increase in the level of ISFM awareness by farmers would increase adoption by 4.149. Additionally, ISFM access negatively affected adoption of ISFM technologies. The results show that limited access to ISFM technologies would decrease adoption by 1.879 units.

### **5.2.2 Adoption intensity**

Gender of the household was also significant in affecting adoption intensity of ISFM technologies negatively. The results reveal that involvement in farming by more female gender can reduce adoption intensity of ISFM technologies by 0.346. The size of the farm owned by the household had positive significance in influencing intensity of adopting ISFM technologies. With increase in the size of land owned by the household, the probability of adoption intensity would increase by 0.247. The results of the main source of information used by a household had negative significance in adoption intensity of ISFM technologies. This shows that increase in the use of formal sources in disseminating agricultural information can decrease adoption by 0.170. Exposure to formal agricultural training positively affected the intensity of adopting ISFM technologies. The results reveal that farmers who have more exposure to formal agricultural training would increase adoption of ISFM technologies.

### **5.3 Effect of ISFM on productivity of sorghum**

Majority of the farmers growing sorghum had adopted ISFM technologies in production of the crop. The adoption of the technologies was in the combinations that included the use of organic fertilizer, inorganic fertilizer, improved seeds, cereal-legume intercropping, zero tillage and crop rotation. Factors that affected the application of any combination of these technologies include, farming for subsistence, decision on information use, extension, ISFM awareness and perception on cost of ISFM. However, farming goal for subsistence, decision on information use, and perception on the cost of ISFM had negative significance in determining adoption of ISFM. In contrast, ISFM awareness and access to extension services affected adoption of ISFM technologies positively.

The use of different combination of ISFM technologies proofed that the technologies has a positive relationship on sorghum yields. Based on the different sets of matching algorithms, the results show that farmers who adopt the technology are better in production by 1.268, 1.120 and 1.192 for nearest neighbor, kernel-based, and radius matches respectively (Table 14). On the other hand, the results in Table 15 reveal that adopters of ISFM technologies would be better in production by 3.272 than if they choose not to adopt the technologies.

#### **5.4 Effect of ISFM technologies on return on investment of sorghum**

In relation to the adoption of different combination of ISFM technologies by farmers growing sorghum, several factors showed varied relationships. Age, education level, prioritization of farming activities, research awareness and cost of ISFM impacted on decision adopt ISFM technologies. The results reveal that age was significant and it had negative correlation on return on investment among both adopters and non-adopters of ISFM technologies. Education level showed a positive correlation on return on investment among the two groups of farmers. Farming activities were significant among non-adopters of the technologies and it displayed a negative relationship in return on investment. Market access showed a positive correlation on adopters and but the relationship on sorghum returns was negative among non-adopters. However, the results were significant among adopters only. Research awareness was significant for the two groups and it showed a positive correlation on sorghum returns. The cost of ISFM was only significant for non-adopters though it revealed a negative relationship on sorghum returns and the use of ISFM technologies.

Consequently, the model estimation on the effect of the technologies on sorghum production revealed diverse outcomes on both groups of farmers based on the actual and counterfactual outcomes. The actual results show that adopters would get returns of 1.945 if they apply any combination of the technologies. In contrast they will realize a return of 0.783 if they fail to adopt the technologies. Counterfactual returns on the other hand show that if non adopters had applied the technologies they would have realized returns of 2.409 while if they fail to use the technologies they would obtain returns of 0.734.

## 5.5 Discussion

### 5.5.1 Factors affecting adoption and adoption intensity of integrated soil fertility management technologies

In the first and second stages, gender of the household respondent had a negative significance in adoption and adoption intensity of ISFM technologies at  $P < 0.05$  and  $P < 0.01$ , respectively. From the marginal results (Table 11 & Table 12), 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 (Chianu *et al.*, 2012; Mponela *et al.*, 2016; Wawire *et al.*, 2021) who reported that gender had no relationship with ISFM adoption. According to Kwadzo & 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 techniques (Ndiritu *et al.*, 2014; Peterman *et al.*, 2014). The study findings, 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.

