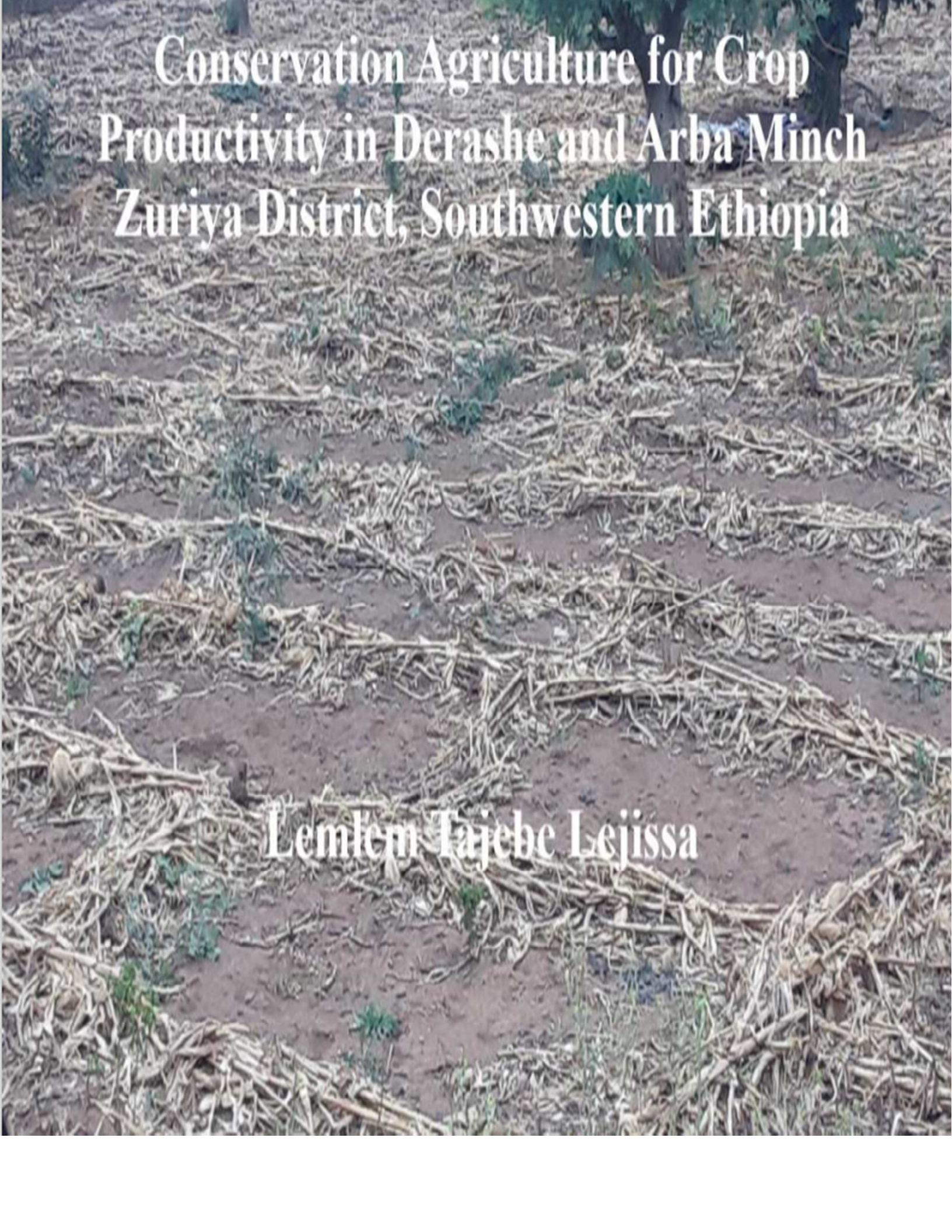


The background image shows a field with rows of dry, yellowish-brown straw or crop residue. Small green plants are growing between the rows. In the upper part of the image, the dark trunks of trees are visible. The overall scene is a rural agricultural landscape.

Conservation Agriculture for Crop Productivity in Derashe and Arba Minch Zuriya District, Southwestern Ethiopia

Lemlem Tajebe Lejissa



**Conservation Agriculture for Crop Productivity in Derashe and Arba Minch
Zuriya District, Southwestern Ethiopia**

**A Dissertation Submitted to the Center of Environment and Development,
College of Development Studies
Presented in the Fulfillment of the Requirements for the Degree of Doctor of
Philosophy (P.hD.) in Development Studies Specialization Environment and
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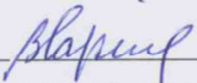
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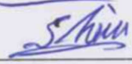
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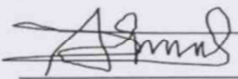
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DEDICATION

I dedicate this thesis to **MY BELOVED MOTHER, EHITU TEWABE, who
unloaded me of all my burdens**

Statement of the Author

I have followed all ethical research principles in this study's processing. I affirm that this dissertation is my original work with my signature below. I have never given a presentation at this or any other university, and the dissertation tools and materials were uninspiring.

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Glossary

Zero tillage: seed is put in the soil without any prior soil disturbance through any kind of tillage activity or only with minimum soil mechanical disturbance.

Conventional tillage: Consists of as excessive tillage, overgrazing, and complete removal of crop residues at harvest leave the soil unprotected, and therefore trigger soil degradation (Araya, 2020a). Higher soil degradation is due to more physical disruption and less production of aggregate stabilizing materials (Bradford and Peterson, 2000). Moreover, the removal of crop residues from field for cattle fodder or burning leaves soils exposed to the actions of rain, wind and heating by the sun, leading to enhanced rate of soil degradation.

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Acronyms/ Abbreviations

\$	United States Dollar
ADLI	Agricultural Development Led Industrialization
AF	Agroforestry
Av. K	Available Potassium
Av.P	Available Phosphorous
AWHC	Available Water Holding Capacity
CA	Conservation Agriculture
Ca	Calcium
CEC	Cation Exchange Capacity
Cm	Centimeter
CRGE	Climate Resilient Green Economy
CSA	Central Statistical Agency
CT	Conventional Tillage
DAs	Development Agents
EC	Ethiopian Calander
ETB	Ethiopian Birr
FAO	Food and Agricultural Organization of the united nations
FC	Field Capacity
GDP	Gross Domestic Product
GTP	Growth and Transformation Plan
Ha	Hectare
ICA	Indigenous Conservation Agriculture
IK	Indigenous Knowledge
IPCC	Intergovernmental Panel on Climate Change
ITPS	Intergovernmental Technical Panel on Soil
Kg	Kilogram
KII	Key Informant Interview
Km	Kilometer
M	Million

Mg	Milligram
Mm	Millimeter
Na	Sodium
NaCl	Sodium Chloride
NGOs	Non-governmental Organizations
°C	Degree Celsius
OLS	Ordinary Least Squares
PASDEP	Plan for Accelerated and Sustainable Development to End Poverty
PBS	Percent Base Saturation
pH	Power of Hydrogen
PLC	Private Limited Company
PWP	Permanent Wilting Point
Q	Quintal
SDPRP	Sustainable Development and Poverty Reduction Program
SIMLESA	Sustainable Intensification of Maize and Legume Systems for Food Security in Eastern and Southern Africa
SLMP	Sustainable Land Management Program
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
SPSS	Statistical Package for Social Science
STATA	Statistics and Data
T	Ton
TLU	Tropical Livestock Units
TN	Total Nitrogen
USA	United States of America
WLS	Weighted Least Squares
Yr	Year

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Conservation Agriculture for Crop Productivity in Derashe and Arba Minch Zuriya District, Southwestern Ethiopia

Abstract

The majority of smallholders in Ethiopia still use conventional tillage (CT) in conjunction with a limited range of soil management practices. Land degradation occurs as a result of soil erosion and soil moisture stress, resulting in crop production declines and food insecurity. As a result of rainwater stress and soil erosion, food insecurity was prolonged in the Derashe Valley. To overcome this challenge, smallholders developed CA with Targa-na-Potayta mulching system. However, the benefits of CA for soil quality, crop productivity, household income, and adoption determinants were not yet well-understood. Therefore, the current study aimed to examine the benefits of CA and CT in the Derashe and Arba Minch Zuriya districts. Four study Kebeles, two from each district, were purposively selected based on proximity and accessibility. 160 non-adopters and 232 CA adopters were selected using proportional sampling. The household survey, key informant interview, transect walk, and soil laboratory test were used to collect primary data. The soil samples were collected at a depth of 30 cm using a zigzag pattern. To complement the data a total of four key informant interviews were conducted in the selected study Kebeles. An independent sample t-test was applied to compare soil physicochemical properties, production, and income from annual + perennial crops. A logistic regression model was employed to identify farmers' CA adoption decision determinants. The results showed, in CA, clay content was $54.4 \pm 2.58\%$, FC $47.8 \pm 1.09\%$, AWHC $15.2 \pm 0.37\%$, pH 8.02 ± 0.07 , SOC $1.8 \pm 0.02\%$, and Sum of cations $68.2 \pm 1.66 \text{ meq/100g}$. CA values in the tested parameters were statistically significant ($P < 0.05$). In Belg 2020 maize and teff production under CA was 1.38 and 1.28 times higher than CT. During meher 2020/21 maize production was 24.62 and 16.36 Q ha^{-1} under CA and CT, in comparison. Maize income was 39,397.63 ETB and 26,176.64 ETB under CA and CT, respectively. In the same season, teff production and income were 1.66 times higher under CA than in CT. In meher 2020/21 production and income from banana fruit was 82.11 Q ha^{-1} and 93,063.42 ETB. The production and income of Moringa stenopetala leaves reached 1.9 Q ha^{-1} and 2889.24 ETB respectively. Moreover, the study identified that age, education, total livestock holding, income from annual + perennial plants, extension service, and lack of access to small-scale irrigation were strong determinants limiting CA practice decisions. The results suggested appropriate policies and extension programs to scale out CA with Targa-na-Potayta mulching for sustainable soil management and crop production to areas with similar agroecology.

Keywords: Conservation Agriculture; Conventional Tillage; Indigenous Knowledge; Targa-na-Potayta; Soil Management; Physicochemical; Crop production; Household Income; Adoption,

Chapter 1 General Introduction

1.1 Background and Justification

Humans depend on soil's quality to meet food demand (FAO, 2015b). Agriculture provides livelihoods for 42 percent of the world's population, and it drives the economies of most developing countries (Aznar-Sánchez et al., 2019). However, worldwide the productive potential of soil is decreasing due to proximate and underlying causes (Braun et al., 2013). Primary causes include biophysical, topographic, and climatic conditions, but the underlying causes include population growth, land tenure, and other socioeconomic factors. According to FAO, (2019a), a total crop yield reduction of 10% projected for 2050 owing to the aforementioned factors.

Soil degradation poses a major global problem, which is felt most strongly in developing countries where many people depend directly on it for their livelihoods (Jat et al., 2014; Tully et al., 2015). Sub-Saharan Africa (SSA) has the highest rate of soil degradation, with approximately 65% of its land area classified as degraded due primarily to agricultural activities (Vlek et al., 2010). Each year, soil degradation costs SSA approximately US\$68 billion and reduces agricultural GDP by 3% (Zingore et al., 2015). In the region, the majority of the population that relies directly on agriculture for food and income has low crop productivity and high malnutrition rates because of soil degradation (Sanchez, 2002).

In Ethiopia, farming started gradually since the fourth millennium B.C., leading to understated soil erosion that remained unnoticed for centuries (Galperin, 1981; cited in Mulugetta, 1988). The Axumite Kingdom, in the northern part of the country, one of the earliest civilizations in Ethiopia, collapsed in the seventh century A.D. due to soil degradation caused by extensive agriculture (Beshah, 2003a). Still, the country experiences excessive soil erosion due to fragile soils, steep slopes, agro-climatic conditions, and intensive tillage by smallholder farmers (Araya et al., 2016; Dabi et al., 2017). In the country, over 90% of the farmland is repeatedly tilled using *maresha*, pulled by a pair of oxen, as the primary source of draught power (Astatke et al., 2003). A farmer who repeatedly tills to achieve fine tilt is considered hardworking while one who fails is often considered sluggish (Temesgen, 2007). Rigorous tillage may aggravate soil erosion by damaging soil structure and depleting time to enhance soil organic matter (Jat et al., 2014). In

2005–06, Ethiopia's annual cost of soil degradation was estimated to be 2–3 percent of the country's agricultural gross domestic product (Yesuf & Mekonnen, 2005). A reduced tillage system could reverse problems posed by traditional tillage practices (Temesgen et al., 2008) and without it, it is less likely to minimize land productivity (von Braun et al., 2014).

In Ethiopia, to minimize soil erosion and enhance crop productivity, smallholders have developed and implemented various soil and water conservation practices since time immemorial. According to Ciampalinia et al. (2012), the Aksum area presents favorable conditions for assessing soil conservation techniques that have been applied over centuries (i.e., since the Axumite kingdom, 400 BC to 800 AD). These techniques have been maintained until today, and parts of the terraced systems are still in use. Traditional terraces in Konso are a remarkable example of a living cultural tradition that spans 21 generations (more than 400 years) (Beshah, 2003b). Furthermore, in different regions of the country, smallholders for the soil and water conservation develop contour plowing, crop rotation, grass strips, surface mulching, weed heaps, agroforestry, and field boundary planting, which can be integrated with conservation agriculture (CA) to improve productivity (Araya, 2020). The title of CA might be novel, its associated practices have long been developed and employed by farmers (Knowler & Bradshaw, 2007), and has become a multi-stakeholder movement (Kassam et al., 2022). As early as 1998, Sasakawa Global 2000, in collaboration with various stakeholders, including the Ministry of Agriculture, began promoting successful CA technologies to regions affected by soil erosion (Fentahun et al., 2019; Aune, 2020). Since then, interest in CA has increased among policymakers, NGOs, and farmers to combat soil loss and prevent drought-related catastrophes (Araya et al., 2012).

CA can reverse soil erosion and improve soil quality when it integrates mulching, the use of nitrogen-fixing crops in the rotation or as intercrops and zero/minimum tillage (Lal, 2015). Plant/crop residues can enhance microbial activity. This increases the secretions of aggregate binding chemicals into the soil and protects them from the deleterious effects of rainfall, gusty winds, and the sun's heating effects (Jat et al., 2014). Currently, the land subjected to CA worldwide is estimated to cover 11 to 14% or ~1.42 billion hectares. It needs to increase to 60% by 2070 to minimize the erosion issue (Borrelli et al., 2020). Despite various studies showing the importance of CA for soil management and crop productivity, CA adoption among smallholder

farmers in Ethiopia remains low. Technology adoption is the outcome of a decision-making process influenced by biophysical, socio-economic, and institutional factors (Teklewold et al., 2013; Dabi et al., 2017).

Therefore, to realize sustainable agriculture and the country's economic development aspirations, the government needs to promote and scale up CA. The invention and implementation of CA have helped smallholders survive the fragile environment for many years (Fentahun et al., 2019). However, various factors must be identified and solved to critically understand smallholders' low CA adoption rate. This study examined CA benefits. It identified the soil physicochemical properties under CA and conventional tillage (CT); assessed and compared the benefits of CA for household income; and identified the factors that limit smallholders' CA adoption.

1.2 Concise Literature Review

1.2.1 Theoretical Literature Review

1.2.1.1 Concept and Definition of Indigenous Knowledge (IK)

Warren & Cashman (1988), defined IK as the sum of experience and knowledge of a given ethnic group that forms the basis for decision making in the face of familiar and unfamiliar problems and challenges. Sillitoe (2016), stated IK as, the expressions, practices, beliefs, understandings, insights, and experiences of indigenous groups, generated over centuries of profound interaction with a particular territory. Further Sillitoe (2007), describe it as any understanding rooted in local culture, and held more or less collectively by a population that informs interpretation of things.

IK comes from a range of sources, and is a dynamic mix of past tradition and present invention with a view to the future. It is understandings, skills and philosophies developed by societies with long histories of interaction with their natural surroundings. For rural and indigenous peoples, local knowledge informs decision-making about fundamental aspects of day to day life. Overall, IK is local knowledge unique to a given culture or society (Warren, 1991). Such knowledge is passed down from generation to generation, in many societies by word of mouth or action. Besides, it can be used to solve problems faced by another society in a similar agro-

ecosystem located in another part of the world. IK has value not only for the culture in which it evolves, but also for scientists and planners striving to improve conditions in rural localities.

1.2.1.2 Description of Conservation Agriculture

In FAO's definition, CA refers to the management of agroecosystems to enhance and preserve its resource base and the environment while improving productivity, and food security (FAO, 2015a). The concept of CA focuses on integrating soil, water, and other agricultural resources to achieve economic, ecological, and social sustainability (Jat et al., 2014). CA is characterized by the practical application of three linked principles, along with other complementary agricultural practices in crop and production management, namely:

Principle 1: Soil disturbance is minimized by direct seeding and fertilizer placement (e.g., no-tillage). As a result, soil erosion is reduced and soil organic matter is preserved.

Principle 2: With crop residues and/or cover crops, soil organic matter will be permanently covered. Protecting the soil surface with vegetation suppresses weeds, prevents extreme weather patterns from damaging the soil, preserves soil moisture, and avoids soil compaction.

Principle 3: Diverse crop sequences and associations involving at least three different crops can lead to species diversification. Crop rotations with a well-designed structure promote healthy soil structure, improve plant nutrition, and foster soil flora and fauna. It also prevents pests and diseases.

CA principles are universally applicable to all agricultural landscapes and land uses with locally formulated and adapted practices (Kassam et al., 2019). The three individual principles when applied together constitute the ecological foundation of CA systems. If the three principles are applied separately, they do not constitute a CA system.

1.2.2 Empirical Literature Review

1.2.2.1. Effects of CA in the Soil Management

In the past 40 years, the world has lost about 430 million hectares. CA is a farming system that can prevent such losses while regenerating degraded lands by (1) reducing tillage, (2) retaining rational amounts of crop residue in the field and (3) using profitable crop diversification (FAO, 2015a). Plant growth and development are supported by CA's minimal soil disturbance because soil life and biological processes are not disturbed. The soil surface is covered with crop residues, which protect the soil against soil degradation agents. In addition, varied crop rotations involving legumes in CA help manage pest and disease problems and improve soil quality through biological nitrogen fixation and the addition of organic matter, all helping soil health (Baudron, et al., 2015; Kassam et al., 2019).

A global meta-analysis of 752 comparisons from 97 papers was conducted to assess the impact of CA on Soil Organic Carbon (SOC) and Total Nitrogen (TN). The study result showed the most significant increase in SOC 21.39% and TN 54.34% when it came to CA practices compared to CT. It also showed a significant increase in SOC and TN stock for all CA components compared to CT (Bohoussou et al., 2022). CA's ability to conserve soil organic carbon and subsequent impacts on soil physical, chemical, and biological properties were assessed using worldwide scientific literature over the last 30 years. The study revealed that CA can lead to higher SOC levels relative to CT, particularly on the surface where the highest SOC occurs. These are also often accompanied by improvements in soil structure, water infiltration and soil water storage, plant nutrient availability, microbial biomass, and diversity (Page et al., 2020).

A study investigating the long-term effect of CA and CT on soil quality indicated a significant impact of CA on soil's physical, chemical, and biological properties. In addition, the estimated soil quality index was significantly higher in soil under CA than in CT (Aziz et al., 2013). In the North China the CA significantly increased SOM, available N, and P by 16.1%, 31.0%, and 29.6% compared to CT treatment (He et al., 2011). In Southern Brazil, a study was conducted to evaluate the SOC storage potential of CA. It also evaluated the contribution of legume cover crops and nitrogen (N) fertilization to this potential in both the surface and subsurface soil layers

of a previously degraded subtropical Acrisol. The results revealed that the legume cover crops contributed to SOC storage potential in CA. High rates of C storage occurred over a prolonged period in subsurface soil layers than in CT (Velooso et al., 2018).

Research results from Southern Africa showed that CA generally increased water infiltration, and reduced soil erosion and run-off. This increased available soil moisture and deeper drainage. Physical, chemical, and biological soil parameters were also improved under CA in the medium to long term (Thierfelder et al., 2015). A study in Ghana showed that CA with residue retention and crop rotation/intercropping maintained higher soil organic carbon, and total soil N compared to CT (Naab et al., 2017). In Malawi, soil pH, soil organic carbon, soil organic matter, nitrogen, and bulk density were acceptable in CA compared to CT. The study suggested that CA improved soil quality (Nyirenda & Balaka, 2021). A study was conducted by Teravest et al. (2015) to assess crop production and soil water management in Malawi. The result showed that in 2013/2014, CA reduced sediment runoff by 1537 kg ha⁻¹ and 1309 kg ha⁻¹ in Nkhotakota and 346 kg ha⁻¹ and 209 kg ha⁻¹ in Dowa, respectively, compared to CT. A study employed in Zambia and Zimbabwe in 2005/2006 and 2006/2007 found significantly higher water infiltration on both sites on CA fields compared to CT (Thierfelder & Wall, 2009)

In the northern Ethiopian highlands, crop yields were affected by serious runoff. To halt the problem, a local soil management derdero, permanent raised beds with 30% standing crop residue retention and no-tillage on the top of the bed were constructed and tested for their contribution to soil fertility. The results show the soil under CA has a high organic matter content and less runoff than CT (Araya et al., 2012). In CA soil erosion was reduced from 30 t/ha in CT plots without mulch to 16 mg ha⁻¹ in zero tillage plots combined with 3 mg mulch ha⁻¹ (Adimassu et al. 2019). The short and medium-term effect of CA on soil quality and crop productivity was assessed at Bako and Melkasa. The results showed that the rate of water infiltration was 16% more at Bako and 15% less at Melkassa for CT. A study in the Sub-Humid Ethiopian Highlands evaluated the impacts of CA with drip irrigation. The results showed that about 18% to 28% significant irrigation water savings were observed for vegetables under CA compared to CT. In addition, CA was found to improve the soil's physicochemical properties with significant improvements in organic matter (10%), field capacity (4%), and total nitrogen

(10%) (Yimam et al., 2020). A good implementation of CA utilizing the three principles enhances crop productivity and helps to manage the soil.

1.2.2.2 Effects of CA in Crop Productivity

To feed the increasing human population the world's agricultural systems need to produce more food in an environment that is increasingly fragile (Page et al., 2020). The wide-ranging use of CT has diminished soil productivity to the extent that many agricultural soils are depleted of nutrients and unable to sustain crop productivity in their natural state (Naab et al., 2017). In order to meet food demand in a degraded environment, it is essential to implement technologies that sustainably improve soil and crop productivity (Bisht et al., 2016). According to Mango et al. (2017), CA enhances soil's physical, chemical, and biological properties and can be used to conserve the environment and sustainably improve crop production.

A study was conducted in Ecuador to assess yield and economic returns of potato, forage, and grain systems. The study results indicated that crop productivity and net benefits of the system were increased by 25 and 24%, respectively. The study concluded that CA increases yields and saves production costs due to less tillage (Barrera Mosquera et al., 2019). The long-term effects of CA and CT on soil properties and crop productivity were investigated in an annual double cropping system of winter wheat–summer maize in the Gaocheng in Hebei, North China Plain over an 11-year period (1998–2009). The results showed wheat and maize yields were 3.5% and 1.4% higher under CA than CT (He et al., 2011).

A study's results in South Africa showed that CA increased crop productivity and reduced on-farm labor, especially when direct seeding techniques and herbicides were used (Thierfelder et al., 2015). In Malawi, CA practices affected crop productivity, and profitability was assessed. The study results revealed positive benefits on maize yield with the highest increases of 2.7Mgha⁻¹ and 2.3Mgha⁻¹ yield in CA monocrop maize and CA maize legume intercrop, respectively, than CT. In the same study, CA systems resulted in gross margins three times higher than CT (Ngwira et al., 2013). A study in Zambia showed an increase in maize yield in a direct seeded CA treatment, using cowpea seeded with a dibble stick in full rotation, by up to 78% after four cropping seasons compared to CT (Thierfelder et al., 2013).

In Ethiopia due to minimum tillage bean grain yield increased by 32% at the Melkassa research center (Liben et al., 2018). In the Tigray region, mulch application increased wheat grain yield by 28% compared to the CT (Araya and Stroosnijder, 2010). In the northern Ethiopia the impact of two indigenous CA, (derdero+ (DER+) and terwah+ (TER+) on long-term soil quality and crop productivity were assessed. The result revealed on average, crop yields under DER+ and TER+ increased by 30% and 16%, respectively, as compared to CT (Araya et al., 2016). In the Hagarghe highlands with a high diversity of cultivated crops had a higher dietary diversity status (73.9%) than non-diversified areas (15.2%) (Goshu et al., 2012). A 3-year study was conducted in the Aba Gerima watershed in northwestern Ethiopia. It investigated the effects of two tillage practices CA and CT on teff yield. And the study showed an increased teff yield in the CA field (Mihretie et al., 2021). A study in Malawi on maize yields indicates that CA yield increases by 3.98–4.43 Mg ha⁻¹ compared to CT, 1.84 Mg ha⁻¹ (Nyirenda & Balaka, 2021). Overall CA helps to increase crop productivity as compared to CT.

1.2.2.3 Determinant Factors in the Adoption of CA

Inappropriate land use, poor soil management, and lack of inputs have led to a decline in productivity to the extent that future production is threatened (FAO, 2016). In Africa, the increasing human population with increasing food demand has put the soils at risk (Thierfelder et al., 2015). If traditional soil management continues, the region will not be able to sustain human and livestock populations (Thiombiano & Meshack, 2009). In recent years CA has been considered a potential means of sustaining soil quality and crop productivity (Thierfelder et al., 2018; Kassam et al., 2019).

Implementing CA enhances farmers' income by creating increased wealth from agriculture, and reducing production costs (Kassam et al., 2022). Despite CA's stated benefits, its adoption by African smallholder farmers is very low. According to Kassam et al. (2022), in 2018/19 the total area of land under CA in Southern and Central America was 68.7% and 1.1% in Africa. In Ethiopia, the total area of farmland under CA and trends in CA adoption rates are difficult to establish because of limited central reporting and data collection initiatives. However Hailu & Teshome (2022), stated, as of 2020/21 more than 8,000 hectares of land were estimated to be under CA farming, particularly in Benishangul-Gumuz, Amhara, Oromia, and SNNP. The same authors added that from 2010-16 the estimated number of CA-practicing households reached

210,289. However, the adoption rate is low compared to the massive problem of soil erosion and crop productivity reduction (Table 1.1)

Table 1.1 Factors Affecting the Adoption of Conservation Agriculture in Different Areas

Country	Determinant factor		Author/s
	Factors increase adoption	Factors decrease adoption	
Mozambique	Female household head, increasing total family size, increasing total livestock size, having good communications, and being a member in farming associations		(Chichongue et al., 2020)
Zambia	Old age, access to loan, labor availability, high in-kind income, extension service, and rainfall variability		(Ng'ombe et al., 2014; Arslan et al., 2014)
Africa		Crop residue used for fodder; lack in immediate increase in income, large livestock holdings	(Giller et al., 2011; Corbeels et al., 2013)(Corbeels et al., 2013)
Ethiopia	Young age, larger land size, close to the market, extension service, soil quality, access to loan and availability of farm inputs	Land shortage, land tenure, lack access to information, slow return, and insufficient policy, and competition for crop residue, lack access to high quality inputs)	(Assefa & Gezahegn, 2010; Marennya et al., 2017; Zerssa et al., 2021; Hailu & Teshome, 2022)
Ethiopia, Malawi Kenya		Competition of crop residues for livestock feed and soil mulching	(Tesfaye et al., 2015)
Tunisia	level of farmers' education, quality of extension services, and the type of land ownership	low farming experience, existence of off-farm income, and by the number of livestock units per hectare available at the farm level	(Fouzai et al., 2018)
Malawi		Lack of sufficient technical support	Chinseu et al., 2019

1.2.3 Conceptual Framework of the Study

In order to understand the levels and trends in CA adoption, this study was guided by three theoretical perspectives on technology adoption used in past studies (Ntshangase et al., 2018): innovation diffusion theory, economic constraints, and adopter perceptions (Adesina and Zinnah, 1993). Innovation diffusion is the process in which an innovation is communicated through certain channels over time among the members of a social system (Rogers, 2003). This model sees changes as a linear process in which innovations generated by smallholders and/or agricultural research are passed down to farmers through extension agents. Thus extension agents act as modes of communication, and farmers are recipients of the innovation. Therefore, information dissemination is at the center of the innovation diffusion theoretical perspectives. There are four elements in the diffusion of innovations (i) innovation; (ii) communication channel; (iii) time, and (iv) a social system.

