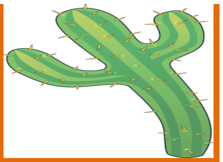

Mekelle Universty

College of Dry Land Agriculture and Natural Resources

Department of Agricultural and Resource Economics

Thesis

on

Drought and Sustainable Intensification Technologies Adoption in Ethiopia

By

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A Thesis Submitted to the Department of Agricultural and Resource Economics

In Partial Fulfillment of the Requirements for the Degree of Master of Science in Agricultural Economics and Policy

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January, 2025

Mekelle

DEDICATION

I dedicated this thesis manuscript to my father Priest Gebrehiwot Gebreslasie for unreserved assistance and his dedicated encouragement in my academic career and who devoted his entire life to my success.

ACKNOWLEDGEMENT

Above all, I would like to thank the almighty God who gave me the potential to make my dream come true. After that I would like to express my special thanks to my advisors; Gebrelibanos Gebremedhin (PhD), Nigussie Abadi (PhD), and Belets Gebremichael (Assistant Professor), for their constructive comments in doing this research paper. Without their advice, the accomplishment of this research would have been difficult. Besides, I am also giving thanks to Mekelle University, which gives me financial support to accomplish my thesis work. Finally, I would like to give special thanks to my family and friends, who played a great role in helping me by giving morals and appreciation to accomplish this thesis.

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LIST OF ABBREVIATIONS

CHIRPS	Climate Hazards Group Infra-Red Precipitation with Station
CSA	Central Statistical Agency
DA	Development Agent
EA	Enumeration Area
ESS	Ethiopian Socioeconomic Survey
ETB	Ethiopian Birr
FAO	Food and Agricultural Organization
GDP	Gross Domestic Product
GPS	Global Positioning System
Km	Kilometer
LSMS- ISA	Living Standards Measurement Study- Integrated Surveys on Agriculture
MVL	Multivariate Logit Model
MVN	Multivariate Normal Distribution
MVP	Multivariate Probit Model
№	Number
NGOs	Non-Governmental Organizations
RH	Rainfall Heterogeneity
SUR	Seemingly Unrelated Regression
SRS	Simple Random Sampling
SI	Sustainable Intensification
SIA	Sustainable Intensification Adoption
SIT	Sustainable Intensification Technology
SITs	Sustainable Intensification Technologies
SNNPR	Southern Nations, Nationalities and Peoples Region

SSA	Sub-Saharan Africa
TLU	Total Livestock Unit
W4	Wave Four
W5	Wave Five
WB	World Bank

ABSTRACT

The agricultural productivity of Ethiopia is highly influenced by rainfall variability. Understanding the relationship between drought and the adoption of multiple Sustainable Intensification Technologies (SITs) is important for informed decision-making. The SITs were well recognized for their important contribution in improving agricultural yield and improving resilience. To achieve the objectives, this study employs two waves of nationally representative data from the Living Standards Measurement Study (LSMS). The socioeconomic data was integrated with the historical monthly rainfall data from 1981 to 2022, obtained from the Climate Hazards Group Infrared Precipitation with Station data (CHIRPS). Using this historical rainfall data, it was constructed various drought indices and presented with multiple model specifications. While the primary focus was to examine the effect of drought on SIT adoption, it was also estimated that models that control for additional covariates identified in the literature as determinants of SIT adoption, using the Multivariate Probit (MVP) model. The findings of the study indicated that exposure to drought during survey years decreases the adoption of high-risk SITs, such as inorganic fertilizer, while increasing the adoption of risk-reducing SITs, such as manure and irrigation. Moreover, most of the correlation coefficients among the SITs were positive, indicating that smallholder farmers tend to adopt multiple SITs simultaneously. These results had significant implications for the adoption of SITs particularly under extreme climate conditions like drought.

Keywords: *Adoption, Drought, Multivariate probit model, Productivity, Sustainable intensification technology*

CHAPTER 1: INTRODUCTION

1.1. Background and Justification

The existing rates of growth in crop yields are not keeping up with the growing worldwide need for agricultural products. But, different studies show that agricultural productivity must increase by more than double to feed the increasing population by 2050 (Godfray, 2010). This emphasizes how agricultural technology is important in fostering economic growth, ensuring global food security, and boosting climate change resilience (Abay et al., 2022; Fuglie et al., 2019; Ray et al., 2013). For instance, in Sub-Saharan Africa (SSA), agriculture has not seen significant productivity improvement over the last fifty years (Evenson R, 2003). Many people believe that this lack of progress is a primary determinant preventing the region from entering a consistent phase of economic growth, contributing significantly to the prevalence of widespread poverty (Abay et al., 2022; Azzarri & Signorelli, 2020; Barrett et al., 2017).

Additionally, smallholder farmers with lower incomes continue to show unwillingness to adopt advantageous new technologies despite their potential profitability (Puerto, 2023). Moreover, in developing countries of Sub-Saharan Africa (SSA) particularly Ethiopia's agricultural practice is characterized by a strong dependence on rain-fed systems, with more than 90% of the population engaged in agriculture for subsistence (Kifle et al., 2022). This dependence makes the country pose significant impacts on food security and the livelihoods of the people (Bouteska et al., 2024). The small-scale agriculture of Ethiopia plays a great role in enhancing food security, reducing poverty, and boosting sustainable development (Gebremariam & Tesfaye, 2018; Amare et al., 2018; Teklewold et al., 2013). However, to meet the expected rise in demands for food, improving agricultural productivity is highly possible through the adoption of modern SITs (Mensah et al., 2018).

Enhancing the well-being of Ethiopia’s smallholder farmers requires the adoption of SITs (Patil et al., 2016). These technologies include the use of improved seed, chemical fertilizer, soil and water conservation, cereal-legume diversification, pesticides, irrigation, manure, agroforestry systems, and so on (Huan et al., 2022).

Through improved seed use and crop diversification, smallholder farmers become more resilient to the impacts of unpredictable weather conditions (Gashure, 2024; Kidane et al., 2022). Long-term sustainability in land use is promoted and agricultural productivity is improved by introducing agroforestry and soil and water conservation measures (Mou, 2011). Furthermore, even in the absence of rainfall, the use of fertilizers and irrigation enables more efficient use of the available water resources and nutrients to increase agricultural productivity (Wang et al., 2023). Adoption of such technologies significantly reduces household poverty by improving farm income, agricultural productivity, and consumption (Rotich et al., 2024; Sisay, 2023; Khonje et al., 2018; Patil et al., 2016). However, despite extensive research on technology adoption in SSA, the persistently low uptake of profitable SIT remains a paradox (Abay et al., 2017).

According to the Food and Agricultural Organization (FAO), Sustainable Intensification Technology (SIT) has five major attributes such as being resource efficient, environmentally friendly, technically sound, economically feasible, and socially acceptable (Chao et al., 2024). So far, the adoption of single agricultural technology innovation has been experienced by smallholder farmers (Abay et al., 2016). However, farmers may face many alternative SITs that need to be adopted as complements or substitutes to address overlapping constraints such as weeds, pests, disease infestations, and low soil fertility (Gebremariam and Tesfaye 2018).

Besides, climate change has severe consequences that disproportionately affect small-scale farmers, posing a significant threat to agricultural production in various global regions (Aragón et al., 2019; Mendelsohn et al., 2015; Morton, 2007). The limited productivity of rain-fed agriculture in numerous Sub-Saharan nations is frequently attributed to unexpected shifts in rainfall (Amare et al., 2018; Asseng et al., 2014). Drought shocks have heterogeneous impacts on the cultivation of crops across different agroecological zones (Amare et al., 2018). These problems present a significant challenge for smallholder farmers who heavily (significantly) depend on rainfed farming methods (Tofu et al., 2022).

Investigating heterogeneity in rainfall among smallholder farmers that experience diverse rainfall patterns could help to identify policy options that are well tailored to the needs of socioeconomically diverse smallholders (Gartaula et al., 2024). Here, looking across different types of technologies is very important to gain a broader image, be able to compare, and identify complementarities and substitutes. In addition to this, they intend to contribute in this direction by analyzing the adoption of multiple agricultural technologies among smallholder farmers in Ethiopia (Wainaina et al., 2016).

By implementing SITs, Ethiopian smallholder farmers can enhance their resilience to climate change impacts (Berhanu et al., 2024). Such SITs improve agricultural productivity and food security, promote sustainability in land use, and help to secure the livelihoods of smallholder farmers in the face of climate challenges (Singh, 2024).

In addition, the importance of adoption of SITs lies not only in conserving but also in improving the natural resources such as increasing soil fertility and soil organic matter, without sacrificing the yield levels (Urra et al., 2019). This makes it possible for fields to act as a sink for carbon dioxide, increase the capability of the soil to hold water and reduce soil erosion (International Bank for Reconstruction and Development/International Development Association or The World Bank, 2012). Furthermore, by retaining fertile soils, the adoption of SITs can also have positive impacts on food security and biodiversity (M. Kassie et al., 2013).

But, the adoption rate of SITs in rural areas of developing countries is still low (Huan et al., 2022; Ahmed et al., 2016; Almeida et al., 2016; Kassie et al., 2009). This is true for Ethiopia, the adoption of many recommended intensified technologies is minimal, and environmental degradation continues to be a major constraint to productivity growth and sustainable intensification (Ahmed et al., 2016; Almeida et al., 2016). A well understanding of constraints that condition farmers' adoption behavior for these technologies is therefore important for designing promising pro-poor policies that could facilitate their adoption and increase productivity (Teklewold et al., 2013).

1.2. Statement of the Problem

Similar to other countries, the smallholder farmers of Ethiopia depend on agriculture as a main source of income and livelihood (Zerssa et al., 2021; Kassie et al., 2009). But there are a lot of factors that influence the agricultural sectors of Ethiopia including limited access to resources, unpredictable climate patterns, and the need for sustainable agricultural technologies to ensure long-term food security and agricultural productivity (Zerssa et al., 2021). One critical factor affecting agricultural productivity in Ethiopia is drought (Shigute et al., 2023). The country experiences significant variations in rainfall patterns across different regions, leading to uneven distribution and timing of precipitation (Alhamshry et al., 2020; Ball, 2015). These irregularities pose a substantial challenge to smallholder farmers who heavily rely on rain-fed agriculture (Amare et al., 2018; Asseng et al., 2014). Hence, the problem here is the impact of drought on the adoption of SITs among Ethiopian smallholder farmers.

Due to this, smallholder farmers encounter difficulties in effectively planning and adopting SITs due to unpredictable rainfall patterns (Amare et al., 2018). The irregularity of rainfall poses environmental degradation (Eticha et al., 2021). Moreover, drought impacts the adoption and successful implementation of SITs among smallholder farmers.

Generally, there has been research and demonstrated efforts on the need to increase or boost productivity in the semi-arid regions of Ethiopia, but less has been achieved. To meet the expected rising demands for food, increasing agricultural productivity through the adoption of modern agricultural technologies such as fertilizer use and improved seeds among others are crucial. Inorganic fertilizers when properly applied to soils have the potential to increase soil fertility, improve crop productivity, and enhance household income and food security.

In addition to this, previous studies have explored agricultural technology adoption; few have examined how rainfall variability (such as drought) influences the adoption of a diverse range of complementary technologies at the national level (Arslan et al., 2017; Kassie et al., 2013). This study fills that gap by focusing on drought heterogeneity across Ethiopia. Studies done by Hitayezu et al., (2017) depend on subjective measurements of rainfall stress by asking just the farmers about the last cropping seasons.

However, the study examined drought heterogeneity and the adoption of multiple SITs using real observed historical monthly rainfall data spanning over 40 years. Besides, examining the relationship between drought heterogeneity and the adoption of SITs using real monthly rainfall data in Ethiopia has received little research attention. Using real historical monthly rainfall data is essential for understanding the adoption of SITs and the relationships between rainfall heterogeneity and SITs; as it provides the necessary context for assessing challenges, impacts, and risks.

In this stand, this study is conducted to evaluate drought heterogeneity and the adoption of SITs in Ethiopia. Consequently, the results provide information that is crucial for developing targeted interventions and policies, efficient resource allocation, ultimately enhancing agricultural resilience, improving food security, sustainability in resource use, and enhancing livelihoods in vulnerable regions. Thus, handling this problem using real rainfall data promotes the adoption of SITs among Ethiopian smallholder farmers, leading to improved agricultural productivity, resilience to climate change, and overall sustainable development in the agricultural sector. Hence, the current study aims to assess the adoption of SITs under drought conditions in Ethiopia.

1.3. Objectives

1.3.1. General objective

The general objective of the study was to assess the adoption of SITs under drought conditions of Ethiopia.

1.3.2. Specific objectives

The specific objectives of the study were:

- To assess SITs adoption under rainfall deficit and rainfall surplus areas.
- To identify the determinants of SITs adoption.
- To assess complementarity and/or substitutability natures among the SITs.

1.4. Research Questions

- How does the adoption of SITs vary between areas affected by drought and areas experiencing rainfall surplus?

- What are the determinants of SITs adoption?
- Are SITs complementary and/or substitutable with each other?

1.5. Hypotheses

- Drought shock positively correlates with the adoption of SITs such as improved seed, irrigation, and manure.
- Drought shock negatively correlates with the adoption of SITs such as soil and water conservation, and inorganic fertilizers.

1.6. Significance of the Study

The outcomes of the study can offer valuable insights for interventions aimed at improving the capacity of smallholder farmers to adopt, adapt, and foster SITs in Ethiopia. For instance, the study leads to agricultural productivity improvement, climate change resilience, sustainable intensification adoption, improving rural livelihoods, poverty reduction, and policy formulation.

1.7. Scope and Limitation

The scope of the topic is broad. However, due to limitations in sample size, the study was concentrated on just five SITs, acknowledging that there are more SITs available. Besides, establishing a causal relationship between drought and SITs was also challenging due to the presence of endogeneity.

1.8. Organization of the Paper

The remaining part of the paper is organized as follows. The second chapter deals with a review of literature, which includes both theoretical and empirical literature reviews. The third chapter deals with a brief description of the research methodology. That is, data source, method of data analysis, theoretical framework of the model, and econometrics model specification. The result of the study is discussed in chapter four. Finally, the conclusion and recommendation of the study are presented in chapter five.

CHAPTER 2: LITERATURE REVIEW

The review includes the concepts and theories of drought and the adoption of SITs in Ethiopia as well as empirical literature about drought and SITs adoption in Ethiopia.