In the first stage farm size was negatively significant ( $p < 0.05$ ) in determining adoption of ISFM technologies (Table 11). Contrastingly, in the second stage it showed a positive significance ( $p < 0.01$ ) 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. 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, however, differs with Martey *et al.* (2014) who concluded that farm size was the most influential factor among adopters of inorganic fertilizer. Similarly, adopting FISP and ISFM practices were positively promoted by the size of land (Adolwa *et al.*, 2019; M. G. 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.

Farming goal for subsistence was one of the variables that was significant ( $P < 0.01$ ) in the study even though it negatively affected adoption of ISFM technologies (Table 11). 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 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. Additionally, Vorley *et al.* (2012) and Giller *et al.* (2021) attributes farming goal for subsistence to limited access to productive resources by farmers.

Dependents showed a positive significance ( $P < 0.05$ ) in influencing adoption of ISFM technologies (Table 11). Arguably, this significance proves that family dependents 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 dependents of the family who are within the productive age; on the other hand, low interest towards technology adoption may result from family dependents who require extra economic care, and thus puts pressure on consumption of the available resources.

Access to extension service was positive and significant ( $P < 0.05$ ) in determining adoption of ISFM technologies among the farmers growing sorghum. The results revealed that, with access to extension services, adoption of ISFM by the farmer increases by 0.160 (Table 7), 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., 2021). 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 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 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 ( $P < 0.05$ ) 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. 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 its 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 favorable 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 11). 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 ( $P < 0.01$ ) 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 11). 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 farmers' full access to supporting resources of the agricultural technology promotes adoption (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 ( $P < 0.01$ ) 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 11). 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; Mudege & Bourdillon, 2003). 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 favors 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 ( $p < 0.01$ ) in the second stage (Table 11). It is thus evidence that formal agricultural training is important 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 behavior and attitude on the impact of agricultural technologies (Lukuyu *et al.*, 2012; Macharia *et al.*, 2014). Additionally, training is vital in knowledge and sensitizing farmers on productivity effects and environmental concerns of agricultural technologies (Njenga, *et al.*, 2021). The findings of 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 *et al.*, 2021). 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)

### **5.5.2 Effect of ISFM technologies on sorghum productivity**

Farmers would always prefer to produce more to ensure the sustainability of food throughout the season and the stability of income as well. This production is however, curtailed by myriad factors in and outside the farm. Given that there are improved technologies that can foster production, such factors tend to influence the decision made by the farmer on whether to use or not use the technologies. From the findings of this study, the PSM results show that contact with the extension service providers and high level of awareness of ISFM technologies affected adoption of ISFM positively. On the other hand, farming goal for subsistence, decision on information use and the perceived cost of ISFM technologies affected adoption of the technologies negatively. These findings relate with the study of Draife *et al.* (2018) who found that some social, economic and institutional factors such extension, source of technology information, knowledge on farming and herd size affected the farmers` choice of innovative technologies.

Combine results of PSM and IPWRA proofs clearly that adopting ISFM technologies guarantees improved productivity of sorghum. The results from PSM through the nearest neighbor, kernel-based and radius matching algorithms show that farmers were better in production by 1.268, 1.120 and 1.192 bags of sorghum respectively. Similarly, adopters were better in production by 3.272 bags of sorghum based on the IPWRA results. Hence, adoption of ISFM technologies have ability to augment crop yields such as sorghum. This conclusion relates well with the findings that agricultural technologies play a crucial role in crop productivity (Kassie *et al.*, 2011). This is because technologies in itself especially ISFM have the potential of improving crop productivity (Shah & Wu, 2019). 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 adoption of ISFM technologies exerts positive and significant impact on sorghum

yields per acre. This conclusion favors the findings that agricultural technologies augment crop yields if the appropriate measures are put in place (Kassie et al., 2011).