The innovation diffusion model has limitations including:

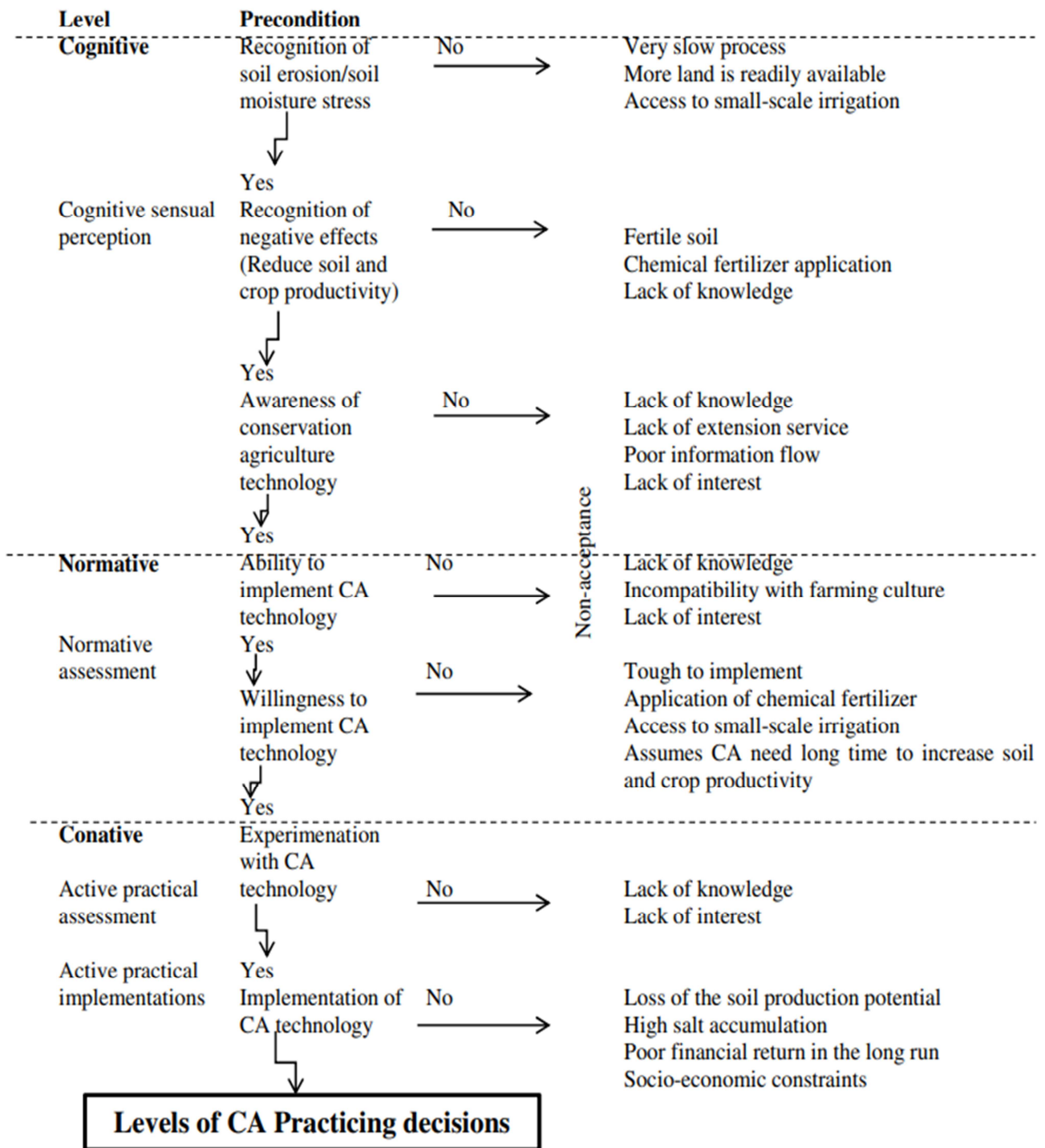
- ✓ It assumes the most important variable is information and the willingness of the individual to change. However, an individual is characterized according to his/her behavior without considering factors that influence his/her behavior.
- ✓ The technology is appropriate for use unless hindered by the lack of effective communication. However, in reality, many other factors are known to influence practicing agricultural innovation. These include the farmer's objectives, the level of the resource endowments, access to resources, availability of support systems, and the characteristics of the innovation (Negatu & Parikh, 1999; Nguthi, 2007).

The economic constraints perspective, as explained by Ntshangase et al. (2018), states that adoption is influenced by access, or lack of access, to economic resources. The theory identifies the complex differences in smallholders access to these resources and postulates that asymmetric distribution of these resources could lead to heterogeneity in adoption (Adesina & Zinnah, 1993; Negatu & Parikh, 1999). In comparison to the innovation diffusion paradigm, the economic constraints model emphasizes the role of economic factors at the individual level in determining practicing decisions, and the lack of access to these resources affects practicing the technology (Ntshangase et al., 2018). However, this model allows for only strictly rational and informed

behavior and fails to capture the effects of individual perceptions of an innovation. This perception is determined by personal characteristics (human values, education, and experience); physical factors of the land; and institutional factors, e.g., raising awareness through extension (Lynne et al., 1988). The adopter perceptions perspective identifies farmers' perceptions as key to the adoption of farming technology (Adesina and Zinnah, 1993). This study integrates the three theories to develop a conceptual understanding of the research problem.

Overall the technology practicing decision illustrates that the practice of innovation is not a characteristic of an individual alone but encompasses a set of phases or levels, such as cognitive¹, normative, and action-oriented that governs it. Recognizing these levels will aid in understanding the prerequisites necessary for successive steps in the adoption of CA in Derashe and Arba Minch Zuriya districts (figure 1.1).

¹ The dominant aspects of cognitive theory involve the interaction between mental components and the information that is processed through this complex network (Neisser, 1967).



Figur 1.1 Levels and Preconditions of CA Practicing Process

Source: Prager & Posthumus, (2010)

Figure 1.2 indicates that the decision to adopt or not adopt CA is an outcome of farmers' perceptions of CA compared with other farming practices or technologies. There are several reasons why farmers may adopt a new farming technology. In the Derashe area, natural factors, i.e., short and erratic rainfall, high temperature, and anthropogenic factors, i.e., intensive tillage without appropriate soil management aggravated soil erosion and reduced soil and crop productivity. These factors increased smallholders' perception on the impact of traditional tillage and considered as drivers that push smallholders to develop and practice CA. These decisions, with socioeconomic and physical factors, also affected by institutional factors like access to information and information/knowledge diffusion mechanisms, mainly through extension agents (Everett, 2003).

Practicing CA technologies is viewed as a variable representing farmers' behavioral changes in accepting technologies (Ray, 2001). In addition, Feder *et al.* (1985) defined adoption as getting the latest technology or innovation when a farmer is fully informed about its potential and benefits. Everett (2003), noted accepting new technology/practice/idea as a mental process through which an individual passes from first hearing about an innovation to final acceptance, and it is a decision to make full use of new ideas as the best course of action available (Rogers & Shoemaker, 1985). However, the uptake/adoption of cutting-edge technology is a process and can be influenced by various factors, including socio-economic, institutional, and physical (Dabi *et al.*, 2017; Teklewold *et al.*, 2013; Abunga *et al.*, 2012; Giller *et al.*, 2009). Characteristics of the household head such as age, formal education level, farming experience, total land holding, annual income from farming activities, and total livestock holdings, farming experience, annual net income, lack of access to small-scale irrigation and extension services are selected variables in the current study expected to affect CA practicing decisions.

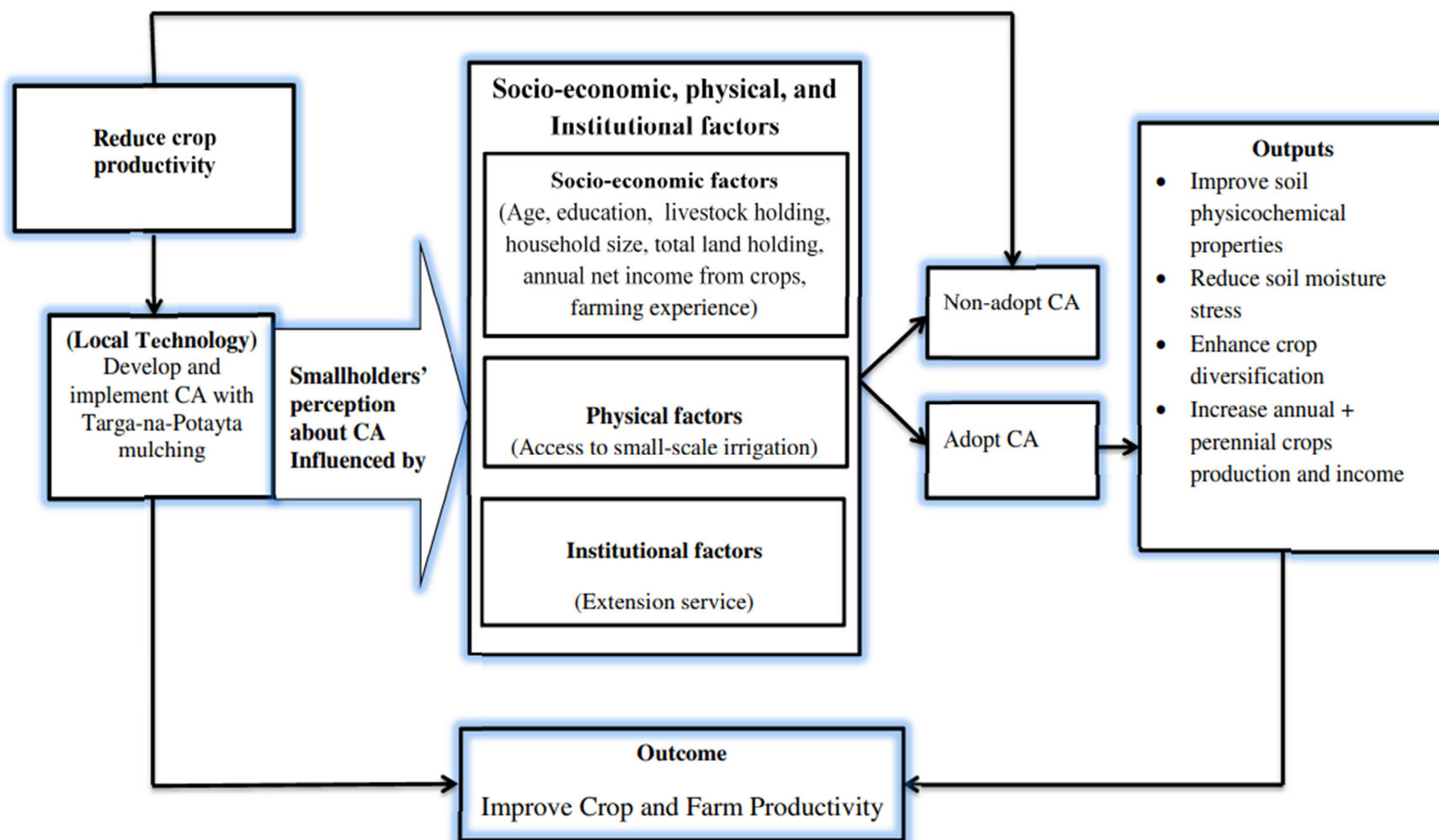
Age is a crucial variable in comparing and selecting beneficial technologies compared to younger groups. Mazvimavi & Twomlow, (2009) say older farmers use their farming experience to practice updated techniques. However, Baidu-Forson (1999), concluded that age negatively influences land-enhancing technology in the Sahel since older farmers keep their traditional farming practices rather than using advancing technologies. The level of formal education is also the most crucial variable that positively influences CA. For instance, Sileshi *et al.* (2019), in their study assessing the determinants for adopting physical soil and water conservation measures by

smallholder farmers in Ethiopia, found the direct influence of education on the adoption of soil and water conservation measures. Smallholder farmers in developing countries mainly rely on family labor for crop production. Therefore, household size is associated with the availability of labor for farm operations and plays a critical role in advancing agricultural technologies/ideas (Idrisa et al., 2012). A larger household was expected to have a positive effect on practicing decisions compared to smaller households (Bisangwa, 2013).

Farm size plays a critical role in implementing an improved technology/idea. Many studies have reported a positive relationship between farm size and agricultural technology (Mwangi & Kariuki, 2015). Also, farmers who hold a lot of livestock may prioritize reserving crop residue for livestock feed rather than using it for mulching; thus, the probability of adopting CA is reduced as livestock numbers increase (Araya, 2020a). Or else, farmers with access to draught power may be reluctant to practice most components of CA as they can opt for a conventional draught animal tillage system (Mazvimavi & Twomlow, 2009). Smallholder farmers who earn less net income practice CA. For instance, smallholders in the Arba Minch Zuria district obtain high income from sole banana fruit production. Their interest in CA adoption is less than that of the Derashe areas. However, a study in Ethiopia revealed farmers who adopted SWC measures earned higher annual income averaging at Birr 20129.33 than the non-adopters who earned an average income of Birr 13,753.03 (Sileshi et al., 2019).

Institutional factors, including extension services, are essential to practicing CA. Smallholder farmers with appropriate extension services can easily practice CA (Twomlow et al., 2008). Further, observations made by Derpsch (2005) and Hobbs (2007) showed farmers who received continued support from both NGOs and government extension services tended to intensify CA practice. A study by Sileshi et al. (2019) also revealed that adopters of SWC measures reported higher contact frequencies with development agents than non-adopters. Therefore, increasing information about CA from smallholder farmers/organizations will enhance practicing CA. Improved CA technology that enhances sustainable food production is particularly relevant to smallholders living and farming in areas where rainfall is low and erratic, soils tend to be infertile, and irrigation tends to be poorly developed (Muzari et al., 2012; Sennuga et al., 2020). However, as Mazvimavi & Twomlow (2009), stated, farmers in high-potential rainfall regions, with better chances of increased crop production, tend to be less risk-averse and are likely to try

new cropping techniques. The current study assumes that with adequate information and support, smallholders will be convinced to adopt CA. This view is based on consistent empirical findings showing that CA raised soil and crop productivity for long. Understanding these variables and how they influence adoption is important in developing strategies for promoting CA in Ethiopia.



Source: Adapted from (Zelege, 2008; Thierfelder & Wall, 2009; Araya et al., 2012; Jat et al., 2014; Thierfelder et al., 2018; Aune, 2020; Araya, 2020a; Araya, 2020b)

Figure 1.2 Conceptual Framework of the Study

1.3 Statement of the Problem

Ethiopia is one of the center origins of crop and livestock domestication that started ten thousand years ago (Diriba, 2020). Ox is mainly used by smallholders for crop farming. Takele et al. (2018), stated the ox plow has 3000 years of history in the northern highlands, but has gradually expanded southwards. This describes Ethiopians as people of the plow, indicating how deeply rooted plowing is with the ard (*maresha*), pulled by a pair of oxen (Aune, 2020). It is believed that ox plowing was first used to prepare land for teff (*Eragrostis teff*) and eleusine (*Eleusine corocana*) (Aune et al., 2001). Apart from tilting the soil, plowing was done to create a favorable environment for plant growth, weeds control, moisture conservation, soil warm-up and manure incorporation (Temesgen et al., 2008). Ethiopian farmers have continued to till their land despite changing ecological and population pressures. Although the intensive tillage favors short-term productivity gains, it has long-term negative consequences for soil fertility, soil health, productivity, and ecosystem services (Hailu & Teshome, 2022).

In Ethiopia, the productivity of the agricultural sector is seriously affected by topsoil erosion resulting in soil productivity loss (Tamene & Vlek, 2008). Nationwide annual gross soil loss is estimated at 1.5×10^9 t, with the highest loss from croplands, 42 t ha^{-1} per year (Hurni, 1988), but may reach $300 \text{ t ha}^{-1} \text{ yr}^{-1}$ in individual fields (Hurni, 1993). The average crop yield from a piece of land is very low compared to its potential capacity (Van loon et al., 2019) and is less than 50% of the yields obtained in experimental farms and research stations (Zerssa et al., 2021).

Conventional tillage (CT) comprises repeated tillage, complete removal of crop residues at harvest, and use of straw for animal feed and dung for fuel (Jat et al., 2014). In Ethiopia, conventional wisdom in soil tillage works the soil repetitively to achieve fine soil (Fentahun et al., 2019). Excessive tillage degrades soil structure, leads to water and wind erosion, and reduces infiltration and soil water holding capacity (Araya et al. 2011). Soil organic matter (SOM) then steadily declines, and soil erosion is widespread (Aziz et al., 2013; Zhang et al., 2018). A decrease in SOM reduces soil fertility, affecting chemical, biological, mechanical, and physical quality (Zhang et al., 2018). The Global Mechanism (2007) estimates that over 85% of Ethiopia's land is moderately to very severely degraded. About 75% of the land is affected by desertification. A study was conducted by the Ethiopian government to assess the impact of soil erosion on the

cropland. The result revealed around 3.54% of cropland found in the Amhara, Tigray, and Oromiya regions had declined productivity due to soil erosion. In addition, 10,285,420.00 ha of land is under stress (FDRE, 2015). Because of this, domestic food production fails to meet the country's food requirements, and the country's imports of cereals (wheat, rice, barley), edible oil, and lint cotton continue to rise dramatically, costing over a billion dollars yearly (Diriba, 2020).

Farmers in different parts of the country realized soil erosion threatens their livelihood and developed indigenous solutions, including CA (Gebreselassie et al., 2015). CA can be considered as an approach to reversing soil degradation (Lal, 2015). Studies in Ethiopia showed that implementing CA reduced surface runoff by 48% (Woyessa & Bennie, 2007) and soil loss by 27% (Erkossa et al., 2005). Other studies (e.g., Ito et al., 2007; Tulema et al., 2008; Temesgen et al., 2012; Bekele et al., 2022) revealed that CA can increase crop yields through moisture conservation and increasing soil quality. However, despite all CA benefits, its adoption rate is very low (Aune, 2020; Araya et al., 2012; Temesgen et al., 2012; Bekele et al., 2022).

Arba Minch Zuriya and Derashe are proximate areas with different tillage in southwestern Ethiopia. Arba Minch Zuriya is known for its intensive production of banana fruit trees (*Musa*) + maize (*Zea mays*) / teff (*Eragrostis tef*). According to Mekonnen (2014), banana fruit production in Arba Minch Zuriya started in the 1980s. The then Arba Minch state farm used sixty-two hectares to grow dwarfed Cavendish banana fruit varieties. During that time, smallholder farmers' land was primarily planted with annual crops: maize, cotton, and sweet potato. Observing the productivity of Cavendish bananas on the state farm, the government insisted smallholders plant them on their plots. Currently, the banana farm covers about 11,000 ha of land in Arba Minch Zuria and Mirab Abaya districts (Mekonnen, 2014). The same author stated that banana fruit from Arba Minch has a market share of more than 40% in Addis Ababa and 80% in Ethiopia. Nevertheless, the growing banana fruit market with well-established profit margins increased frequent tillage with abundant mineral fertilizer applications.

Recently in Derashe district *Moringa stenopetala* + sorghum (*Sorghum bicolor*)/maize (*Zea mays*)/teff (*Eragrostis tef*) based Agroforestry (AF), with various mixed/rotational crops, i.e. chickpea (*Cicer arietinum*), and haricot bean (*Phaseolus vulgaris*) are practiced using rainwater. Before hundred-plus years ago, smallholders cultivated mono-crops using CT. The short and

unpredictable rainfall with high temperatures made the soil easily susceptible to water erosion. This increases topsoil erosion and reduces crop production. As Bewket et al. (2007), stated that land degradation and unreliable rainfall in the country have caused agricultural productivity to decline. As a result, smallholder farmers in the area are adversely affected. However, the overwhelming situation awakened the early smallholders and created CA with an innovative mulching known as *Targa-na-Potayta*. A well-designed crop residue with a rectangular shape aids in tilling in rows increases rainwater infiltration, decreases soil water evaporation, reduces runoff, releases nutrients into the soil through residue decomposition, improves soil fertility, and increases crop productivity. By drilling each partition with a wooden or metal rod, smallholders minimize soil disturbance. Using the invented technology, the Derashe people able to minimize their dependence on rainwater as they are able to produce crops twice a year.

In the Arba Minch Zuriya district, various studies (e.g., Yisehak et al., 2011; Mekonnen, 2014; Alemu, 2017) were conducted solely to investigate the impact of banana fruit farming on soil fertility and household income. However, despite the presence of a well-designed CA with the *Targa-na-Potayta* mulching in the proximate Derashe district, a comparative study of soil property under the two tillage systems and smallholders' CA adoption decisions has not been undertaken until now. Additionally, only a few scientific studies have been conducted in the Derashe district to determine the impact of *Targa-na-Potayta* on soil physicochemical properties in Holte Kebele (Fikre et al., 2018). Therefore, the current study aimed to examine the design and benefits of *Targa-na-Potayta*; identify and compare the impact of CA and CT on soil physicochemical properties; assess smallholders' production and income from the dominant annual + perennial crops; and identify the various factors that determine CA adoption decisions in the two districts of southwestern Ethiopia.

1.4 Research Questions

The following key questions were addressed in the study.

1. Why and when did *Targa-na-Potayta* originate, and how did it benefit smallholders?
2. What are the impacts of CA and CT on soil physicochemical properties?
3. How are practicing CA and CT benefits farmers differently?

4. What socio-economic, physical, and institutional factors influence smallholder farmers' decisions for CA practices?

1.5 Objectives of the Research

1.5.1 General Objective

The overall objective of the study was to examine the soil quality and crop productivity and factors that influence conservation agriculture adoption by smallholders in the southwestern Ethiopia.

1.5.2 Specific Objectives

The specific objectives of the study are to:

- Assess the indigenous conservation agriculture practices in the study area
- Assess the effects of conservation agriculture and conventional tillage on the soil physicochemical properties in the study area;
- Examine the contributions of conservation agriculture and conventional tillage for crop productivity and household income in the study area;
- Assess factors influencing the adoption of conservation agriculture in the study area;

1.6 Significance of the Study

Agriculture has long dominated the country's economy, and has a considerable share of GDP. Besides, agriculture heavily supports employment and export earnings. This implies that the agricultural sector's performance will largely determine the growth of all other sectors and the country's aspiration to achieve overall economic growth (Dube et al., 2019).

As part of its effort to implement Agricultural Development Led Industrialization (ADLI), the Ethiopian government has devised various plans and programs. Participatory Demonstration and Training Extension System (PADETES), Sustainable Development and Poverty Reduction Program (SDPRP), a Plan for Accelerated and Sustained Development to End Poverty, Growth and Transformation Plan (GTP I), Growth and Transformation Plan II (GTP II). However, all of these programs were designed to increase short-term agricultural productivity. Extra focus on

yield may have a short-term productivity advantage, but the ability to produce sustainably may be impaired.

The Climate Resilient Green Economy Strategy (CRGE) (2011), and Natural Resource Conservation Strategy (1994) are considered as leading policy frameworks for CA implementation (Hailu & Teshome, 2022). The CRGE lists CA as one of the technologies identified for climate change adaptation. The 1994 Natural Resource Conservation Strategy emphasized the need to focus on soil, water, and agricultural practices that ensure sustainable productivity gains while conserving the natural resource base. In both strategies, policy support is available for scaling up CA in areas where it can improve sustainable productivity and conservation (Hailu & Teshome, 2022).

After long years of research and advocacy, the Ministry of Agriculture (MoA) adopted conservation agriculture-based sustainable intensification (CASI) as part of its extension package. In 2019 cascaded it to regional agriculture bureaus for implementation. Despite this, there remains confusion about the benefits of CA and the various determinants of technology adoption in various areas. As a result, CA received largely insignificant attention from decision-makers and influential actors (Hailu & Teshome, 2022). Therefore, the current study findings are vital for policymakers to empirically understand CA's benefits for soil management and crop production. Furthermore, the finding can simplify the process of scaling up CA by government extension agents since it identifies the determinant factors that lead to limited adoption by smallholders.

A comprehensive study evaluating the contribution of CA and CT to soil management and crop productivity is being conducted for the first time in selected study areas. In light of this, the study findings could help the scientific community gain a deeper understanding of the different tillage practices in the area. It can also contribute as additional literature to studies conducted in the area and beyond. In addition, the study is essential to spread awareness about the local communities farming, i.e., a well-designed CA with Targa-na-Potayta mulching and its contribution the soil management and crop production, by reducing soil erosion and soil moisture stress. Local communities can use this opportunity to gain recognition from relevant stakeholders and demonstrate their work further.

1.7 Scope of the Study

Ethiopia is an agrarian country where the livelihood security among smallholder farmers is strongly dependent on rain-fed agriculture, with which over 95% of the food is produced (Araya, 2020a). In the country, more than 90% of the land is repetitively tilled using CT without appropriate soil management practices (Aune, 2020). In combination with other factors, these factors exacerbated soil erosion and led to a drastic reduction in soil productivity. The problem is most acute for smallholders, who are primary producers and consumers and rely on agriculture for their livelihood. Aside from that, it also affects the country's subsistence, since agriculture is the primary source of economic growth. It is therefore necessary to take the appropriate soil management measures before it further deteriorates. The current study aimed to understand soil management and crop productivity under CA and CT in southwestern Ethiopia. The research intended to identify how and why *Targa-na-Potayta* mulching was invented, the soil physicochemical properties under CA and CT, households' production and income from annual and perennial crops, and CA adoption as determinant factors.

Understanding how and why smallholders invented CA with *Targa-na-Potayta* mulching is crucial to identifying its origin, designing techniques, and the benefits gained from this technology. To minimize soil erosion and survive in their place of origin, smallholders developed indigenous solutions that increased soil moisture, crop productivity, and soil fertility. Therefore, detailed information about local technology was collected from elderly farmers. Physicochemical variables were tested in soil under CA and CT to determine soil quality. It is therefore possible to use soil test results for crop production and scale out CA based on the results. To identify crop production under CA and CT, production and income from annual + perennial crops were collected. This helped to investigate the gross income obtained under different soil management. The study by Thierfelder et al. (2018); Kassam et al. (2019); Jat et al. (2021) revealed that CA improves soil quality and crop productivity. However in Ethiopia, the majority of smallholders use CT, and CA adoption is low (Aune, 2020). In order to pinpoint the low adoption rate in a specific area with proper remedies, it is important to identify the various determinant factors. Using socioeconomic, physical, and institutional factors, we examined the determinants of CA adoption. Although the research is limited to two districts of southwestern

Ethiopia, the study results can be useful and applicable to regions with similar agroecology and problems.

1.8 Limitations of the Study

The study is limited to soil data and crop production collected from primary farmland², excluding other lands owned by sampled households. In addition, the research was restricted to southwest Ethiopia. To identify the system productivity crop production and income data were obtained in two agricultural seasons, Belg³ 2020 and Meher⁴ 2020/21. A recall method was used to collect production and income data in the first season. Despite previous research on the method, smallholders and traders may forget the previous production and income due to the frequently changing nature of the Ethiopian market. For this reason, the crop harvest method was used to isolate the problem. Through this method, it is possible to get specific crop production data and convert crop production and income into hectares.

1.9 Structure of the Dissertation

This dissertation has six chapters. Chapter one discusses the background, statement of the problem, research questions, objectives of the research, significance, scope, limitation of the study, general methodology, and structure of the thesis.

Chapter 2 presents history and benefits of indigenous *Targa-na-Potayta* mulching technique. Using structured questionnaire, key informant interview and transect walk data was collected. Smallholders stated the significant benefits obtained by practicing the technology. Chapter 3 presents the effect of CA and CT on soil physicochemical properties. Using various soil property measuring parameters the soil fertility status at the selected study sites was determined. Chapter 4 deals with the gross production and income from annual and perennial crops. Chapter 5

² We define primary farmland as the land smallholder farmers depend on. In the case of the current study, farmland that grows Banana + maize/teff in Arba Minch and *Moringa stenopetala* + maize/sorghum/teff in Derashe areas was only considered. This excluded production and income from homestead farmland and other second lands that only produce mono-crops.

³ Crops harvested between Megabit (March) and Nehase (August) are considered part of the Belg season crop (Alemayehu et al., 2012)

⁴ Meher is the primary crop season encompassing crops harvested between September and February

investigated smallholders' CA adoption. Variables that affect CA adoptions were identified using socioeconomic, physical, and institutional data. The finding helps to awaken and seek attention from the responsible bodies so that they can fully appreciate the contributions of the technology. It also helps to scale-out to other regions with the same agroecology. In the final chapter, the major findings, the significance of the study, the benefit of the study for policy makers and academia, and the recommendations for future research were explained.

1.10 Description of the Study Area

1.10.1 Biophysical Settings

The study was conducted in the southwestern region, Arba Minch Zuriya, and Derashe districts (Figure 1.3). Arba Minch Zuriya is one of the 14 Gamo Zone districts with 18 Kebeles⁵. It is about 505 km south of Addis Ababa. Its elevation ranges from 1250 - 2600 masl (Balemie & Kebebew, 2006). The district has received the mean annual total rainfall of 892 mm with maximum and minimum temperatures of 30.4 and 15.6°C, respectively (Feyso & Mensa, 2021). Among the total kebeles, the study was conducted in two neighboring Kebeles, namely Zeyise Eligo and Zeyise Wezeqa. Derashe district is 525 km from Addis Ababa. The elevation ranges from 1250 – 2300 masl (Balemie & Kebebew, 2006). The area receives a mean annual rainfall of 952.1mm. The area receives in the long rainy season (June-September), 261.2 mm, and in the short rainy season (March-May), 413.8mm (Suryabhagavan, 2017). Most parts of the Southern region are considered short rainy seasons (Belg⁶) growing areas with rainfall reaching its peak during April/May and the daytime temperature reaching its maximum. There is also erratic nature to the Belg growing season (in terms of amount, distribution, onset, and cessation of growth). From 19 Kebeles, Walessa and Holte Kebeles were carefully selected based accessibility and proximity to the Arba Minch Zuriya district. The study districts geographically located between 5°35'00'' to 5°55'00'' Easting, 37°20'00'' to 37°30'00'' Northing (USGS, 2020).