2.1. Theoretical Literature Review

Different Researchers proposed different theories of rainfall variability and SIT adoption among smallholder farmers over different periods. Therefore, this section reveals definitions and concepts of drought and the adoption of SITs in Ethiopia and some of the very prominent theoretical literature on drought and the adoption of SITs in Ethiopia.

This study examines the adoption of Sustainable intensification (SI) technologies, with a primary focus on the role of drought as a driving factor, alongside household characteristics, wealth, and institutional variables such as access to agricultural extension and credit. The framework draws upon established theoretical models of constrained decision-making in agricultural technology adoption, which emphasize risk, uncertainty, and resource limitations (Feder et al., 1981, 1985). These seminal works show how farmers' decisions are shaped by both their resource endowments and the broader institutional environment.

The decision to adopt SI technologies is conceptualized as an optimization problem in which households aim to maximize expected utility under various constraints. Building on the work of Feder et al., (1981) and Feder et al., (1985) this framework considers that farmers assess potential benefits from adopting SI technologies, such as enhanced productivity and resilience to climatic shocks, against associated costs, including investment and risk exposure. Drought is treated as an exogenous shock that influences both the perceived benefits and costs of adoption, amplifying risk (especially in technologies such as chemical fertilizer) and altering household resource allocation strategies. Institutional factors, such as access to extension services and credit, are critical enablers that can mitigate these constraints by reducing information asymmetry and providing financial resources. The modeling framework models adoption as a utility-maximizing choice, where farmers evaluate the net benefits of adopting each SI technology relative to not adopting it.

Households are assumed to derive utility U_{ij} from adopting SI technology j, and utility U_{i0} from not adopting. The adoption decision is modeled as a comparison of these utilities:

$U_{ij} = V_{ij} + \in_{ij}$, $U_{i0} = V_{i0} + \in_{i0}$ ……………………………………. Equation (1)

Where V_{ij} and V_{i0} are the deterministic components of utility, and $\in_{ij}$ and $\in_{i0}$ represent unobservable factors. A household i adopts technology j if:

$V_{ij} > V_{i0}$

The deterministic component V_{ij} is a function of factors such as drought, household characteristics, the benefits and costs of adoption, and institutional support programs such as access to extension and credit:

$V_{ij} = \beta_0 + \beta_1 D_{ij} + \beta_2 X_{ij} + \beta_3 I_{ij} + \in_{ij}$ …………………………………. Equation (2)

Where D= drought, X= demographic characteristics of the household, and I= Institutional factors.

Several models can be employed to estimate the adoption of SI technologies. Since the technologies are not mutually exclusive, meaning a household can adopt one or more technologies simultaneously, the study utilized a Multivariate Probit (MVP) model, which relaxes the mutual exclusivity constraint inherent in other models. This approach allows for the simultaneous estimation of adoption decisions while accounting for potential correlations between the unobserved factors influencing the adoption of each technology.

2.1.1. Definitions and concepts of RH and SIA among Ethiopian smallholder farmers

Rainfall: Rainfall is the measurement of the amount of precipitation in the form of rain that descends onto the surface of Earth, whether it is on land or water in a certain period (Khalaf, 2018).

Drought: is a temporary phenomenon related to the rainfall deficit over an extended period, causing adverse impacts on vegetation, animals, and people (NOAA, 2018; NOAA & NDMC, 2006).

Rainfall heterogeneity: Rainfall heterogeneity refers to the variability or uneven distribution of rainfall across a given area (Alhamshry et al., 2020; Ball, 2015). Rainfall heterogeneity significantly influences agricultural practices and technologies in Ethiopia (Marenya et al., 2020). Due to this, farmers can adopt technologies that enhance productivity, food security, resilience, and sustainability by understanding local rainfall patterns (Bhatnagar et al., 2024).

Rainfall heterogeneity and agricultural adaptation: Rainfall heterogeneity and agricultural adaptation refer to the diverse and variable rainfall patterns across different regions of the country, which significantly impact agricultural practices and food security (Sinore & Wang, 2024). Smallholder farmers can enhance their resilience to climate variability, ensuring food security and sustainable livelihoods in the face of changing environmental conditions by adopting innovative technologies (Yeleliere et al., 2023).

Sustainable intensification: sustainable intensification refers to the way to achieve the FAO's vision for sustainable food and agriculture. It is a system to improve yields without adverse environmental impacts (Poudel, 2004).

Sustainable intensification adoption: refers to the process where agricultural yields are increased without adverse environmental impact (Hamazakaza et al., 2022; Jones-Garcia & Krishna, 2021; Marenya et al., 2020; Mutyasira, 2020). Smallholder farmers in Ethiopia face several challenges and barriers when trying to adopt sustainable intensification (SI) technologies. The challenges include limited access to resources, knowledge gap, climate variability, having small land size, lack of infrastructure, and many others that can hinder their ability to improve productivity and resilience (Zerssa et al., 2021). Sustainable Intensification (SI) is highly related to resilience-building and climate change adaptation. Sustainable Intensification (SI) helps to ensure food security, resilience to climate change, and sustainability for the communities by enhancing productivity and improving resource management (FAO, 2006).

Smallholder farmers: are the individuals who engage in small-scale farming such as pastoralists, forest keepers, and fishers who oversee land ranging from less than one hectare up to ten hectares in land size (Food and Agriculture Organization of the United Nations, 2012; Morton, 2007).

Rainfall heterogeneity and sustainable intensification adoption among Ethiopian smallholder farmers: This refers to the variations in rainfall patterns across different regions of Ethiopia and the adoption of SITs that promote productivity, environmental sustainability, and resilience to varying rainfall patterns (Jones-Garcia & Krishna, 2021; Marenya et al., 2020).

2.1.2. Determinants of SI Technologies Adoption

Farmers' decisions to use sustainable agricultural production methods are affected by factors such as perceived advantages, feasibility concerning capacity, the influence of society on agricultural extension activities, the availability of resources including human and physical capital, as well as access to other resources, and household demographics (Hamazakaza et al., 2022; Coulibaly et al., 2021). Here, farmers are confident enough in the benefits that the measures provide and can practice the measures without having too many challenges in terms of resources and information (Statistics, 2017).

In Ethiopia, SI technologies are affected by several factors like access to extension services, the availability of resources including human and physical capital, as well as access to other resources and household demographics, and are not uniformly distributed; there are significant regional differences (Rika Widianita, 2023). Cultural standards have a significant impact on socioeconomic variables such as education and income, which influence agricultural practices and economic prospects. Understanding the factors that hinder education, promoting equitable land tenure, and boosting inclusive economic policies can help to improve the overall development and well-being of communities in Ethiopia (Zaipa & Matemba, 2023).

2.1.3. Impacts of Drought on Agriculture

The deficiency of water availability in soils leads to significant declines in agricultural productivity (Zhang et al., 2022). Drought results from large reductions in the quantity of surface and groundwater supplies, farm production (Cenacchi, 2014).

2.1.4. Complementarity and substitutability of SI technologies

The agricultural productivity of one intensified technology is improved by the adoption of other technologies by preparing a reward for the adoption of multiple technologies when technologies are complementary, keeping other things constant (Biru et al., 2020). On the other hand, some technologies can substitute other technologies (Udimal & Road, 2017).

For instance, some SITs were complementary for example chemical fertilizer and improved seed, while others substituted, such as technologies that offer the same benefits for instance organic fertilizer and chemical fertilizer (Haile, 2017).

Jabbar et al., (2020) suggested that many technologies can be adopted at the same time when they are not mutually exclusive. Quantifying complementarities among different alternative technologies is important because these effects can be correlated with some other observable and unobservable variables that affect households' adoption decisions (Abay et al., 2016). From a policy perspective, quantifying these complementarities while controlling for the unobserved heterogeneities can offer further highlights into the processes of technology adoption (Abay et al., 2016).

Adoption of SITs has evidence in a pair of SITs that are positively correlated between improved seed and chemical fertilizer (Haile, 2017). This is similar to the complementarity effect among SITs and simultaneously, the decision to adopt can be influenced by the availability of substitution as indicated in negatively correlated SIT pairs (Oyetunde-usman et al., 2021).

In Ethiopia, there were a lot of complementary SI technologies including minimum tillage and soil and water conservation, cropping system diversification and manure, minimum tillage and improved seed, soil and water conservation and manure as well as improved seed and chemical fertilizer adoption (M. Kassie et al., 2015). In addition, there were many complementary SI technologies such as chemical fertilizer and crop rotation, chemical fertilizer and improved seed, chemical fertilizer and organic fertilizer as well as crop rotation and manure adoption in Ethiopia (Gebremariam & Tesfaye, 2018).

On the other hand, there are substitutive SI technologies like organic fertilizer and chemical fertilizer adoption (Belete, 2022; Kassie et al., 2015), irrigation and crop rotation adoption (Gebremariam & Tesfaye, 2018) as well as minimum tillage and manure adoption (M. Kassie et al., 2015) in Ethiopia.

However, many constraints can affect the adoption of complementary SI technologies by smallholder farmers in Ethiopia. The constraints can be access to financial services, access to education or information access to extension services, and other related factors (Nguru et al., 2021).

2.1.5. SI technologies adoption heterogeneity

SITs can be heterogeneous (cannot be a homogenous process) and determine who intensifies and who does not intensify (Xie et al., 2019). So, efforts to promote SITs in smallholder farming systems need to appreciate the underlying heterogeneity in farmer characteristics, socioeconomic characteristics, agroecological conditions, and diversity in production objectives (Mutyasira, 2020).

In diverse agroecological zones of Ethiopia, the variability of SITs adoption is structured by a complex interplay of economic, environmental, social, and cultural factors (Hlpe, 2019; B. T. Kassie, 2014). Understanding these factors is important for designing targeted agricultural interventions that can effectively enhance productivity and sustainability across the country's varied landscapes (Berhanu et al., 2024). Modifying strategies to suit local circumstances and needs of smallholder farmers can enhance the rates of adoption and improve food security in various regions of Ethiopia (Alliance, 2022). The adoption of SI technologies in Ethiopia is influenced by regional challenges related to water availability, soil type, financial resources, cultural practices, and access to information (Teklu et al., 2023).

The adoption of SITs in Ethiopia is influenced by farm size, access to resources, and social norms (Mutyasira et al., 2018). Considering these factors are essential for promoting effective adoption across different segments of the population, ultimately enhancing agricultural productivity and sustainability (Mutyasira et al., 2018; Working Paper 158, 2017).

2.1.6. Impacts of Rainfall Heterogeneity on Agriculture

There is evidence of increased risk of pests and diseases of crops under rainfall variability (Kyei-Mensah et al., 2019). There is a cause for concern over the possible spread of major diseases that attack smallholder crops in SSA: for example; sorghum head smut (fungal disease) in areas where rainfall decreases, and maize Streak and Cassava Mosaic (Viral disease) in areas where rainfall increases (Morton, 2007).

Rainfall heterogeneity poses a critical challenge to agricultural productivity in Ethiopia's rain-fed farming systems (Habte et al., 2023). Moreover, rainfall heterogeneity poses a significant risk to agricultural stability in Ethiopia, leading to crop failures and reduced yields (B. T. Kassie, 2014). However, there are a lot of techniques to reduce these impacts. For instance, strengthening soil and water management, adopting drought-tolerant improved seeds, and improving agricultural practices like early planting, are essential for supporting farmers facing these challenges (Berhanu, Ayele, Dagnew, et al., 2024).

2.1.7. Multiple technology adoption decisions and unobserved heterogeneity

Using multiple inputs and technologies, agricultural productivity can be increased, and facing households to make multidimensional adoption decisions (Zegeye et al., 2022). When farm households are rational, they are expected to choose a combination of technologies (inputs) that maximize their profits (Abay et al., 2016). This gives rise to the input complementarity (synergy) argument. Therefore, higher productivity can be achieved through the adoption of multiple technologies than a single technology (Abay et al., 2017).

The adoption of SITs by smallholder farmers of Ethiopia was influenced by many unobserved factors such as access to information, social norms, farmer preferences, access to resources, and many others (Hailemariam et al., 2024; Li et al., 2024). Addressing these factors is important to design effective policy interventions to improve agricultural productivity and achieve sustainable development goals in Ethiopia (Maldayo et al., 2024).

2.2. Empirical Literature Review

It has often been argued that the adoption of SI technologies is low amongst educated smallholder farmers in developing countries like Ethiopia. The empirical evidence is mixed. However, M. Kassie et al., (2015) reviewed the experience of various countries and argues that there is no strong evidence to support the existence of widespread educated smallholder farmer SIT adopters in developing countries. A recent study of SIT adoption in areas that experience variable rainfall reveals an increase in adoption rates of SITs among smallholder farmers. Moreover, Ketema & Bauer, (2012) suggested that educated smallholder farmers highly adopt important SI technologies such as intercropping and low tillage.

Female household heads have lower SIT adoption rates and face with lack of income, cultural constraints, lack of access to information, and hesitation to adopt new technology as compared to male household heads. Empirical evidence indicates that the female-headed households' SITs adoption rates were very low between the age groups 40 – 50 was less than 19.5 percent, but more than 81.5 percent for male-headed households in that age category during the same year (Gartaula et al., 2024; Gebremariam & Tesfaye, 2018; M. Kassie et al., 2015).

These numbers defy the overall pattern for the Sub-Saharan Africa (SSA) region, which shows that male-headed families are more likely than female-headed households to adopt SITs (Gartaula et al., 2024; Gebremariam & Tesfaye, 2018; M. Kassie et al., 2015). The data indicated that male household heads experience higher levels of SI technology adoption than their female household heads in Ethiopia. This is consistently true for all working age groups. On the other hand, the impact of age on technology adoption is uncertain, and it has been argued that women face greater barriers in accessing crucial farming resources and are often subject to discrimination when it comes to acquiring external inputs and information (Dallow, 1992).

Three empirical studies investigated the adoption of SI technologies in SSA countries: Gebremariam & Tesfaye, (2018), Wainaina et al., (2016) and M. Kassie et al., (2015). All the studies used the same methodology. Not surprisingly, the results of the study are quite similar, especially in the adoption of inorganic fertilizers in Ethiopia. However, the adoption rates of the SI technologies such as improved seed, manure, irrigation, and soil and water conservation were quite different.

The authors found that access to extension services has powerful effects on the adoption of SITs as other literatures suggest. Gartaula et al., (2024) investigated the adoption of improved wheat trait seeds in Ethiopia.

Smallholder farmers who obtained (received) extension services were more likely to adopt improved seed and inorganic fertilizer, indicating the significance of extension services for the adoption of SITs by smallholder farmers (Amankwah, 2023). Furthermore, the adoption of SITs is supported by the accessibility of financial services, whereas smallholder farmers in Ethiopia have limited access to credit services (Deresse & Zerihun, 2018; Argaw-Gizachew, 2017).