### **Effect of ISFM technologies on return on investment of sorghum**

The benefits attached to the adoption of agricultural technologies is always obvious, however, given the potential profitability of these technologies, inherent and dynamic characteristics surrounding the farm and the farmer interferes with this imperial relationship. The estimates from ESR model show that negative and positive relationship exist on the interaction of variables. The results show that age had negative correlation on returns among adopters while farming activities and market access showed negative correlation on returns of sorghum among non-adopters. Cost of ISFM were negatively correlated with the returns of sorghum among the two groups of farmers. The negative relationship of age could be attributed to the decreased involvement in learning as adopters become older. This could thus affect decisions that in turn alter returns obtained by the household. Non-adopters who prioritized farming activities and have little knowledge on farming techniques will lead them producing less which may not be sufficient to make reasonable returns. In addition, farmers may focus on more production of subsistence food such that surplus are not considerable in making good returns. Similarly, non-adopters may end up producing poor quality produce which does not fetch better market prices. Based on the cost of ISFM, more dependence on the external sources of ISFM technologies increases the cost of production and this decreases the revenue of the enterprise.

On the other hand, the level of education and research awareness influenced the returns of ISFM technologies on sorghum positively. This relationship is attributed to the importance of education as it foster understanding on the various farming techniques. For research awareness, farmers who have interacted previously with the sites where the technologies have been relished are likely to put right measures that boost their production and thus improve returns. Market access was positive and significant for adopters only. Its relationship on the returns of the technologies may be attributed to the ready market available for the surplus produce obtained from production under these technologies.

The results of the treatment effect show that adopters realized more sorghum returns by 1.162 while non-adopters would have gained 1.675 more if they had adopted ISFM technologies. These findings correspond the report that ISFM technologies improved production of cereals by 52-134%. This is also similar to the report by Tufa et al. (2019) who found that adoption of improved varieties of soybean increased income by 53%. The study of Bekunda et al. (2022) adds that income is among the benefits associated with use of ISFM technologies.

## **5.6 Conclusions and recommendations**

The first objective of this study was to identify the socioeconomic and institutional 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 impacted adoption intensity of ISFM technologies. This is an implication on the need to promote the uptake and use of ISFM technologies in relation to the significant socioeconomic and institutional factors. This can be done through collaboration of the national government with other agricultural stakeholders by facilitating appropriate education to farmers, disseminating research findings through frequent training, and by providing subsidies on external ISFM inputs so as to enhance livelihoods among farmers in marginal areas.

Further, the study focused on determining the effect of ISFM technologies on productivity and return on investments of sorghum. The propensity score matching (PSM) and inverse probability weighting regression adjustment (IPWRA) models were used to measure the effect of the technology on productivity. Endogenous switching regression (ESR) model was used in determining return on investment of sorghum under ISFM technologies. From the survey, data relating to the productivity and return on investment of ISFM technologies was captured. Despite the importance attached to the technologies the choice of using the

technologies is still hampered by the characteristics surrounding farming in general as depicted by the first stage results of the PSM and ESR models. In contrast, the second stage results show that farmers using ISFM technologies had better yields and returns of sorghum compared to those who had not applied the technologies in production. These findings confirm the potentiality of the technologies in improving the benefits based on productivity and income of the respective households. In this regard ISFM promoters such as governments and other stakeholders should develop proper systems of production using the technologies and facilitate the marketing channels of the produce obtained by the farmers. To ensure the production and income sustainability of sorghum under the technologies, the government should ensure that policies surrounding promotion of ISFM should be monitored and evaluated regularly. Such policies may be set to advance marketing channels of sorghum that involve the farmer, industry and local consumer. This will aid in enhancing resilience and improvement in the use of the technologies by farmers which in return harness outcomes that is beneficial to both environment and farmer.