1.10.2 Socio-economic Settings

In the Arba Minch Zuriya and Derashe districts, agriculture is the mainstay of the community. In Holte and Walessa Kebeles of the Derashe district smallholders cultivate maize (*Zea mays*), sorghum (*Sorghum bicolor*), teff (*Eragrostis tef*), and haricot beans (*Phaseolus vulgaris*) in integration with *Moringa stenopetala* trees in an agri-silviculture system. The Derashe are among the hardest working people in Ethiopia, as all household members spend time ensuring crop success (Agena, 2011). Given their commitment to the harsh environment, they may be considered among the most effective managers of the ecosystem. In Zeyise Eligo and Zeyise

⁵ Kebele is the smallest administrative unit of Ethiopia, similar to a neighborhood or a localized and delimited group of people.

Wezeqa Kebeles' of Arbaminch Zuriya district, agroforestry system, maize (*Zea may*), Teff (*Eragrostis tef*), sweet potato (*Ipomoea batata*), cotton (*Gossypium*), haricot beans (*Phaseolus vulgaris*), cassava (*Manihot esculenta*), and vegetables are mixed with mango (*Mangifera indica*) and banana fruit trees (*Musa*).

Table 1.2 Total Land Covered by Perennial and Annual Crops in Hectare

Land Covered in Hectare	Zeyise Wezeqa	Zeyise Eligo	Walessa	Holte
Annual	2942	2243	3352	3394
Perennial	2064	3622	265.25	129.5

Source: Own survey from study *Kebeles* unpublished report 2021

Population

According to the 2007 national census of the country, the total population of Arba Minch Zuriya district was 164,529, of which 82,199 (49.96%) were Male and 82,330 (50.04%) were Female (CSA, 2008). In 2017, the total population was projected to be 195,858, with males 97,905 (49.99%) and females 97,953 (50.01%) (CSA, 2013). In Derashe district, the total population of urban and rural dwellers was 142,758, of which 70,111 (49.11%) were male, and 72,647 (50.89%) were female (CSA, 2008). In 2017, the population was projected to be 154,246, with males 75,765 (49.1%) and females 78,481 (50.9%) (CSA, 2013).

Table 1.3 Total Population and Household Heads Size

District	Kebele	Total Population			Total Household Head		
		Both	Male	Female	Both	Male	Female
Ara Minch Zuriya	Zeyise Eligo	8,602	4,095	4507	1,170	1,100	70
	Zeyise Wezeqa	35,109	17,211	17898	1,897	1,685	212
Derashe	Holte	13,034	6,413	6621	2,450	2,189	261
	Walessa	20,843	10,121	10722	1,985	1,746	239
	Total	77,588	37,840	39748	7,502	6,720	782

Source: Own survey from study *Kebeles* unpublished report 2021

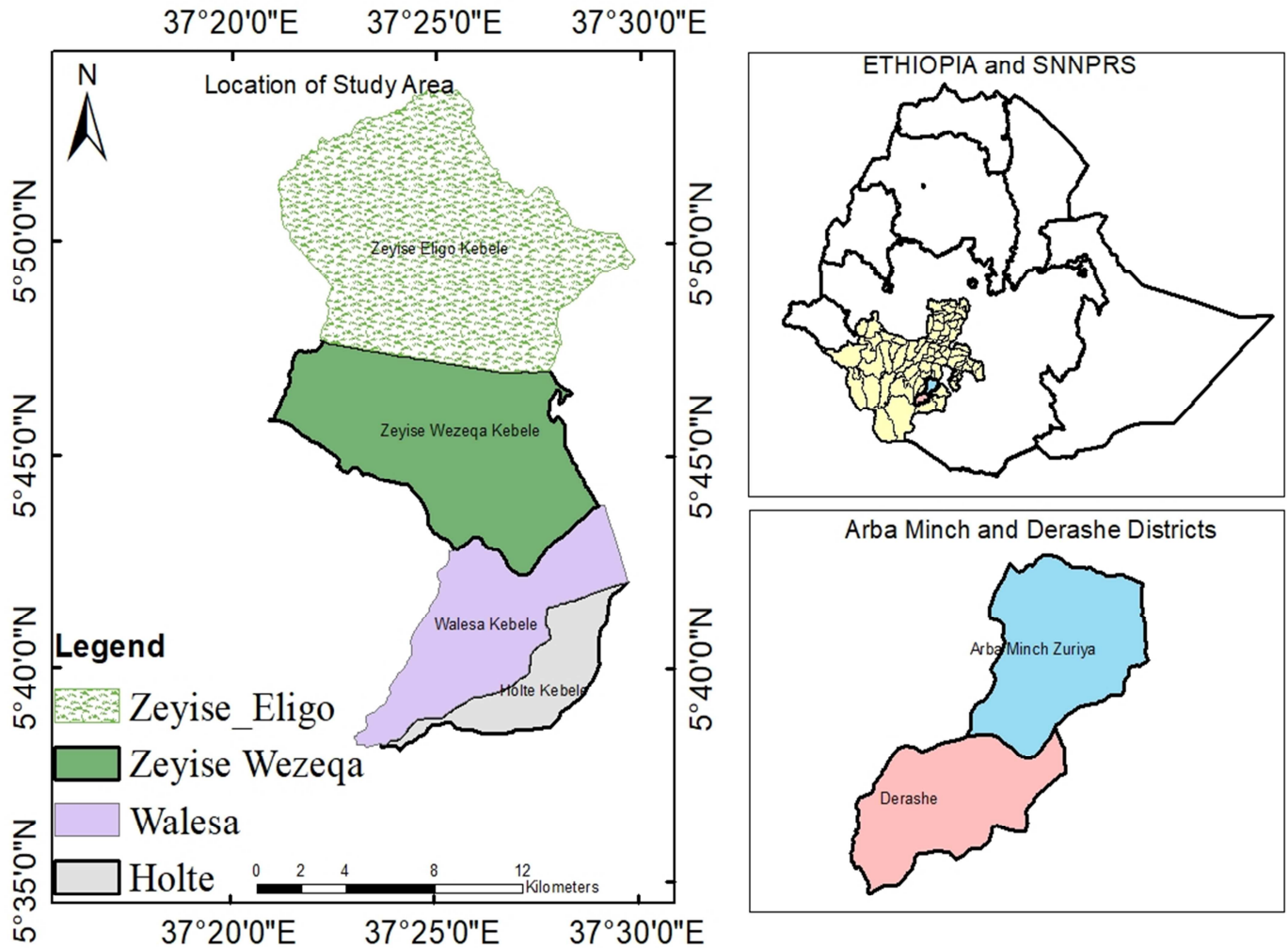


Figure 1.3 Map of the Study Area

1.11 General Methodology and Approach

1.11.1 Research Design

The research design of this study is a cross-sectional survey employing mixed approaches. Cross-sectional is less time consuming compared to the longitudinal studies. This design has an advantage for the investigation of population-wide features at a single point in time. However, the cross-sectional approach has demerit for exploring the developmental stage of subjects over the period (Cohen et al., 2000). Researchers are always expected to explain their philosophical justifications and rationale for selecting a specific research design. Thus, the next paragraph

presents the justification behind each research approach, and reasons for selecting mixed methods in the current study.

For more than a century, quantitative and qualitative research paradigm advocates have engaged in an eager argument. From these debates, purists have emerged on both sides. Quantitative purists articulate assumptions consistent with positivist philosophy. They believe that social observations should be treated as entities like physical scientists treat physical phenomena (Johnson & Onwuegbuzie, 2004). Further, they contend that the observer is separate from the entities subject to observation. Positivism claims that science or knowledge creation should be restricted to what can be observed and measured since research uncovers an existing reality (Bhattacharjee, 2012).

Qualitative purists (also called constructivists and interpretivism) reject positivism. They argue for the superiority of constructivism, idealism, relativism, humanism, hermeneutics, and, sometimes, postmodernism (Lincoln & Guba, 2000). These purists contend that multiple constructed realities flourish and that time and context free generalizations are neither desirable nor possible. Research is value-bound, and it is impossible to differentiate fully causes and effects that logically flow from specific to general (Johnson & Onwuegbuzie, 2004). Thus, explanations are generated inductively from the data, and the knower and the known cannot be separated because the subjective knower is the only source of reality (Guba, 1990). Qualitative purists also dislike a detached and passive writing style, detailed, rich, and thick (empathic) descriptions written directly and somewhat informally.

Later on, frustration with positivist philosophy's extreme and strict empirical nature led to post-positivism during the mid-late 20th century. Post-positivists view science as ambiguous, but probabilistic and social science focuses on confidence and how much we can rely on our findings. As Robson (2002) points out, researchers will never be able to uncover the reality through research. According to the subjectivist philosophy, the world results from our minds rather than an objective reality. Social constructionism stems from the view that truth is not accurate and external but socially constructed and given meaning by people (Robson, 2002).

It is problematic to take a polarizing approach that takes an extreme subjectivist or positivist approach (Tashakkori and Teddlie, 1998). Thus, pragmatism has gained acceptance from a few scholars who argue for mixing quantitative and qualitative approaches in single research (Kelemen and Rumens, 2012). Mixed methods research is not to replace either of these approaches but rather to draw from their strengths and minimize their weaknesses in single research studies and across studies. If qualitative research is anchored at one pole and quantitative analysis arrives at the other, mixed methods research covers the large set of points in the center (Johnson & Onwuegbuzie, 2004). Therefore, mixed methods study offers significant promise for practicing researchers who want to see methodologists describe and develop techniques closer to what researchers use in practice.

1.11.2 Sampling Techniques

The current study used a multi-stage sampling technique applying both random and purposive sampling techniques to select sample households and study areas. In the first stage, purposive sampling was used to determine the two study districts (Derashe and Arba Minch Zuriya) due to the different tillage practice and proximity. In the second phase, neighboring kebeles that practice different tillage practice and proximate to Arba Minch Zuriya district were identified and purposefully selected. This was done with the support of district and kebele administrators. The sample households (HHs) were determined by forming strata, CT and CA practitioners. Thus, using proportional sampling technique sample household was selected. The total number of households in the two districts of 2020/21 was obtained from the district agriculture office and the respective study kebeles. Therefore, Arba Minch Zuriya's population was 43,711, Derashe's was 33,877, and the total population was 77,584. The total number of household heads in the selected four kebeles was 7502. In order to obtain a representative sample for proportions for large populations, (Cochran, 1977) developed an equation.

$$n_0 = \frac{Z^2 * p * q}{e^2} \dots\dots\dots (1)$$

This is valid where n_0 is the sample size, Z^2 is the abscissa of the normal curve that cuts off an area α at the tails ($1 - \alpha$ equals the desired confidence level), e is the desired level of precession, p is the estimated proportion of an attribute that is present in the population, and q is $(1 - p)$.

$$Z= 1.96; p= 0.5; e = 0.05$$

Based on the above formula the calculated minimum sample size was 384.

When the population size is known (finite) the formula is:

$$n = \frac{n_0}{1 + \frac{n_0 - 1}{N}} \dots \dots \dots (2)$$

Where n_0 : Cochran's sample size computed using the formula for ideal sample size;

N : the size of the population

$$n = \frac{384}{1 + \frac{384 - 1}{7502}} = 365.7 \approx 366$$

The data was collected from 392 (232 adopters and 160 non-adopters). The sample households were proportionally selected using the following proportional sampling methods:

$$n_1 = \frac{N_1}{N} * n \dots \dots \dots (3)$$

$$n_2 = \frac{N_2}{N} * n \dots \dots \dots (4)$$

Proportionally allocated total 392 households in the four kebeles were stratified using tillage practice as shown in Table 1.4. Finally, a simple random sampling technique was used to select participant households to fill the survey questionnaire.

Table 1.4 Sampling Strategies for the Household Survey

District	Kebele	Total Household head	Sampled Household
Arba Minch	Zeyise Eligo	1,170	61
	Zeyise Wezeqa	1,897	99
Derashe	Holte	2,450	128
	Walessa	1,985	104
	Total	7,502	392

1.11.3 Data Sources and Methods of Data Collection

The study used both quantitative and qualitative data types, and it was based on cross-sectional data. Post-harvest production and income for annual and perennial plants were collected using farmers' recall methods whereas the last season⁷ was collected using both farmers' estimation and crop harvest methods. In most cases, postharvest estimations were conducted at the farmer's household or on site where the harvest was stored for the enumerator to cross-check with the available storage capacity (Casley & Kumar, 1989). The ripe crops from the previous cultivation seasons were either sold or consumed in all study kebeles. However, for the last season, harvested products were checked in the field. Recall periods may range from six months or one season to three years or three-to-six seasons (Erenstein et al., 2007). For yield estimation, a structured interview was conducted that included information about both harvested perennials and annual crops.

The recall methods were supported by the harvesting of crops from 60⁸ (30 Arba Minch and 30 Derashe districts) farmers' fields that were ready for harvest (Figure 1.3). From each plot, annual crops were harvested from 3 subsamples forming 2 x 2 m quadrants. After harvesting, crop was mixed and the yield was converted to quintals per hectare. In the area smallholders leave maize crop till it dry, this helps to produce “*cheka*” and consuming grains in the green form is not common. Furthermore, to get total banana fruit production from a single tree, 10 banana farm plots were purposively⁹ selected, and 10m x 10m quadrants were formed. The larger the quadrants were because most farmers planted banana seedlings within 3m x 3m spacing.

⁷ The season where last data was collected, during the time cultivated crops reached for harvesting.

⁸ In the Derashe area there were three dominant annual crops, namely maize, sorghum and teff. A smallholder seasonally rotates the crops. Therefore, 10 maize, 10 sorghum, and 10 teff growers were systematically selected from the two studied kebeles. Besides, in Arba Mich Zuriya smallholders rotationally cultivate maize and teff and 5 from each kebele and a total of 20 were purposively selected.

⁹ We purposively formed the quadrants because farmers cut and sale banana fruit every month and the probability of getting harvestable banana bunches can be less if we randomly select and set the quadrants.

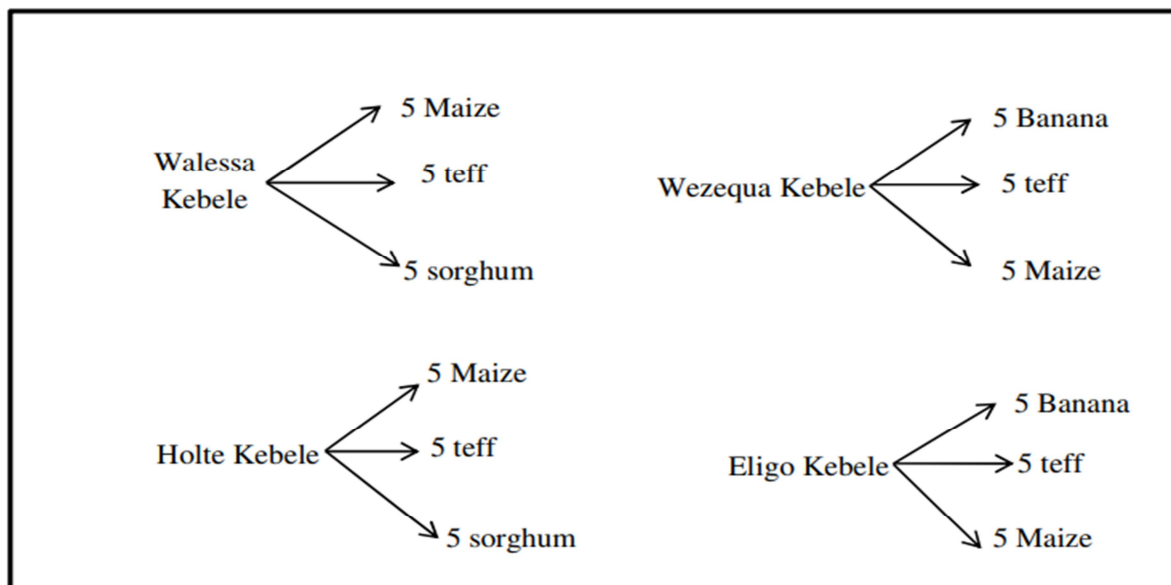


Figure 1.4 Selected Plot for the Crop Harvest Method

In all subsamples, fruits were mixed, measured, and converted into quintals. However, since the production potential of *Moringa stenopetala* leaves was different in each month of the year, only farmers' estimation methods were used to estimate leave production and income.

$$\text{Crop yield} = \frac{\text{Production}}{\text{Per unit area}}$$

Obtaining yield estimations through crop harvests was both time and labor-intensive. In contrast, the use of farmer estimations does not require laborious measurements and allows for a more efficient, random sampling design (Casley & Kumar, 1989). Compared to crop harvests, the use of farmer estimations is thus a cheap and quick method that saves time and money; in the current study, both crop cuts and farmers' estimations were used as a primary source of data.

Following Jat et al. (2021), to obtain the gross income from CA and CT practices, crop production in quintal ha⁻¹ and the market price were assessed from the local markets. Gross income was determined as annual + perennial crops production/yields multiplied by the market price of each crop. To make the comparison uniform production was converted to hectares

Preliminary Work: To meet the objectives, data were collected from CA and CT practicing household heads and their main farmland. Accordingly, data like yield per quintal from perennial

and annual crops, soil samples, and the market price of banana fruit, *Moringa stenopetala* leaves, and annual crops were obtained from the local market.

1.11.3.1 Study Data Collection Tools

(1) Household survey: A structured questionnaire was prepared (Appendix 1). The questionnaire was developed using a reconnaissance survey, consultation with experts, and literature references. The questionnaire contained seven sections, and the first part included general information about farmers and enumerators. The second part consisted of information about households' socioeconomic and demographic characteristics. The third part was about land holdings and income from major cultivated crops in three farming seasons. The fourth part included information on the significant land use and its contribution to soil fertility. Detailed questions were asked to investigate the considerable soil management differences in the two adjoining districts. The fifth part contained information regarding factors determining indigenous conservation agriculture adoption. The sixth part was supposed to provide information on market and extension services. The seventh part was designed to know more about the proximate and underlying causes of land use and land cover change. The last part included Derashe district women's role in agriculture and farming practices.

The data were collected from December 2020 – March 2021. However, several preparatory activities were conducted before data collection. First, one-day training for enumerators was given on research objectives, interview schedule content, and data collection methods. Second, the interview schedules were pre-tested on sixteen randomly selected farmers and four household heads from four selected study kebeles. Based on the pre-test results, significant questionnaire modification was made. The data was collected by 16 enumerators working as high school teachers in each kebele. They were believed to know the area and the system better.

(2) Market survey: To estimate the value of goods sold and bought on the local market, we used the market price method. Respondents were asked about the prevailing market prices of goods traded in the area marketplace as part of this study. These goods included crops, banana fruit, and *Moringa stenopetala* leaves. Thus, their answers were tested at the nearest market the study Kebele residents used. The local market assessment was conducted to determine the actual price of goods and the real income of households derived from annual and perennial crops.

Key informant interviews (KII): were conducted with Derashe and Arba Minch Zuriya district elderly farmers. The contents of the KII guide include issues about the trends of crop cultivation, the history of CA with Targa-na-Potayta mulching, smallholder farmers' benefits from banana fruit cultivation, smallholder farmers' knowledge and interest in practicing the *Targa-na-Potayta* mulching technique, and the economic and environmental benefits that smallholders obtained from practicing CA. A total of four key informant interviews were conducted in each of the four study kebeles.

Field data collection procedures: In most studies, DAs are considered appropriate data collectors and supervisors as they have contact with farmers and are familiar with the local setting. However, their familiarity with the area and knowledge of smallholders may give them the courage to fill out the questionnaire by themselves. Therefore, to avoid the problem, the researcher selected high school teachers who lived in the selective districts for a long time and fluently spoke the Amharic, Derashegna, and Gamo languages.

(3) Soil sample collection: The primary purpose of this data set was to determine the effect of CA and CT on soil physicochemical properties. Chapter 3 presents detailed sample collection methods.

Secondary data collection methods: Additional information was collected from various published and unpublished sources. Besides, relevant documents were collected from Derashe district, Arba Minch Zuriya district, Holte kebele, Walessa kebele, Zeyise Eligo kebele, and Zeyise Wezeka kebele.

1.11.4 Methods of Data Analysis

Quantitative information on households practicing CA and CT from the formal survey was examined using descriptive, inferential, and econometric statistical analysis. The collected soil samples from selected CA and CT smallholder farmers' farmland were analyzed and compared using an independent sample t-test. To observe the effects of predictor variables, soil management, on the predicted variables, i.e., CEC, pH, and the sum of exchangeable cations, a linear regression model was employed (Jaremko & Kalembasa, 2014). To investigate household gross income, information obtained in two consecutive cultivation seasons allowed estimation of

the production and income contributions of cultivated annual + perennial crops. This was done for a group of CA and CT smallholder farmers. An independent sample t-test was used to test the significant differences in production and revenue of CT and CA practicing groups with a comparison test at a 0.05 probability level.

A two-stage regression was used to analyze the data and investigate CA adoption decisions in the two study districts. The models estimated included: (1) the probability of farm households adopting CA and (2) the extent of CA practices as measured by acquired total highly fertile land in hectares once the farmer has implemented CA (only for CA adopters). In the first model, all surveyed households were included in the analysis. In the second model, only CA-practicing households were considered. The first model was estimated using binary logit regression, and the second using the ordinary and weighted least squares method. To compare the results from the OLS/WLS models with estimates derived from regressions with censored dependent variables, a Tobit analysis was also performed to analyze the amount of highly fertile land in hectares by CA groups using data from all surveyed households. P-tests were performed to test the significance of differences between the independent variables (Table 1.5). The collected data was analyzed using Statistical Package for Social Sciences (SPSS) version 26 and STATA version 14.

Table 1.5 Summary of Specific Objectives, Indicators, Target Group for Data Collection, Data Collection Method and Data Analysis

Major research themes	Variables and indicators		Sample/target group for data collection	Data type and collection method	Data analyses
	Indicators	Variables			
Obje.1: Assess the indigenous CA practices in the study area	History and benefits of <i>Targa-na-Potayta</i> using information from CA practicing smallholders	- History of the technology - Benefit of the technology for soil erosion and crop productivity	Survey households	Mixed qualitative and quantitative data - Structured interview - key informant interview	Descriptive (Mean and percentage) Inferential statistics (independent sample t-test) Tobit
Obje.2 Assess the effects of CA and CT on the soil physicochemical properties	Soil physical property	Particle size, FC, PWP, AWHC, and BD	CA and CT practicing smallholders Plot	Quantitative data 32 composite soil (16 from CA, and 16 CT practicing groups) using a zigzag shape.	Inferential statistics (independent sample t-test)
	Soil Chemical property	Soil pH, SOC, CEC, Ava. P, TN, sum of cations (Na, K+, Ca ²⁺ , Mg ²⁺), CEC, PBS			
Obje. 3: Examine the contributions of CA and CT for crop productivity and household income	Production and Income from annual + perennial crops in the two consecutive production seasons	- Market assessment - On-farm measurement - Store (Pile of crops) estimation in the field / house	- Survey households - Market price assessment for the nearby market - Smallholder plot - Smallholders crop store	Quantitative data - Structured interview - Direct measurement - Direct estimation - Key informant interview	Inferential statistics (independent sample t-test)
Obje.4 Assess factors influencing the adoption of CA	Adoption and non-adoption	Socio-economic, physical and institutional data	Survey households	Mixed qualitative and quantitative data Primary data - Structured interview - key informant interview	Descriptive (Mean and percentage) Logistic regression

Chapter 2 Indigenous Conservation Agriculture Practices in the Derashe District, Southwestern Ethiopia

Abstract

*In previous years, the mountainous topography, erratic and high rainfall intensities, high temperatures, and intensive CT exacerbated soil erosion and soil moisture stress. This caused droughts and famines to plague the area for a long time. To escape the problem, progenitors invented CA with Targa-na-Potayta mulch a hundred-plus years ago. In this study, we sought to understand CA with Targa-na-Potayta mulch and its benefits for soil management. Two Kebles in the Derashe district were purposely chosen, and 232 sample household heads were randomly selected. The data were collected using structured questionnaires, key informant interviews, and a transect survey. CA with Targa-na-Potayta mulching is one of the indigenous technologies used by the Derashe community for centuries. It is practiced by mulching maize and sorghum residues in a rectangular shape, roughly 60 cm x 80 cm, in repeated patterns in the field. Apart from residues/mulching, they also include (a) minimum tillage, (b) mixed cropping with leguminous crops like chickpeas and haricot beans, (c) integration of agroforestry trees, mainly *Moringa stenopetala*, and (d) crop rotations like sorghum/maize/teff. In each Potayta, they sow seeds by counting their footsteps using a metal stick locally known as a "Totale." These activities enhance soil quality and crop productivity in the Potaytas. In the area, women have an indispensable role in farm management. Apart from routine household tasks, they are actively engaged in land preparation, Targa-na-Potayta designing, weeding, harvesting, and marketing crops. After household chores are completed, they usually travel to farmland. Farmers' perception was used to classify farmland soil fertility status according to the area's classification criteria. Using the total hectare of highly fertile land as a dependent variable, nine independent variables were used to determine soil fertility extent. Thus, increasing age, larger land holdings, and higher net income from perennial + annual crops positively and significantly contribute to soil fertility compared to other variables. Smallholders can manage the soil by implementing CA with Targa-na-Potayta mulching. In order to reap the benefits of Targa-na-Potayta mulching, appropriate bodies need to recognize local solutions, and policy support is required to scale the technology out for wider use.*

Keywords: Conservation agriculture, Indigenous knowledge; Targa-na-Potayta; Soil management; crop productivity

2.1 Introduction

Indigenous knowledge (IK) is the expressions, practices, beliefs, understandings, insights, and experiences of the indigenous groups' generated over centuries of profound interaction with a particular territory (Sillitoe, 2016). Local communities generate this knowledge through first-hand learning. This knowledge is mostly relevant for decision-making at the local level in agriculture, soil and water conservation, and any other activities planned at the local level. However, the role of local indigenous knowledge has not been adequately acknowledged and considered by many researchers and policymakers in developing countries (Warren & Cashman, 1988).

Soil erosion is a major problem limiting crop production and increasing famine risk in Ethiopia. Loss of topsoil due to intensive tillage and mono-cropping significantly destroys soil fertility and crop production in many parts of the country. Out of the 60 million ha of productive land, an estimated 27 million ha are considered significantly eroded, 14 million ha are seriously eroded, and 2 million have reached the point of no return (Girmay et al., 2020). Along with the accelerated soil erosion, the loss of water as runoff have caused low productivity (Haregeweyn et al., 2015). This warrants more proactive efforts to develop and practice soil and water-conserving technologies. This will minimize soil erosion and utilize rainwater effectively and efficiently.

According to Jat et al. (2021), practicing conservation agriculture improves the soil ecosystem's health, through increasing land productivity and providing more benefits to farmers. However, like in many African countries, in Ethiopia, CA remains obstinate due to smallholders' trapped obsession with traditional tillage and crop residue use for other purposes (J. B. Aune, 2020). Crop residues are estimated at 22.4 million tons, of which 10.3 million tons are used as fuel and livestock feed (Negash et al., 2017). Nevertheless, when soil erosion and moisture stress are exacerbated, smallholders use indigenous knowledge (IK) to originate soil and water conservation technologies as an integral part of their farming systems.

IK is a cumulative body of knowledge maintained and developed by people with extended environmental interaction histories. Farmers have acquired knowledge about agriculture, treatment for some recurring diseases, and methods of cropping on fertile and infertile soils, and this knowledge has survived over centuries (Warren and Cashman, 1988). The same authors added that drawing upon local indigenous knowledge systems is essential for

sustainable development. Such knowledge is pragmatic and beneficial to farmers and agricultural scientists.

IK is unique knowledge developed over time and continues to grow by people in a given community or geographical area (Samal et al. 2010). For instance, in the Derashe area, the prolonged problem of moisture stress, soil erosion, and frequent famine prompted the ancestors to develop perpetual skip technology, *Targa-na-Potayta*. It is about complete crop residue management on the farm and mulching in ridges around cropping microsites. Currently, smallholders intensively implement their descendants' technology. Mulching has benefits attributed to physical effects that minimize raindrop impact and improve rainwater infiltration by enhancing soil structure. This helps to increase soil fertility, crop productivity, and reduce soil moisture stress (Lejissa et al., 2023).

The benefits of physical soil and water conservation measures are expected later stages. For instance level Fanya juu reduces surface runoff on average by 71%, whereas stone bunds, bench terraces, tied-ridges and trash lines reduce it by 51–57% (Wolka et al., 2018). In Debre Mewi, Ethiopia, stone bunds, and soil bunds reduced soil loss by 72.9 and 83.7%, respectively, compared to untreated land (Teshome et al. 2013). A study in the Tigray region found that stone bunds trap 64% of soil moved by water erosion (Vancampenhout et al., 2006).