Gebremariam & Tesfaye, (2018), investigated the factors such as large household size and livestock ownership (TLU) were frequently linked to the willingness of households to take risks, the availability of labor, and the wealth of the household. The smallholder farmers who have larger household sizes and more TLU adopt more complementary and substitute innovative agricultural technologies.

Haile, (2017) indicated (suggested) that educated smallholder farmers who have large family sizes positively influence the decision to adopt Sustainable Intensification Technologies (SITs). So that, family size has a positive effect on the adoption decision of SITs (Chao et al., 2024; Kassie et al., 2013). However, Zheng et al., (2022) investigated the inverse relationship between family size and SITs adoption. The households with a lower family size were more likely to exercise and invest in SITs, as the result revealed a negative relationship between family size and SIT adoption. Furthermore, Paltasingh & Goyari, (2018) also suggested that farmers with higher levels of education had greater access to non-farm income, were more capable of purchasing inputs, were more aware of the advantages of modern technologies, possessed better skills to decode new information, less inclined to invest in labor-intensive technologies, and assessed the significance of new technologies. Therefore, the likelihood and extent of adopting SITs increases as the educational level of farmers rises (Kafando et al., 2022).

George Marechera and Joseph Ndwiga, (2015) indicated the availability of market access is directly associated with the transaction costs. This factor can have a detrimental impact on smallholder's adoption of SITs by the time and expenses required from travel and transportation. Transaction costs serve as barriers that hinder farmers' engagement in the market (Teklewold et al., 2013; Makhura, 2001).

According to Etsay et al., (2019), the socioeconomic factors and plot characteristics have an impact on the decisions to adopt Sustainable Intensification Technologies (SITs). While gender differences have little effect on the adoption of compost and chemical fertilizer, the decision to adopt conservation tillage is significantly influenced by male household head (Bedeke, 2023). In contrast, the decision to adopt chemical fertilizer is not affected by age. This implies that younger farmers might be less risk-averse and more willing to adopt innovative practices (M. Kassie et al., 2009).

Haile, (2017) showed gender of the household head is significantly related to the adoption of SITs, but that is marginally and negatively correlated with the adoption of improved seed. In addition; soil characteristics correlate with the adoption of soil conservation technologies such as contour ploughing and chemical fertilizer (Decision et al., 2019). Moreover, Abebe & Debebe, (2019) indicated higher education level of the household head was positively correlated with the use of organic fertilizers.

Jabbar et al., (2020) investigated the positive and significant correlation between improved seed, chemical fertilizer, and crop rotation. Furthermore, the experience of farmers was significantly correlated with chemical fertilizer (Zheng et al., 2022). Moreover, plot size can significantly influence the adoption of most SITs. Hence, the increase in the size of the plot leads to an increase in the adoption level of SIT (Jabbar et al., 2020).

Joan et al., (2023) and Teklewold et al., (2013) conducted different studies in different developing countries and provided empirical evidence on the variables affecting farmers' adoption of SI technologies, such as age, gender, ethnicity, education, family size, agricultural labor, off-farm work, diversified crops, farm size, experience, land holdings, community level meetings, credit access, output, revenue, extension services, awareness creating training, institutions, household resources, and household dependents. Oyetunde-usman et al., (2021) indicated the adoption of different SITs and their intensity of use depending on age, gender (specifically female-headed), education level, family size, and access to extension services.

In general, the study found that the probability of adoption of improved seeds and chemical fertilizer increases among younger farmers (Oyetunde-usman et al., 2021; Admassie & Ayele, 2009). In addition, the study found that the variables listed above were significant variables that affect the adoption of SITs (Oyetunde-usman et al., 2021).

CHAPTER 3: RESEARCH METHODOLOGY

3.1. Description of the Study Area

The study was focused on Ethiopia. It is specifically conducted in the nine regions of Ethiopia. The regions include Tigray, Afar, Amhara, Oromia, Somali, Benishangul Gumuz, Southern Nations, Nationalities and Peoples Region (SNNPR), Gambella, and Harari. This study used the nine specific regions of Ethiopia because the remaining regions of Ethiopia were included in the SNNPR region for the past three to four years and the data were collected as SNNPR. In these regions significant variations in rainfall patterns are exhibited, which immediately influence the adoption of Sustainable Intensification Technologies (SITs). By understanding the challenges that hinder the adoption of SITs, smallholder farmers can enhance their productivity and sustainability across diverse agroecological zones of Ethiopia. This is because Ethiopian smallholder farmers depend on agriculture for their economic activities and livelihood, and rainfed agriculture dominates.

The rainfall patterns of Ethiopia are shaped by the geographical diversity. The elements such as elevation, topography, and regional climatic conditions result in significant differences in rainfall across highlands, lowlands, and various agroecological zones (Fashing et al., 2022; Van den Hende et al., 2021). Moreover, the geographical diversity of the country influences the adoption of different SITs. Differences in rainfall, soil fertility, access to resources, cultural norms, and risk perceptions all play an important role in shaping how smallholder farmers in different regions adopt new SITs.

Figure 1 and 2 below presents the Enumeration Area (EA) location map in which rainfall data was collected. The points found in the location map indicate the collected rainfall data in different regions of the country. In 2022, rainfall data was not collected in the Tigray region, because Tigray was in deep war and siege.

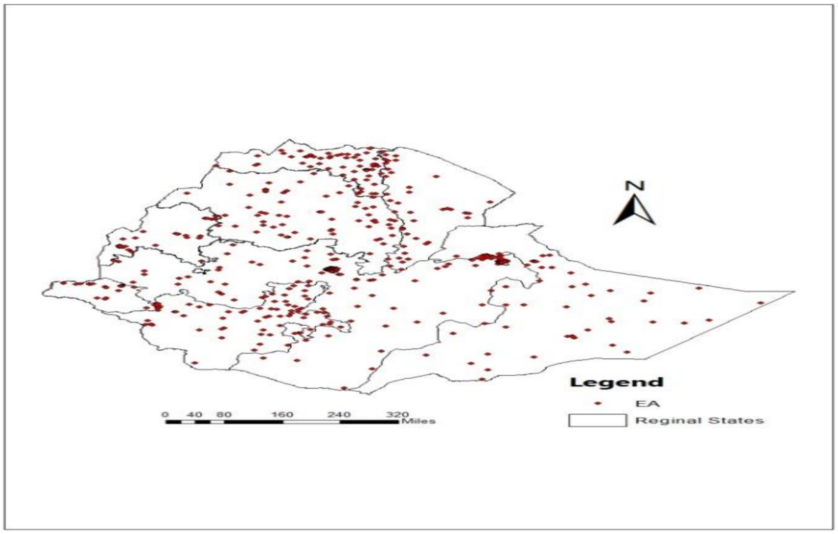


Figure 1: Household EA location 2018

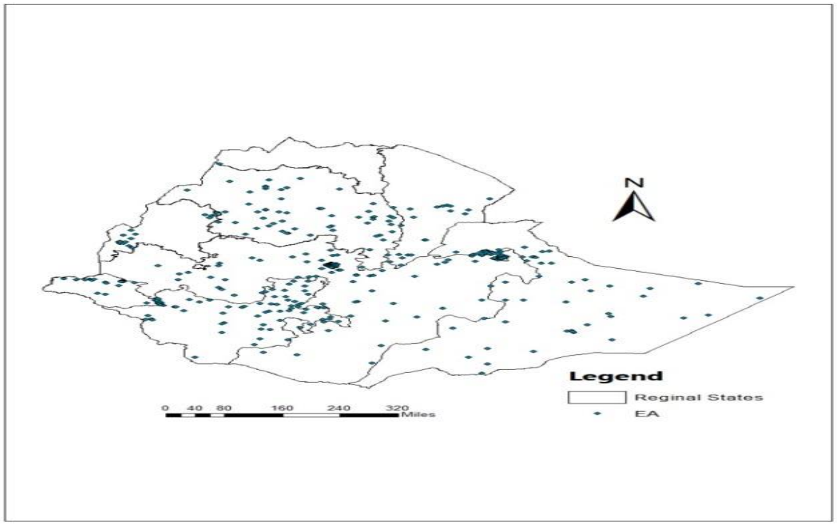


Figure 2: Household EA Location 2022

3.1.1. Location

Ethiopia is found in the eastern region of Africa and is a nation within Sub-Saharan Africa (SSA). It is located in the horn of Africa and shares its borders with Eritrea to the north, Sudan and South Sudan to the west, Kenya to the south, Somalia to the east, and Djibouti to the northeast. Geographically, Ethiopia lies between 3 and 15 degrees north latitude and 33 and 48 degrees east longitude (Country profile, 2019).

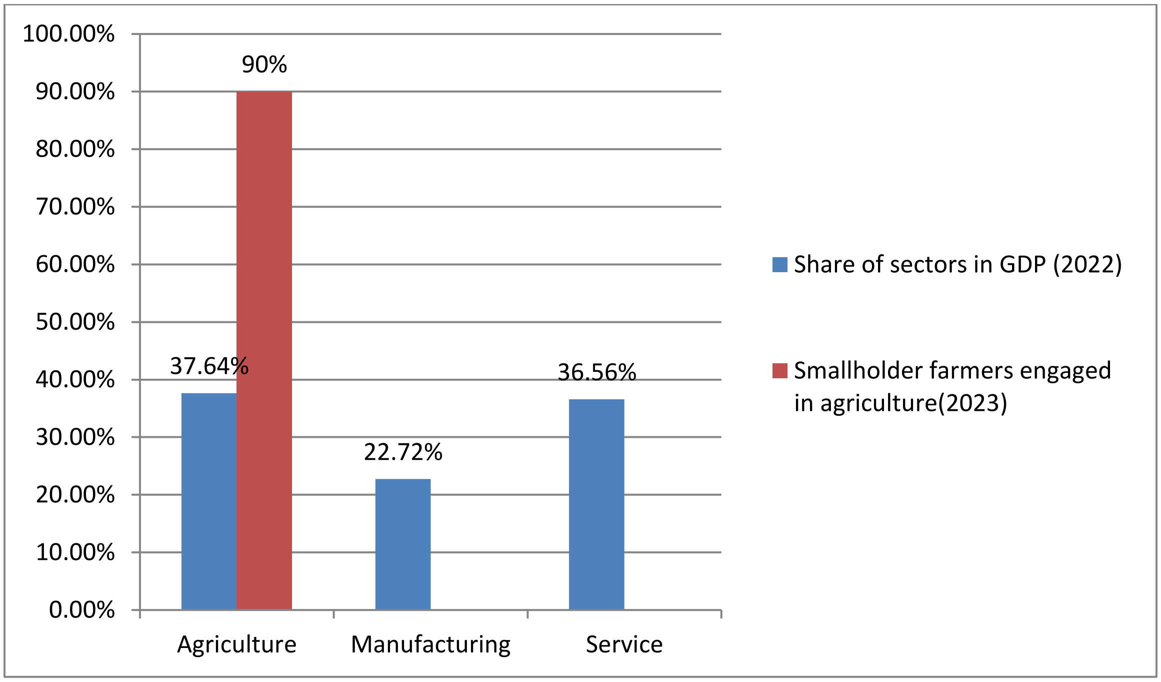
Ethiopia has a varied geographical landscape; including highlands, lowlands, plateaus, and the Great Rift Valley. The central part of the country is home to the capital city, Addis Ababa (Shiferraw, 2022).

3.1.2. Population

An estimated 128,004,290 people are living in Ethiopia. Ethiopia is the eleventh most populous country in the world, with this number representing roughly 1.57% of the world's total population. With a total surface area of 1,000,000 square kilometers, Ethiopia has a population density of about 127 people per square kilometer. In 2023, approximately 27,959,894 people, or 22.1% of the population, would live in urban areas. Ethiopians are roughly 18.8 years old on average. The gender distribution of the population is as follows: 50.2% of people are female, and 49.8% of people are male (World Meter - reference website, 2023). In Ethiopia, families typically consist of five people. The life expectancy of Ethiopians was approximately 67.44 years as of 2022.

3.1.3. Economic activities and livelihood

The agricultural, service, and manufacturing sectors make up the majority of Ethiopians' economic activity and means of subsistence. In 2022, the manufacturing, service, and agricultural sectors will account for roughly 22.72%, 36.56%, and 37.64% of the GDP, respectively (World Bank, 2024). So, the economic contribution of the service sector in Ethiopia is significant next to agriculture. In addition, more than 90% of smallholder farmers were engaged in agriculture in 2023. Figure 3 below presents the shares of the sectors in the Ethiopian economy and the proportion of smallholder farmers engaged in agriculture.



Source: World Bank, 2024

Figure 3: Share of sectors in GDP and proportion of smallholder farmers engaged in agriculture

3.2. Sources of Data and Method of Data Collection

Two different kinds of data sources were used in this investigation. Initially, socioeconomic and demographic data were collected using a nationally representative home survey. To examine climate trends, historical monthly rainfall data covering more than 40 years were also acquired.

3.2.1. Household survey data

The data were obtained from the Ethiopian Socioeconomic Survey (ESS) that was administered through the Living Standards Measurement Study-Integrated Surveys on Agriculture (LSMS-ISA)[1] initiative of the World Bank (WB) in collaboration with the Central Statistical Authority (CSA) of Ethiopia. The household survey gathers detailed information on socioeconomic characteristics, consumption expenditure, assets, and access to services.

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[1] Comprehensive information about the survey, including details such as sample size, sampling methods, data, and additional supporting materials, can be accessed at the following website: www.worldbank.org/lsms-isa.

Simultaneously, the agriculture survey collects plot-level data on sustainable intensification technologies applied in each plot, land holdings, agricultural inputs, crop production, disposition patterns, and livestock ownership (Tesfaye et al., 2021). Furthermore, the ESS collects information on extension services related to crop production and natural resources management at the community level. Both the households and their plots are geo-referenced using a Global Positioning System (GPS), enabling the inclusion of relevant biophysical factors such as rainfall, temperature, and soil nutrient constraints in the analysis.

The Ethiopian Socioeconomic Survey (ESS) is structured to provide an overall picture of the socioeconomic landscape in Ethiopia, capturing essential data points across various domains. The variables that are most relevant for this study were extracted from the ESS including the household demographic variables, assets owned, access to services (financial, credit, and extension), land holdings, agricultural inputs, crop production, rainfall patterns, and livestock ownership.