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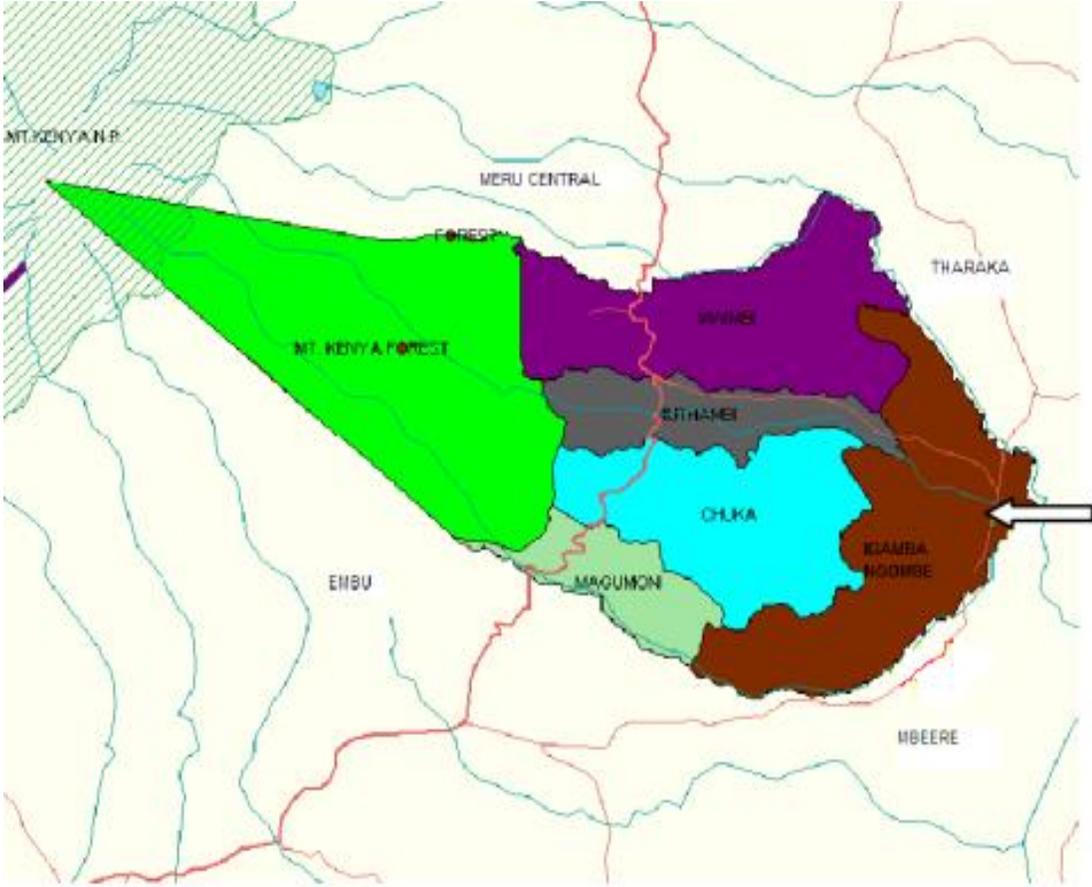
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**Appendix 1: Map of Tharaka-Nithi County, Kenya**



Source: <https://www.researchgate.net>

## Appendix 2: Questionnaire

This is a questionnaire on the adoption, perception, productivity and return on investment of integrated soil fertility management (ISFM) technologies among sorghum smallholder farmers in Tharaka-Nithi County, Kenya. All the responses will be treated with the highest degree of confidentiality and the information will be used to meet the objectives of this study.

### Section 1: General information

- **Code of enumerator** .....
- **Date** .....
- **Division** .....
- **Location** .....
- **Sub-location** .....
- **Village** .....

Do you grow sorghum? (Part of preliminary questions)

### Section 2: Socioeconomic factors

1. Gender of HH MALE [  ] FEMALE [  ]

2. Age of HH ..... (In years)

3. Source of income.....

4. Size of land.....(In acres)

5. Size of land allocated to sorghum production.....acres

6. Level of education

Below primary [  ]

Partial primary [  ]

Completed primary [  ]

Partial secondary [  ]

Completed secondary [ ]

Partial tertiary level [ ]

Completed tertiary level [ ]

7. Size of household dependents.....

### **Section 3: Institutional factors**

#### **A. Research institution**

- i. Are you aware of any research programs in your area? YES [ ] NO [ ]
- ii. If yes, are they related to any of your farm enterprises? YES [ ] NO [ ]
- iii. Do they have an effect on your farm? YES [ ] NO [ ]
- iv. If yes, which effect?.....

#### **B. Enterprise**

1. Which other enterprises exist in your farm apart from sorghum?.....
2. Indicate the type of enterprise(s) that is/are important to you.....

#### **C. Infrastructure**

(a). How is the state of infrastructure in your area?