Smallholders in various parts of the country have developed local CA technologies; however, the Derashe people's practice is particularly suited to the lowland climate. Therefore, the current study aimed to understand and comprehend the Derashe community's indigenous soil and water conservation technique, *Targa-na-Potayta*. Using farmers' perceptions, the study investigated the technology's benefit for soil fertility. The findings could help practitioners and responsible bodies understand the technology's contribution and spread practices in areas with similar agroecology and problem.

2.2 Data Sources and Methods of Data Collection

Two Kebeles from the Derashe district namely Holte and Walessa were purposefully selected. To get the required number of households from each kebele proportional sampling was employed, and a total of 232 households were randomly selected and interviewed. Respondents were randomly selected since *Targa-na-Potayta* technique well intensified and implemented by almost all smallholders in the selected study kebeles.

The study employed both qualitative and quantitative methods in data collection and analysis through the application of Participatory Rural Appraisal (PRA) techniques. Participatory Rural Appraisal (PRA) describes a growing family of approaches and methods to enable local people to share, enhance and analyze their knowledge of life and conditions, to plan and to act (Chaiviberst, 1994). Besides, PRA is capable of capturing the dynamic qualities of the environment and community in general (Longhofer, 2012). To collect data, a transect walk, key informant interview, and household survey has been used to complement each other. Before the actual data collection, a reconnaissance survey were undertaken to test and modify the questionnaire.

With having three elders, two key informant interviews were conducted in the selected Kebeles. The interview specifically focused on the history of *Targa-na-Potayta* mulching technique, the problem of soil erosion, soil moisture stress and crop productivity before and after the invention and implementation of *Targa-na-Potayta*. Additionally, through a formal questionnaire, the authors identified the role of women in farmland management and farmland soil fertility status using their perceptions.

2.3 Methods of Data Analysis

To meet the objectives of the study, descriptive, inferential, and econometric analysis were employed. The collected data was analyzed using Statistical Package for Social Sciences (SPSS) version 26 and STATA version 14.

2.3.1 Descriptive Statistics

Descriptive statistics such as mean, standard deviation and standard error were employed and an independent sample t-test conducted as an inferential statistics.

2.3.2 Econometrics Model

Despite *Targa-na-Potayta*'s contribution to relieve moisture stress and enhance soil fertility, it is essential and policy-relevant to identify factors determining the extent to which soils are highly productive. In this case, selected smallholder farmers were asked to classify their farmland as highly, moderately, and poorly productive. This was done based on smallholders' knowledge and experience. In the area, soil fertility status mainly determined by soil water infiltration rate and crop yield (productivity). In the model, nine independent variables, namely, age, total land holding, tropical livestock unit, level of

formal education, year of practicing *Targa-na-Potayta*, and net income, were included in determining the dependent variable, the extent of soil fertility.

To remedy the problem of heteroscedasticity, as revealed by the Breush and Pagan test in the exploratory analysis of the data, a weighted least squares (WLS) procedure was applied. Tobit regression was also employed to compare OLS and WLS results with estimates derived from regressions with censored dependent variables.

$$FERLAN = \beta_0 + \beta_1 AGE + \beta_2 FAMSIZE + \beta_3 TLANHOLD + \beta_4 TLU + \beta_5 MARDIS + \beta_6 EDU + \beta_7 EXT + \beta_8 CA + \beta_9 NETINCO$$

2.4 Choice of Independent Variables for Econometric Estimations

The choice of relevant independent variables is based on empirical review of previous literature, and data availability. These variables have been grouped as socio-economic and institutional variables. Brief descriptions alongside the direction of the hypothesized effects of these variables on soil fertility are presented in (Table 2.1). The positive sign means a positive relationship is expected, while the minus sign means that a negative relationship is expected.

Table 2.1 Definition of Independent Variables that Included in the Econometric Model and Expected Sign

Variable code	Description	Types of variable	Unit of measurements	Expected sign/s
Extent	Extent of highly fertile land	Continuous	Measured in hectare	
AGE	Age of the HHH	Continuous	Measured in Years	+
FAMSIZE	Family size in adult equivalent (in number)	Continuous	Number of family member	+
TLANDHOLD	Total Land Holding	Continuous	Measured in hectare	+
TLU	Total livestock holding of the HHH	Continuous	Measured in Tropical Livestock Unit (TLU)	-
MARDIS	Market distance	Continuous	Measured in Km	-
EDU	Formal educational level of the HHH	Continuous	The level of formal education	+
EXTEN	Extension visit	Dummy	1 = Yes, 0 = No	+
CA	Total year of implementing CA	Continuous	Measured in Years	+
NETINCO	Annual net income from annual + perennial crops in ETB	Continuous	Measured in Ethiopian Birr	+

2.5 Results and Discussion

2.5.1 History of *Targa-na-Potayta* Mulching

The Derashe district is located in the southwestern Ethiopia and has a mountainous topography. A short and erratic rainstorm combined with high temperatures causes soil erosion and soil water evaporation. This caused frequent droughts and famines, since crop production was threatened by chronic soil moisture stress (Fikre et al., 2018). During the key informant interview, age 65 (model farmer at Holte Kebele), stated:

“Historically, our ancestors suffered from soil erosion and soil moisture stress. Most survived with continued government assistance and others migrated. Being dependent on others while having enough farmland and the ability to work is awful. However, nature damaged the area and compelled them to rely on it. After many trials, hundreds-plus years ago, they developed Targa-na-Potayta, a novel soil and water conservation structure using crop residues. From that time, Targa-na-Potayta became the identity of the Derashe area.”

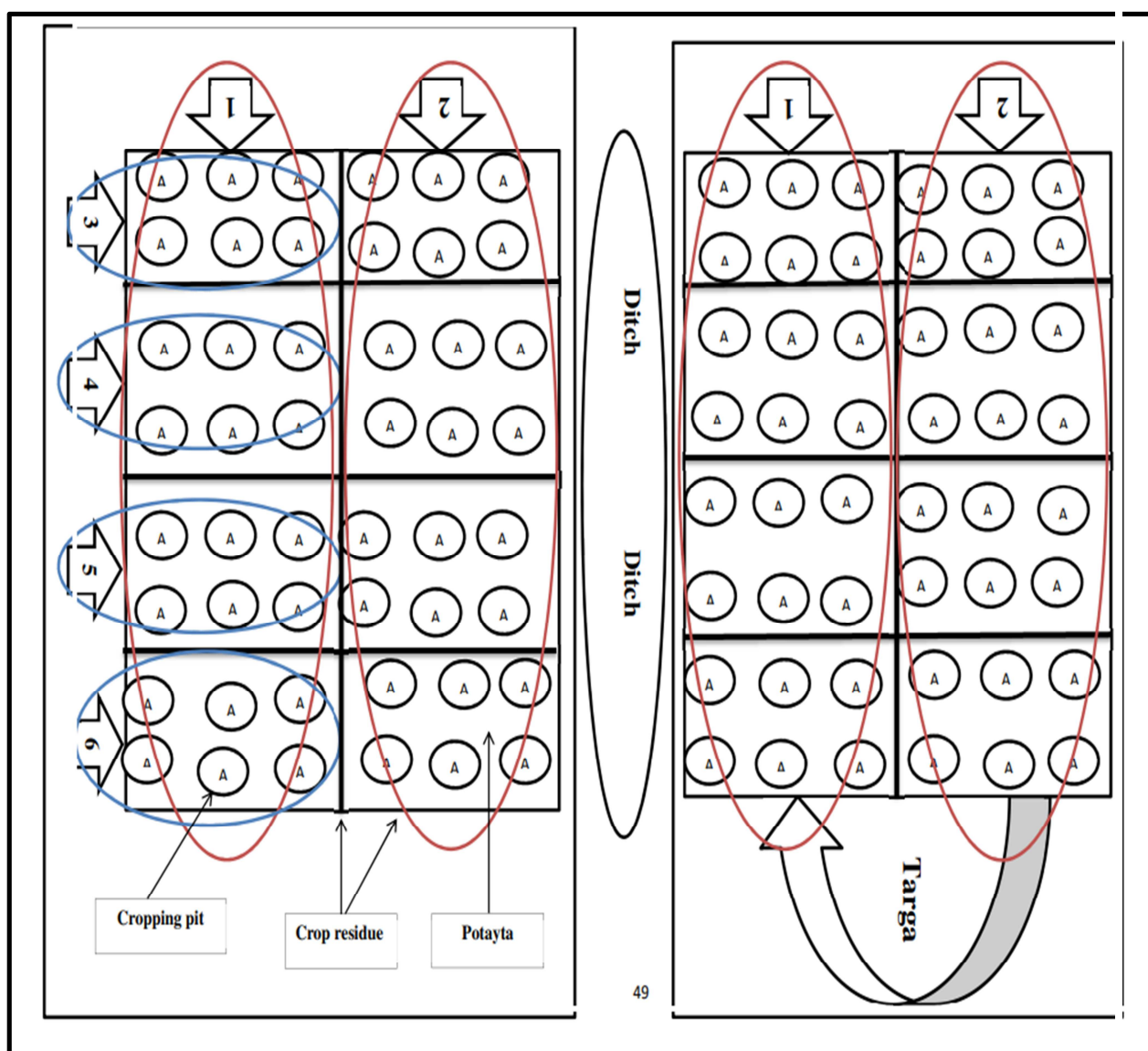


Figure 2.1 Schematic representation of *Targa-na-Potayta* Mulching

- **Apha** constituting *Targa-na-Potayta*, an indigenous mulching technique in the Derashe district. (1 and 2 refers to "*Targa*," which is a group of adjacent **Potayta**; 3, 4, 5, and 6 refer individual **Potayta**. The border is made of crop residues that are used as mulch).

Targa-na-Potayta is one of the indigenous conservation agriculture technologies being used by the Derashe community for centuries. It is practiced in such a way that, maize and sorghum residues are mulched in a rectangular shape, roughly 60 cm x 80 cm, in repeated patterns in the field (Agena, 2011). The more extended parallels are known as "*Targa*." The shorter transverse residue stem makes the rectangular partition is called "*Potayta*." In a one hectare of farmland one long *Targa-na Potayta* can use 0.17 ha of land and is known as "*Apha*." They separate each "*Apha*" using a ditch/trench, and

6 Apha can be found in one hectare of land. Between the ridges of *Targa-na Potayta*, when water fills up as small ponds following heavy rainfall, they open the residue ridge partly and pass it on to the next Potayta. If one Apha is ponded, they pass it to the trench/ditch that connects the next Apha (Figure 2.1). With this technology soil erosion reduced with improved soil moisture and soil fertility. Mr. Getahun, age 60 from Walessa kebele stated:

“You will not find anybody in the house, except kids, if a single raindrop falls; all will run to the field and adjust Targa-na-Potayta. One raindrop has value in this area. The crop residue helps to reduce soil erosion, let the rainwater infiltrate slowly, and reduces soil-water evaporation. Besides, all residue nutrients are returned to the soil through decomposition. This helps to increase soil moisture, particularly during rainwater shortages and enhances soil fertility and crop productivity. Thus, the destructive effect of moisture stress and soil erosion became history in the Derashe area with Targa-na-Potayta.”

According to Jat et al. (2014), mulching improves rainwater infiltration, reduces soil erosion, improves soil quality, reduces soil compaction, moderates soil temperature, gives higher and stable yields, saves inputs, and reduces cultivation costs.

Apart from the novel permanent soil ridge cover with crop residues/mulching techniques, the technology consists of (a) minimum tillage, (b) mixed cropping with leguminous crops like chickpeas and haricot beans, (c) integration of agroforestry tree species, mainly *Moringa stenopetala*, and (d) crop rotations like sorghum/maize/teff. Using a metal stick locally known as “*Totale*,” in each *Potayta*, they sow seeds by counting their footsteps (Figure 2.2). Weeds are continuously controlled, cleared by manual weeding technique, and used as residue. In the Derashe community, the crop land is completely kept weed free and never allowed to be weed invaded. Mr. Getahun, from Walessa kebele also stated:

“As weeds compete for nutrients with crops, removing weeds from the field has been our tradition. Those who do not regularly remove the weeds from their land are considered as sluggish farmers, and nobody wants to drink “cheke”(traditional homemade brew) with them. If he is single, no one will let him marry his daughter.”

In the study area, farmers harvest sorghum twice a year. One is the “seed crop” from direct seeding in the moisture-conserved *Potayta* seeding area between the mulch materials.

When the varieties of sorghum crops mature, they bear grains of different heads. In the Derashe tradition, only the head with the grains is removed, and the rest of the stalk is used for mulching. This means a minimal amount of nutrients from the soil is extracted from grain removal. All vegetative biomass is returned to the soil as mulch for subsequent crops' slow decay, decomposition, and nutrient release. As part of the same year's sorghum harvest, the ratoon crop yields the second crop. Derashes practice ratooning by cutting the seed crop stalk one node above the ground. This allows resprouting and growing to bear grain for the second harvest. After the second harvest, the stalk is uprooted and layered to form the *Targa-na-Potayta*. The cycle is on again with the seed crop in the new year. This adaptation strategy helped the Derashe people survive and sustain crop productivity. In keeping with the traditional methods of managing farmlands, the current generation continues to use innovation without modification. Mr. Tamirat age 67 from Walessa kebele stated:

“Smallholders have a huge store inside or near the main house. Most farmers store harvested grains for five years. You see! With Targa-na-Potayta, we make food self-insufficiency history.”



Figure 2.2 Typical Farmland and Sowing Practice in the Derashe Area

(A). Farm field covered by *Moringa stenopetala* trees + *Targa-na-Potayta* mulching; (B) Zero tillage practice; a smallholder till the land using “*Totale*”, a traditional digging tool, and put seeds in rows counting his footsteps.

2.6 Functions of *Targa-na-Potayta* in the Soil Management

In the study area, moisture stress in the dry season and soil erosion caused by the unpredictable erratic heavy rain during the cropping season are severe. CA with *Targa-na Potayta* mulching is therefore, an indigenous solution by smallholder farmers, along with crop rotation, minimum tillage, and integration of trees with crops in the farm field. Mr. Asfaw, 65 from Holte kebele stated:

“In our culture its common practices to take all family members to farmland during the major farming seasons. All farming activities have similar rules with different tasks. The weeding season, for example, is characterized by a "Targa" laying as mulching materials assigned to someone. To move to the next "potayta," weed clearing must be completed in the initial "potayta." The same rule applied to sowing and harvesting. Therefore, youngsters are familiarized to the indigenous farmland management during their early ages. When they form their own family, they manage farmlands similarly.”

Many interviewed farmers, 78.35% in Walessa and 77.17% in Holte Kebele of the Derashe district, stated that *Targa-na-Potyta* technology enhances soil fertility and crop productivity. Mulching, a part of CA, halts soil erosion by providing a protective layer on the soil surface. This increases resistance against the overland flow and enhances soil surface aggregate stability and permeability (Erenstein, 2003). The practices improve soil fertility and crop productivity at minimal input costs. Crop residues increase organic matter in the soil, which enhances water-holding capacity, soil aggregation, rooting environment, and nutrient retention (Abera et al., 2020). Mulching is a promising technology and an integral component of conservation farming. It is increasingly seen in the light of integrated soil management for sustainable agriculture (Kassam et al., 2019).

The key informants stated that in the area, the soil water infiltration capacity and crop productivity are the two-soil fertility status classification criteria. Smallholders were asked to classify their farmland fertility status as highly fertile. In the Derashe area, using farmers perception, from an average of 1.73 ha of farmland, 0.96 ha was highly productive (Table 2.2).

Table 2.2 Soil Fertility Status Classification by Smallholders

Kebele	Total Land Holding	Highly productive farmland
Walessa	1.56	0.78 ± 0.15^a
Holte	1.89	1.13 ± 0.19^b
t-value		-1.45**

Mr. Asfaw boldly explained the benefits of *Targa-na-Potayta* in enhancing soil fertility and crop productivity. As he stated:

“My farmland is located in a sloppy area; hence I use Targa-na Potayta extensively and plant many Moringa trees. Last summer (2019), a sudden and powerful storm hit us. Although the rain could only disrupt the mulch structure, the straw caught the soil and minimized its potential impact on the crops. You see, if Targa-na Potayta mulch were not there, the whole family would be on the streets begging for food.”

Mwango et al., (2016) conducted similar field experiments from 2011 to 2014 in Majulai and Migambo villages with contrasting climatic conditions in the Usambara Mountains, Tanzania. The authors investigated effectiveness of mulching in reducing soil erosion and restoring soil fertility for maize (*Zea mays*) and beans (*Phaseolus vulgaris*) productivity under *miraba*, a unique indigenous soil conservation measure in the area. Soil loss was significantly higher ($p < 0.05$) under *miraba* sole than *miraba* with mulching. Soil fertility status was significantly higher ($p < 0.05$) under *miraba* with *Tughutu* mulching.

In the Derashe area, its common *Moringa stenopetala* trees scattered in the farm land in traditional parkland agroforestry, along with mulching, and crop rotation (Figure 2.3). CA with high-value trees combines rapid livelihood improvement with sustainable crop production, productivity, and environmental resilience (Kassam et al., 2022). Integrating trees into CA is crucial for reducing soil erosion, improving soil fertility by bringing nutrients from deeper soil layers, mitigating climate change by storing carbon, and increasing soil infiltration capacity to enhance crop yield (Araya, 2020a). For example, incorporating *Faidherbia albida* perennial trees into cropland in northern Ethiopia improved soil fertility (Birhane et al., 2018). Smallholders stated from a hectare of land that covered with *Moringa stenopetala* + annual crops, 0.38 ha of land covered by the *Moringa* tree.



Figure 2.3 Ratoon Crop of Sorghum in the *Targa-na-Potayta* Structure at Derashe valley

2.7 Factors for the Extent of Fertile Soil in the Conservation Agriculture

Seven continuous and two dummy explanatory variables were identified to explain factors influencing the extent of highly fertile land in hectares by CA adopters. The signs of coefficients of the significant variables from the OLS and WLS regression estimates of highly productive land once smallholders implement *Targa-na-Potayta*. Therefore, households with large farmland, and higher net annual income from both perennial + annual crops were more likely to have high hectares of fertile land (Table 2.3).

Table 2.3 Ordinary and Weighted Least Squares Regression Results for the Extent of Highly Fertile Farmland in Hectare

Independent Variables	OLS	P > /t/	WLS	P > /t/
Age	0.034**	0.02	0.019*	0.08
Edu	-0.02	0.95	-0.01	0.5
Fam Size	-0.06	0.12	-0.04	0.22
Landholding	0.36***	0.00	0.413*	0.00
TLU	-0.016	0.43	-0.02	0.29
EXT	0.074	0.65	0.224	0.40
Markdist	0.008	0.60	0.00084	0.94
CA	0.014	0.18	0.02	0.32
Net income	3.39e ⁻⁰⁶ *	0.07	1.08 e ⁻⁰⁶ *	0.08
Constant	-1.14	0.04	-0.67	0.97
R ²	49		71.69	
Adjusted R ²	45.27		69.62	
Observation	133		133	

Significant variables affecting the extent of highly fertile land in hectares at *** (1%), ** (5%), and * (10%) probability level

The significant variables and their direction of impact were consistent in the OLS and WLS regressions (Table 2.4). There were slight differences between the results of the two procedures in the size of the coefficients, the levels of significance of some variables, and the explanatory power of the models as measured by R² values. Both the R² and adjusted R² values from WLS regressions were higher than the R² values from OLS regressions. Overall, weighting had a limited impact on the regression results suggesting that heteroscedasticity was a minor issue.

Table 2.4 Tobit Regression Results of the Model for the Extent of Highly Fertile Land

Independent Variables	WLS	P > /t/	Tobit	P > /t/
Age	0.019*	0.08	0.035**	0.02
Edu	-0.01	0.5	-0.003	0.906
Fam Size	-0.04	0.22	-0.06	0.106
Landholding	0.413***	0.00	0.36***	0.00
TLU	-0.02	0.29	-0.016	0.417
EXT	0.224**	0.40	0.09	0.56
Markdist	0.00084	0.94	0.008	0.595
CA	0.02	0.32	0.014	0.18
Net income	1.08e ⁻⁰⁶ *	0.08	3.2 e ⁻⁰⁶ *	0.076
Constant	-0.67	0.097	-1.197	0.027
R ²	71.69			
Adjusted R ²	69.62		22.95	
Log-likelihood			-150.62	
Observation	133		133	

Significant variables affecting the extent of fertile land in hectares at *** (1%), ** (5%), and * (10%) probability level

1. AGE: The results presented in Table 2.4 (OLS & WLS regressions) and 2.5 (Tobit analysis) showed that the age of the household head (AGE) was positively and significantly related to having highly fertile land in hectares. The positive sign and statistical significance were consistent in the OLS, WLS, and Tobit regressions. Coefficients from WLS regressions indicate that all other factors being the same, a one-year increase in the age of the household head will likely increase having fertile land from the total farmland holdings by 0.019ha. This is related to the relationship between age and CA farming experience. As the year of land management using CA increases, the probability of acquiring healthy soil will also increase. CA's short-term effects on crop yield and soil fertility may be positive, neutral, or negative (Jat, et al., 2012). However, in the long term, CA with *Targa-na-Potayta* has been reported to increase crop yields due to associated benefits such as prevention of soil degradation, improved soil quality, better moisture regimes, timely field operations (mainly sowing), and crop rotational benefits. Over time, the benefits from reduced soil degradation and improved physical, chemical, and biological properties from mulching and legumes in rotations improve soil fertility and stable yields in CA fields (Sisti et al., 2004)

2. Lholdng: The size of total landholding was positively and significantly related to having fertile land in hectares. The positive sign and statistical significance were consistent in the OLS, WLS, and Tobit regressions. Coefficients from WLS regressions indicate that all other factors being the same as the total land holding increased by a hectare, the amount of highly fertile land will increase by 0.413ha. This is related to the increasing crop production from the large areas of land. As yield increase the amount of crop residue increase. In the area it's a farming culture to use the crop residue as mulch with *Targa-na-Potayta* design. In CA, the soil surface is covered by crop residues, which provide physical protection for the soil against agents of soil degradation; and, equally importantly, provide food for soil life (Jat et al., 2014). At the same time, various crop rotations involving legumes in CA improve soil quality through biological nitrogen fixation and organic matter addition (Baudron et al., 2015). Therefore the increase in land holdings under CA enhances soil fertility.

3. NETINCO: Net income from annual + perennial crops was positively and significantly related to having highly fertile land in hectares. The positive sign and statistical significance were consistent in the OLS, WLS, and Tobit regressions. Coefficients from WLS regressions indicate that all other factors being the same, a one ETB increase in net annual income will likely increase the extent of highly fertile land by $1.08e^{-06}ha^{-1}$. In the long run, CA's positive impacts on the soil management, soil quality, input use efficiency, etc., accumulate, and farmers become more acquainted with CA technologies. Many studies have reported, in the long run, a significant decrease in the cost of cultivation in fields designed by CA due to a less input cost (labor, time, etc.) (Liu et al., 2010; Araya, 2020a; Jat et al., 2014). This will increase farm profitability due to increased soil fertility, and the reverse is also true.

2.8 Policy Implications

In Ethiopia, more than half of the population relies on agriculture. However, land degradation has become severe. As Wegayehu and Lars (2003) stated, land degradation is one of Ethiopia's immediate problems. The most common form of land degradation is soil erosion by water. This is the most significant environmental challenge to food security and development prospects. A study by Tsighe (1995) stated that land degradation in Ethiopia had been variously attributed to peasants' ignorance of proper land management practices or their pure laziness. However, when the problem becomes severe, farmers in different parts of the country realize soil erosion is an immediate threat to their livelihood and apply different traditional soil and water conservation practices (Gebreselassie et al., 2015).

The study was conducted in the Derashe district to understand indigenous CA benefits. The study found that soil erosion and moisture stress led the Derashe people to invent a local solution, *Targa-na-potayta* mulching. The technology was invented hundred-plus years ago, yet through then-developed technology; the current generation has overcome the challenge. Therefore, the study raises the following policy implications based on the above findings.

- ✓ Smallholders have a deep understanding of the local environment and indigenous solutions to problems. As a result, it is better for governmental, non-governmental organizations, and other responsible bodies to understand smallholder and apply indigenous remedies rather than implementing their own cutting-edge technology;

- ✓ To easily scale-out appropriate indigenous technologies, capacitating and working with the extension agents is mandatory. They have to have updated information, grasp important knowledge from smallholders, and disseminate it to other areas with similar problems and agroecology.
- ✓ Throughout, the region smallholders invent and implemented many indigenous solutions. Thus, it is necessary for researchers to recognize, examine and record technologies appropriate for different agro-ecology.

2.9 Conclusions

The study was conducted to understand *Targa-na-Potayta* mulching technology and its benefits in the Derashe district, southwestern Ethiopia. Two kebeles were purposefully selected based on accessibility. Data was collected using a structured questionnaire, key informant interviews, and field walks. Based on the study results, the progenitors invented *Targa-na-Potayta* mulching technology to combat soil erosion and moisture stress. Through the application of technology, the problem of soil erosion and moisture stress was highly reduced, increased crop productivity, and empowered smallholders to become more food-self-sufficient.

As a result of the past problems, the current Derashe district residents have learned a lot. Managing their land is a priority for all the family members. The major farming activities in most parts of the country are seasonal. As the time to cultivate approached, smallholders became overburdened. Unlike other regions, Derashe farmers are busy throughout the year. Even after harvesting their crops, they are full of activity weeding their land. Weed-free environment and a well-designed rectangular shape, *Targa-na-Potayta* mulch give the area a spectacular look. First-time visitors can recognize the place simply by looking at their farmland.

The Derashe area women, like their fellow men, were highly engaged in farming. They are busy both at home and on the farm. Besides, they prepare and sell “cheke,” local beer in the area to generate extra income. It is common to see the Derashe women in the field holding their manual digging tool, “Totale,” to clean the farm from weeds and designing *Targa-na-Potayta*. Derashe women have equal decision making power in farming as of men.

Smallholders are very aware of fertility status of their farmland. In the area, soil infiltration capacity and crop productivity are usually used to categorize soil as high, moderate, and poor. Tobit was used to identify factors influencing the extent of highly fertile soil as smallholders implement Targa-na-Potayt mulching. The regression results showed that higher age, large land holdings, and high annual net income increase the extent of highly productive land. Once smallholders implement *Targa-na-Potayta*, the average age of the household is related to the technology age since they start applying the technology when they are young. The benefit of mulching and other CA principles increased with years of application. Besides, having large farmland and high per annum net income increases the extent of highly productive farmland. The study concluded that smallholders' indigenous knowledge needs to be respected to prevent soil erosion in the long term.

Chapter 3 Effects of Conservation Agriculture (CA) and Conventional Tillage (CT) on the Soil Physicochemical Properties in the Derashe and Arba Minch Zuriya Districts, Southern Ethiopia



Abstract

Ethiopia's soil degradation has continued for centuries and causes food insecurity. Local smallholders invented and implemented various indigenous restoration practices to cope with soil fertility loss and related stress. However, the contributions of indigenous soil management to enhance soil quality and crop productivity were not well studied. The current study selected two neighboring districts, Derashe and Arba Minch Zuriya, with different tillage practices. The Derashe people, as an adaptation strategy, designed indigenous soil management locally known as Targa-na-Potayta with zero tillage and mixed/rotational cropping. However, in the neighboring Arba Minch Zuriya district, smallholder farmers use conventional tillage using animal power. Representative soil samples were collected from four selected adjacent kebeles in the two districts. Eight farm plots per kebele were established, and 32 composite samples were taken following a zigzag pattern to a depth of 30 cm. Bulk Density (BD), Field Capacity (FC), Permanent Wilting Point (PWP), particle size, soil textural classes, power of Hydrogen (pH), Cation Exchange Capacity (CEC), Available Potassium (Av. K), Available Phosphorous (Av. P), Total Nitrogen (TN), Exchangeable bases (Na, Mg, Ca, and K), and Soil Organic Carbon (OC) were analyzed using standard laboratory methods. The collected data were analyzed using an independent sample t-test. The results showed that in soils under indigenous management, clay content was $53.74 \pm 2.68\%$, FC $47.8 \pm 1.09\%$, AWHC $15.2 \pm 0.37\%$, pH 8.02 ± 0.07 , SOC $1.8 \pm 0.02\%$ and Sum of cations $68.2 \pm 1.66 \text{ meq/100g}$. The values in the tested parameters were statistically significant ($P < 0.05$) and favor an effective soil management practice compared to conventional tillage. To sustainably maximize land productivity, smallholders must integrate appropriate CA technologies. CA with Targa-na-Potayta mulching benefits for sustainable land management must be scaled out to similar agroecological zones with policy support.