3.2.2. Rainfall data and drought indicators

The historical rainfall data was obtained from the Climate Hazards Group Infra-Red Precipitation with Station data (CHIRPS), a more than 40 years, quasi-global rainfall dataset covering the latitudinal range of 50∘S to 50∘N. CHIRPS integrates 0.05∘ resolution satellite imagery with in-situ station data, generating a gridded rainfall time series (Gartaula et al., 2024; Michler et al., 2019; Funk et al., 2015). Employing the geographical coordinates for village boundaries obtained from the LSMS-ISA data, it was calculated the total rainfall observed within each village from 1981 to 2019 for the first wave of the data and from 1981 to 2022 for the second wave of the data, by aggregating the village-level monthly rainfall data to annual levels.

Subsequently, it was computed the historical mean, standard deviation, and coefficient of variation of rainfall for each survey year as well as the lagged year for each survey wave, encompassing both the cropping season and lagged years.

Building upon prior studies (Gartaula et al., 2024; Marenya et al., 2020; Rocha & Soares, 2015), after that, it was intended to calculate rainfall shocks by determining the normalized deviations in seasonal rainfall within a single season from the anticipated average seasonal rainfall over 40 years spanning from 1981 to 2022. These village-level averages are applied to each household within the respective village. The computation of the rainfall shock indicator follows this equation:

$$R_{wt} = \left(\frac{r_{wt} - \bar{r}_w}{\sigma_{rw}}\right) \quad \text{Equation (3)}$$

The rainfall shock is computed for each household in a year t, where $r_{wt}$is the observed amount of rainfall for the whole agricultural season, $\bar{r}_w$ is the average seasonal rainfall for the household over 40 years, and $\sigma_{rw}$is the standard deviation of rainfall over 40 years.

Building on different previous studies (e.g., Björkman-Nyqvist, 2013; Maccini & Yang, 2009; Oguntunde et al., 2011; Rocha & Soares, 2015), it was constructed several rainfall-related variables. Our main variable of interest is drought (rainfall deficit), which is estimated using Equation 3, following methodologies from prior research (Amare et al., 2018). The adoption of farm-enhancing inputs is shaped by both liquidity constraints and the degree of uncertainty in the production environment, responding directly to rainfall shocks from the preceding year. In addition to analyzing drought conditions during the survey year, the study also investigates drought in the previous year. Focusing on past drought shocks is crucial, as they are exogenous to current decisions and serve as a reliable proxy for income, which in turn influences households' ability to invest in inputs (Alem et al., 2010; Dercon & Christiaensen, 2011).

These drought shocks are measured as the logarithmic deviation from the historical average and are calculated as follows[2]:

$$R_{wt} = \begin{cases} \left(\frac{r_{wt} - \bar{r}_{w}}{\sigma_{rw}}\right) & if\ <\ -0.5, \\ 0, & Otherwise \end{cases} \qquad \text{Equation (4)}$$

Similarly, a measure of none 0 drought conditions can be estimated as:

$$R_{wt} = \begin{cases} \left(\frac{r_{wt} - \bar{r}_{w}}{\sigma_{rw}}\right) & if\ >\ -0.5, \\ 0, & Otherwise \end{cases} \qquad \text{Equation (5)}$$

By equations (4) and (5) it was categorized the households into drought-prone and none 0 drought prone groups. It then tested among the two groups of households on their SIT adoption preferences. It was also included the total rainfall of the lagged year's growing season period and the rainfall shock indicator of the lagged year (equation 3), in the analysis to control for rainfall related shocks among the rural households in many specifications.

3.3. Study Design

The study used a pooled panel data study design that is representative of Ethiopian smallholder farmers. Pooled panel data is appropriate for controlling unobserved heterogeneity and analyzing temporal dynamics in both the adoption of SITs and variations in rainfall patterns.

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[2] Various cutoff points can be proposed in the literature to classify households as drought-prone or non-drought-prone. We tested several specifications, including categorizing households as drought-prone if the value from Equation 4 was less than -1. However, under this specification, only seven households were identified as drought-prone in the first wave of the data. Consequently, we adjusted our drought indicator to classify households as drought-prone if the value of Equation 4 is less than -0.5. This cutoff point is consistent with recent studies, such as Amare et al. (2018) and Rocha et al. (2021), which have also used this threshold to define drought conditions.

3.4. Sampling Procedure and Sample Size Determination

The Ethiopian Socioeconomic Survey (ESS) used different sampling methods to select sample households. It was planned to survey about 3,792 households in 316 rural Enumeration Areas (EA) in Wave Four (W4) in 2019.

In addition, it was also planned to survey about 3,792 households in 316 rural Enumeration Areas (EA) in Wave Five (W5) in 2022. The ESS was planned to survey about 7,584 rural households in both waves. However, it was surveyed about 4,714 rural households, while the remaining 2,870 rural households were not surveyed due to security issues. So, it was extracted the 4,714 rural households that were surveyed in both waves as sample sizes or observations of this study.

3.5. Methods of Data Analysis

To analyze the collected data both descriptive and econometric models are employed.

3.5.1. Descriptive analysis

Descriptive data analysis was employed to condense the data into a concise format through tabulation (table) and measures of central tendency (mean and standard deviation). The rationale behind employing descriptive statistics is to facilitate a comparison of various determinants.

3.5.2. Econometric analysis

The farmers' choice of interrelated SIT is modeled using a Multivariate Probit (MVP) model and it was analyzed the objectives, using the MVP model, as multiple observations per household were presented. This is because the MVP model is used to estimate several (three or more) correlated binary dependent variables jointly. Moreover, due to its flexible correlation structures, normality assumption, and excellent handling of latent variables and correlated errors across multiple binary outcomes, but it does not directly address endogeneity without additional modifications or techniques., the Multivariate Probit (MVP) model is a more appropriate model for correlated binary outcomes. Other models, such as the Seemingly Unrelated Regression (SUR) and Multivariate Logit (MVL) models, have their advantages, but they might not provide the same benefits when working with binary data in particular. The MVP model is a more suitable model than other models for studying correlated binary outcomes, despite certain limitations such as complexity, assumptions about error correlations, and difficulties in interpretation.

Adoption of inorganic fertilizer, improved seed, soil and water conservation, irrigation, and organic fertilizer/manure are among the SITs considered in this study. To know the challenges in the use of multiple SITs, the MVP model is employed to analyse the decisions to use and the intensity to use the multiple SITs (Jan, 2023).

Moreover, farmers have adopted a mix of technologies to solve agricultural production constraints, so the adoption decision can be inherently multivariate. However, Univariate Models such as Probit and Logit models use a single equation for each practice and can exclude useful economic information about interdependent and simultaneous adoption decisions (Jan, 2023; Teklewold et al., 2013).

MVP model and correlation are applied to determine and predict the current quantitative findings and their effects on rainfall heterogeneity and sustainable intensification adoption among Ethiopian smallholder farmers. The general form of the MVP model is:

$$Y_{ik}^{*} = X_i \beta_i + \mu_i \qquad \text{Equation (6)}$$

Where $\mathbf{Y}_{ik}^{*}$ is the probability that farmer i adopts technology k (k = F, S, Sw, I, M), $\mathbf{X}_i$ is the vector of the exogenous variables that affect the adoption decision, and β_i is the vector of parameters to be estimated.

The MVP model is characterized by a set of binary dependent variables K, that is equal to 1 if the ith respondent adopts SI technology K[3], and zero otherwise, such that:

$$Y_k = \begin{cases} 1 & if \quad Y_{ik}^{*} > 0 \\ 0 & otherwise \end{cases} \quad K(F, S, Sw, I, M) \qquad \text{Equation (7)}$$

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[3] F = fertilizer, S = improved seed, Sw = soil &water conservation, I = irrigation and M = manure

The multivariate model allows the simultaneous adoption of multiple SI technologies, and the error terms are assumed to follow a Multivariate Normal Distribution (MVN). The MVN has a zero conditional mean and the variance is standardized to unity (for identification of the parameterization) where $(\mu_A, \mu_Y, \mu_s) \approx MVN(0, \Omega)$ and the symmetric covariance matrix Ω is given by:

$$\Omega = \begin{bmatrix} 1 & \rho FS & \rho FSw & \rho FI & \rho FM \\ \rho SF & 1 & \rho SSw & \rho SI & \rho SM \\ \rho SwF & \rho SwS & 1 & \rho SwI & \rho SwM \\ \rho IF & \rho IS & \rho ISw & 1 & \rho IM \\ \rho MF & \rho MS & \rho MSw & \rho MI & 1 \\ & & & & \end{bmatrix} \qquad \text{Equation (8)}$$

The value of Ω becomes 1 on the main diagonal and correlations $\rho_{lk} = \rho_{kj}$ as minor diagonal elements. The minor diagonal elements in the covariance matrix are of interest since they represent the unobserved correlation between the stochastic components of the different types of technologies. This assumption means that Equation (6) gives the MVP model that jointly represents decisions to prefer a particular technology, which is explained by the hypothesized explanatory variables. This specification with non-zero minor diagonal elements allow for correlation across the error terms of the several latent equations, which represent unobserved characteristics that affect the choice of alternative technologies. The MVP estimator generates an error term correlation matrix that is highly informative about the interdependence between the various types of technologies.

A positive and significant correlation between the error terms of two technologies indicates that unobserved factors influencing the adoption of one technology also increase the likelihood of adopting the other. This is often interpreted as complementarities or synergies, meaning the two technologies are mutually reinforcing (e.g., adopting one makes adopting the other more beneficial or likely), while a negative correlation suggests that unobserved factors influencing the adoption of one technology reduce the likelihood of adopting the other. This is typically interpreted as substitutability or trade-offs, meaning the two technologies compete for resources or are alternatives to each other (Gartaula et al., 2024; Börsch-Supan & Hajivassiliou, 1993; Cappellari & Jenkins, 2003; Gebremariam & Tesfaye, 2018). Besides, Insignificant correlations suggest that the relationship (positive or negative) is weak or nonexistent.

For instance, the correlation coefficient (ρ) ranges from -1 to 1. The correlation coefficient equals one (perfect positive correlation), indicating that if one outcome occurred, the other outcome definitely occurred as well. Moreover, the correlation coefficient equals negative one (perfect negative correlation), indicating that if one outcome occurred, the other outcome definitely not occur. Furthermore, the correlation coefficient equals zero (no correlation), suggesting that the outcomes were independent of each other indicating insignificant or both outcomes did not occur.

But, in this case, the threshold or criteria to categorize SI technologies as complementary or substitutive was both the magnitude and sign of the correlation coefficient (ρ) of the significant variables at 1%, 5%, and 10% significance levels. When the sign of the correlation coefficient (ρ) of the significant variables is positive, indicating the complementarity of SI technologies. These SI technologies are adopted together by smallholder farmers.

On the other hand, when the sign of the correlation coefficient (ρ) of the significant variables is negative, indicating that substitutive of SI technologies. These SI technologies offer the same benefits to smallholder farmers. The complementary or substitutive SI technologies can lead to effective policy recommendations. By understanding these smallholder farmers need to adopt multiple SI technologies especially complementary SI technologies to improve their agricultural productivity and food security.

3.6. Variable Descriptions

3.6.1. Dependent variable

The dependent variables (SITs) considered in this study were inorganic fertilizer, improved seed, soil and water conservation, irrigation, and organic fertilizer/manure.

3.6.2. Independent variables

The independent variables are the variables that influence the dependent variable. They are variables that affect the outcome. Therefore, the independent variables are listed below.

Drought shock:

Drought shock is what the household experiences. This is calculated by taking the absolute value of the difference between the total rainfall of the growing season and the historical average of the 41 years of rainfall divided by the standard deviation of rainfall in the 41 years.

Drought shock includes rainfall surplus and rainfall deficit. Different areas that experience different amounts of rainfall can adopt different types of SITs. Therefore, drought shock positively affected the adoption of irrigation and manure, but the adoption of soil and water conservation is affected negatively.

Gender:

Gender is a dummy variable which takes 1 if the household head is female and 0 if male. Women mostly engage in household activities, while men engage in farming activities due to cultural barriers. Due to this, male-headed households are better adopters of SITs. Therefore, the adoption of SITs like fertilizer, soil and water conservation, irrigation, and manure are negatively related to women.

Age:

The age of the household head is a continuous variable measured in years. Therefore, the age of the household head positively and negatively affected the adoption of manure and soil and water conservation, respectively.

Education level:

The education level of the respondent is a dummy variable, which takes 1 if the household is literate and 0 if illiterate. Education is very important to know the way of living through a lifetime. If the household's education level increases the households are more likely to participate in the adoption of SITs than illiterate rural smallholder farmers and can analyze cost and benefit to improve their food security status. Those farmers who have a better level of schooling have a high chance of adoption of SITs. Education helps the individual to utilize farming activities because the capacity created would help the individual to analyze, interpret, and make use of it than illiterate individuals. Then based on the above perspectives, the level of education positively affected the fertilizer, improved seed, soil and water conservation, and manure adoption.

Household size:

Household size is a continuous variable measured by the number of household members. The larger the number of family members, ceteris paribus, the more the labor force available for production purposes and consumes large amounts of food. A large labor force needs more production for consumption so they demand more finance. Families with larger family sizes can earn additional income by engaging in different activities.

The labor force is an important demographic variable that can affect the adoption of SITs. Therefore, household size influenced positively the adoption of improved seed, soil and water conservation, irrigation, and manure.

Farm size:

This variable is continuous and refers to the total cultivated farm size in hectares owned by the household. Those farmers who have large size of land require more labor and that demands additional capital that might be obtained through farming activities. The farmers who have large size of land can utilize more capital and can adopt more SITs. The size of own land has a strong and positive effect on SITs adoption. Therefore, farm size has a positive relationship with fertilizer, improved seed, soil and water conservation, and manure adoption, thereby increasing farmers' income.

Total Livestock Holding:

The livestock holding variable is continuous and defined in terms of Tropical Livestock Unit (TLU). Livestock is considered an asset that is liquid and a security against crop failure. Moreover, livestock are used in production processes, that is for threshing, transporting, etc. For this reason, it has an important role in improving the welfare of the household. Those farmers who have a higher number of livestock holdings have a high chance of adopting SITs. It was hypothesized the variable to have a positive impact on SITs adoption. However, this variable can harm the adoption of fertilizer, improved seed, soil and water conservation, irrigation, and manure.

Asset owned:

Asset owned is calculated from different types of assets owned by the smallholder farmers. Smallholder farmers who have many different types of assets can adopt SITs. Based on the above justification it was hypothesized the variable to have a positive impact on SITs adoption. However, this variable can hurt the adoption of fertilizer, improved seed, soil and water conservation, irrigation, and manure.