- i. New tarmac [ ]
- ii. Maintained tarmac [ ]
- iii. Unmaintained tarmac [ ]
- iv. New Murram road [ ]
- v. Maintained tarmac [ ]
- vi. Unmaintained tarmac [ ]
- vii. Other [ ]

(b). Does the state of infrastructure affect your production?

(c). If yes, how?.....

#### **D. Credit facilities**

1. Did you acquire loan during the last two seasons? YES [ ] NO [ ]

2. If YES, what type of loan?

Type of loan	Commercial bank	Microfinance bank	SACCO	Community group	Friends/r elatives	Mobile money	Other sources
Purpose of credit							
Amount received							

3. If NO, what was the reason?

No need	Not aware of the available credit facilities	High interest rates	No sufficient security to acquire credit	People loose properties due to sanctions	Other specify

### E. Source of information

What is your main source of agricultural information?

Radio ( )

Television ( )

Extension ( )

Group ( )

Internet ( )

Neighbor/Friends/Family ( )

Other ( )

**Section 4: ADOPTION OF ISFM TECHNOLOGIES**

**1. Adoption**

- a. Are you aware of ISFM technologies? YES [ ] NO [ ]
- b. If yes, which any of the following ISFM technologies do you use?

Technology	Are you aware of this technology? (YES/NO).	Which of these technologies do you use?	When did you learn about this technology?	What motivated you to use this technology?	How long have you used this technology?	What benefit did you find in this technology?
Liming						
Use of organic fertilizers						
Use of inorganic fertilizers						
Cereal – legume intercropping						
Improved germplasm						
Crop residue						
Crop rotation						
Zero tillage						

- c. Which combination of this/these technology(technologiess) are you implementing currently and why?

Technology(s)	Reason

- d. Does your culture support adoption of the listed ISFM technologies? YES [  ]  
NO [  ]

- e. If yes, what is the specific role-played by culture in adoption of ISFM technologies?

.....

- f. State the traditional activities that are related to soil fertility management in your community?

.....

.....

.....

- g. What is your opinion on what can be done to improve soil fertility in your area?.....

.....

.....

**2. Perception**

- (i). What is your perception on ISFM technologies?

	Strongly disagree	Disagree 2	Not sure 3	Agree 4	Strongly agree
--	-------------------	---------------	---------------	------------	----------------

	1				5
ISFM technologies improves soil fertility					
Technologies are accessible					
It increase yields					
They are labour intensive					
They are cheap					
Soil fertility is not a problem in my farm					

(ii). When you receive information about the new technology, which reaction do you take?

(iii). Learn and implement [ ] Wait for friend to implement [ ] Do nothing about it [ ] Other [ ]

(iv). After how long do you think the impact of ISFM is felt?.....yrs

(v). Do you think the use of ISFM technologies can expose your farm to risk?

(vi). If yes, which risks?

(vii). Which challenges do you face when you are using ISFM technologies?

High cost	Soil deterioration	Low payoff	Not aware of the recommended proportions	Other reasons

**Section 5: Policy**

(I). Are there any agricultural policies you know? YES [ ] NO [ ]

(II). What is its implementation status if yes?

Useful [ ]

No impact [ ]

Slow [ ]

Other [ ]

(III). Does the status of the policy affect your farming objectives?.....

.....  
.....

**Section 6: Legal**

1. Which government regulations do you know and are affecting your farm operations?.....

.....  
.....

2. How do they alter your farm operations?.....

.....  
.....

**Section 7: Productivity**

(i). Indicate inputs that you used in production of sorghum in the last season.

.....

(ii). How many bags of sorghum did you harvest in the last season?.....bags of  
.....Kgs/acre

## Section 8: Profitability

(i). Information on the last season of sorghum production under ISFM technologies.

Rent of leased lands.....

Maintenance of waterpans and irrigation facilities.....

Activity	No. of persons	Days taken to complete	Total cost
Ploughing			
Transport services			
Planting			
Weeding			
Application of chemicals			
Chasing birds			
Harvesting			
Threshing			
Drying			
Bulking			
Sorting			
Packaging			

(ii). Total yield obtained.....

(iii). Total revenue at the prevailing market price.....

(iv). Profit.....

**Thank you for your participation**