Keywords: Conservation agriculture; conventional tillage; *Targa-na-Potayta*; Physicochemical

3.1 Introduction

Ethiopia's population is increasing and is projected to reach 133.5 million in 2032 and 171.8 million in 2050 (Bekele and Lakew, 2015). Agriculture is the mainstay of the Ethiopian economy and the primary employment sector for about 80% of the country's population (Njeru et al., 2016). The sector is dominated by smallholder¹⁰ farming, and 95 percent of the land is cultivated to generate a critical share of total production for the main crops (Alemayehu et al., 2012). Approximately 90% of the total tilled land is plowed using backward technology to produce main crops such as cereals, pulses, oilseeds, vegetables, root crops, fruits, and cash crops (Gelaw, 2017). However, smallholders face various constraints that hamper crop productivity, including soil erosion, poor soil fertility, erratic and variable rainfall, and flooding (Gebregziabher et al., 2006; Zerssa et al., 2021). These problems are further exacerbated by the rapid population growth rate and high dependence on inappropriate and excessive soil management by conventional tillage (CT).

CT includes post-harvest removal or burning of crop residues and intensive soil disturbances using tillage (Zhang et al., 2018). This causes structural degradation of the soil and results in the formation of crusts and compaction, leading to the severe loss of vital soil physicochemical properties (FAO, 2018; Chandini et al., 2019). Besides, the practice often uses high amounts of mineral fertilizers to enhance the productive potential of degraded land (Fess and Benedito, 2018). Apart from impairing the natural soil quality, the activity contributes to environmental pollution and affects ecosystem functioning (Choudhury et al., 2014). Therefore, appropriate soil management is urgently needed to resolve constraints and increase crop production without altering its potential for future generations.

CA was initiated as a solution to CT, and based on three fundamental principles: zero/minimum tillage; keep the soil covered as much as possible (no burning and grazing in the field); mixed planting and rotate crops (i.e., leguminous cover crops) (FAO, 2018; Thierfelder et al., 2018). Studies (e.g., Verhulst et al., 2011; FAO, 2018; Michler et al., 2019) have recommended CA as a

¹⁰ The average small farm size in Ethiopia is 0.9 hectares and is managed with family labor (Rapsomanikis, 2015)

soil management approach to increase carbon sequestration, soil fertility, and to reduce soil erosion. Overall, CA comprises a package of crop production technologies that can achieve sustainable agriculture production through improving the soil quality (FAO, 2018).

For thousands of years, Ethiopian farmers have implemented CT using traditional farm equipment called “*Maresha*,” commonly drafted by oxen (McCann, 1995; Gebregziabher et al., 2006). Owing to the incomplete and V-shaped plowing pattern by “*Maresha*,” farmers often have to perform repeated tillage. CT may have several short-term advantages, such as loosening soil, improving the circulation of water and air within the soil, increasing the release of nutrient elements, and controlling weeds by burying weed seeds and facilitating emerging of seedlings (Gajri et al., 1999; Steckel et al., 2007; Reicosky and Allmaras, 2008; Salem et al., 2015; Shahzad et al., 2016). Despite all these, the V-shaped furrows result in higher relative surface area exposure leading to increased surface runoff, lower water availability to crops due to high evapotranspiration, a rapid loss of soil organic matter due to rapid decomposition, and a high potential for soil degradation (Araya et al., 2012; Temesgen et al., 2012; Desta et al., 2021; Mihretie et al., 2021). Therefore, finding solutions that improve and manage the land for sustainable crop production is essential.

Smallholders initiate and practice CA to manage soil degradation, soil moisture stress and increase soil fertility. These include manuring, minimum/zero tillage, and inter and mixed cropping (Taddese, 2001; Beshah, 2003; Araya, 2020; Aune, 2020). These technologies were then promoted/ scaled out through Sasakawa Global 2000¹¹ using Extension Management Training Plot (EMTP), as a technology transfer approach, to reach as many smallholder farmers in different parts of Ethiopia (Aune, 2020). However, the wide application of CA with mulching is challenging as farmers prefer to use crop residue as fodder and as a source of biomass energy because it gives them an immediate benefit. Smallholders also accepted no yield difference between CT and CA practices (Aune, 2020) since little is known about the comparative benefits of soil management.

¹¹ The Sasakawa Global 2000 (SG 2000) extension strategy was initiated in Ethiopia in 1993 by the Sasakawa Africa Association and the Global 2000 of the Carter Center (Belay, 2008)

In this study, hypothesized that CA, in contrast to CT helps to increase soil quality, improving physical and chemical properties. This study compared soil physicochemical properties under CA and CT tillage in selected neighboring plots of southwestern Ethiopia. Derashe and Arba Minch Zuriya districts were chosen since they are proximate, have similar agroecologies, and practice different tillage. In the Derashe district smallholders' dominantly cultivate *Moringa stenopetala* + maize (*Zea mays*)/teff (*Eragrostis tef*)¹²/sorghum (*Sorghum bicolor*) using CA. In the adjacent plots of Arba Minch Zuriya, smallholders intensively grow banana fruit (*Musa*) + maize (*Zea mays*)/teff (*Eragrostis tef*) with CT. They use chemical fertilizers to enhance banana fruit production and have access to small-scale irrigation. Thus, the soil under two tillage was tested and compared using five physical and six chemical soil quality-indicating variables.

3.2 Methodology

3.2.1 Soil Sample Preparation and Analysis

From the selected four neighboring study Kebeles, eight (8) composite soil samples and a total of 32 soil samples were collected with a slope of about 15-20% using a zigzag approach (Figure 3.1 & 3.2), a design best recommended for field sampling (Hudak-Wise and David, 2014) and the soil test results from the sample are used to represent the entire sampling area (Hardy, 2014).

¹² Teff (*Eragrostis tef*) is a traditional Ethiopian cereal endemic to Ethiopia and Eritrea. The grain is ground into flour, fermented, and made into enjera, a sour-dough flatbread.

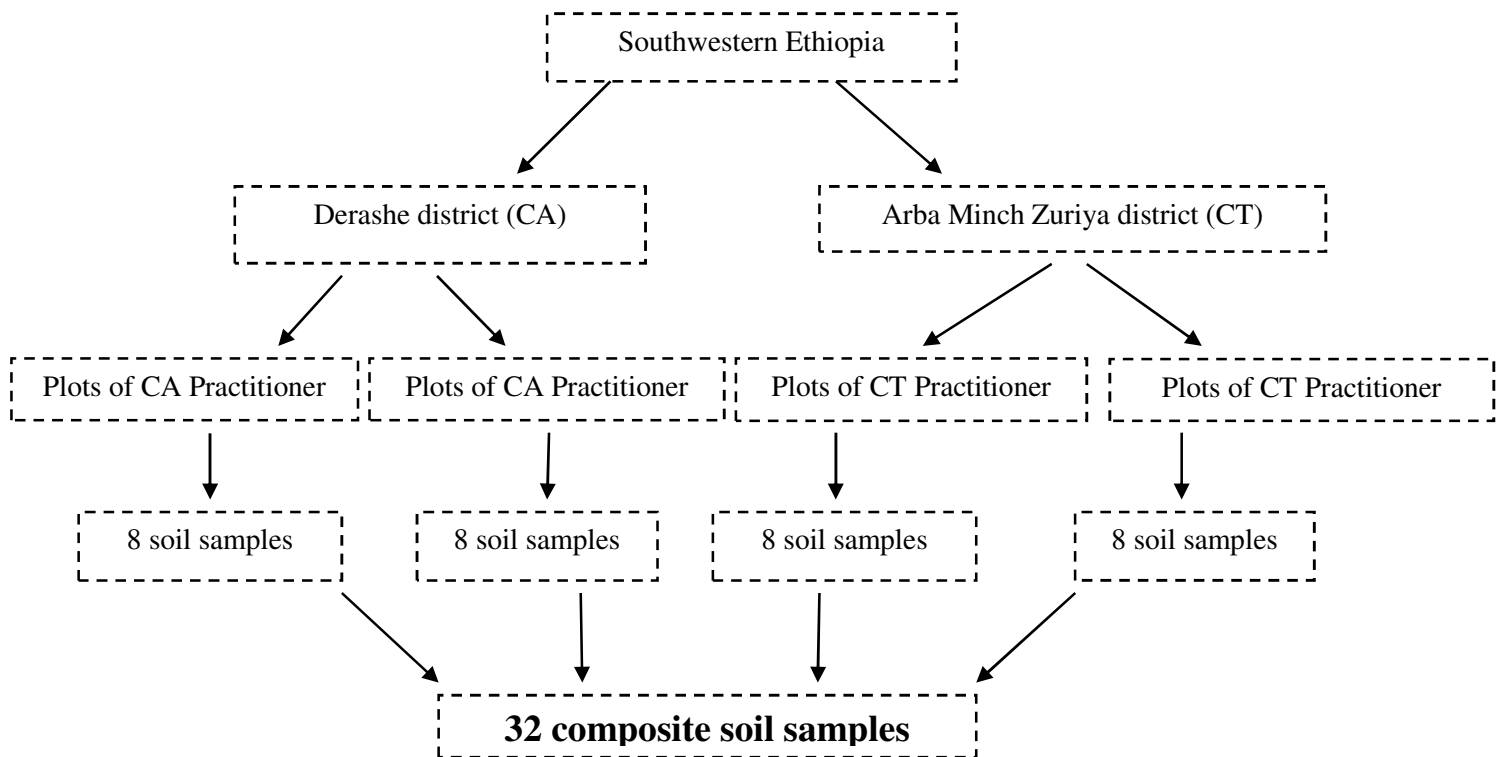


Figure 3.1 Soil Sample Collection Methods under CA and CT

Using a Zigzag shape, 16 soil sub-samples to the depth of 30cm from farm plots were collected as a composite, representing the topsoil using a soil auger. Each star represents points where soil sub-samples were taken from one plot (Figure 3.2). The study selected eight farmers' plots of land in each of the four selected Kebeles. Therefore, 32 soil samples were collected from 32 farmers' fields.

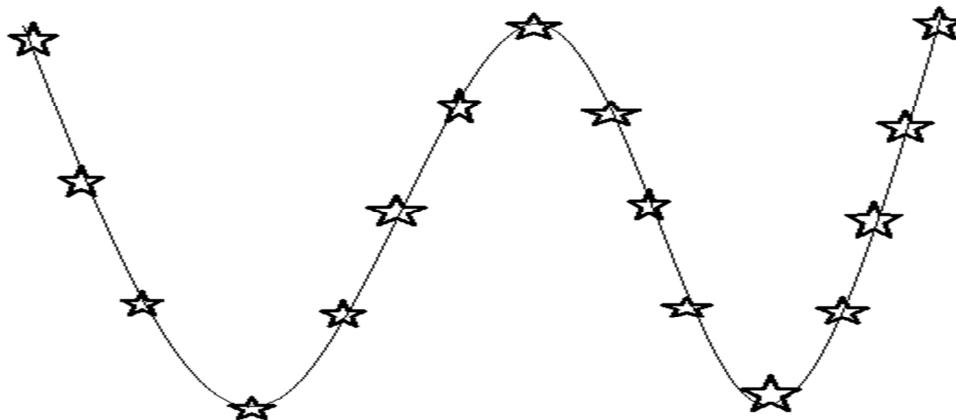


Figure 3.2 A Zigzag Shape Methods for Soil Sub-sample Collection

Soil samples were collected before planting and/or fertilization. Before and after the collection of soil samples, rocks, and debris were extracted by hand, because these often cannot be distinguished empirically from soil organic matter or litter (IPCC, 2003).

For bulk density determination, undisturbed core samples were taken carefully from the soil profile between 0 and 30 cm at intervals of 5 cm) core sampling was made using cylinders of 5 cm diameter and 5 cm high, the collected sample was oven-dried at 105°C for 24 h. Apart from the bulk density samples, the rest of the samples were air-dried in a room with good ventilation. After a week, the dried soil was ground and passed through a 2-mm sieve and made ready for further laboratory analysis.

3.2.2 Soil Laboratory Analysis

A soil physical and chemical analysis was conducted at Arba Minch University, College of Agriculture Soil Laboratory, and Ethiopian Construction Design and Supervision Works Corporation Laboratory.

3.2.2.1 Analysis of Physical Properties

Soil particle size distribution was determined using the Bouyoucos hydrometer method (Bouyoucos, 1962). The soil textural classes were determined using the soil textural triangle from USDA-NRCS online. The BD was calculated by the core method (Blake and Hartge, 1986) from the relationship of oven-dried mass of a known volume of soil as follows:

$$BD \left(\frac{g}{cm^3} \right) = \frac{W}{\pi * r^2 * L} \dots\dots\dots (1)$$

Where r is the internal radius of a soil core sampler, L is the length of the soil core, and w is the total weight (g) of oven-dried soil; the soil sample was oven-dried at 105°C for 24 h.

The soil's field capacity (FC) and permanent wilting point (PWP) were measured using the pressure plate apparatus at 1/3 and 15 bars of soil water potential, respectively. The available water holding capacity (AWHC) is the difference between soil moisture held at field capacity (FC) and permanent wilting point (PWP) (Grewal et al., 1990).

$$AWHC = FC - PWP \dots\dots\dots (2)$$

3.2.2.2 Analysis of Chemical Properties

The pH of the soil was measured in water suspension in a 1:2.5 (soil: liquid ratio) potentiometrically with a glass-calomel combination electrode (van Reeuwijk, 2002). Walkley and Black (1934), cited in (FAO, 2019b) used wet digestion to determine soil carbon content. Percent of soil OM was obtained by multiplying the percent SOC by a factor of 1.724 based on the assumption that OM is composed of 58% carbon (Pribyl, 2010). Total N was analyzed using the Kjeldahl digestion, (van Reeuwijk, 2002).

Cation exchange capacity (CEC) and exchangeable bases (Ca, Mg, K, and Na) were determined after extracting soil samples with ammonium acetate (1N NH₄OAc) at pH 7.0. Exchangeable Ca and Mg in the extracts were analyzed using an atomic absorption spectrophotometer, while Na and K were analyzed by a flame photometer (van Reeuwijk, 2002). Cation exchange capacity was then estimated titrimetrically by distillation of ammonium displaced by sodium from NaCl solution (van Reeuwijk, 2002). The percentage base saturation (PBS) was calculated by dividing the sum of the charge equivalents of the base-forming cations (Ca, Mg, Na, and K) by the soil CEC and multiplying by 100.

3.2.3 Statistical Analysis

The contributions of CA and CT to the mean values of soil physicochemical properties were compared using an independent sample t-test at 0.05 level of significance. To observe the effects

of predictor variables, land management, on the predicted variables, i.e., CEC, pH, and the sum of exchangeable cations, a linear regression model was applied. Descriptive and inferential statistics were employed to compare production, mean gross, and net income from both annual and perennial plants. The collected data was analyzed using Statistical Package for Social Sciences (SPSS) version 26.

3.3 Results and Discussion

3.3.1 Effects of Conservation Agriculture (CA) and Conventional Tillage (CT) on the Soil Physical Properties

3.3.1.1 Soil Particle Size and Field Capacity

The amount of clay was significantly higher ($P < 0.05$) in the CA. The findings agreed with Ngwira et al. (2012); Thierfelder et al. (2013) and Teravest et al. (2015), found that CA's three principles significantly improved soil properties, such as soil moisture retention. The soil in both land management systems contained a less sand fraction (Table 3.1).

Table 3.1 Sand, Silt and Clay (%) Distribution under CA and CT

Tillage type	Particle size (Mean ($\pm$ SE))		
	Clay	Silt	Sand
CT	45.79 $\pm$ 2.19 ^a	45.01 $\pm$ 1.41	9.2 $\pm$ 1.35
CA	53.74 $\pm$ 2.68 ^b	40.01 $\pm$ 2.07	6.25 $\pm$ 0.86
t-value	0.029	0.056	0.076

Means with the different letters across column are significantly different ($P < 0.05$) to land management.

Note: CA: Conservation Agriculture, CT: Conventional tillage

Soil texture is an inherent soil property; however, management practices may contribute indirectly to particle size distribution changes. In the selected plots of CA practitioners, farmers manage their land, leaving maize and sorghum residues on the farmland, locally known as *Targa-na-Potayta*. The soil particle size combined with the effects of crop residue reduce the rain drop splash effect and the problem of sheet erosion which intern reduce the removal of clayey soil particles (Hamanaka et al., 2019).

The soil serves as a reservoir, holding water withdrawn from plants. The amount of water the reservoir retains at the upper or full end is Field Capacity (FC) (Murray and Shanmugham, 2015). In the current study, the FC value was significantly different ($P \leq 0.05$) among the two land management (Table 3.2). Soil water conservation may support no-till crops through short drought periods without severe plant moisture stresses.

The Permanent Wilting Point (PWP), or the water content at which plants wilt during the daytime, was higher in CA (32.5 bar) than in CT (32.2 bar). Additionally, the Available Water Holding Capacity (AWHC) was also increased in CA (15.2%) than in CT (10.6%) (Table 3). The results agree with Yimam et al. (2020), in the sub-humid Ethiopian highlands, where the CA's water-holding capacity was higher than CT in the drip-irrigated field. According to the study, CA with drip irrigation was more efficient for agricultural water management than CT.

Table 3.2 Soil Field Capacity (%), Permanent Wilting Point (%), and Available Water Holding Capacity (%) under CA and CT

Tillage Type	Water Holding		
	FC	PWP	AWHC
CA	47.8 $\pm$ 1.09 ^a	32.5 $\pm$ 0.85	15.2 $\pm$ 0.37 ^a
CT	42.9 $\pm$ 1.21 ^b	32.2 $\pm$ 1.19	10.6 $\pm$ 0.09 ^b
P-value	0.02	0.87	0.001

Means with the different letters across column are significantly different ($P < 0.05$) to land management.

Note: CA: Conservation Agriculture, CT: Conventional tillage

Silt clay and clay soil were the study sites' dominant textural classes. The dominant textural classes were clay in CA and silt clay in CT. In addition, FC, PWP, and AWHC were compared to soil texture classes, with FC and AWHC highest in clay and PWP highest in silt clay. A study of soil textural classes and lithology in Brazil revealed that surface horizons, FC, were more prominent in clay and loamy soils, intermediate in sandy loam soils, and lowest in sandy soils (Costa et al., 2013). The increase in FC and PWP in soils with higher clay and silt contents was also observed in the Rio Grande do Sul, RS (Reichert et al., 2009), the USA (Rawls et al., 1982), and France (Al Majou et al., 2008).

3.3.1.2 Bulk Densities

Soil bulk density (BD) was not statistically significantly different ($P \leq 0.05$) among the two land management methods (Table 3.3). According to Reynolds et al. (2007), a BD in the range of 1.4 to 1.6 g/cm³ severely restricted root growth. In both study districts, with different land management approaches, the BD was lower than the above-explained ranges and indicated favorable soil bulk density for plant growth. Long-term CA practice will decrease BD values due to residue retention (Blanco-canqui & Ruis, 2018).

Table 3.3 Soil Bulk Density under CA and CT

Land Mag't type	Bulk Densty (BD)	P-value
CA	1.07 $\pm$ 0.025	0.39
CT	1.03 $\pm$ 0.033	

After long-term CA practice, residue retention will result in a decrease in BD values (Blanco-canqui & Ruis, 2018). Besides, in the Derashe area, practicing CA started hundred-plus years ago.

3.3.2 Effects of Conservation Agriculture (CA) and Conventional Tillage (CT) on Soil Chemical Properties

3.3.2.1 Soil pH, Organic Matter (SOM), Available Phosphorous (Av. P), and Total Nitrogen (TN)

Slightly higher (8.02) soil pH-H₂O values were recorded in CA compared to CT (Table 5). Land management significantly affected soil pH-H₂O ($P \leq 0.01$). The higher pH value under the CA could be related to cations released from decomposing mulch material. Farmers try to restore minimal rainwater using *Targa-na-Potayta*. Annually received low precipitation causes relatively limited leaching of base cations, associated with carbonates and bicarbonates found naturally in soils and irrigation water, resulting in a rather large degree of base saturation and pH values greater than 7 (McCauley et al., 2009).

SOM is considered an indicator of soil quality because it influences soil biological, chemical, and physical properties and crop yields (Islam & Weil, 2000). In the current study, the SOM was higher in CA than in CT due to the heavy inputs obtained from crop residues. The difference

between the two land management systems was statistically significant ($P \leq 0.01$) (Table 7). The finding aligns with Araya et al. (2016) who reported higher SOM in permanent raised beds than plots under the CT in Tigray vertisols in northern Ethiopia. Baudron et al. (2015) noted the importance of mulching to improve soil quality, as the amount of topsoil was twice that of plots with residue retention compared to those without. Veloso et al. (2018) and (Balota et al., 2014) reported improved and built-up SOM and CA system physical, chemical, and biological characteristics. However, the finding was against Liu et al. (2006), who reported slow rates of organic matter decomposition in CA compared to CT because tillage enhanced short-term CO₂ evolution and microbial biomass turnover and accelerated organic C oxidation to CO₂. In the present study, soil organic matter is high in CA due to continued and sustained crop residue input as mulch material. It is never used as livestock feed or burned, as in other land management.

The Av. P value was significantly affected by land management ($P \leq 0.01$). Av. P and TN were higher in CT than in CA (Table 3.3). The higher Av. P in the CT compared to CA could be due to an abundant application of Di Ammonium Phosphate (DAP) fertilizer to increase soil fertility and banana fruit production. Fertilizer applications such as P and N alter soil properties. Among them, chemical fertilizers significantly enhance Av. P content since soil possesses strong adsorption of phosphorus, which chemical fertilizers can release (Cai et al., 2015).

Table 2.4 Soil Chemical Properties under CA and CT

Parameters	CA	CT	P-Value
pH	8.02 ± 0.07 ^a	7.69 ± 0.06 ^b	0.01
SOC	1.8 ± 0.02 ^a	1.6 ± 0.05 ^b	0.001
SOM	3.09 ± 0.03 ^a	2.75 ± 0.08 ^b	0.001
Av. P	47.35 ± 1.62 ^a	90.53 ± 7.6 ^b	0.001
TN	0.04 ± 0.003	0.06 ± 0.004	0.07

Means with the different letters across column are significantly different ($P < 0.05$) to land management.

Note: CA: Conservation Agriculture, CT: Conventional tillage

3.3.2.2 Cation Exchange Capacity (CEC) and Percent Base Saturation (PBS)

The soil's potential to attract, retain and hold exchangeable cations (K⁺, Na⁺, Ca²⁺, Mg²⁺, etc.) is governed by the soil's cation exchange capacity (CEC). CA's CEC was higher than CT's, and

the values were significantly different ($P \leq 0.01$) (Table 8). Based on Landon's (1991) classification, the CEC value was generally high in both land management systems.

Concentrations of exchangeable cations were generally $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{Na}^+ > \text{K}^+$ in CA and $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+ > \text{Na}^+$ in CT. Ca^{2+} is more strongly absorbed than Na because it is divalent and has the smallest hydrated radius. Ca^{2+} and K^+ values were significantly higher in CA than in CT (Table 3.4). The CT K^+ value was significantly higher ($P \leq 0.01$) than CA. Many research results indicated that weathering and generally harvesting all parts of the crop for different purposes affect the distribution of K in the soil systems and enhance its depletion (e.g. Bakker et al., 1999; Saikh et al., 1998). In the CT (banana-based AF), since the fruit is perennial and densely planted, sunlight impacts the soil less. Besides, the unconditional fall of banana leaves during fruit collection and pruning may enhance the available K^+ .

Table 3.5 Soil of Exchangeable Bases (meq/100 gm of soil) and PBS (meq/100 gm of soil) under CA and CT

	CA	CT	
Parameters	Mean ($\pm$ SE)	Mean ($\pm$ SE)	P-Value
Na^+	1.05 $\pm$ 0.1	0.96 $\pm$ 0.05	0.47
K^+	0.94 $\pm$ 0.04 ^a	1.46 $\pm$ 0.23 ^b	0.03
Ca^{2+}	44.69 $\pm$ 3.52 ^a	34.95 $\pm$ 1.63 ^b	0.01
Mg^{2+}	15.97 $\pm$ 2.86	14.27 $\pm$ 0.32	0.56
Sum of Cations	68.21 $\pm$ 1.66 ^a	60.67 $\pm$ 1.52 ^b	0.002
CEC	68.2 $\pm$ 1.66 ^a	60.67 $\pm$ 1.52 ^b	0.002
Percent Base Saturation (PBS)	113.4 $\pm$ 23.2	85.15 $\pm$ 1.8	0.24

Means with the different letters across row are significantly different ($P \leq 0.01$) to land management.

A positive relationship exists between pH and soil CEC content (Figures 3.3 & 3.4). Foth (1990) found a positive correlation between soil pH and CEC.

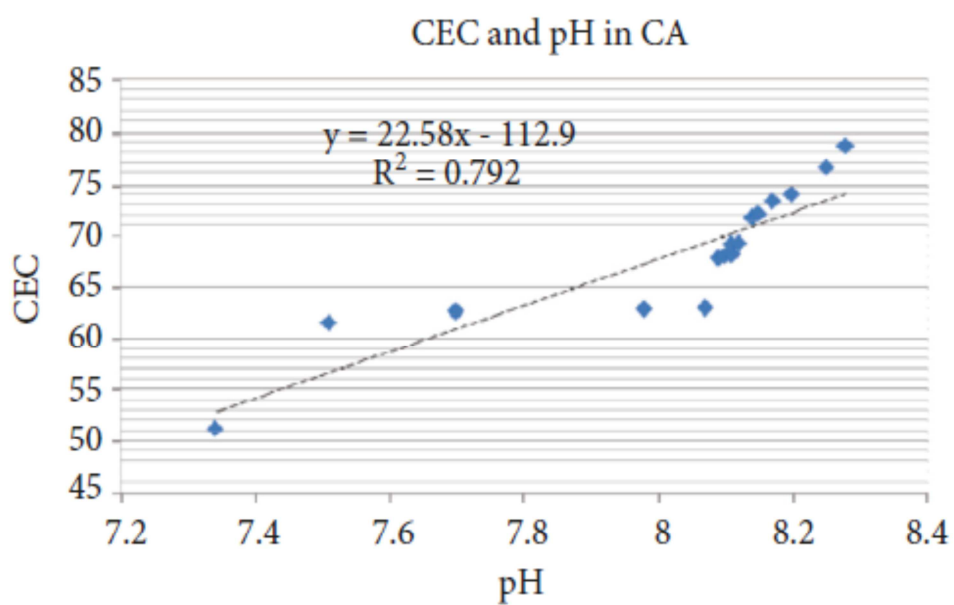


Figure 3.3 Positive Relationship Between Soil pH and CEC under CA

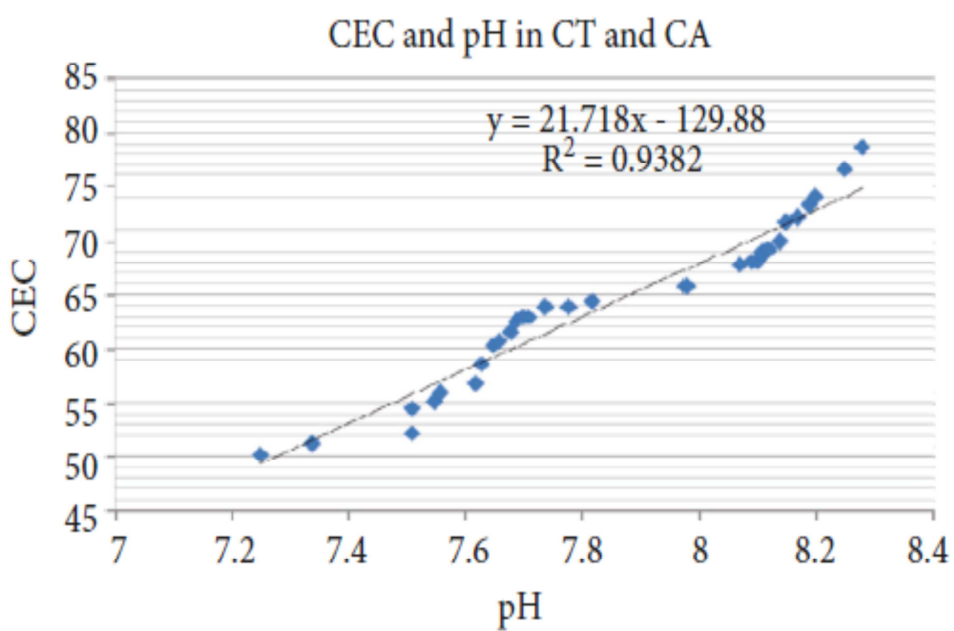


Figure 3.4 Positive Relationship Between Soil pH and CEC under CA and CT

3.4 Conclusions

Previously, the Derashe district known with the problem of soil erosion and moisture stress. To minimize the problem, hundred plus years ago, progenitors innovated CA with an indigenous mulching technique, locally known as *Targa-na-Potayta*. The technology helped smallholders to manage the soil. However, the neighboring Arba Minch Zuriya district smallholders still depend on CT with limited soil management practices. Therefore, the study compared the effect of CA and CT on the soil physical and chemical properties under different tillage. Representative soil samples were collected from selected four study Kebeles of the Derashe and Arba Minch Zuriya districts.