Access to financial services:

Access to financial services is a dummy variable that refers to the ability of smallholder farmers to obtain financial services, including credit, deposit, payment, insurance, and other risk management services. Smallholder farmers who obtain financial services can adopt SITs. Based on the above justification access to financial services has a positive relationship with the adoption of fertilizer, soil and water conservation, irrigation, and manure.

Access to credit:

Amount of credit is a dummy variable that refers to the amount of borrower's money from financial institutions in birr. If the households obtain credit, they will have a higher chance to adopt SITs as compared to households who cannot obtain credit. Based on the above justification it hypothesized the variable to have a positive impact on SITs adoption. However, this variable can have an insignificant impact on SITs adoption.

Access to extension service:

Access to extension service is a dummy variable that refers to the number of contacts with extension agents that the household made in the year. Accessibility of extension advice is helpful as farmers could have better income as a result of the use of new technologies. Moreover, farmers who have frequently contacted Development Agents (DA) are likely to have better information on updated prices of agricultural products. Farmers who have frequent contact with extension agents can have more information that could influence farm households' demand for surplus products. Households frequently contact the extension agent and have better access to farm technologies than non-participants. Based on the above justification access to extension services has a positive relationship with the adoption of fertilizer, improved seed, soil and water conservation, irrigation, and manure.

Distance to market:

Distance to market is a continuous variable measured in kilometers from the household home to the nearest market center. Proximity to the market centers creates access to additional income by providing non-farm employment opportunities, and easy access to SITs and transportation of farm outputs, this leads to participation in the market to engage in income activities. Therefore, a household nearer to the market center has a better chance to adopt SITs, and leads to improved household food security status than others. Location further away from the market significantly reduces the adoption level of SITs. Distance to market centers has a positive relationship with the adoption of fertilizer, improved seed, and manure.

Market shock:

Market shock is a dummy variable that refers to the unexpected disturbances of the market concerning the price rise of agricultural inputs. So, the price fall of inputs has a better chance to adopt SITs and leads to improved household food security status than others. However, price falls significantly enhance the adoption level of SITs. So, price fall has a positive relationship with the adoption of fertilizer, improved seed, soil and water conservation, and manure.

Generally, the independent variables can be grouped into demographic and socioeconomic variables such as drought shock, gender, age, education, family size, farm size, TLU, asset index, access to financial services, access to credit, access to extension services, distance of farm from input market and market shock.

Table 1: Summary of working variables

№	Variables	Types of variables	Definition of variables	Expected sign
1	Drought shock	Index	Rainfall deficit or rainfall surplus	+/-
2	Gender	Dummy	Gender of the household head (1= female,0=male)	-
3	Age	Continuous	Age of household head (years)	+/-
4	Education	Dummy	Education Level of the HH head (literate = 1, illiterate = 0)	+
5	Household size	Continuous	HH size of the household head (persons)	+
6	Farm size	Continuous	Land holding size of the HH (hectare)	+
7	TLU	Continuous	Livestock owned (Tropical Livestock Unit)	+
8	Asset owned	Index	Asset owned (index)	+
9	Financial services	Dummy	Access to financial services (yes=1, 0=no)	+
10	Access to credit	Dummy	Access to credit service(1=yes,0=no)	+
11	Extension services	Dummy	Access to extension service(1=yes,0=no)	+
12	Distance to input market	Continuous	Distance to input market (km)	-
13	Market shock/ price shock	Dummy	Market shock/ price shock (1= if household faces price fall of inputs,0=no)	-

CHAPTER 4: RESULTS AND DISCUSSION

4.1. Descriptive Statistics

The analysis is based on the nationally representative data from the Ethiopian Socioeconomic Survey (ESS) that is administered through the Living Standards Measurement Study-Integrated Surveys on Agriculture (LSMS-ISA) initiative of the World Bank (WB) in collaboration with the Central Statistical Authority (CSA) of Ethiopia.

Table 2 presents the descriptive statistics of the variables used in the model. The choice of the variables is guided by previous literature on the adoption of SI technologies. Based on the available data set, it was focused on five different SITs (use of fertilizer, improved seed, soil and water conservation, irrigation, and manure) in this study as dependent variables. From Table 2, it can be seen that improved seed is adopted by about 84.6% of the educated households. This is the most adopted SIT and it could be justified as it is the cheapest and commonly used strategy to reduce drought risk exposure. Moreover, soil and water conservation practices are adopted by about 82.9% of educated households. Furthermore, fertilizer is adopted by about 81.8% of the educated households. The use of irrigation by educated smallholder farmers is about 81.2% of their crop fields. In addition, about 73.7% of the educated households use manure (table 2).

The descriptive statistics presented the adoption of SI technologies by different regions of Ethiopia. The regional variations in the adoption of SI technologies were due to economic-related factors, differences in farm size, variations in rainfall patterns, availability of infrastructure, differences in skills, availability of training, market demand, and many other factors. The smallholder farmers in the SNNP region are the least irrigation adopters, but regions other than (Tigray, Amhara, and Oromia) are the most adopters (table 2).

Generally, the SITs (fertilizer, improved seed, soil and water conservation, irrigation, and manure) adopted by smallholder farmers of Tigray are low. This is due to the small population size, occurrence of the war and siege in the region, lack of awareness, lack of access to (finance, credit, extension services, and information), inadequate infrastructure, and hesitancy to adopt new SI technology. In addition to this, the small adoption rates of SITs in the Tigray region were due to a lack of both socioeconomic and rainfall data. Since no socioeconomic and rainfall data were collected in the Tigray region in 2022 due to the presence of war and siege.

Addressing the factors that hinder the SI technologies adoption difference among the regions; can foster the adoption rates of SI technologies, and enhance agricultural productivity and resilience among smallholder farmers in all regions of Ethiopia.

The average age of household heads that adopted fertilizer, improved seed, irrigation, and manure was 45.699 years (table 2). This result is almost consistent with the studies done by Gebremariam & Tesfaye, (2018), but with a slight difference. Since, they found the average age of household heads that adopted fertilizer, improved seed, irrigation, and manure was 45.49 years. In addition, the average household size is approaching 5. This was done by rounding down and this result is as similar as Gebremariam & Tesfaye, (2018).

Table 2: Descriptive statistics of variables used in the model (Mean and standard deviation)

Variable	F	S	SW	I	M
Drought Shock (Rs<-0.5)	0.226	0.242	0.215	0.310	0.257
	(0.419)	(0.428)	(0.411)	(0.463)	(0.437)
Drought Shock (Rs<-0.5) Lagged Year	0.137	0.171	0.136	0.087	0.155
	(0.344)	(0.377)	(0.343)	(0.282)	(0.362)
Total Rainfall (ln)	7.040	7.063	7.027	6.659	7.056
	(0.366)	(0.399)	(0.449)	(0.579)	(0.383)
Total Rainfall Lagged Year (ln)	7.035	7.061	7.009	6.717	7.054
	(0.293)	(0.329)	(0.373)	(0.503)	(0.293)
Gender of Head (Female=1)	0.177	0.178	0.168	0.169	0.191
	(0.382)	(0.382)	(0.374)	(0.376)	(0.393)
Age of Head (Years)	46.122	45.459	44.403	44.407	46.807
	(14.789)	(14.371)	(13.616)	(14.079)	(14.957)
Education of Head (Literate=1)	0.818	0.846	0.829	0.782	0.812
	(0.386)	(0.361)	(0.377)	(0.413)	(0.391)
Household Size	5.285	5.460	5.405	5.390	5.322
	(2.182)	(2.246)	(2.156)	(2.305)	(2.189)
Farm Size	0.974	1.040	0.813	0.736	0.811
	(1.045)	(1.063)	(0.979)	(0.691)	(0.979)

TLU	2.877	3.005	2.745	2.731	2.798
	(2.534)	(2.828)	(2.871)	(2.737)	(2.498)
Asset Index	-1.867	-1.924	-1.932	-1.845	-1.918
	(0.830)	(0.783)	(0.796)	(0.955)	(0.835)
Access to Financial Service (Yes=1)	0.419	0.390	0.440	0.402	0.427
	(0.493)	(0.488)	(0.496)	(0.491)	(0.495)
Access to Credit (Yes=1)	0.138	0.134	0.134	0.133	0.122
	(0.345)	(0.341)	(0.341)	(0.340)	(0.327)
Access to Extension (Yes=1)	0.675	0.756	0.496	0.576	0.499
	(0.469)	(0.429)	(0.500)	(0.495)	(0.500)
Distance to Input Market (km)	0.627	0.616	0.574	0.574	0.609
	(0.484)	(0.487)	(0.495)	(0.495)	(0.488)
Market Shock (Yes=1)	0.344	0.371	0.321	0.346	0.347
	(0.475)	(0.483)	(0.467)	(0.476)	(0.476)
Year (2022=1)	0.440	0.490	0.395	0.436	0.448
	(0.497)	(0.500)	(0.489)	(0.496)	(0.497)
Tigray =1	0.108	0.066	0.103	0.063	0.067
	(0.311)	(0.249)	(0.305)	(0.243)	(0.250)
Amhara =1	0.240	0.258	0.186	0.274	0.210
	(0.427)	(0.438)	(0.389)	(0.446)	(0.407)
Oromia =1	0.248	0.297	0.175	0.109	0.218
	(0.432)	(0.457)	(0.380)	(0.312)	(0.413)
SNNP =1	0.211	0.212	0.258	0.029	0.278
	(0.408)	(0.409)	(0.438)	(0.168)	(0.448)
Other Regions==1	0.192	0.167	0.277	0.525	0.227
	(0.394)	(0.373)	(0.448)	(0.500)	(0.419)
Observations	1,973	1,014	2,494	413	2,337

Note: Robust standard errors in parentheses. F = fertilizer, S = improved seed, SW = soil & water conservation, I = irrigation and M = manure

4.2. SIT Adoption under Drought Exposure

The study examined the determinants of sustainable intensification (SI) adoption among households. Given that SIT adoption is not mutually exclusive; households may adopt multiple SI technologies within a season. The study employed a Multivariate Probit (MVP) model to analyze the factors affecting the adoption of Sustainable Intensification Technologies (SITs). Its primary interest was to assess the impact of drought shocks on the adoption of Sustainable Intensification Technologies (SITs), as droughts are significant factors that potentially change household decision-making around farming strategies.

The SITs considered in this study include the use of inorganic fertilizers, improved seeds, soil and water conservation practices, irrigation, and the use of organic fertilizers (manure). These Sustainable Intensification Technologies (SITs) represent the most commonly adopted technologies among rural Ethiopian households. By focusing on these widely used technologies, the study aims to understand the range of strategies that households employ to improve agricultural productivity and resilience in the face of economic and climatic challenges.

To ensure robustness, the study examined several model specifications and included multiple drought indicators. As indicated in Table 3 below, it was started with a simple model that just incorporated cropping season droughts as a baseline condition. Before adding other variables that can interact with drought, like household demographics and economic characteristics, this first specification allowed me to separate the impact of season-specific droughts. The method offers a thorough grasp of how environmental elements, such as droughts, affect the use of Sustainable Intensification Technologies (SITs) in farming.

According to the findings, drought shocks significantly reduce the use of inorganic fertilizers. This negative effect may be due to households' reluctance to invest in costly inputs like inorganic fertilizers when returns are uncertain under low rainfall conditions. This result is consistent with existing literature, which frequently associates drought shocks with decreased fertilizer adoption rates.

For instance, the adoption of fertilizer and their exposure to drought were found to be negatively correlated at the district level in India (Bora, 2022). These more general conclusions are supported by our study, which indicates that drought conditions have a significant influence on farmers' decision-making to spend on agricultural inputs.

In contrast, during drought (rainfall deficit) conditions, smallholder farmers are more likely to adopt risk-reducing Sustainable Intensification Technologies (SITs), like irrigation and manure (organic fertilizer). These SITs provide resilience by reducing drought-related hazards, which makes them attractive options for households dealing with unpredictable rainfall. The findings are consistent with other research that indicates households exposed to drought are more likely to deploy risk-reducing technologies to protect agricultural output (Gashure 2024, Islam and Farjana 2024, Cavatassi et al., 2011). This consistency emphasizes how adaptive methods play a part in household decision-making when climate stress is present.

Smallholder farmers faced with a lack of rainfall are more likely to adopt irrigated fields and field organic fertilizer use during rainfall deficit. This is due to the immediate benefits of irrigation (including immediate water supply, crop resilience, and more production) as well as the availabilities of benefits of manure (such as nutrient supply, cost-effective, better water retention, and reduced erosion) making them as an alternative option for households when drought occurs. In this case, the rainfall shock was found to be positively related to the adoption of irrigated field and field organic fertilizer use but negatively related to inorganic fertilizer use, and soil and water management.

Inorganic fertilizer uses and soil and water management are highly preferred in rainfall surplus areas than in rainfall deficit areas. The preference for inorganic fertilizers and soil and water management practices in rainfall surplus areas is due to the availability of water, enhanced nutrient efficiency, economic incentives, and lower risk of crop failure. However, these SI technologies are less effective in rainfall deficit areas. Because fertilizer is highly dependent on water and it is expensive.

In addition to this, soil and water conservation requires a significant labor force, takes a long time, and gives inconsistent production. So, during rainfall deficit (drought) the smallholder farmers prioritize their immediate survival needs instead of buying fertilizer and conserving soil and water.

For instance, a one-unit increase in drought shock leads to a 0.092 decrease in fertilizer adoption. This interpretation gives some insight to the smallholder farmers on how to adopt and not to adopt fertilizer when rainfall is variable. The above interpretation suggests that as drought conditions worsen, smallholder farmers are less likely to use fertilizers. Using fertilizer, the areas affected by drought lead to decreased agricultural productivity and are highly vulnerable to food shortage and economic instability (table 3).

Table 3: Determinant of SIT Adoption - Survey Year Drought Shock Only (Rs<-0.5)

VARIABLES	F	S	SW	I	M
Drought Shock (Rs<-0.5)	-0.092**	0.004	-0.207***	0.163***	0.099**
	(0.043)	(0.047)	(0.042)	(0.056)	(0.043)
Constant	-0.194***	-0.801***	0.106***	-1.391***	-0.042**
	(0.021)	(0.024)	(0.021)	(0.030)	(0.021)
Observations	4,714	4,714	4,714	4,714	4,714

Note: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

F = fertilizer, S = improved seed, SW = soil & water conservation, I = irrigation and M = manure

The rainfall shock in the lagged year was found to be positively related to the adoption of improved seed use but negatively related to inorganic fertilizer use, soil and water management, and irrigated fields. The result indicates that inorganic fertilizer use, irrigated fields, and soil and water management are highly preferred in rainfall surplus areas than in rainfall deficit areas in the lagged year.