Five physical and seven chemical soil property indicators were used to test the soil quality under the two tillage. The results showed the soil physical and chemical property under CA was promising as compared to CT. These were majorly due to the use of the three principles of CA, that is cropping rotation, crop mixture with legumes, and mulch application using *Targa-na-Potayta* technique. Besides, they apply minimum tillage using “totale” the local manual tilling tool, to reduce the soil disturbance and soil moisture evaporation. Legume incorporation helps to fix the atmospheric nitrogen, release in the soil high-quality organic matter, facilitate soil nutrients’ circulation, and water retention. Based on these multiple functions, legume crops have high potential for conservation agriculture, being functional as growing crop. Crop rotation also helps to increase the soil nutrients, and improves the soil structure. Crop residue application on the other hand helps to increase the soil moisture and soil nutrients that returned back from added crop residues through decomposition.

Chapter 4 Contributions of Conservation Agriculture (CA) and Conventional Tillage (CT) for Crop Production and Household Income in Derashe and Arba Minch Zuriya Districts, Southwestern Ethiopia

Abstract

In Ethiopia to minimize the problem of soil erosion and soil moisture stress smallholders developed indigenous conservation agriculture (CA). However, yet the majority of smallholders are still practicing conventional tillage (CT). Smallholders before accepting and implementing a new technology, they want to know the comparative benefit to maximize their yield. However, in the selected study districts the contributions of CA and CT to crop productivity and household income were not studied. Therefore, the current study identified smallholders' production and income from dominantly planted annual crops. The study also identified the production and income of perennial crops under both tillage method using two consecutive cropping season data. Two districts and four research kebeles were chosen, and 392 sample household heads were deliberately and randomly selected using proportional sampling. An informant interview and a transect survey were conducted in addition to structured questionnaires to collect cross-sectional data. Descriptive (mean) and inferential (independent sample t-test) statistics were employed to analyze the data. The study findings revealed In Belg 2020 maize and teff production under CA was 1.38 and 1.28 times higher than CT. During meher 2020/21 maize production was 24.62 and 16.36 Q ha⁻¹ under CA and CT, in comparison. Maize income was 39,397.63 ETB and 26,176.64 ETB under CA and CT, respectively. In the same season, teff production and income were 1.66 times higher under CA than in CT. In meher 2020/21 production and income from banana fruit was 82.11 Q ha⁻¹ and 93,063.42ETB. The production and income of Moringa stenopetala leaves reached 1.9Q ha⁻¹ and 2889.24ETB respectively. CA groups obtained higher production and income from annual crops using minimal inputs. In order to maximize the benefits to smallholders, CA with Targa-na-Potayta technology needs to be scaled out to similar agroecological zones with policy support.

Keywords: *Conservation Agriculture; Conventional Tillage; Targa-na-Potayta; Crop Production; Income*

4.1 Introduction

Without appropriate soil management practices, tilling harms soil quality, water, biodiversity, and ecosystem services (Dumanski et al., 2014). This activity aggravates land degradation and yield reduction (Jat et al., 2014). As a soil management concept, tillage was questioned for the first time in the 1930s, when dustbowls devastated the mid-west United States (Kassam et al., 2019). After 30 years, in the 1960s, the move-off of conventional tillage (CT) and conservation agriculture (CA) came into practice in the USA. During the past few decades, rapid progress has been made worldwide to develop and disseminate CA. In 2015/16, worldwide cropland under CA was about 180 million ha (12.5% of global cropland) (Kassam et al., 2019), in 2018/2019, it became 205.4 M ha, corresponding to 14.7% (Kassam et al., 2022).

CA includes the simultaneous application of different soil management practices, such as keeping the soil covered using crop residue, (no burning and grazing in the field), zero/minimum tillage, intercropping and/or crop rotation (FAO, 2018; Thierfelder et al., 2018). The appropriate implementations of the three principles of CA would enhance the crop production and environmental conservation. Conversely, CT comprises intensive, repeated tillage, a complete removal of crop residues at harvest, often intensive stubble grazing, burning of crop residue, and use of straw for animal feed and animal dung for fuel (Zhang et al., 2018). Therewith the organic matter return to the soil is limited, as is the replenishment of soil nutrients by inorganic fertilizer (Araya et al., 2016). Intensive tillage leads to soil erosion, reduced soil organic matter, and reduced land productivity (Kassam et al., 2009; Araya et al., 2016). Thus, introducing minimum soil disturbance involves shifting from conventional plow-based farming systems to a minimum or zero tillage or seeding directly into untouched soil. This may help curb soil tillage's negative impacts, improve soil quality, and crop productivity (Kassam et al., 2009).

In Ethiopia, smallholders have initiated various soil management activities. This helps to reduce soil erosion, soil moisture stress and enhance crop productivity (Araya, 2020a). These comprise applications of contour plowing, furrow and raised bed systems, stone terraces, tied ridges, thrash lines, agroforestry, intercropping, fallowing, manuring, kraal shift, and minimum tillage (Beshah, 2003; Araya, 2020). FAO (2009), proposed CA as a suitable alternative tillage practice to address smallholders' predominantly rain-fed crop production challenges. In Ethiopia, in

2020/21, from the total arable land, an estimated 8,000 hectares of land is under CA and the majority of smallholders are still practicing CT (Hailu & Teshome, 2022). Studies overlook CA's role in improving the crop production and household income (Su et al., 2021). This causes persistently low uptake of CA by smallholders due to a lack of awareness about its benefits for livelihoods (Nyssen et al., 2011; Marennya et al., 2017).

Derashe and Arba Minch Zuriya are neighboring districts with different tillage and soil management practices. In earlier times, Derashe residents suffered with the short and erratic rainfall, high temperature, and anthropogenic factors, i.e., intensive tillage without appropriate soil management. These factors aggravated soil erosion, reduced soil and crop productivity and the area affected by frequent droughts and famine. The overwhelming situation in the area led the progenitors to introduce an indigenous CA with *Targa-na-Potayta* mulching. The technology helped to abate the area's serious problems and enhance the soil quality (Lejissa et al., 2022). Agricultural innovations play a significant role in fighting poverty, lowering the per-unit costs of production, boosting rural incomes, and reducing hunger (Kassie et al., 2011). On the other hand, the neighboring Arba Minch Zuriya district smallholders still practice CT with limited soil management practices and with abundant mineral fertilizer. Despite CA's benefits in conserving the soil (e.g., Jat et al., 2014; Kassam et al., 2019; Araya, 2020; Page et al., 2020; Bohoussou et al., 2022) and increasing the crop production (e.g., He et al., 2011; Thierfelder et al., 2015; Araya et al., 2016; Liben et al., 2018; Barrera Mosquera et al., 2019), limited study conducted in the districts of selected study Kebeles to identify the contributions of different tillage for crop production and household income. Therefore, this study initiated to investigate the impacts of CA with *Targa-na-Potayta* mulching and CT for the crop production and household income in the southwestern Ethiopia. We hypothesize that CA with *Targa-na-Potayta* mulching practice increase the annual crop production and income of smallholders as compared to CT.

4.2 Methodology

4.2.1 Data Analysis

Crop production and income from the dominantly cultivated annual and perennial crops under CA and CT were assessed. The comparison was made for annual crops (maize, sorghum, and teff) since the cultivated perennial crops (banana fruit and *Moringa stenopetala*) were different in the selected study Kebeles). Banana is a fast-growing plant which requires continuous supply of nutrients and water for high yield (Al-Harhi & Al-yahyai, 2009). Due to accessible small-scale irrigation, banana fruit trees are intensively cultivated in the Arba Minch Zuriya district, and the huge production makes the area to be known nation-wide. However, in the Dearshe district, smallholders not capable to benefit from banana fruit cultivation, majorly due to lack of small-scale irrigation, and the area dependence on rainwater. Quantitative information was assessed using structured questionnaire. To identify the total income from all crops, the production and income from perennial crops were also quantified. All the collected data was analyzed using descriptive and inferential statistics. Mean and an independent sample t-test were used to test the significant differences in production and income under CT and CA with a comparison test at a 0.05 probability level. The collected data was analyzed using Statistical Package for Social Sciences (SPSS) version 26.

4.3 Results and Discussion

4.3.1 Household Characteristics of Respondents

Most households and farming activities in the Arba Minch Zuriya district are headed by men, and women's roles are limited to domestic affairs. According to Feyso & Mensa (2021), in Arba Minch area, males/husbands usually carryout field agricultural production related works like land clearing, ploughing, planting, crop management, harvesting, and transporting of harvested farm produces from field to marketing and storage areas. Females/wives job is limited to reproductive and social, however widowed/divorced women actively engaged in both field agricultural production and household tasks. In the Derashe area the situation is different, where women actively participate as fellow men in farmland management and conservation. In addition to the routine domestic endeavors, they spend much time in the field, understanding the benefits of

farmland management. Commonly, women in the Derashe area have three responsibilities: 1) managing the house and caring for the family, 2) earning extra income by selling “Cheka”¹³, and 3) managing the farmland. They back to farmland management tasks few weeks after child delivery. They often weed and layer *Targa-na-Potayta* while carrying babies on their back. The key informants stated:

“They are busy weeding their farmland, and designing Targa-na-Potayta carrying the newborn babies at their back. For resting, drinking cheka, and feeding the baby, they built a small thatched roof house. They come and stay for many days in the field alone.”

A study conducted in the Aira Woreda indicated 86.3% of respondents witnessed the active role of women in activities such as clearing, weeding, harvesting, and preparing the threshing grounds (MoA, 2019).

The average age was of CA and CT practitioners were 45 years. With this, CA and CT practicing group age were 44.8 and 45.2 years, respectively (Table 4.1). Most respondents attended primary education, and in both study districts the highest formal education level was grade 6. Besides, 3.32% of CA and 15.81% of CT practicing groups completed high school. Jumbe & Nyambose (2016), stated an increase in schooling increases the chances of practicing CA because educated farmers are more likely to conserve the farmland and receptive to advancing technology or innovations. Contrasting to Jumbe & Nyambose (2016), in the study areas, CT practicing groups had higher average ages and formal education however; they still till their land using *maresha* (traditional farming tool). Of the total sampled households, 77.4% were natives to the area, and the rest, 22.6% were not natives. Being native to a particular area, makes them familiar with developed and implemented technologies.

¹³ Cheka is a fermented beverage from cereal and vegetables consumed mainly in southern Ethiopia. People of all ages, including infants, pregnant women, and lactating mothers, drink Cheka. In addition to drinking it whenever they are thirsty, they also use it as food.

Table 4.1 Household head Description under CA and CT

Variables	CA (n = 196)		CT (n = 196)		Pooled data	
	Mean	%	Mean	%	Mean	%
Age**	44.78		45.18		44.98	
Family size***	7.7		6.9		7.29	
Educational level	5		6.89		6.15	
% Nativity		72		82.7		77.4
Farming experience***	32		25.73		28.83	

Source: Household survey data

Means with the different letters across columns are significantly different ($P < 0.01$) to different tillage.

4.3.2 Assets and Livelihood Activities under CA and CT

4.3.2.1 Land and Livestock Holding

The average total land holding under CT was 1.32 times larger than CA (Table 4.2). CT groups have smaller family sizes, which mean a more extensive holding per household. CT had an average land holding of 0.31 ha per capita, while CA had an average land holding of 0.22 ha (Table 4.2).

Table 4.2 Size of the Total Land Holdings and Main Farmland in Hectare

Land Management Type	Total land holding ¹⁴	Main farmland ¹⁵
CA	1.73 ± 0.098 ^a	1.59 ± 0.095 ^a
CT	2.29 ± 0.08 ^b	2.15 ± 0.08 ^b
t-value	-4.4***	-4.5***

Source: Household survey data

Means with the different letters across columns are significantly different ($P < 0.01$) to different tillage.

The average livestock holdings of the CA and CT groups were 3.12 and 7.3 TLU, respectively (Table 4.3). The highest mean TLU among livestock was cows. Except for chicken, horse, and

¹⁴ Total land holding consists of homestead farmland + grazing land + woodlot land + main farmland

¹⁵ Main farmland is the land where smallholder farmers cultivate the major crops and use as a main means of livelihood. For instance in Derashe area in the main farmland they cultivate *Moringa stenopetala* + maize + sorghum + teff. And in Arba Minch Zuriya they cultivate Banana fruit tree + Maize + Teff

mule, CT had higher livestock holdings than CA. Since they use cattle to plow, the number of oxen and young bulls was nearly five times greater than CA. A study by (Giller et al., 2011; Corbeels et al., 2013; Corbeels et al., 2013; Tesfaye et al., 2015) stated as livestock holding increased smalholders interest to practice CA reduced since they use the crop residue for livestock feed. A study conducted in the Jimma and Illu-Ababora Zones of the Oromia Region, Ethiopia, showed that households with fewer cattle in possession practiced CA (Fentahun et al., 2019). Since, CA is especially advantageous to resource-poor households without draught power as it allows them to manage their land instead of renting and sharing it (Asresie et al., 2015).

Table 4.3 Total Livestock Size in TLU

Livestock	CA Practitioners		CT Practitioners		t-value
	Mean ($\pm$ SE)	Sta. Dev	Mean ($\pm$ SE)	Sta. Dev	
Ox	0.38 $\pm$ 0.07 ^a	0.93	1.89 $\pm$ 0.13 ^b	1.84	-10.185 ^{***}
Cow	0.43 $\pm$ 0.07 ^a	0.97	2.21 $\pm$ 0.15 ^b	2.13	-10.61 ^{***}
Bull	0.26 $\pm$ 0.06 ^a	0.84	1.74 $\pm$ 0.12 ^b	1.7	-10.946 ^{***}
Calve	0.04 $\pm$ 0.01 ^a	0.16	0.35 $\pm$ 0.03 ^b	0.41	-9.83 ^{***}
Sheep	0.09 $\pm$ 0.01 ^a	0.2	0.04 $\pm$ 0.02 ^b	0.21	2.56 ^{***}
Goat	0.27 $\pm$ 0.03 ^a	0.37	0.53 $\pm$ 0.05 ^b	0.74	-4.34 ^{***}
Donkey	0.96 $\pm$ 0.09 ^a	1.26	0.17 $\pm$ 0.04 ^b	0.6	7.86 ^{***}
Chicken	0.47 $\pm$ 0.051	0.66	0.37 $\pm$ 0.06	0.78	1.38
Horse	0.2 $\pm$ 0.1 ^a	1.4	0.01 $\pm$ 0.01	0.16	1.79
Mule	0.01 $\pm$ 0.007 ^a	0.11	0.006 $\pm$ 0.006	0.008	0.58
TLU	3.12 $\pm$ 0.24 ^a	3.4	7.31 $\pm$ 0.43 ^b	5.9	-8.517 ^{***}

Source: Household survey data

Mean values with different superscript letters along the same rows are statistically different (p<0.01)

4.3.3 Households Production and Income from Annual Crops

Agricultural activities are the primary income source in the study districts. Among the total sampled households, 89 percent of CA and 66 percent of CT practicing households rely on crop cultivation; and 28 percent of CT groups rely on banana (*Musa*) + maize (*Zea mays*) / teff (*Eragrostis tef*) based agroforestry. Farmers cultivate crops for household consumption and/or as an income source.

During Belg (March – August, 2020) production period Maize (*Zea mays*) production under CA and CT was 24.89 and 18.02 quintal ha⁻¹, respectively. The gross financial return for CA practitioners was 14,933.74ETB and for CT practitioners 10,813.65ETB ha⁻¹. The income difference was statistically significant (P<0.01). CA practitioners' income from the maize production exceeds CT practitioners by 1.38 times. *Teff* (*Eragrostis tef*) production under CA and CT was 13.75 and 10.76 quintal ha⁻¹, respectively. The gross income of CA and CT practitioners was 34,375ETB and 26,904.96ETB, respectively. The income difference was statistically significant (P<0.01) and teff income under CA exceed CT 1.28 times. Sorghum (*Sorghum bicolor*) was only cultivated under CA. Thus, among the total sampled household 22.45 per cent plant Sorghum and produced 13.74 quintal ha⁻¹, with the gross financial return of 12,126.11ETB ha⁻¹ (Table 4.4). In the area smallholders mainly cultivate sorghum to prepare the local drink called “*cheka*”.

During Meher (September - February 2020/21) Maize (*Zea mays*) production under CA and CT was 24.62 and 16.36 quintal ha⁻¹, respectively. The gross financial return for CA practitioners was 39,397.63ETB and for CT practitioners 26,176.64ETB ha⁻¹. The production and income difference was statistically significant (P<0.01) and maize income under CA exceeds CT 1.51 times. *Teff* (*Eragrostis tef*) production under CA and CT was 14.88 and 8.98 quintal ha⁻¹, respectively. The gross income of CA and CT practitioners was 74,385.97ETB and 44,896.97ETB ha⁻¹, respectively. The income difference was statistically significant (P<0.01) and teff income under CA exceed CT 1.66 times. Sorghum (*Sorghum bicolor*) was only cultivated under CA. Thus, among the total sampled household 22.45 per cent plant Sorghum and produced 10.15 quintal ha⁻¹, with the gross financial return of 22,335ETB ha⁻¹.

An increase in crop production and income under CA could be the application of the three principles of CA with a well-designed indigenous *Targa-na-Potayta* mulching. In the area smallholders after harvest, crop residues stalks are uprooted and horizontally placed on the ground as a moisture conserving mulch on the top of water harvesting soil raised structure. They use minimum tillage and no weeds allowed growing in the moisture harvesting structures. The organic inputs from recycling of crop residues are the main source of nutrients for subsequent crop growth and the soil nutrient removal (mining) is only through the grain harvest (Agena, 2011).

A study result in South Africa showed that CA increased crop productivity and reduced on-farm labor as compared to CT (Thierfelder et al., 2015). The current study finding was with He et al. (2011). They investigated the long-term effects of CA and CT on crop productivity in an annual double cropping system of winter wheat summer maize in the Gaocheng in Hebei, North China Plain over an 11-year period (1998–2009). The results showed winter wheat and summer maize yields were 3.5% and 1.4% higher under CA than CT (He et al., 2011). In Malawi, CA practices affected crop productivity, and profitability on maize yield with the highest increases of 2.7Mg ha⁻¹ and 2.3Mg ha⁻¹ yield in CA monocrop maize and CA maize legume intercrop, respectively, than CT. In the same study, CA systems resulted in gross margins three times higher than CT (Ngwira et al., 2013). A 3-year study was conducted in the Aba Gerima watershed in northwestern Ethiopia. It investigated the effects of two tillage practices CA and CT on teff yield. And the study showed an increased teff yield in the CA field (Mihretie et al., 2021).

Experiences of Sasakawa Global 2000 showed that reduced tillage with mulching gave an average gross margin of 144 US\$ ha⁻¹ across four years, while CT gave an average gross margin of 125 US\$ha⁻¹(Ito et al., 2007). The study examined Ecuador's crop yields and economic returns to identify best practices. Results indicate that the system's crop productivity and net (cost of production) benefits were increased by 25 and 24%, respectively, using a feasible CA compared to CT (Barrera et al., 2019). Again, a yield advantage of 13-29% and additional benefits of Birr 7.25 for each additional Birr were calculated in the west Gojjam Zone of Ethiopia using CA combined with herbicides (FAO, 2016).

4.3.4 Financial Return from Perennial Crops

Until the early 1980s, maize, cotton, and sweet potato were the main crops farmers in Arba Minch Zuria and Mirab Abaya districts produced. However, crop production was not sufficient to ensure food security. Irrigated bananas were introduced in 1984 in the hope of transforming mainly cereal-based subsistence smallholder agriculture into a more market-oriented system. After repeated discussions with cooperative leaders and extension staff, bananas were planted on 4.2 ha of cooperative land. However, cooperative leaders and members were not completely convinced of bananas' ability to improve livelihoods; furthermore, they believed banana consumption would negatively impact biological fertility. Continuous awareness of banana

benefits changed the perception of cooperative members. In addition to the first introduction of Lante cooperatives, individual plots were scaled out to Lante and Chano Mille Peasant Associations. Irrigated bananas (Dwarf, Medium height, and Giant Cavendish) now cover more than 11,000 ha of land in Arba Minch Zuria and Mirab Abaya districts (Mekonnen, 2014).

To capture the monthly banana fruit production and income from the selected study kebeles, two consecutive cropping season data was collected (Figure 4.1 and 4.2). Thus, the mean total banana fruit production and income in Belg 2020 was 72.87 quintal ha⁻¹ and obtained 50,422.13ETB and during Meher 2020/21 the production was 82.11 quintal ha⁻¹ and received mean income of 93,063.42ETB. CSA's (2019) report revealed that among the significant fruits during the 2018/19 cropping season, nationwide banana fruit production was 5,015,286 quintals, with a national share of banana coverage 55.55%. Besides, banana fruit production in the Southern region was 3,529,707 quintals, with a production percentage of 62.60.

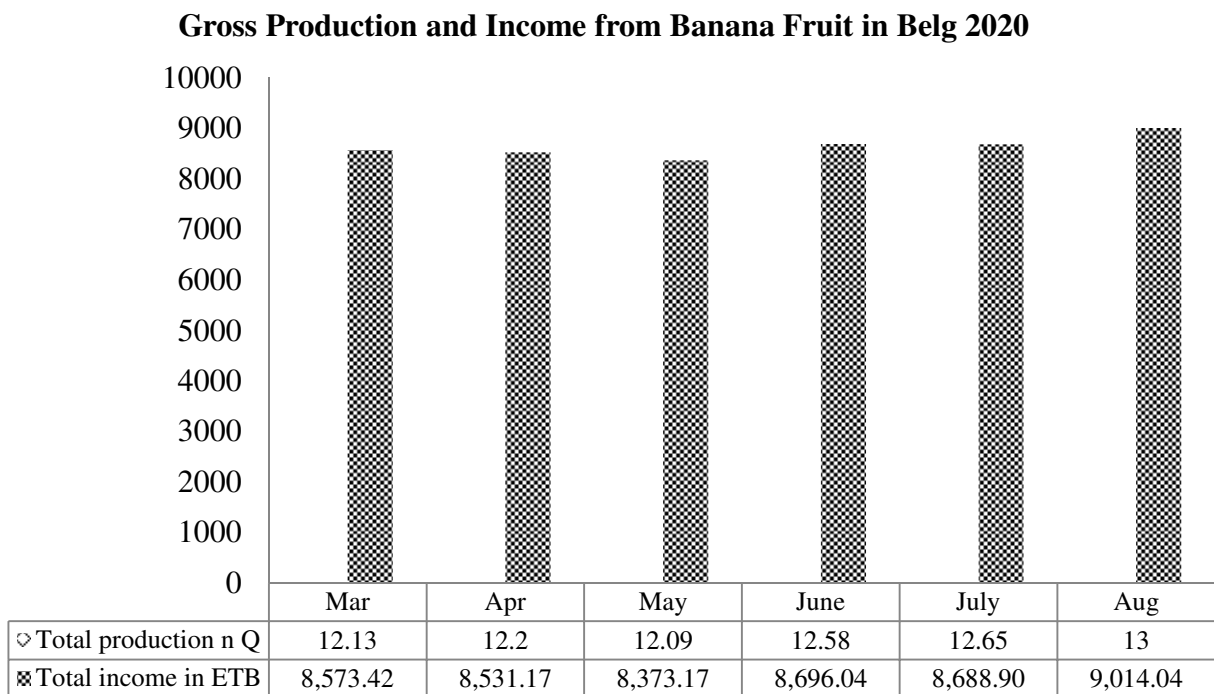


Figure 4.1 Banana Fruit Production and Income in Belg 2020

Production and Income from Banana Fruit in Meher 2020/21

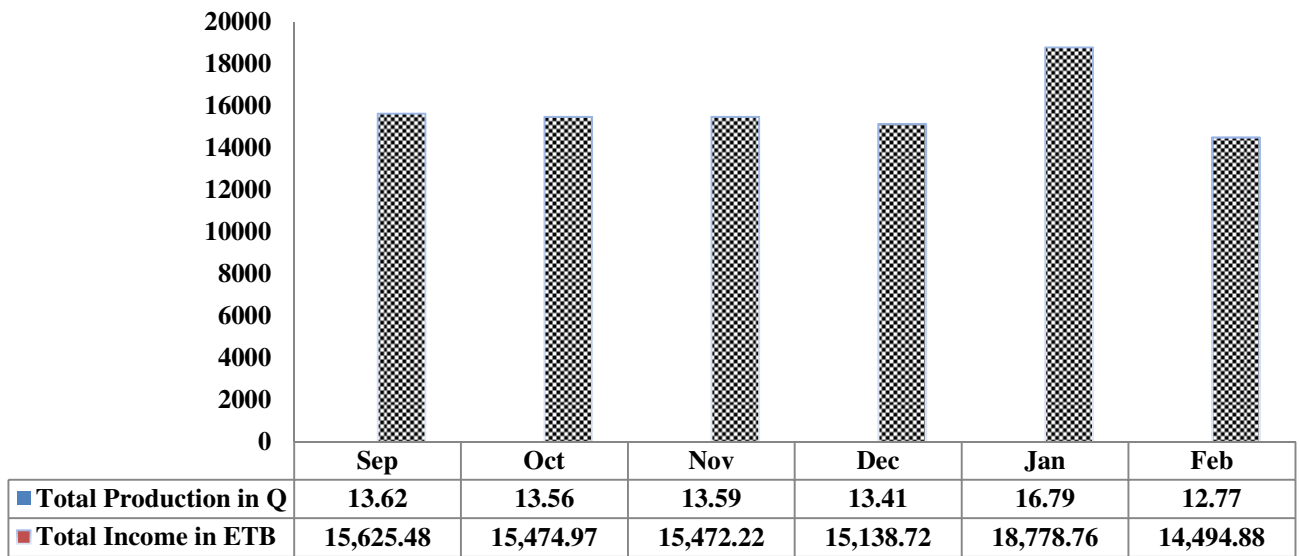


Figure 4.2 Banana Fruit Production and Income in Meher 2020/21

In the Arba Minch Zuriya district, smallholders benefit from banana fruit production and income. During the key informant interview, elderly farmer with the age of 62 from Zeyise Eligo kebele stated:

“Before starting banana fruit plantations, most of us grew annual crops like cotton, sorghum, sweet potato, and maize. Crop production was less, even to feed the entire household. But after starting the banana fruit plantation, we made an enormous profit that notably changed our livelihood and the actors involved in the marketing chain.”

Banana is a fast-growing plant which requires continuous supply of nutrients. These nutrients may be partly supplied by the soil and through cycling within banana plantation. But fertilizer application is generally needed to satisfy plant requirements for obtaining profitable production (Al-Harthi & Al-yahyai, 2009). In the current study, smallholders of Arba Minch Zuriya district use on average 175.73K.g ha⁻¹ of mineral fertilizer of Urea, Di Ammonium Phosphate (DAP), and Nitrogen, Phosphorous, Sulfur, and Boron (NPSB).



Figure 4.3 Banana Producers Selling to Traders at the Farm Gate, Picture by the author

In Derashe district, it is common planting *Moringa stenopetala* trees in integration with annual crops. The tree is densely scattered and lush in appearance in the /maize/teff/sorghum field is an additional source of leafy vegetable for the daily household consumption and source of income. Marketing of *M. stenopetala* leaves started very recently, and some farmers supply fresh *M. stenopetala* leaves to urban retailers (Figure 4.5). This is a crucial area that requires the popularization of *Moringa* leaves. This will enable farmers to have a market and realize better prices for their produce (Agena, 2011). The productivity of *Moringa stenopetala* leave was different in different months of the year (Figure 4.4). Among the total respondents in the Derashe district 58.4 per cent stated January as the most productive month of the year. 57.4 percent stated medium production in November, 36.6 per cent explained low production in April and 52.3 per cent stated almost no production in May.