However, improved seed adoption is highly preferred in the rainfall deficit areas in the lagged year. The findings regarding rainfall shock in the lagged year provide valuable insights into how past rainfall conditions influence the adoption of agricultural SI technologies.

So, smallholder farmers need to adjust their adoption based on the previous year's experiences, but this adjustment can also include flexibility in resource allocation, aiming to enhance resilience in the face of environmental variability. Generally, table 4 describes the adoption of SITs under rainfall deficit in the lagged year.

Table 4: Determinant of SIT Adoption - Lagged Year Drought Shock Only (Rs<-0.5)

VARIABLES	F	S	SW	I	M
Drought Shock (Rs<-0.5) Lagged Year	-0.121**	0.114**	-0.154***	-0.317***	0.045
	(0.052)	(0.056)	(0.052)	(0.083)	(0.052)
Constant	-0.199***	-0.817***	0.080***	-1.314***	-0.026
	(0.020)	(0.022)	(0.020)	(0.027)	(0.020)
Observations	4,714	4,714	4,714	4,714	4,714

Note: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

F = fertilizer, S = improved seed, SW = soil & water conservation, I = irrigation and M = manure

The total annual rainfall was found to be positively related with the adoption of fertilizer, improved seed, soil and water conservation and manure. However, the total annual rainfall is negatively correlated with the adoption of irrigation. The result indicates that, as the total annual rainfall in one area increases, the smallholder farmers are more likely to adopt fertilizer, improved seed, soil and water conservation and manure, but decreases the adoption of irrigation. Almost all the SITs were adopted in the areas having excess rainfall except the adoption of irrigation (table 5).

Table 5: Determinant of SIT Adoption - Total Annual rainfall only

VARIABLES	F	S	SW	I	M
Total Rainfall (ln)	0.688***	0.588***	0.733***	-0.307***	0.856***
	(0.034)	(0.047)	(0.039)	(0.040)	(0.036)
Constant	-4.969***	-4.877***	-4.991***	0.748***	-5.919***
	(0.234)	(0.332)	(0.267)	(0.272)	(0.249)
Observations	4,714	4,714	4,714	4,714	4,714

Note: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

F = fertilizer, S = improved seed, SW = soil & water conservation, I = irrigation and M = manure

Generally, the improved seed becomes insignificant during the survey year drought shock only, but it was significant and positive in the lagged year drought shock only due to the time lag effects, measurement error, or external factors (like weather, market price, or pest infestation).

4.3. Determinants of SIT Adoption

In this section, attempts have been made to explain the main demographic and socio-economic determinants of SITs. As mentioned earlier, the MVP model was selected to identify the determinants of SITs among Ethiopian smallholder farmers. However, before fitting the MVP model, it was important to check whether a serious problem exists between explanatory variables. In the model, a total of 18 independent variables that may affect the dependent variables' adoption of SITs were considered. Among them, 17 of the variables were found significant variables which affect the adoption rate of SITs. However, it found that one of them (access to credit) was statistically insignificant (table 6).

The results demonstrate further, the importance of household demographic characteristics on SITs adoption in Ethiopia. For instance, the explanatory variable education level has a positive and significant effect on the adoption of fertilizer and improved seeds as of (Amankwah, 2023).

Moreover, manure and soil and water conservation adoption are positively correlated with education level, but have no significant effect on the adoption of irrigation, at ceteris paribus. The positive and significant effect of education with the adoption of fertilizer, improved seed, soil and water conservation, and manure is due to informed decision-making, increasing knowledge and awareness, networking opportunities, and many other factors. Smallholder farmers are empowered through education to make informed decisions that enhance agricultural productivity and sustainability.

The result also highlights the complex and heterogeneous effects of drought shocks on the adoption of different SI technologies. In contrast, drought shocks harm the adoption of some SITs; this study shows new light that drought shocks would also induce households to adopt SITs. It was found that drought shocks have a significant effect on the adoption of most of the SITs but with different signs. This result is consistent with the studies done by (Gartaula et al., 2024). Rainfall deficit encourages the use of irrigation and manure but discourages the use of soil and water conservation. This is because rainfall deficits may increase farmers' aversion to investing in long-term practices (like soil and water conservation) due to the uncertainty of future returns. Instead, they focus on short-term, tangible solutions like irrigation and manure application. The occurrence of drought increases the adoption of irrigation and manure by 0.485 and 0.14 at 1% and 5% significance levels respectively, other things remain constant. On the other hand, drought shock decreases the adoption level of soil and water conservation by 0.123 at a 10% significance level, at the ceteris paribus (table 6).

Households with access to extension services are more likely to adopt fertilizer and improved seed. This result is the same as with (Amankwah, 2023). Moreover, access to extension services has a positive relationship with soil and water conservation, irrigation, and manure adoption, indicating the importance of extension services in the adoption of SITs. As access to extension services increases by one day, the adoption of fertilizer, improved seed, soil and water conservation, irrigation, and manure increases by 1.646, 1.224, 0.691, 0.575, and 0.633 at 1% significance levels respectively, at ceteris paribus (table 6).

Generally, access to financial services plays a great role in supporting the adoption of SI technologies, while access to credit cannot be significant due to many factors such as credit constraints, immediate investment priorities, risk aversion, influence of education, and social factors. Moreover, credit markets are still underdeveloped for smallholder farmers in Ethiopia (Deresse & Zerihun, 2018; Argaw-Gizachew, 2017).

On the other hand, the asset index has a negative significant effect on manure adoption. This result is consistent with (Teklewold et al., 2019). In addition, it demonstrates a negative correlation with fertilizer, improved seed, soil and water conservation, and irrigation adoption.

Smallholder farmers who live near the market are more likely to adopt improved seeds and organic fertilizers. Different studies found the same positive significant relationship between distance to input market and fertilizers as well as improved seed adoption (Gebremariam & Tesfaye, 2018). Moreover, table 6 presents that distance to the input market has a positive significant effect on manure adoption. This result highlights households located far away from the input market adopt manure instead of fertilizer use. However, studies done by Zerfu & Larson, (2010) indicate that smallholder farmers who adopt manure also adopt more fertilizer to improve their productivity.

The explanatory variable, the age of the household head is negatively correlated with manure adoption. Moreover, Gebremariam & Tesfaye, (2018) found that the age of the household head was positively associated with manure adoption. On the contrary, soil and water conservation adoption increases with the age of the household head.

In addition, the variable gender of household head (female household head) has a negative significant effect on the adoption of fertilizer, soil and water conservation, irrigation, and manure. Being a female-headed household decreases the adoption of fertilizer, soil and water conservation, irrigation, and manure. The reason is, that female household heads might face with lack of income as compared to male household heads, cultural constraints, lack of access to information, and hesitation to adopt new technology. Due to this, they have reduced the adoption of most SITs.

Moreover, as it was expected, household size is positively correlated with improved seed, soil and water conservation, irrigation, and manure adoption. The positive correlation between household size and the adoption of improved seed, soil and water conservation practices, irrigation, and manure use can be attributed to increased labor availability, diverse farming needs, and better access to support services. These factors collectively improve the capacity of larger households to adopt SI technologies, contributing to improved agricultural productivity.

Furthermore, the explanatory variables, farm size, and market shock (price fall) have a positive significant effect on the adoption of fertilizer, improved seed, soil and water conservation, and manure. Smallholder farmers that have access to finance improve the adoption of fertilizer, soil and water conservation, irrigation, and manure. The variable livestock ownership measured in TLU has a negative significant effect on the adoption of all SITs. When rainfall deficit (drought) occurs, the livestock could be sold, looted, killed, and affected by diseases. Hence, the variable, livestock ownership is negatively correlated with fertilizer, improved seed, soil and water conservation, irrigation, and manure adoption.

In addition, Ethiopian smallholder farmers enhanced the adoption of manure in the year 2022 as compared to the data collected in 2019. This finding is consistent with Gebremariam & Tesfaye, (2018). Moreover, the collected data in 2022 shows that smallholder farmers improved the adoption of fertilizer, improved seed, and soil and water conservation. The smallholder farmers located in Tigray, Amhara, and Oromia regions increase the adoption of fertilizer and irrigation but decrease the adoption of manure. In addition, the smallholder farmers found in Amhara and Oromia regions improve the adoption of irrigation, but reduce the adoption of soil and water conservation. On the other hand, smallholder farmers found in regions other than Tigray, Amhara, and Oromia regions discourage the adoption of fertilizer, improved seed, soil and water conservation, and manure, but encourage irrigation adoption (table 6). The relationship and magnitude of influence of significant variables are analyzed here below.

Table 6: Determinants of SIT Adoption - Survey Year Drought Shock Only (Rs<-0.5) and other controls

VARIABLES	**F**	**S**	**SW**	**I**	**M**
Drought Shock (Rs<-0.5)	-0.031	0.034	-0.123*	0.485***	0.140**
	(0.071)	(0.074)	(0.065)	(0.082)	(0.063)
Gender of Head (Female=1)	-0.196***	-0.022	-0.364***	-0.143**	-0.243***
	(0.057)	(0.062)	(0.052)	(0.072)	(0.050)
Age of Head (Years)	-0.000	-0.002	-0.008***	-0.001	0.009***
	(0.002)	(0.002)	(0.001)	(0.002)	(0.001)
Education of Head (Literate=1)	0.134**	0.201***	0.330***	0.016	0.235***
	(0.060)	(0.064)	(0.051)	(0.074)	(0.052)
Household Size	0.006	0.021*	0.057***	0.043***	0.031***
	(0.012)	(0.013)	(0.011)	(0.014)	(0.011)
Farm Size	0.353***	0.210***	0.230***	-0.002	0.202***
	(0.046)	(0.043)	(0.033)	(0.031)	(0.031)
TLU	-0.021***	-0.019*	-0.040***	-0.023***	-0.028***
	(0.008)	(0.010)	(0.007)	(0.007)	(0.005)
Asset Index	-0.049**	-0.103***	-0.246***	-0.106***	-0.148***
	(0.024)	(0.030)	(0.026)	(0.030)	(0.026)
Access to Financial Service (Yes=1)	0.348***	0.047	0.412***	0.224***	0.360***
	(0.073)	(0.077)	(0.060)	(0.078)	(0.062)
Access to Credit (Yes=1)	-0.026	0.077	-0.098	-0.075	-0.060
	(0.073)	(0.077)	(0.068)	(0.087)	(0.069)
Access to Extension (Yes=1)	1.646***	1.224***	0.691***	0.575***	0.633***
	(0.050)	(0.050)	(0.046)	(0.060)	(0.046)
Distance to Input Market (km)	0.200***	0.108**	-0.032	0.009	0.090**
	(0.047)	(0.050)	(0.042)	(0.054)	(0.042)
Market Shock (Yes=1)	0.194***	0.107*	0.159***	0.167***	0.240***

	(0.056)	(0.055)	(0.049)	(0.065)	(0.049)
Year (2022=1)	0.635***	0.303***	0.185**	-0.098	0.248***
	(0.086)	(0.090)	(0.073)	(0.096)	(0.072)
Tigray =1	0.639***	-0.087	0.050	0.941***	-0.789***
	(0.108)	(0.115)	(0.098)	(0.162)	(0.099)
Amhara =1	0.232***	0.183**	-0.542***	1.201***	-0.471***
	(0.075)	(0.078)	(0.074)	(0.135)	(0.074)
Oromia =1	0.269***	0.348***	-0.848***	0.564***	-0.564***
	(0.073)	(0.073)	(0.072)	(0.141)	(0.072)
Other Regions==1	-0.793***	-0.587***	-0.956***	1.080***	-1.241***
	(0.066)	(0.071)	(0.063)	(0.130)	(0.063)
Constant	-1.561***	-2.029***	-0.311**	-2.993***	-0.864***
	(0.137)	(0.144)	(0.121)	(0.205)	(0.123)
Observations	4,714	4,714	4,714	4,714	4,714

Note: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

F = fertilizer, S = improved seed, SW = soil & water conservation, I = irrigation and M = manure

4.4. Correlates of SIT Adoption

The significant pairwise correlation coefficient between the error terms of the five SITs adoption is presented in Table 7 below. The correlation coefficients are statistically different from zero in the five SITs of the ten combinations in the rainfall deficit areas of Ethiopia. This suggests that SITs adoptions are not mutually independent except for the correlation between fertilizer and manure.

The MVP model using STATA result described that the correlation coefficient of all the SITs became statistically significant at a 1% significance level under drought exposure (table 7). In this case, the correlation between all the SITs becomes positive and significant, indicating complementarities or synergies between the two given technologies.

The complementarity between SI technologies suggests that the adoption of one technology positively influences the adoption of others. These complementarities need to be practiced through risk reduction, resource efficiency, enhanced market access, and sustainability practices.

These interactions improve both individual farm productivity and contribute to the overall resilience and sustainability of agricultural systems. Encouraging the adoption of complementary SITs can lead to agricultural productivity that benefits not only the smallholder farmers but also the community as well as the society as a whole.

Practically, some smallholder farmers implement the adoption of multiple SI technologies at once; others choose a subset that best meets their needs. The decision on which SI technology to adopt is influenced by various factors; including local conditions, resource availability, external support, variability of rainfall, and individual household goals. However, when farm households are rational, they are expected to choose a combination of SI technologies that maximize their profits (Abay et al., 2016). The study suggests that smallholder farmers need to adopt more SI technologies than single SI technology to improve their agricultural yields. the finding is the same with Abay et al., (2017).

It was expected that the correlation between fertilizer and manure to become negative and significant indicating substitutability or trade-offs between two given technologies as of (Haile, 2017, Wainaina et al., 2016), but the actual result becomes in the contrary. Studies done by Zerfu & Larson, (2010) presents the same result, smallholder farmers adopt both manure and fertilizer together to improve their productivity.

However, smallholder farmers may not view manure and fertilizer as complementary in certain areas. They see substitutive SI technologies without considering the nutrient content of the different fertilizers (inorganic fertilizer and manure). The reason is that for smallholder farmers located in areas that were highly affected by rainfall deficit (severe droughts) or rainfall deficit (above-average rainfall), the adoption of both SI technologies may not work, but it does work in the areas that account for small variations in rainfall.

Due to this, the adoption of both manure and fertilizer is mandatory to protect the moisture content of the soil and to improve agricultural productivity. When the farmers use either of them, the moisture content of the soil facilitates drying by increasing the soil acidity and may reduce productivity due to the insufficient availability of the manure.

Complementarities or synergies are indicated by a positive and substantial correlation between the SITs, but substitutability or trade-offs between two specific technologies are suggested by a negative correlation (Gartaula et al., 2024; Börsch-Supan & Hajivassiliou, 1993; Cappellari & Jenkins, 2003; Gebremariam & Tesfaye, 2018).

For instance, considering Table 7 results below, all the SITs are complementarities or synergies. Agricultural productivity can be improved by the adoption of multiple SI technologies when the technologies are complementary, keeping other things constant as per our findings and (Biru et al., 2020).

The STATA result below presents (indicates) a positive and significant correlation between SITs like fertilizer and improved seeds as well as fertilizer and manure, consistent with the findings of (Amankwah, 2023; Gebremariam & Tesfaye, 2018). A significant positive correlation between fertilizer and improved seeds implies that farmers who adopt one are more likely to adopt the other. This relationship highlights that the two technologies are complementary, often working together to improve agricultural productivity. Improved seeds are designed to achieve higher yields, but their potential is often fully realized only when combined with appropriate nutrient levels, which fertilizers provide. Farmers recognize this synergy and adopt both technologies together. Fertilizer ensures adequate nutrient availability, while improved seeds make better use of these nutrients. In many agricultural development initiatives, improved seeds and fertilizers are promoted together as part of input packages. Farmers may adopt both simultaneously due to such programs. By adopting both technologies, farmers mitigate risks associated with partial adoption. For example, using improved seeds without fertilizers may lead to suboptimal yields, while using fertilizers on low-performing seeds may waste resources.

In addition, a positive correlation between fertilizer and manure suggests that these two inputs are not substitutes but rather complementary, with farmers using both to enhance soil fertility. Farmers may combine manure (a natural, organic input) with fertilizer (a synthetic, inorganic input) to balance short-term nutrient availability with long-term soil health. Manure improves soil structure, water retention, and microbial activity, while fertilizer provides immediately available nutrients. Limited quantities of manure may not meet the nutrient demands of crops on their own, especially for high-yielding varieties. Combining it with fertilizers allows farmers to optimize nutrient management. Farmers may use manure in one season (e.g., before planting) and fertilizers during the growing season for optimal nutrient delivery.

Moreover, Table 7 presents the positive and significant correlation between fertilizer and improved seeds, fertilizer and soil and water conservation as well as improved seeds and soil and water conservation. This result is consistent with (Moshi & Isinika, 2016). Fertilizer and Improved Seeds are Complementary technologies adopted together to maximize crop yields due to mutual reinforcement. Furthermore, fertilizer benefits from SWC practices, which conserve soil nutrients and moisture, enhancing fertilizer efficiency. Lastly, improved seeds thrive in the stable soil and moisture conditions created by SWC practices, making the two technologies complementary. Therefore, the correlations of the significant variables are analyzed here below.

Table 7: Correlation of SITs adoption

SITs	Correlation coefficient				
	A	**B**	**C**	**D**	**E**[4]
F & S	0.904*** (0.032)	0.915*** (0.032)	0.914*** (0.032)	0.852*** (0.032)	0.443*** (0.035)
F & SW	0.582*** (0.024)	0.557*** (0.024)	0.557*** (0.024)	0.469*** (0.024)	0.196*** (0.028)
F & I	0.331*** (0.031)	0.287*** (0.031)	0.294*** (0.031)	0.380*** (0.034)	0.178*** (0.036)
F & M	0.712*** (0.026)	0.708*** (0.026)	0.710*** (0.026)	0.619*** (0.026)	0.387*** (0.030)
S & SW	0.472*** (0.025)	0.486*** (0.025)	0.486*** (0.025)	0.414*** (0.025)	0.185*** (0.029)
S & I	0.273*** (0.030)	0.288*** (0.030)	0.293*** (0.030)	0.345*** (0.031)	0.197*** (0.036)
S & M	0.536*** (0.025)	0.536*** (0.025)	0.538*** (0.025)	0.459*** (0.026)	0.199*** (0.029)
SW & I	0.832*** (0.032)	0.821*** (0.030)	0.842*** (0.032)	1.033*** (0.042)	0.924*** (0.042)
SW & M	0.595*** (0.024)	0.576*** (0.024)	0.581*** (0.024)	0.466*** (0.025)	0.285*** (0.026)
I & M	0.291*** (0.028)	0.256*** (0.027)	0.264*** (0.027)	0.342*** (0.028)	0.170*** (0.029)

Note: Robust standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

F = fertilizer, S = improved seed, SW = soil & water conservation, I = irrigation and M = manure

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[4] A = Survey year Drought Shock Only (Rs<-0.5), B = Lagged year Drought Shock Only (Rs<-0.5), C = Survey year Drought Shock Only (Rs<-0.5) and Lagged year D = Total Annual Rainfall Only E = Survey year Drought Shock Only (Rs<-0.5) and Other Controls

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

Sustainable Intensification Technologies (SITs) play an important role in enhancing agricultural productivity while concurrently reducing environmental impact. In the model, the SITs such as inorganic fertilizer, improved seed, soil and water conservation, irrigation, and manure were taken as dependent variables, and 18 explanatory variables were included. Based on the STATA result, 17 of the explanatory variables (drought shock, gender, age, education, household size, farm size, TLU, asset index, access to finance, access to extension service, distance to input market, and market shock) were found significant determinants of the dependent variables adoption of SI technologies and one explanatory variable (access to credit) was found insignificant.

The variable, access to extension service has a positive relationship with fertilizer, improved seed, soil and water conservation, irrigation, and manure adoption. Hence, access to financial services plays a great role in supporting the adoption of SI technologies, while access to credit cannot be significant due to many factors such as credit constraints, immediate investment priorities, risk aversion, influence of education, and social factors.

On the other hand, the gender of the household head (female household head) has a negative significant effect on the adoption of fertilizer, soil and water conservation, irrigation, and manure. Being female-headed household decreases the adoption of fertilizer, soil and water conservation, irrigation, and manure. The reason is, that female household heads might face with lack of income as compared to male household heads, cultural constraints, hesitation, and lack of information access to adopt new technology.

This study shows new light that drought shocks would induce households to adopt SITs. It was found that drought shocks have a significant effect on the adoption of most of the SITs but with different signs. The drought shock was found to be positively related to the adoption of irrigated field and field organic fertilizer use but negatively related to inorganic fertilizer use, and soil and water management. This result indicates that smallholder farmers located in areas having shortages of rainfall adopt irrigation and manure to improve their productivity.

This is due to the immediate benefits of irrigation (including immediate water supply, crop resilience, and more production) as well as the availabilities of benefits of manure (such as nutrient supply, cost-effective, better water retention, and reduced erosion) making them as an alternative option for households when drought occurs.

In contrast, fertilizer and soil and water conservation are highly preferred in rainfall surplus areas. The preference for inorganic fertilizers and soil and water management practices in rainfall surplus areas is due to the availability of water, enhanced nutrient efficiency, economic incentives, and lower risk of crop failure. However, these SI technologies are less effective in rainfall deficit areas. Besides, smallholder farmers adopt improved seeds in rainfall surplus and rainfall deficit areas.

Agricultural productivity can be improved by the adoption of multiple SI technologies when the technologies are complementary, keeping other things constant. In this case, the correlation between inorganic fertilizer and improved seed, inorganic fertilizer and soil and water conservation, inorganic fertilizer and irrigation, inorganic fertilizer, and manure, improved seed and soil and water conservation, improved seed and irrigation, improved seed and manure, soil and water conservation and irrigation, soil and water conservation and manure, irrigation and manure is positive and significant; indicating complementarities or synergies of technologies. The complementarity between SI technologies suggests that the adoption of one technology positively influences the adoption of others.

These complementarities manifest in practice through integrated use, resource efficiency, risk reduction, community engagement, enhanced market access, and sustainability practices. So, when farm households are rational, they are expected to choose a combination of SI technologies that maximize their profits.

Generally, this study aligns with previous research studies on the importance of climate variability in influencing agricultural technology adoption, while adding a nuanced understanding of how drought shocks specifically impact the adoption of complementary technologies.

5.2. Recommendations

Based on the above findings of the study, the following recommendations can be drawn for further consideration to enhance the adoption of SITs to improve agricultural productivity.

Extension service has a positive effect on the adoption of fertilizer, improved seed, soil and water conservation, irrigation, and manure**.** Therefore, extension agents should provide training to the farmers, educating, provide technical support and advice, create awareness of farmers on the economic importance of the SITs through extension, and promote other complementary services to improve the participation of farmers in the adoption of such technologies. So, smallholder farmers' knowledge and abilities in implementing various complementary SITs can be improved through enhancing agricultural extension services and providing capacity-building training.

Market shock (simply price fall) also has a positive effect on the adoption of fertilizer, improved seed, soil and water conservation and manure, and the creation of appropriate market channels including the creation of cooperative marketing systems, better access to market information, and price stabilization mechanisms is very important to increase the demand for adoption. Providing relevant and timely information for the farmers enables them to make informed decisions and understand the benefits and opportunities associated with the adoption of the SITs.

The result shows smallholder farmers face different constraints regarding the adoption of SITs. So, the federal government in coordination with the regional government should increase financial support; provide necessary agricultural inputs at an acceptable price, expand awareness through training, create market contracts, subsidize the price of output, and other important strategies to improve the adoption and productivity of smallholder farmers.

Adoption has a substantial contribution to improving agricultural productivity, crop income, food security, and livelihood. Hence, there is a need to motivate non-adopter households through awareness-creating campaigns to adopt the SITs to improve their living standard.

Policy and institutional support play a crucial role in promoting the adoption of SITs. Local governments can promote SITs adoption by creating partnerships between smallholder farmers and Non-Governmental Organizations (NGOs), smallholder farmers with agricultural cooperatives as well as smallholder farmers with the private sectors. Furthermore, to strengthen (encourage) smallholder farmers, governments and policymakers can enact laws that provide incentives like price support and input subsidies.

Targeted interventions for particular demographic groups, like age and gender, as these factors were important in my research. So, it would be useful to provide extension programs that should specifically target female household heads and older farmers who may face unique barriers to technology adoption, such as lack of mobility or access to education.

Adopting long-term SI technologies in a sustainable manner like drought tolerant improved seed, irrigation, and manure makes an attractive option for farmers found in the regions highly affected by climate change and water scarcity. Furthermore, smallholder farmers need to adopt inorganic fertilizers and soil and water conservation practices sustainably in the rainfall-surplus areas. Therefore, in light of climate change, implementing such technology can support sustainable agricultural practices and food security.

Finally, there are certain restrictions (limitations) on this study. First, although a wider variety of SI technologies are known to exist, the study only concentrates on five of them. For a more thorough examination, future studies should broaden the focus to include other technologies. Second, the data used in this study comes from post-adoption, in which farmers choose to adopt. The possibility of endogeneity or unseen influences impacting the adoption SITs, is therefore introduced. The study used two-period data to try to alleviate this problem, although bias is still possible. The results should therefore be regarded cautiously. It was stressed that the findings point to correlations rather than causes.

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APPENDICES

Appendix 1: Determinant of SIT Adoption – Survey Year Drought Shock Only (Rs <-0.5) Lagged and Total Rainfall

	(1)	(2)	(3)	(4)	(5)
VARIABLES	**F**	**S**	**SW**	**I**	**M**
Drought Shock (Rs<-0.5)	0.382*** (0.051)	0.341*** (0.059)	0.247*** (0.052)	0.094 (0.063)	0.774*** (0.055)
Drought Shock (Rs<-0.5) Lagged Year	-0.177*** (0.057)	0.060 (0.060)	-0.135** (0.056)	-0.323*** (0.087)	-0.102* (0.058)
Total Rainfall (ln)	0.809*** (0.038)	0.716*** (0.056)	0.806*** (0.043)	-0.290*** (0.041)	1.157*** (0.044)
Constant	-5.870*** (0.267)	-5.862*** (0.402)	-5.533*** (0.303)	0.643** (0.282)	-8.181*** (0.307)
Observations	4,714	4,714	4,714	4,714	4,714

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1
F = fertilizer, S = improved seed, SW = soil & water conservation, I = irrigation and M = manure

The variables such as drought shock in the survey year, drought shock in the lagged year and total rainfall highly affected the adoption of SITs. The significant and positive coefficient of the drought shock in the survey year, drought shock in the lagged year and total rainfall indicates that, the adoption of SITs in rainfall deficit areas; whereas the significant and negative coefficient indicates that, the adoption of SITs in rainfall surplus areas (appendix 1).

Appendix 2: Determinant of SIT Adoption - All shock variables only

	(1)	(2)	(3)	(4)	(5)
VARIABLES	**F**	**S**	**SW**	**I**	**M**
Drought Shock (Rs<-0.5)	-0.141*	-0.166*	0.113	-0.146*	0.162**
	(0.075)	(0.085)	(0.075)	(0.083)	(0.077)
Drought Shock (Rs<-0.5) Lagged Year	0.135**	0.374***	-0.058	-0.183**	0.261***
	(0.065)	(0.072)	(0.064)	(0.093)	(0.066)
Total Rainfall (ln)	-0.979***	-1.083***	0.358**	-1.082***	-0.923***
	(0.186)	(0.213)	(0.181)	(0.220)	(0.190)
Total Rainfall Lagged Year (ln)	2.003***	2.023***	0.493**	0.866***	2.350***
	(0.202)	(0.246)	(0.196)	(0.243)	(0.208)
Constant	-7.270***	-7.344***	-5.819***	0.169	-9.944***
	(0.302)	(0.517)	(0.331)	(0.336)	(0.354)
Observations	4,714	4,714	4,714	4,714	4,714

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1
F = fertilizer, S = improved seed, SW = soil & water conservation, I = irrigation and M = manure

Appendix 2 above presents; the adoption of SITs under all shock variables. The significant and positive coefficient of the all-shock variables indicates that, the adoption of SITs in rainfall deficit areas; whereas the significant and negative coefficient indicates that, the adoption of SITs highly preferred in rainfall surplus areas.