Moringa stenopetala tree Productive Months of the Year

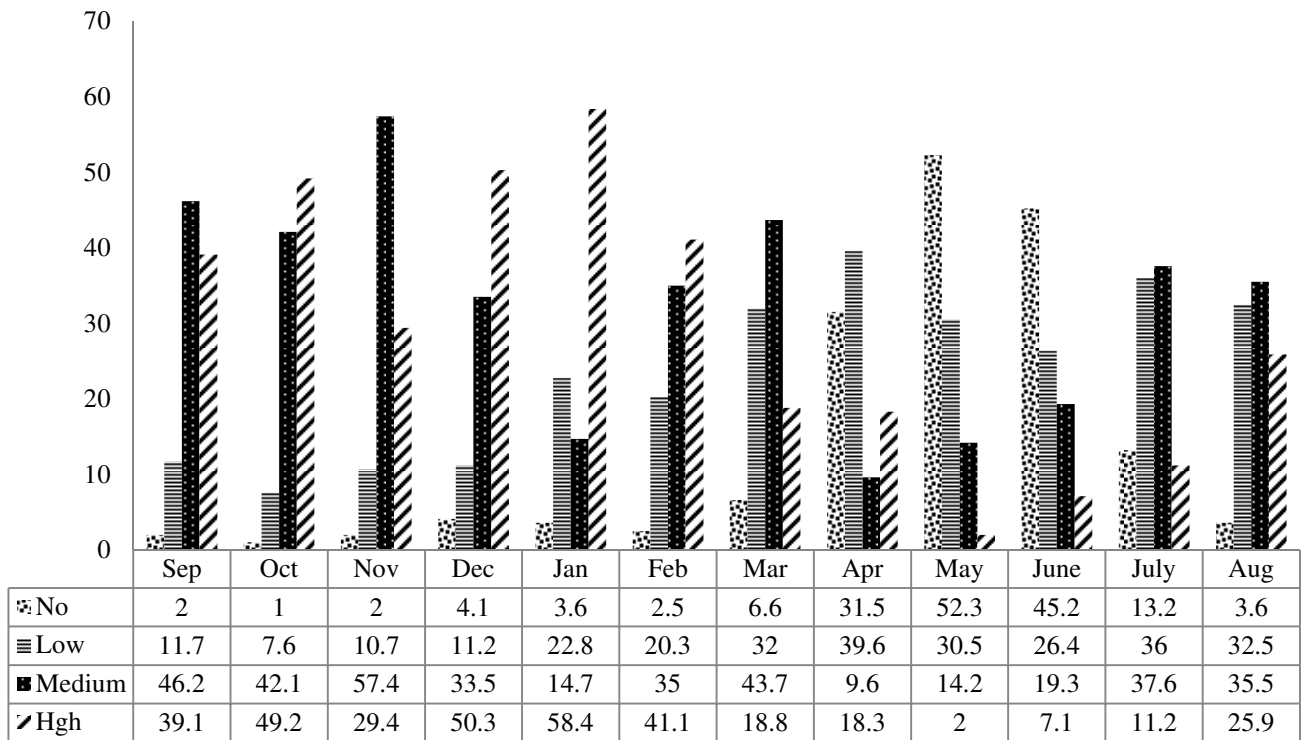


Figure 4.4 *Moringa stenopetala* Leaves Productive Months of the Year

In each productive (high, medium and low) months of the year smallholders either after finishing daily farming activities or purposely to collect *Moringa stenopetala* leave move to their main farmland and pick much leaves considering enough to feed the family members for that day. On average smallholders collect 1.9 Q of *Moringa stenopetala* leave with the income of 2889.24ETB.

Table 4.4 Mean Production and Income of *Moringa stenopetala* Leave in Meher 2020/21

<i>M.stenopetala</i> Leave Collection	Production (Q)	Income (ETB)
High production	0.68	1020.86
Medium production	048	725.55
Low production	0.28	422.69

In the Derashe area, most smallholders do not use mineral fertilizer, since the use of CA with *Targa-na-Poayta* mulching naturally enhanced soil quality (Lejissa et al., 2022). The few smallholders who use mineral fertilizer applied an average of 25.82 kg ha⁻¹, mostly Urea.



Figure 4.5 Marketing of *Moringa stenopetal* Leaves in the Gumayde Area, Photo by the Author

CA is a sustainable cropping system that may help reverse soil degradation, increase yield, reduce labor time, and produce a higher net return (Ngwira et al., 2013). Besides, CA gives more stable yields than CT mainly due to timely planting, proper soil moisture regime maintenance, improved soil quality, less soil erosion, and fewer incidences of diseases (FAO, 2001; Hobbs and Govaerts, 2010). In India, rice grain yield increased by up to 12% under the CA-based approach (Bell et al., 2019). CA impacts were studied across different regions of Zimbabwe, and the results revealed increased maize yield with CA in five agroecological regions of the country compared to CT (Marongwe et al., 2011). CA was evaluated at Bako (short-term CA study) and Melkassa (medium-term CA study) in Ethiopia for effects on crop yield and soil properties. Results showed maize yield was 10.14 Mg ha⁻¹ for CT compared with 9.01 Mg ha⁻¹ for CA in 2015 at Bako, but maize yields were more significant with CA at Melkassa in 2016. Therefore, for sustainable productivity, continuous soil management is essential.

4.4 Conclusions

The Derashe area was known for soil erosion and moisture stress. To relieve the problem, hundreds-plus years ago, CA was designed using an indigenous mulching technique, locally known as *Targa-na-Potayta*. This technology minimizes soil erosion and improves soil moisture and crop productivity with minimal/without mineral fertilizers. CA improved the productive potential of once unproductive land and increased smallholders' livelihoods. However, neighboring Arba Minch Zuriya farmers still practice CT. Therefore, using two different soil tillage and management practices, the current study analyzed CA and CT practicing groups' production and income from annual and perennial crops.

Smallholders in the Derashe area cultivate *Moringa stenopetala* trees + maize/teff/sorghum. In the Arba Minch Zuriya district, smallholders crop banana fruit tree+maize/teff. Annual + perennial crop production and income data were collected from the two study districts. The results showed that annual crop production and income under CA were higher than in CT. This was due to the use of the tree principles of CA i.e. cropping rotation, crop mixture with legumes, and mulching the *Targa-na-Potayta* technique. However, access to small-scale irrigation and well-structured banana fruit marketing enabled Arba Minch Zuriya smallholders to receive higher revenue from sole banana fruit production.

Derashe smallholders planted banana trees. However, the fruit tree appeared promising during the rainy season and immediately wilted in dry spells. Rivers border the two districts, but the smallholders in Arba Minch Zuriya revert the river water to them, not allowing the neighboring Derashe farmers to use it. Thus, CT practicing groups earned high gross income from banana fruit plantations and marketing. The Derashe people, with strong determination, enhanced the soil's productive potential and produce annual crops using rainwater. Indigenous mulching techniques decreased moisture stress and soil erosion. Therefore, to maximize soil productivity, neighboring Arba Minch Zuriya smallholder farmers ought to integrate the CA with the indigenous *Targa-na-Potayta* of the Derashe people. To benefit the Derashe people, appropriate bodies need to establish small-scale irrigation.

Chapter 5 Smallholders' Conservation Agriculture Adoption Decision in Arba Minch and Derashe Districts of Southwestern Ethiopia



Conservation Agriculture (CA) Using *Targa-na-Potayta* Mulching Technique in the Derashe District, Photo by the Author

Abstract

Conservation agriculture enhances the soil fertility and crop productivity. Despite the technology's benefit its adoption among smallholders is still low. This study examines smallholders' conservation agriculture (CA) adoption decisions from a soil management perspective in the southwestern Ethiopia. The analysis was based on a survey of 392 household heads in each of the mixed maize/sorghum/teff + Moringa stenopetala of Derashe district and maize/teff + Banana fruit tree in Arba Minch Zuriya district farming systems. Two groups of smallholders that practice different land management i.e conservation agriculture and conventional tillage were selected. A binary logistic regression model was used to answer the question of factors that determine smallholders' initial decision to adopt CA. Nine explanatory variables including the age of the household head, level of formal education, family size, total landholding, livestock owned, farming experience, net income from annual + perennial crops, provided extension service, and lack access to small-scale irrigation was included in the analysis. The study result revealed that non-practicing groups have higher schooling, farmland holding, and livestock relative to CA practicing households. Households with increasing age, schooling, total livestock holding, and higher net per annum income were less likely to practice CA. However, the CA practicing decision was high with an increase in extension service and lack of access to small-scale irrigation. Though CA with Targa-na-potayta mulching technique is an age-old practice in the Derashe area, the impact of extension service has indispensable benefits in extending the knowledge to younger smallholders. CA adoption decisions are influenced by various factors. Therefore, the concerned bodies need to investigate adoption determinants before disseminating cutting-edge technologies.

Keywords: *Conservation Agriculture; Targa-na-potayta, Determinant factors, practicing decisions*

5.1 Introduction

Agriculture remains one of the most critical sectors for African economies (Suri & Udry, 2022), and its success is heavily influenced by soil and water management, among other factors. In many parts of Africa, inappropriate land use, poor land management, and lack of appropriate inputs have led to soil erosion, biodiversity loss, declining productivity, and food insecurity (Schauer et al., 2015; Mukasa et al., 2017). Like many other African countries, .of the gross domestic product (GDP) and more than 80% of its exports (Njeru et al., 2016). Using a small parcel of land, smallholders produce over 90% of the main crops for the nation (Muluaalem, 2017). Despite its role, with an average population growth rate of 2.6% (A. Bekele & Lakew, 2015), most smallholders suffer from food insecurity and poverty due to excessive reliance on traditional, nature-dependent, and low-productive agriculture. Eradicating extreme poverty without adequately addressing land degradation is highly unlikely (Braun et al., 2013).

The Ethiopian government has carried out various land management practices on cultivated land, including contour (level) bunds, hillside terraces with afforestation, and hillside closures over the past five decades to restore land productivity (Hurni et al., 2016). Sasakawa Global 2000, the Sustainable Land Management Programme, and other related projects have increasingly promoted soil and water management through conservation agriculture (CA) in Ethiopia (J. B. Aune, 2020). CA is defined as soil management practices that minimize disturbance to the soil structure, composition, and biodiversity (Thierfelder et al., 2018; FAO, 2018; Kassam et al., 2019). As used in this paper, CA refers to soil management combined with zero-till, plants mulched using an indigenous technique, and intercropping practices on the undisturbed soil within partitioned land. The crop is planted directly into the preceding year's crop residue on the soil surface for the entire season. In Nepal, the Terai plains lie at the lowest altitude (<1,000 m.a.s.l.) and support 20% of agricultural land, which is conducive to growing up to three crops, rice (*Oryza sativa* L.)–wheat (*Triticum aestivum* L.)–rice, rice–wheat, rice–maize (*Zea mays* L.), a year if irrigation facilities are present (Joshi et al., 2021).

In Ethiopia, many smallholders use conventional tillage (CT) since the decision to adopt CA is influenced by socio-economic, institutional, and biophysical factors (Teklewold et al., 2013; Aune, 2020). The formal education of household heads, family size, age, frequent contact with

development agents, and smallholders' average income have all been major influencing factors for practicing CA (Dabi et al., 2017). In addition, livestock ownership has an impact on CA, as farmers with easy access to traction animals are less inclined to switch to minimum tillage (Marenya et al., 2017). Furthermore, the massive demand for animal fodder may reduce their interest in practicing CA (Jat et al., 2014).

Derashe and Arba Minch Zuriya are neighboring districts with contrasting tillage and soil management practices; however, both dominantly cultivate Maize (*Zea mays*) and Sorghum (*Sorghum bicolor*) in common. In the early years, Derashe district residents suffered from soil erosion, rainwater shortages, and soil moisture stress (Fikre et al., 2018). As a result of erratic rainfall as well as smallholders' traditional tillage practices lacking appropriate soil management practices, the situation became critical. These factors led to the invention of CA, using an indigenous moisture conservation technique known as *Targa-na-Potayta*. In this technique, own farm input is used for mulching, and decomposed crop residue is used as a nutrient supplement (USAID, 2005; Fikre et al., 2018; Zebire et al., 2019). In this land management system, only the cob of maize or the head of the sorghum harvest is taken and leaves the stalk in the field to minimize nutrient mining from biomass removal. Uprooted maize/sorghum stalks layered in such a way serve as moisture-conserving mulch from which nutrients can be released for the next crop. After practicing the technology, the problem of soil moisture stress and soil erosion was significantly reduced.

Smallholders in the neighboring Arba Minch Zuriya district practice CT using mineral fertilizer and over-irrigating their fields with flooding (Feyso & Mensa, 2021). Even though chemical fertilizer use has enhanced crop productivity and soil fertility, excessive use has resulted in a decline in soil organic matter (SOM) content and a consequent decline in soil quality (Krasilnikov et al., 2022). Besides, in the Arba Minch area, over-irrigation using lake water leaches nutrients from the soil. The state has increased the rate of salinization and thus removed more banana fields from production (Feyso & Mensa, 2021). Despite all the benefits of CA, smallholders have had a low adoption rate in the Arba Minch Zuriya district.

A large body of research has focused on the importance of CA for soil fertility from own farm input use, sustainable crop productivity, and household income (Jat et al., 2014; Ntshangase et

al., 2018; Araya, 2020b). Smallholders' CA practice decisions are less studied than their acquired benefits, and there are few universal factors that can explain their decisions (Knowler & Bradshaw, 2007). Many studies attribute CA acceptance to several empirically derived farmer characteristics without considering the farmers' decision process (rationally weighing the economic constraints, the information diffusion process, and the utility of adopting the new technology). Therefore, the current study attempted to understand factors that limit CA adoption decisions among the neighboring Derashe and Arba Minch Zuriya districts.

5.2 Independent Variables and their Expected Outcomes

The independent variables used in the study are given in Table 1, and the literature guided the choice of independent variables. The table below shows the independent (explanatory) variables, their description, and the expected outcome of the dependent variable.

Table 5.1 Definition of Independent Variables that Included in the Econometric Model and Expected Sign

Variable code	Description	Types of variable	Unit of measurements	Expected sign/s
Adoption	CA adoption	Dummy	1 = Adopter, 0 = Non-adopter	
AGE	Age of the HHH	Continuous	Measured in Years	+
EDU	Formal educational level of the HHH	Continuous	The level of formal education	+
FAMSIZE	Family size in adult equivalent (in number)	Continuous	Number of family member	+
TLANDHOLD	Total Land Holding	Continuous	Measured in hectare	+
TLU	Total livestock holding of the HHH	Continuous	Measured in Tropical Livestock Unit (TLU)	-
EXP	Farming experience (in years)	Continuous		+
NETINCO	Annual net income from annual + perennial + crops in ETB	Continuous	Measured in Ethiopian Birr	-
IRRIGATION	Lack access to small-scale irrigation	Dummy	1 = Yes, 0 = No	+
EXTEN	Extension visit	Dummy	1 = Yes, 0 = No	+

Source: By authors; (+/-) indicates a positive or negative relationship with the dependent variable

The independent variable, age, measured as a continuous variable, can be used as a proxy for farming experience. Age was expected to affect practicing CA positively. This means older farmer's use CA more than younger farmers since enjoying all the benefits comes with time. Education was measured as a continuous variable (the farmer's formal education years). The assumption was that willingness to practice CA increases with more schooling years. Thus, a more educated person will likely appreciate creative ideas better and quicker than their counterparts (less educated farmers). An increase in family size is related to available family labor. The increase in family size was expected to positively influence CA practice by increasing available labor. A household will have more energy to practice CA than a small family. Practicing CA is expected to be positively affected by total landholdings, which means farmers with large landholdings take risks to practice new technologies/practices/ideas. Besides, the mulch application technique in the Derashe area, *Targa-na-Potayta*, covers large land areas with crop residues. This may reduce the total hectares of land available for cultivation. Total livestock holding will likely negatively influence CA practices since households may use crop residue for animal fodder. Experience in farming was measured as a continuous variable. The variable measures farmers' knowledge of agriculture acquired. It was assumed that experienced farmers were likelier to practice CA than those with hardly any farming experience. Net income from annual + perennial crops is expected to influence smallholder farmers' decision to practice CA negatively. For instance, Arba Minch Zuriya district smallholder farmers get high income from banana fruit production, and their interest in soil management is less than in the adjacent Derashe district. This shows smallholder farmers' decision to practice CA decreased as farmers' net per annum income increased using conventional tillage. Lack of access to small-scale irrigation positively increases CA practicing decisions. Since CA has made a massive contribution to enhancing the water infiltration and the available soil water. The frequency of extension visits was used to measure both access to and intensity of extension services. Practicing CA was expected to be higher with increased extension contacts.

5.3 Methods of Data Analysis

A logistic regression model was applied to analyze the determinants of farmers' CA practice decisions in the two study districts. The model helps to estimate the probability of farm households practicing CA using various independent variables. STATA version 14 was used to analyze the collected data from all surveyed households.

5.3.1 Econometrics Model

5.3.1.1 Determinants of Farmers' Decision to Practice CA

A binary logistic regression model was applied to answer the factors that influence CA practice using the *Targa-na-Potayta* mulching technique. The model describes the relationship between a dependent variable and a set of independent variables. The dependent variable was binary or dichotomous and had only two groups: practicing and non-practicing, whereas the explanatory variables could be continuous, categorical, or dummy (Long & Freese, 2001). The logistic function was selected since it approximates the cumulative normal distribution (Gujarati & Porter, 2009). Most technology-practicing studies have used the logistic regression model to analyze dichotomous practicing decisions in which the dependent variable is binary: 1 if the household head is practicing, 0 otherwise (Mercer, 2004). As a result, the probability of practicing CA is:

$$P_i = \frac{1}{1 + e^{-Z_i}} = \frac{e^{Z_i}}{1 + e^{Z_i}} \dots\dots\dots (1)$$

Where, in the notation, P_i represents the probability that an individual will make a certain choice, in this study whether the i^{th} farmer practice CA or not;

e denotes the base of natural logarithms which is approximated at 2.718.

Z_i is a function of explanatory/ independent variables (X_i), and expressed as:

$$Z_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \dots + \beta_m X_{mi} \dots\dots\dots (2)$$

If P_i is the probability of the i^{th} farmer to adopt CA, is given by (equa. 1), then $(1 - P_i)$, is the probability of the i^{th} farmer to not adopt the traditional CA.

$$1 - P_i = \frac{1}{1 + e^{Z_i}} \dots\dots\dots (3)$$

Dividing [1] by [3], we get

$$\frac{P_i}{1 - P_i} = \frac{1 + e^{-Z_i}}{1 + e^{Z_i}} = e^{Z_i} \dots\dots\dots (4)$$

$\frac{P_i}{1 - P_i}$ is simply the odds ratio (likelihood) in favor of the i^{th} farmer to practice to the probability to not practice it.

Taking the natural logarithm of the odds ratio in both sides of [4] will result in what is known as the logit model as indicated below:

$$\ln \left(\frac{P_i}{1 - P_i} \right) = \ln \left(\frac{1 + e^{z_i}}{1 + e^{-z_i}} \right) = \ln (e^{z_i}) \dots (5)$$

$$\ln \left(\frac{P_i}{1 - P_i} \right) = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \dots + \beta_m X_{mi} \dots (6)$$

The data obtained from all respondents (392 from each site, including both CA adopters and non-adopters) were considered in the model. The explanatory variables (X_i) included in the model were the age of the household head (AGE), level of formal education (EDU), family size (FAMSIZE), size of total landholding in hectares (TLANHOLD), size of livestock owned in a tropical livestock unit (TLU), farming experience (EXPER), net income from annual + perennial crops (NETINCO), provided extension services by development agents (EXTE), and lack access to small-scale irrigation (IRRI). This logistic analysis used the dependent variable, whether or not the farmer practiced CA, where practicing group = 1 and not practicing group = 0. Given the above explanatory variables, Eq. [6] was rewritten to represent the likelihood of practicing CA in the two study districts.

$$\ln \left(\frac{P_i}{1 - P_i} \right) = \beta_0 + \beta_1 AGE + \beta_2 EDU + \beta_3 FAMSIZE + \beta_4 TLANHOLD + \beta_5 TLU + \beta_6 EXPER + \beta_7 NETINCO + \beta_8 EXTE + \beta_9 IRRI, \dots (7)$$

In this study, the above econometric model was used to identify factors that influence the decision to practice CA.

The above econometric model was used in this study and treated against potential variables assumed to affect practicing CA. Thus, for the model to be an unbiased estimator, it is essential to check if there is a relationship between the variables. Therefore, explanatory variables were checked for multicollinearity and association before logistic regression. Accordingly, a Variance Inflation Factor (VIF) and Tolerance method were employed to detect multicollinearity between continuous variables. Tolerance is an indicator of how much of the variability of the specified independent variable is not explained by the other independent variables in the model. According to Pallant (2007),

$$Tolerance (X_i) = 1 - R_i^2$$

If the value is minimal (less than 0.10), it indicates that the multiple correlations with other variables are high and suggests multicollinearity. The other is VIF (Variable Inflation Factor), the inverse of the tolerance value.

$$VIF (X_i) = \frac{1}{Tolerance} \text{ or } \frac{1}{1 - R_i^2}$$

R_i^2 is the multiple correlation coefficients between explanatory variables. The larger the R_i^2 value, the higher the VIF (X_i) value, causing higher collinearity in the variable (X_i). Thus, a VIF value above ten indicates multicollinearity (Gujarati, 1995). However, in the current study, the tolerance and VIF values show that all continuous independent variables have no multicollinearity problem. Similarly, contingency coefficients were used to check an association between dummy variables. The contingency coefficient is computed as follows:

$$C = \sqrt{\frac{\chi^2}{N + \chi^2}}$$

C= Coefficient of contingency

N= Total sample size

χ^2 = Chi-square random variable

The contingency coefficients result also showed that there is no problem of multicollinearity between the dummy variables.

5.4 Results and Discussion

5.4.1 Household and Socio-economic Characteristics

5.4.1.1 Household Characteristics

Among the total sampled respondents, 97.45 percent were male, and 2.55 percent were female household heads. This was related to respondents' marital status; in the area, 96.7 percent were married. In Ethiopia, men are the heads of the house and representatives of their families. The average age was 45 years. With this, the average age of CA adopters and non-adopters was 44.8 and 45.2 years, respectively (Table 5.2). The average year of formal education for CA adopters and non-adopters was grade 6. Also, 3.32% of CA and 15.81% of CT practicing groups have completed high school. However, studies have shown that higher education levels increase the chances of engaging in CA because educated farmers are more likely to quickly understand and be receptive to advancing technology or innovations (Jumbe & Nyambose, 2016). Although CT practicing groups had a high average age, agriculture experience, and formal knowledge, they still tilled their land with maresha. This indicates the lack of understanding/perception about CA's comparative benefits among CT practitioners.

The average family size of CA practicing and non-practicing groups was 7.7 and 6.9 per household (Table 5.2). Sileshi et al. (2019) state that having a more prominent family increases smallholder farmers' interest in soil and water conservation technologies. It is expected that households with more household members are more likely to practice CA since it is assumed that larger families have more labor available for farm operations, such as weeding, which is critical in CA (Ntshangase et al., 2018).). However, this assumption does not always hold since labor availability depends on how large a household is and the ages and types of persons in that household. In this study, though the total household size was higher for CT practicing groups, the proportion of economically active members was slightly higher for CA practicing groups (0.67) compared to CT (0.66). In the Arba Minch Zuriya district, most banana fruit producers do not use family labor. Instead, they recruit laborers during major agricultural activities because they get massive income from banana fruit marketing. However, a lack of awareness and/or interest in CA's sustainable environmental and economic benefits keeps CT smallholder farmers trapped in traditional farming.

CA's total land holding¹⁶ was higher than CT practitioners'. However, the size of the primary farmland¹⁷ of CT practicing groups was significantly larger than CA. According to Ntshangase et al. (2018), more significant pieces of land were associated with farmers being less likely to implement CA technology than those with smaller land sizes. CT practicing groups in the Arba Minch Zuriya district had a large banana fruit production area. Even some farmers have expanded their land to Lake Chamo. CT practices had a mean higher net income of 157,980.60 ETB compared to 49,672.86 ETB from annual + perennial crops (Table 18). This was due to considerable revenue from banana fruit production and marketing. It was assumed that higher income meant that the farmer could buy inputs for farming and hence could engage in CA; however, with this income still, most CT practicing groups practiced traditional tillage probably because these households did not have deep knowledge of CA or its benefits and/or probably perceived it to be tiresome because of their lack of knowledge. Of the sampled households, 77.4 percent were native to the area, and the rest, 22.6 percent, were not native (Table 5.2). Being native to a particular area increases smallholder farmers' interest in trying cutting-edge technologies.

Table 5.2 Household Head Description under CA and CT

Variables	CA Practitioners (n = 196)		CT Practitioners (n = 196)		Pooled data	
	Mean	%	Mean	%	Mean	%
Age**	44.78		45.18		44.98	
Family size***	7.7		6.9		7.29	
Educational level	5		6.89		6.15	
% Nativity		72		82.7		77.4
Farming exp***	32		25.73		28.83	
Total land holding	2.43		2.39		2.41	
Main farmland***	1.59		2.25		1.92	

Variables in which practicing and non-practicing groups have a significant difference: *** at 0.01 and ** at 0.05 level of significance.

5.4.2 Determinants Factors for Practicing Conservation Agriculture

Seven continuous and two dummy explanatory variables were identified to explain factors influencing practicing CA in Arba Minch Zuriya and Derashe districts. The effects of the independent variables on the log odds of practicing CA are reported as odds ratios

¹⁶ Which consists of Homestead land + woodlot land + main farmland + grazing land

¹⁷ The land used to cultivate Moringa stenopetala + sorghum/maize/teff in Derashe and Banana fruit tree + maize/teff in Arba Minch Zuriya district

alongside the parameter estimates (β). For an independent variable, the odds ratio (e^β) represents the amount by which the odds favoring the decision to adopt CA (adopter =1) change for a change in that independent variable (Table 5.3).

Table 5.3 Maximum Likelihood Estimate of the Binary Logit Model for CA Adoption Decisions

Explanatory Variables	Coefficient	Robust Std. Err.	Z	P> z	e^β
AGE	-0.11**	0.05	-2.42	0.015	0.89
EDU	-0.26**	0.1	-2.58	0.01	0.77
FAMSIZE	0.18	0.2	0.90	0.4	1.2
TLANHOLD	-0.09	0.315	-0.28	0.78	0.9
TLU	-0.16**	0.06	-2.57	0.01	0.85
EXP	0.13*	0.048	2.6	0.09	1.13
NETINCO	-0.00003***	5.45E ⁻⁰⁶	-4.82	0.000	0.99
EXT	2.95***	0.55	5.31	0.00	19.01
IRRIGA	4.97***	0.8	6.24	0.00	144.43
CONS	-0.12	1.75	-0.07	0.95	0.89

Log likelihood (X^2) = -43.36

Pseudo R^2 = 79.57

*, **, and *** represents statistically significant at 10, 5 and 1% level of significance, respectively

1. AGE: the direction of influence of age variables on practicing CA was predicted to be positive. However, as shown in the model summary table, age influences practicing CA negatively and significantly at a 5% probability level. The negative coefficient and the odds ratio indicate that other factors are constant. The likelihood of a household adopting CA decreases by 0.89 for an increase in age by one year. The endpoints of a 95% confidence interval (CI) of the odds ratio are (0.81, 0.99), suggesting that CA adoption could be decreased by as little as 0.81 to as much as 0.99 times for an increase in age by one year. The negative relation of age with practicing CA was due to the vast labor and energy requirements in structuring *Targa-na-Potayta*. Similarly, older farmers want to stick to traditional farming practices rather than adopt cutting-edge technologies. However, young farmers could be more likely to try innovations with lower risk aversion and a longer planning horizon. This could justify investments in technologies whose benefits are realized over time. The finding was similar to that of Nyanga (2012), arguing that older farmers were accustomed to conventional farming methods and unlikely to change. The current result, however, is contrary Ntshangase et al. (2018). They revealed that practicing updated technology among older farmers may be due to their better access to resources (for

example, land ownership), coupled with experience and knowledge gained over time compared to younger farmers.

2 EDU: the education variable was predicted to influence CA practice. However, as shown in the model summary table, education influenced practicing CA negatively and significantly at a 5% probability level. According to the negative coefficient and the odds ratio, a change in educational level by one year reduced the favor of practicing CA by 0.77, with the endpoints of the 95% confidence interval (CI) set at 0.65 to 0.93. This suggests implementing CA among smallholders could be as little as 0.65 times to as much as 0.93 times decrease as the level of education increases by a year. However, some studies have shown that higher education levels increase the chances of practicing CA because educated farmers are more likely to quickly understand and be receptive to new technology or innovations (Knowler and Bradshaw, 2007; Ntshangase et al., 2018; Jumbe and Nyambose, 2016).

3. TLU: As hypothesized, the total number of cattle in the tropical livestock unit was statistically significant at a 5% probability level and negatively related to practicing CA. Keeping other factors constant, the odds ratio favoring practicing CA decreased by 0.85 as livestock ownership increased by 1 TLU. The negative relation of livestock size with practicing CA was that smallholder farmers choose to use crop residues as animal fodder, where benefits from livestock are realized over a short period (Jat et al., 2014). Due to livestock's high economic and cultural importance for smallholders, smallholder farmers prioritize using crop residues as cattle fodder in the tropics and subtropics. Also, ownership, particularly oxen ownership, reduced the practice of minimum tillage with mulching, probably because easy access to traction animals makes it less attractive for farmers to switch to minimum tillage (Marennya et al., 2017).

4. It has been hypothesized that net income from annual + perennial plants is significant at a 1% probability level and has a negative relationship with practicing a profession of law. By keeping other factors constant, the odds ratio indicated that when net annual income increases in one ETB, adoption decreases by 0.99, with the endpoints of a 95% confidence interval (CI) of the odds ratio being (-0.000037, -0.000016), respectively. This may be due to the increased net income from practicing CT, causing farmers to lack interest in CA since many smallholder farmers desire short-term returns and overlook sustainable land management. However, as the productive potential and annual income from farmland are

reduced, farmers will be more likely to adopt CA. The current finding was by Nyanga (2012), as the most resource-rich farmers are less likely to adopt CA since they did not see any need to embrace it. This could mainly be because relatively wealthy farmers are comfortable with their production levels and do not see any need to allocate their resources toward CA. However, the finding was against Marenja et al. (2017), as poor farmers were less likely to practice minimum tillage with mulching than more assets owned by smallholder farmers.