Appendix 3: Determinant of SIT Adoption - Survey Year Drought Shock Only (Rs<-0.5)

	(1)	(2)	(3)	(4)	(5)
VARIABLES	**F**	**S**	**SW**	**I**	**M**
Drought Shock (Rs<-0.5)	0.097 (0.076)	0.041 (0.077)	-0.060 (0.067)	0.509*** (0.083)	0.232*** (0.065)
Drought Shock (Rs<-0.5) Lagged Year	-0.458*** (0.081)	-0.036 (0.073)	-0.265*** (0.066)	-0.030 (0.091)	-0.360*** (0.064)
Gender of Head (Female=1)	-0.188*** (0.057)	-0.022 (0.062)	-0.359*** (0.052)	-0.140* (0.071)	-0.239*** (0.050)
Age of Head (Years)	-0.000 (0.002)	-0.002 (0.002)	-0.008*** (0.001)	-0.001 (0.002)	0.009*** (0.001)
Education of Head (Literate=1)	0.130** (0.060)	0.201*** (0.064)	0.329*** (0.051)	0.019 (0.074)	0.232*** (0.052)
Household Size	0.006 (0.012)	0.021* (0.013)	0.057*** (0.011)	0.043*** (0.014)	0.031*** (0.011)
Farm Size	0.358*** (0.046)	0.210*** (0.043)	0.230*** (0.033)	-0.002 (0.031)	0.202*** (0.031)
TLU	-0.018** (0.008)	-0.019* (0.010)	-0.039*** (0.007)	-0.023*** (0.007)	-0.027*** (0.005)
Asset Index	-0.047** (0.024)	-0.103*** (0.030)	-0.245*** (0.026)	-0.108*** (0.030)	-0.146*** (0.025)
Access to Financial Service (Yes=1)	0.318*** (0.074)	0.043 (0.077)	0.391*** (0.060)	0.222*** (0.077)	0.338*** (0.063)
Access to Credit (Yes=1)	-0.013 (0.074)	0.079 (0.077)	-0.091 (0.068)	-0.073 (0.087)	-0.050 (0.069)
Access to Extension (Yes=1)	1.660*** (0.051)	1.224*** (0.050)	0.692*** (0.046)	0.577*** (0.060)	0.638*** (0.046)
Distance to Input Market (km)	0.213*** (0.047)	0.108** (0.050)	-0.028 (0.042)	0.012 (0.054)	0.097** (0.043)

Market Shock (Yes=1)	0.206*** (0.056)	0.109** (0.055)	0.162*** (0.049)	0.167*** (0.064)	0.245*** (0.049)
Year (2022=1)	0.645*** (0.087)	0.302*** (0.090)	0.182** (0.073)	-0.095 (0.096)	0.248*** (0.073)
Tigray =1	0.525*** (0.109)	-0.095 (0.117)	-0.027 (0.100)	0.947*** (0.164)	-0.880*** (0.102)
Amhara =1	0.119 (0.077)	0.175** (0.080)	-0.611*** (0.076)	1.204*** (0.139)	-0.554*** (0.077)
Oromia =1	0.225*** (0.073)	0.347*** (0.073)	-0.879*** (0.073)	0.561*** (0.143)	-0.595*** (0.073)
Other Regions==1	-0.924*** (0.070)	-0.592*** (0.073)	-1.024*** (0.065)	1.084*** (0.133)	-1.333*** (0.065)
Constant	-1.449*** (0.138)	-2.020*** (0.147)	-0.229* (0.123)	-3.008*** (0.204)	-0.768*** (0.125)
Observations	4,714	4,714	4,714	4,714	4,714

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

F = fertilizer, S = improved seed, SW = soil & water conservation, I = irrigation and M = manure

Appendix 3 above shows, the variables that influence the adoption of SITs in survey year drought shock only. The significant and positive coefficient of the variables indicates that, adoption of SITs increases by that coefficient; whereas the significant and negative coefficient of the variables indicates that, adoption of SITs decreases by that coefficient.

Appendix 4: Determinant of SIT Adoption - Survey Year Drought Shock Only (Rs<-0.5)

	(1)	(2)	(3)	(4)	(5)
VARIABLES	**F**	**S**	**SW**	**I**	**M**
Drought Shock (Rs<-0.5)	-0.123** (0.053)	-0.150** (0.060)	-0.267*** (0.052)	0.370*** (0.064)	-0.017 (0.053)
Drought Shock (Rs<-0.5) Lagged Year	-0.240*** (0.087)	-0.110 (0.094)	-0.266*** (0.085)	-0.050 (0.117)	-0.306*** (0.087)
Drought Shock (Year*Lagged)	0.278** (0.115)	0.451*** (0.125)	0.372*** (0.114)	-0.714*** (0.171)	0.559*** (0.116)
Constant	-0.177*** (0.022)	-0.792*** (0.024)	0.126*** (0.022)	-1.392*** (0.031)	-0.023 (0.022)
Observations	4,714	4,714	4,714	4,714	4,714

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1
F = fertilizer, S = improved seed, SW = soil & water conservation, I = irrigation and M = manure

Appendix 4 above highlights, drought shock in the survey year, drought shock in the lagged year and drought shock in in both years affected the adoption of SITs. The significant and positive coefficient of the drought shock in the survey year, drought shock in the lagged year and drought shock in in both years indicates that, the adoption of SITs in rainfall deficit areas; whereas the significant and negative coefficient indicates that, the adoption of SITs in rainfall surplus areas.

Appendix 5: Determinant of SIT Adoption - Survey Year Drought Shock Only (Rs<-0.5)

	(1)	(2)	(3)	(4)	(5)
VARIABLES	**F**	**S**	**SW**	**I**	**M**
Drought Shock (Rs<-0.5)	0.266*** (0.082)	0.027 (0.088)	0.020 (0.072)	0.573*** (0.087)	0.279*** (0.072)
Drought Shock (Rs<-0.5) Lagged Year	-0.012 (0.112)	-0.059 (0.102)	-0.080 (0.090)	0.151 (0.121)	-0.243*** (0.081)
Drought Shock (Year*Lagged)	-0.759*** (0.155)	0.039 (0.143)	-0.362*** (0.130)	-0.373** (0.180)	-0.218* (0.123)
Gender of Head (Female=1)	-0.196*** (0.057)	-0.021 (0.062)	-0.359*** (0.052)	-0.136* (0.072)	-0.239*** (0.050)
Age of Head (Years)	-0.001 (0.002)	-0.002 (0.002)	-0.008*** (0.001)	-0.001 (0.002)	0.009*** (0.001)
Education of Head (Literate=1)	0.135** (0.060)	0.198*** (0.064)	0.333*** (0.051)	0.022 (0.074)	0.234*** (0.052)
Household Size	0.002 (0.012)	0.022* (0.013)	0.056*** (0.011)	0.042*** (0.014)	0.030*** (0.011)
Farm Size	0.368*** (0.046)	0.210*** (0.043)	0.233*** (0.033)	0.000 (0.031)	0.204*** (0.031)
TLU	-0.017** (0.008)	-0.019* (0.010)	-0.038*** (0.007)	-0.022*** (0.007)	-0.026*** (0.005)
Asset Index	-0.048** (0.023)	-0.103*** (0.031)	-0.245*** (0.026)	-0.106*** (0.030)	-0.146*** (0.025)
Access to Financial Service (Yes=1)	0.318*** (0.074)	0.045 (0.077)	0.394*** (0.060)	0.227*** (0.077)	0.340*** (0.063)
Access to Credit (Yes=1)	-0.018 (0.075)	0.078 (0.077)	-0.093 (0.068)	-0.076 (0.087)	-0.051 (0.069)
Access to Extension (Yes=1)	1.673*** (0.052)	1.224*** (0.050)	0.693*** (0.046)	0.580*** (0.060)	0.640*** (0.046)

Distance to Input Market (km)	0.216*** (0.047)	0.111** (0.050)	-0.025 (0.042)	0.012 (0.054)	0.098** (0.043)
Market Shock (Yes=1)	0.216*** (0.056)	0.109** (0.056)	0.168*** (0.049)	0.175*** (0.064)	0.248*** (0.049)
Year (2022=1)	0.625*** (0.087)	0.304*** (0.090)	0.180** (0.073)	-0.090 (0.095)	0.247*** (0.073)
Tigray =1	0.506*** (0.109)	-0.092 (0.117)	-0.043 (0.100)	0.917*** (0.163)	-0.888*** (0.102)
Amhara =1	0.068 (0.079)	0.179** (0.080)	-0.646*** (0.078)	1.155*** (0.138)	-0.572*** (0.077)
Oromia =1	0.192*** (0.074)	0.350*** (0.073)	-0.905*** (0.074)	0.517*** (0.140)	-0.609*** (0.073)
Other Regions==1	-0.999*** (0.072)	-0.588*** (0.074)	-1.068*** (0.068)	1.029*** (0.133)	-1.357*** (0.067)
Constant	-1.424*** (0.138)	-2.023*** (0.147)	-0.212* (0.124)	-2.981*** (0.202)	-0.759*** (0.125)
Observations	4,714	4,714	4,714	4,714	4,714

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1
F = fertilizer, S = improved seed, SW = soil & water conservation, I = irrigation and M = manure

Appendix 5 above presents, the determinants that influence the adoption of SITs in survey year drought shock only. The significant and positive coefficient of the variables indicates that, adoption of SITs increases by that coefficient; whereas the significant and negative coefficient of the variables indicates that, adoption of SITs decreases by that coefficient.

Appendix 6: Determinant of SIT Adoption - Total Annual rainfall only and controls

	(1)	(2)	(3)	(4)	(5)
VARIABLES	**F**	**S**	**SW**	**I**	**M**
Total Rainfall (ln)	0.059	-0.013	0.368***	-0.655***	0.391***
	(0.054)	(0.066)	(0.053)	(0.060)	(0.047)
Gender of Head (Female=1)	-0.194***	-0.022	-0.349***	-0.201***	-0.229***
	(0.057)	(0.062)	(0.052)	(0.070)	(0.051)
Age of Head (Years)	-0.000	-0.002	-0.008***	0.000	0.009***
	(0.002)	(0.002)	(0.001)	(0.002)	(0.001)
Education of Head (Literate=1)	0.127**	0.203***	0.283***	0.113	0.193***
	(0.060)	(0.065)	(0.052)	(0.073)	(0.053)
Household Size	0.008	0.022*	0.071***	0.024*	0.047***
	(0.012)	(0.013)	(0.011)	(0.014)	(0.011)
Farm Size	0.346***	0.210***	0.192***	0.061**	0.145***
	(0.047)	(0.043)	(0.032)	(0.030)	(0.029)
TLU	-0.019**	-0.020*	-0.030***	-0.043***	-0.017***
	(0.008)	(0.010)	(0.007)	(0.008)	(0.005)
Asset Index	-0.048**	-0.102***	-0.246***	-0.118***	-0.144***
	(0.024)	(0.030)	(0.026)	(0.031)	(0.026)
Access to Financial Service (Yes=1)	0.340***	0.044	0.363***	0.301***	0.322***
	(0.073)	(0.077)	(0.060)	(0.078)	(0.063)
Access to Credit (Yes=1)	-0.030	0.077	-0.121*	-0.056	-0.072
	(0.074)	(0.077)	(0.067)	(0.089)	(0.068)
Access to Extension (Yes=1)	1.636***	1.224***	0.635***	0.665***	0.574***
	(0.051)	(0.051)	(0.047)	(0.063)	(0.046)
Distance to Input Market (km)	0.199***	0.109**	-0.045	0.053	0.080*
	(0.047)	(0.050)	(0.042)	(0.054)	(0.043)
Market Shock (Yes=1)	0.194***	0.107*	0.150***	0.184***	0.227***
	(0.056)	(0.055)	(0.049)	(0.063)	(0.049)
Year (2022=1)	0.627***	0.317***	0.191***	0.020	0.423***
	(0.079)	(0.083)	(0.064)	(0.083)	(0.067)

Tigray =1	0.681*** (0.113)	-0.100 (0.124)	0.312*** (0.104)	0.484*** (0.168)	-0.515*** (0.103)
Amhara =1	0.251*** (0.077)	0.174** (0.079)	-0.427*** (0.075)	0.959*** (0.136)	-0.384*** (0.074)
Oromia =1	0.285*** (0.075)	0.345*** (0.075)	-0.751*** (0.073)	0.345** (0.138)	-0.457*** (0.073)
Other Regions==1	-0.758*** (0.074)	-0.594*** (0.078)	-0.754*** (0.070)	0.680*** (0.136)	-1.035*** (0.068)
Constant	-1.995*** (0.416)	-1.937*** (0.502)	-3.005*** (0.408)	1.709*** (0.475)	-3.718*** (0.368)
Observations	4,714	4,714	4,714	4,714	4,714

Robust standard errors in parentheses, *** $p<0.01$, ** $p<0.05$, * $p<0.1$

F = fertilizer, S = improved seed, SW = soil & water conservation, I = irrigation and M = manure

The same to appendix 5, appendix 6 above emphasizes, the factors that influence the adoption of SITs under total annual rainfall only and other controls. The significant and positive coefficient of the variables indicates that, adoption of SITs increases by that coefficient; whereas the significant and negative coefficient of the variables indicates that, adoption of SITs decreases by that coefficient.

Appendix 7: Correlates of SIT Adoption

SITs	Correlation coefficient			
	Survey year Drought Shock Only (Rs<-0.5) lagged and total rainfall	**All shock variables only**	**Survey year Drought Shock Only (Rs<-0.5)**	**Total annual rainfall only and controls**
F & S	0.847***	0.826***	0.445***	0.442***
	(0.032)	(0.032)	(0.035)	(0.034)
F & SW	0.462***	0.461***	0.188***	0.193***
	(0.024)	(0.024)	(0.028)	(0.027)
F & I	0.372***	0.362***	0.177***	0.207***
	(0.034)	(0.034)	(0.036)	(0.037)
F & M	0.607***	0.589***	0.380***	0.386***
	(0.026)	(0.026)	(0.030)	(0.030)
S & SW	0.412***	0.411***	0.184***	0.188***
	(0.025)	(0.025)	(0.028)	(0.029)
S & I	0.348***	0.341***	0.198***	0.198***
	(0.031)	(0.031)	(0.036)	(0.035)
S & M	0.442***	0.422***	0.198***	0.201***
	(0.026)	(0.026)	(0.029)	(0.029)
SW & I	1.031***	1.027***	0.925***	1.047***
	(0.042)	(0.042)	(0.042)	(0.049)
SW & M	0.464***	0.467***	0.280***	0.276***
	(0.025)	(0.025)	(0.026)	(0.026)
I & M	0.342***	0.339***	0.168***	0.217***
	(0.028)	(0.028)	(0.029)	(0.029)

Robust standard errors in parentheses, *** $p<0.01$, ** $p<0.05$, * $p<0.1$
F = fertilizer, S = improved seed, SW = soil & water conservation, I = irrigation and M = manure

All the SI technologies were adopted in all cases of drought shocks, total annual rainfall only and other controls. This is because their correlation is significant and positive indicating complementarity of SI technologies (appendix 7).