5. EXT: As hypothesized, getting extension services is significant at a 1% probability level and positively correlates with practicing CA. Keeping other factors constant, the odds ratio indicated that as smallholder farmers get information about CA, the favor of implementing will increase by 19.01, with endpoints of a 95% confidence interval (CI) of the odds ratio (1.86, 4.03). This is due to frequent outreach and explanation of the contributions of technology for sustainable soil fertility and crop production. This will enhance farmers' perception of CA benefits and practice decisions. The current finding was similar with Ntshangase et al. (2018) and Sileshi et al. (2019). Increasing extension contact with farmers is essential to positively influencing CA practice. A study of socioeconomic and institutional factors influencing CA practice in Zimbabwe also revealed a positive and significant relationship between extension services and CA practice (Mazvimavi and Twomlow, 2009). Developing new technologies to improve soil fertility and food production, like CA with *Targa-na-Potayta* mulching, will not end unless the target beneficiaries are appropriately reached.

Poor adoption of better technologies results from ineffective scaling methods to bring them to farmers. Scaling methods, such as training and support programs, are needed to disseminate improved practices to the highest number of farmers in widespread geographical locations. Despite improved technologies, their low use in Ethiopia shows a problem with how they are promoted and disseminated to farmers.

6. IRRIGA: As hypothesized, the lack of access to small-scale irrigation was significant at a 1% probability level and positively correlated with adopting CA. Keeping other factors constant, the odds ratio indicated that as smallholder farmers lack access to small-scale irrigations, the favor of CA adoption increased by 144.43, with endpoints of a 95% confidence interval (CI) of the odds ratio (3.4, 6.54). This showed that the CA adopters practice an indigenous mulching technique, *Targa-na-Potayta*, invented hundreds-plus

years earlier for the same reason as the innovators, i.e., due to lack of small-scale irrigations or because the area suffered from moisture stress. However, several Arba Minch Zuriya district CT practitioners have easily accessible small-scale irrigations (Figure 5.1).



Figure 5.1 River Water used as a Small-scale Irrigation in the Arba Minch Zuriya district

This discourages smallholder farmers from practicing CA with the indigenous mulching method, *Targa-na-Potayta*. However, if they did not have access to irrigable water, CA adoption rate would increase. During the key informant interview, the elderly Derashe area smallholder farmers stated:

“The problem of short and erratic rainfall coupled with lack of irrigable water was a critical challenge for the Derashe people's survival for many years. However, the progenitors' dedicated efforts and creative minds invented *Targa-na-Potayta*, an indigenous mulching technique. This technology drastically reduced rainwater demand, enhancing soil moisture content, soil fertility, and crop productivity. The current generation highly appreciates their progenitor's brainy work since our survival depends on their dedicated effort.”

This disclosed smallholder farmers of the Derashe area use *the Targa-na-Potayta* mulching technique inherently innovative to relieve soil moisture stress and fertility loss.

It was theorized that smallholder farmers' evolving ideas/practices/technology implementing decisions were influenced by the innovation diffusion process and/or economic constraints. Referring to various literature, three factors, i.e., socio-economic, institutional, and physical, were identified, and nine explanatory variables were selected to influence CA adoption decisions. The results showed that age, year of schooling, total livestock holdings, and net per annum income from annual + perennial crops negatively affect CT implementing groups from adopting CA. As a result of extension agent visits and lack of access to small-scale irrigation, CA practicing groups are compelled to adopt the technology from their predecessors and practice it extensively on their plots.

Targa-na-Potayta was innovated and used by the Derashe people a hundred-plus years ago. But, the decision-making practice by neighboring Arba Minch Zuriya district smallholder farmers is slow. They are still in the first stage of the practicing process, the awareness stage. Time alone does not make people accept and implement new practices. However, an active role in communication channels using extension agents is indispensable. In the Derashe area, due to the outwardly overwhelming problem that happened to their progenitors, the current smallholder farmers have a deep understanding of CA benefits. Families and extension agents also help smallholder farmers practice CA intensively as their ancestors did.

Rogers (1983), also stated the effectiveness of innovation when spread through a social system considering their cultural similarities. It is generally accepted that innovation diffusion has a location-specific solid component, with geographical proximity and spatial accessibility as essential factors (Massard & Mehier, 2009). However, people practice innovation based on subjective values and social norms diffused through interpersonal networks (Coleman et al., 1957; Rodgers, 2003; Ryan and Gross, 1943). Innovation can quickly be diffused into different areas if technology is considered appropriate by a particular society. According to Assefa and Gezahegn (2010), farm-level productivity can be increased by introducing technology from other areas and diffusing it with farmers. It is possible only if practicing groups get appropriate information and farmers' risk-taking behavior is known beforehand. Further, Lanckriet et al. (2014), stated in their study on CA that spatial factors are essential, but interpersonal relations play a role. Their study findings noted the importance of social networks between different villages. The innovation source

comes from kinship, friendship and marriage. 39.2% of CT practicing groups mentioned such factors as reasons for their CA knowledge.

In the Derashe area, practicing CA using the *Targa-na-Potayta* mulching technique became their farming culture, and they even developed various norms related to the unique soil management approach. Most Arba Minch Zuriya district smallholder farmers stated that designing *Targa-na-Potayta* seems tedious, but they express interest in it if they lack access to small-scale irrigation. Despite the importance of a social system to ease innovation diffusion, a robust extension network has more of the central power to scale out an innovation outside of a social network. Agricultural research/smallholder farmers are considered the source of innovation, extension agents act as modes of communication, and farmers are recipients of the invention. Farmers' rationality is judged by adopting or rejecting innovations seen as the outcome of an innovation-decision process (Mwaseba et al. 2006). A lack of scientifically proven research on the relevance of CA with *Targa-na-Potayta* makes extension agents hesitant to accept and spread the indigenous practice in Arba Minch Zuriya. This slows diffusion and keeps farmers stuck on CT.

The study findings showed that CT practicing groups have higher age, schooling, and net per annum income than CA practicing groups. The economic constraints model assumes that individuals strive for profit or utility maximization, but observed adoption patterns are determined by the asymmetrical distribution of resource endowments among individuals (Adesina and Zinnah, 1993; Negatu and Parikh, 1999). A farmer chooses to adopt a technology if he/she perceives increased utility from its adoption. That is, adoption will occur if $U_1 > U_0$. Where U_1 is the utility if technology is adopted and U_0 is the utility without adoption, the economic constraints model recognizes the importance of profitability and financial constraints (access to capital, learning costs associated with innovation, or risk).

Observing the comparative benefits, CT practicing groups obtained higher net per annum income from sole banana fruit production. This was compared to CA practicing groups' income from annual + perennial crops. The high monthly income from banana fruit production causes smallholder farmers to overlook the sustainable benefits obtained from CA with *Targa-na-Potayta* mulching for soil fertility and productivity. Additionally, looking at Derashe, people adopt CA since it helps them enhance soil fertility and soil moisture conservation. It also helps them reduce rainwater dependence and improve crop

production. In the past, the Derashe people, who lived in the area a century ago, suffered greatly from lack of food, and most lived in abject poverty. Suppose the new residents stop practicing CA using the *Targa-na-Potayta* mulching method. In that case, the problem faced by their ancestors will become increasingly apparent since the same problem still exists in the area. Hence, both groups used different tillage and soil management methods based on utility and profit.

A study of the sustainability of CA and CT practices. In the Arba Minch Zuriya district, smallholder farmers abundantly use mineral fertilizer to enhance income from banana fruit production. However, in the Derashe area, smallholder farmers' need for mineral fertilizer is shallow, and most interviewed farmers did not apply. One respondent of the Derashe farmer said: "Once I started applying chemical fertilizer, the land will be hooked to it, and through time the productive potential of the soil will reduce since the chemical burns essential elements of the soil. I want to transfer the land to my son without damaging it. Therefore, in the area, CT practicing groups are maximizing profit (utility) without considering the sustainable, productive potential of the land will be ruined with improper management.

The economic constraint model links lack access to input with reduced technology adoption. However, in the Arba Minch Zuriya district, CT's net per annum income was higher than the CA practice groups' due to nationwide fruit demand and well-structured marketing. Apart from the theory, the study findings showed that economically wealthy smallholder farmers were not interested in practicing CA simply because they were financially secure. However, in the Derashe area, smallholder farmers intensively practice CA even if they get less net per annum income than Arba Minch Zuriya smallholder farmers. Thus being economically well alone does not change farmers' decision to adopt CA.

5.5 Policy Implications

In Ethiopia, smallholders obsessed with traditional tillage without appropriate soil management. This causes soil erosion, land degradation, and reduced crop production. Smallholders developed CA to reverse the problem of CT. As per FAO's definition CA is based on three principles (1) zero or minimal tillage; (2) apply cover crops; a minimum of 30% of the farmland needs to be covered by crop residue; and (3) crop rotations/mixture (Thierfelder et al., 2018). Each principle improves soil productive potential; however,

smallholder adoption in Ethiopia is low. The current study was conducted in the Derashe and Arba Minch Zuriya districts of Southwestern Ethiopia to assess the determinant factors in CA adoption decisions. Study sites are neighboring districts with similar agroecology but different tillage and soil management practices.

The study identified the major challenge that limits CT practicing smallholders from adopting CA was the high net per annum income obtained from sole banana fruit production. It makes smallholders focus on short-term economic returns rather than sustainable production. However, the lack of irrigation and frequent extension visits encourage smallholders in the Derashe area to practice CA intensively. Therefore, the study raises the following policy implications based on the above findings.

In any agricultural practice, there is a need not to focus solely on the short-term return. Still, substantial emphasis must be given to sustainable production since, without appropriate management, the soil's productive potential will be ruined. Furthermore, capacitating extension agents will help smallholders to practice CA with the *Targa-na-Potayta* mulching technique. Additionally, each society has keen and model farmers. Fellow farmers will likely make CA practice decisions if the updated technology is implemented on their farmland.

5.6 Conclusions

Data from primary and secondary sources were used to assess CA practice decisions in southwestern Ethiopia, Derashe, and Arba Minch Zuriya districts. The study was conducted in 4 adjacent kebeles (2 from each district) that engage in different tillage and soil management activities. The logistic regression model was used to understand the various determinant factors that limit smallholders' CA practice decisions. In the selected districts, nine independent variables were examined that were supposed to influence CA practice decisions.

The logistic regression findings suggested that households with older age, education, total livestock holdings, and net per annual income were less likely to adopt CA. Increasing extension services and a lack of access to small-scale irrigation systems influenced the decision to practice CA. One of the principal factors preventing Arba Minch Zuriya district smallholder farmers from adopting CA was receiving the most net income per year from banana fruit production. The economic constraint assumes that any rational person intends

to maximize profit (utility). Similarly, the primary objective of smallholders in the area was to enhance income using CT at the expense of the soil. Smallholders focused on the momentary benefits of banana fruit, overlooking sustainable productivity because of the high demand nationwide. Lack of an irrigable water source, soil moisture stress, rainwater shortage, and soil erosion make smallholders in the Dershe district practice CA more intensively with the *Targa-na-Potayta* mulching technique. In the area, the culture of practicing CA and a structured extension system inform smallholders about the importance of CA for sustainable soil and crop productivity. If the government pays careful attention to the importance of soil and water conservation practices, the probability of CA adoption by Arba Minch Zuriya district farmers will increase.

Chapter 6 General Discussions/Conclusions and Recommendations

6.1 Introduction

Soil is the most precious of all resources as it sustains fauna and flora, and the world's more than 99% of food comes from it (Wu et al., 2019; Jónsson et al., 2019). During the last seven decades, worldwide food demand has increased substantially due to the rapidly growing human population, rise in per capita income, and change in dietary habits (Gomiero, 2016). As a result, much pressure is exerted on the soil by increased intensive agriculture, using fertilizers and pesticides. The situation affects soil's physical, chemical, and biological properties and impairs soil fertility and productivity for a long time. Experts estimate that more than 10 million ha of cropland is degraded yearly as rain and wind sweep away topsoil (Jat et al., 2014). Increasing soil degradation and the ever-growing risk of climate change worsen the task of feeding an additional 1.7 to 2.3 billion people by 2050; and are considered a significant challenge facing humanity (Gupta, 2019).

In Ethiopia, about 95% of main crops (e.g., cereals, pulses, oilseeds, vegetables, root crops, fruits, and cash crops) are produced by smallholder farms (Mulualem, 2017). However, these farms are facing various constraints that hamper crop productivity. The major factors responsible for low productivity include reliance on traditional farming techniques (Deressa et al., 2011). It is estimated that 90% of the farmland intensively tilled by traditional tillage (Aune, 2020). Annually farmers till four to seven times to prepare the land removing crop residues from agricultural fields for feed, fuel, and free grazing (Hailu & Teshome, 2022). Therefore, the degradation of agricultural land poses a serious threat to current and potential food production. To minimize the problem, in various regions, smallholders by themselves developed soil and water conservation structure alone and/or in integration with CA. These include, contour plowing, crop rotation, grass strips, surface mulching, weed heaps, agroforestry, and field boundary planting (Araya, 2020).

Practicing CA can help to minimize land degradation, i.e., soil erosion, soil fertility decline, and hydrological challenges, through simultaneously practicing activities such as minimal soil disturbance, crop residue retention, and crop rotation (Araya, 2020a). CA improves soil properties, both as a result of mulching and by introducing nitrogen fixation crops in the rotation system or in intercropping. Besides it helps to increase the water infiltration, by improving the soil's water-holding capacity, and by reducing evaporation

through lowering the soil's surface temperature (Aune, 2020). This helps to enhance the crop production and stallholders' livelihood.

In Ethiopia Smallholders started practicing CA long time ago (Beshah, 2003a). But, institutionally, promoting CA technologies started in 1998 by Sasakawa Global 2000 in collaboration with the Sustainable Land Management Programme of the Ministry of Agriculture and other stakeholders (Fentahun et al., 2019; Aune, 2020). After promotion CA technology has increased interest among policymakers, NGOs, and farmers since it minimize soil losses and prevent drought-related catastrophes (Araya et al., 2012). However, despite the technologies benefit to minimize the problem of soil erosion, enhancing the soil quality and crop productivity the adoption rate by smallholders is very low (Araya, 2020a; Aune, 2020).

This study was conducted in the Derashe and Arba Minch Zuriya districts of southwestern Ethiopia. The Derashe area was affected by the problem of soil erosion and soil moisture stress. To reduce the problem progenitors developed CA with *Targa-na-Potayta* mulching technique. The rectangular shaped mulching structure with crop rotations and integration of nitrogen fixing crops, made the soil fertile. This technology helped to reduce the problem of soil erosion, enhance the soil fertility and crop productivity. The crop residue as its effects to slow and/or hold the top soil during stormy rainfall also helps to enhance the soil fertility through releasing nutrients during decomposition. Therefore in the Derashe area the aggravated problem of soil erosion and soil moisture stress reduced and smallholders becomes food secured. The neighboring Arba Minch Zuriya district smallholders heavily rely on CT mainly for banana fruit production. In the area, smallholders have access to irrigation water, along to meet the huge nation-wide banana fruit demand they use mineral fertilizers. In the area smallholders are highly interested in enhancing short-term productivity impairing the soil long term productivity. In the Arba Minch Zuriya district, various studies (e.g., (Yisehak et al., 2011; Mekonnen, 2014; Alemu, 2017), were conducted solely to investigate the impact of banana fruit farming on soil fertility and household income. Besides in the Derashe district only a few scientific studies have been conducted to determine the impact of *Targa-na-Potayta* on soil physicochemical properties in Holte Kebele (Fikre et al., 2018).

Despite the presence of a well-designed CA with *Targa-na-Potayta* mulching in the Derashe district, the studies we reviewed did not try to understand the different tillage practices in the adjacent districts and their impact on the soil fertility, and crop productivity. Therefore, the current study explored the history and benefits of *Targa-na-Potayta*, soil quality under CA and CT plots, smallholders' revenues from annual + perennial, and factors influencing smallholders' decision to adopt CA. To obtain primary and secondary data, the study use structured questionnaire, soil sample, research reports, and reviews from scientific papers. In addition, two consecutive agricultural seasons data using recall and crop harvest method was collected to strengthen the crop production data.

The author hypothesized that implementing CA for long time enhance the soil quality and crop productivity from annual crops as compared to CT. Because through implementing CA, they able to diversify the crops and helps to enhance the production; also crop rotations and mulching enhance the soil fertility. Therefore the synchronized effect of a well-designed, implemented and practiced CA increases the soil and crop productivity. However, smallholders CA adoption decision is influenced by socioeconomic, biophysical, and institutional factors. As a result, empirical evidence on the benefits of CA and CT for soil fertility and crop productivity is crucial for effective and proactive promotion of CA in Ethiopia. Further, this study posed the following specific research questions:

- I. Why and when did *Targa-na-Potayta* originate, and how did it benefit smallholders?
- II. What are the impacts of CA and CT on soil physicochemical properties?
- III. How are practicing CA and CT benefits farmers differently?
- IV. What socio-economic, physical, and institutional factors influence smallholder farmers' decisions for CA practices?

Throughout this chapter, we examine the main findings from the study and their implications for soil quality, rural livelihood development, and policy issues in the future. It also forwards some policy implications and future research areas that arise from the study results.

6.2 General Discussions

Parts of the Derashe and Arba Minch Zuriya districts are characterized by rainfall irregularity in terms of onset, dry spells, and early cessation (Jirata et al., 2016).

I. Why and when did *Targa-na-Potayta* originate, and how did it benefit smallholders? (Chapter 2)

The first research question explores the aggravated problem of soil erosion and soil moisture stress. It relies on smallholder relieving technology such as CA with *Targa-na-Potayta* mulching in the Derashe district. In previous years, the mountainous topography, erratic and high rainfall intensities, high temperatures, and intensive CT exacerbated soil erosion and soil moisture stress. This caused droughts and famines to plague the area for a long time. In order to escape the problem some smallholders moved to other parts of the country. However, to survive in their place, their progenitors invented CA with *Targa-na-Potayta* mulch hundred-plus years ago and sustained soil erosion and crop productivity.

CA with *Targa-na-Potayta* mulching is one of the indigenous technologies being used by the Derashe community for centuries. It is practiced in such a way that, maize and sorghum residues are mulched in a rectangular shape, roughly 60 cm x 80 cm, in repeated patterns in the field (Agena, 2011). The more extended parallels are known as "Targa." The shorter transverse residue stem makes the rectangular partition is called "Potayta." In a one hectare of farmland one *long* Targa-na Potayta can use 0.17 ha of land and is known as "Apha." They separate each "Apha" using a ditch/trench, and 6 Apha can be found in one hectare of land. Between the ridges of Targa-na Potayta, when water fills up as small ponds following heavy rainfall, they open the residue ridge partly and pass it on to the next Potayta. If one Apha is ponded, they pass it to the trench/ditch that connects the next Apha. With this technology soil erosion reduced with improved soil moisture and soil fertility.

CA with *Targa-na-Potayta* mulching enhances soil fertility and crop productivity. According to Thierfelder et al. (2018), CA is the simultaneous application of minimum soil disturbance, crop residue retention, and crop diversification and is a key approach to addressing declining soil fertility. In the Derashe district apart from the novel permanent soil ridge cover with crop residues/mulching techniques, the technology consists of (a) minimum tillage, (b) mixed cropping with leguminous crops like chickpeas and haricot beans, (c) integration of agroforestry tree species, mainly *Moringa stenopetala*, and (d)

crop rotations like sorghum/maize/teff. In each *Potayta*, they sow seeds by counting their footsteps using a metal stick locally known as a "Totale." These activities help to enhance soil quality and crop productivity. Currently, the Derashe people benefit from CA with *Targa-na-Potayta* mulching and can harvest diversified crops two times a year.

II. What are the impacts of CA and CT on soil physicochemical properties? (Chapter 3)

The current study (in Chapter 3) revealed the importance of CA to enhance soil's physical and chemical properties. Eleven soil physical and chemical parameters i.e. Field Capacity (FC), Permanent Wilting Point (PWP), particle size, soil textural classes, power of hydrogen (pH), Cation Exchange Capacity (CEC), Available Potassium (Av. K), Available Phosphorous (Av. P), Total Nitrogen (TN), Exchangeable bases (Na, K, Ca, and Mg), and Soil Organic Carbon (SOC) were analyzed as per the standard laboratory procedures. The amount of clay in the soil, permanent wilting point, field capacity, and available water holding capacity of the soil under CA were high compared to CT. Soil that holds more moisture can support more soil nutrients and is critical for plant growth, and allows plants to better survive during a dry spell (FAO, 2018). Soil pH under CA was higher than CT, because of OM accumulation due to crop residue maintenance. In Arba Minch Zuriya, smallholders frequently use irrigation to water their banana farmland; this phenomenon of continued watering leaches cations from the soil. During the rainy season, water received in the Derashe area percolated into the soil with *Targa-na-Potayta* mulching. This process could maintain soil cations and store them high compared to CT groups, increasing soil pH.

Ensuring permanent soil cover by using cover crops or crop residue retention is one of the major actions anchored in CA pillars. This is to decrease run-off, soil loss, improve infiltration and increase soil organic matter. CA had high soil organic carbon levels, due to crop residue decomposition and nutrients return to the soil. Crop residue retention enhances enzymatic activities mainly in soil surface layers (Alvear et al., 2005; Nurbekov et al., 2016). Soil enzymes catalyze organic matter decomposition and nutrient cycling reactions. Melese (2017) says areas of the highest CA potential in Ethiopia are those with high mulch availability, high soil organic matter content, and high temperatures. Thus, it is possible to conclude that CA soil has favorable physical and chemical properties compared to CT. However, appropriate bodies must introduce and promote planting machines such as hand-jab planters, Li seeders, and rolling injector planters. These machines can further

enhance soil's physical properties by reducing soil compactions. The seed size, planting depth, and spacing settings of the planters and seeders would be calibrated for the respective crop types and varieties (FAO, 2018). These simple machines may reduce soil compaction and disturbance during sowing.

On the other hand, in the Arba Minch Zuriya district smallholder farmers intensively till their land, apply abundant mineral fertilizer mainly to enhance banana fruit production, and use small-scale irrigation to water their banana farm. However, intensive tillage without appropriate soil management may cause soil aggregation and ease wind/water erosion. Chemical fertilizers may damage soil microbes which naturally enhance soil fertility, and excessive farmland watering may increase soil salt accumulation. Thus, in the long run, the productive potential of the land may deteriorate with the continued supply of mineral fertilizers. As a result, development agents, governmental organizations, and non-governmental organizations are needed to promote indigenous CA using the *Targa-na-Potayta* mulching technique to overcome sustainability problems at an early stage. Besides, CA's contributions with *Targa-na-Potayta* mulching for sustainable soil and water management need to be scaled out with policy support.

III. How is practicing CA and CT benefits farmers differently? (Chapter 4)

The third research topic looks at the benefits of various tillage practices for crop productivity, and Chapter 2 results are used as indicators. This study (in Chapter 4) examined the production and income from banana + maize/teff in Arba Minch Zuriya and *Moringa stenopetala* + maize/sorghum/teff in Derashe districts. In CA and CT, the author collected data from 392 households and conducted key informant interviews. This was done to determine production and income from perennial and annual crops. Recall and crop harvest methods were used to collect data for two consecutive agricultural seasons.

The study results revealed that CA and CT contribute to household income, but annual crop revenue was significantly higher under CA than CT. Similarly, the studies of (Araya and Stroosnijder, 2010; He et al., 2011; Goshu et al., 2012; Ngwira et al., 2013; Thierfelder et al., 2013; Thierfelder et al., 2015; Liben et al., 2018; Barrera Mosquera et al., 2019; Mihretie et al., 2021; Nyirenda & Balaka, 2021) revealed the benefits of CA to increase productivity and revenue. This was mainly due to available promising soil moisture and soil fertility in the area. Implementation of the three principles of CA i.e., crop rotation

with nitrogen-fixing crops, the use of *Targa-na-Potayta* mulching, and digging the farmland using manual tool “*Totale*”, helped to reduce soil disturbance and soil water evaporation. The simultaneous effect of all activities enhanced soil and crop productivity. However, production and gross income from perennial crops was significantly higher under CT. This was due to nationwide well-structured banana fruit marketing, access to small-scale irrigation, and application of mineral fertilizers. On average 25kg of Urea and 175 kg of Urea, DAP, and NPSB fertilizer were respectively used under CA and CT. Smallholders receive massive profits due to banana trees' fast fruit-bearing nature and high market demand throughout the year. At lower price, traders from various regions of the country come and buy banana fruit at the farm gate.

Derashe area smallholders, to expand their income, planted banana trees using rainwater. However, the fruit seemed promising in the rainy seasons but immediately wilted when the dry spell started. It is common to observe wilted banana fruit trees while visiting the Derashe area. Thus, to further improve the livelihood of the Derashe people, appropriate governmental and non-governmental institutions need to support the establishment of a small-scale irrigation scheme to benefit from banana fruit production as of Arba Minch Zuriya district smallholders.

IV. What socio-economic, physical, and institutional factors influence smallholder farmers' decisions for CA practices? (Chapter 5)

The fourth research topic looks at, despite significant experimental evidence on CA's agronomic and economic benefits, various determinant factors limit its adoption. Results from Chapters 3 and 4 were used as input to initiate the research question. This study (in Chapter 5) investigated the socioeconomic, institutional, and physical factors that limit CA adoption in the study area. Nine independent variables were identified and their effect on the dependent variable, CA adoption, was identified using logistic regression.

The study results indicated that, although CA improves soil quality and crop productivity, smallholders' CA with *Targa-na-Potayta* mulching technology adoption is influenced by household characteristics, asset ownership, and physical, and institutional factors. The study findings highlighted that increased net revenue from annual + perennial crops reduced CA adoption. This was observed among smallholders in the Arba Minch Zuriya

district. As smallholders obtained massive profits from CT, their interest in adopting CA was reduced. Since their main motivation was to maximize profits from crop production at the expense of the environment. In order to meet the huge demand for banana fruit, they use an abundance of chemical fertilizers and irrigation water. However, this activity may impair the soil's long-term productive potential.

The Derashe district, increased extension services and lack of access to small-scale irrigation positively affected smallholders' CA adoption decisions. Similar studies by (Assefa & Gezahegn, 2010; Fouzai et al., 2018; Chichongue et al., 2020), revealed the benefits of extension services to improve CA adoption. While CA with *Targa-na-Potayta* mulching became the farming culture in the Derashe district, an extension service would support their working culture. Compared to CT practitioners, development agents may need less effort to convince smallholders to practice CA in this area. Furthermore, the result indicates lack of access to small-scale irrigation forced Derashe area smallholders to adopt CA. If they had access to small-scale irrigation, they wouldn't have invented the technology. A study by Arslan et al., 2014 revealed that extension services and rainfall variability are the strongest determinants of adoption. This suggests that farmers use these practices as an adaptation strategy to mitigate the negative effects of variable and delayed rainfall in Zambia.

CA practice decisions were heavily influenced by the extension system, so it is imperative to improve development agents' knowledge of CA functions, benefits, and communication with smallholders. Soil is a limited natural resource, and its productive potential can only be renewed through appropriate management. Agricultural development agents must educate smallholders concerning sustainable soil management practices. The overall findings suggest that CA with *Targa-na-Potayta* mulching is widely practiced in the Derashe Valley. Smallholders clearly understand its benefits from practical observations of its contribution to soil management and crop production. To understand the technology's benefits for sustainable soil management and productivity, appropriate governmental and non-governmental bodies need to scale out the technology.

6.3 Conclusions and Recommendations

First, this study tried to identify the initial factors for the invention of CA with the *Targa-na-Potayta* mulching. In the Derashe district, the mountainous topography coupled with erratic and high rainfall intensities, high temperatures, and intensive CT exacerbated soil

erosion and soil moisture stress. This caused prolonged drought and famine in the area, forcing smallholders to migrate to other sites. However, progenitors understood that the exacerbated problem could not allow them to stay in their place of origin for long. Therefore, through many trials, they invented CA with *Targa-na-Potayta* mulch, a hundred-plus years ago.

For centuries, the Derashe community has used the CA with *Targa-na-Potayta*. It is customary to mulch maize and sorghum residues in a rectangular shape. In the design, the more extended parallels are known as "*Targa*." The shorter stem of the transverse residue makes the rectangular partition called "*Potayta*." They separate each "*Apha*" using a ditch/trench. When water fills up as small ponds following heavy rainfall; they open the residue ridge partly and pass it on to the next *Potayta*. When one *Apha* is ponded, it is passed to the trench/ditch connecting the next *Apha*. With this technology, soil erosion is reduced with improved soil moisture and soil fertility.

Second, the study analyzed the impacts of CA and CT on soil physicochemical properties. Representative soil samples were collected from four selected adjacent Kebeles of the two districts. Eight farm plots per Kebele were established, and 32 composite samples were taken following a zigzag pattern to a depth of 30 cm. Five physical and seven soil chemical properties indicators i.e., Bulk Density (BD), Field Capacity (FC), Permanent Wilting Point (PWP), particle size, soil textural classes, power of hydrogen (pH), Cation Exchange Capacity (CEC), Available Potassium (Av. K), Available Phosphorous (Av. P), Total Nitrogen (TN), Exchangeable bases (Na, Mg, Ca, and K), and Soil Organic Carbon (OC) were analyzed. The results revealed that, in soils under CA with *Targa-na-Potyta* mulching, clay content was $53.74 \pm 2.68\%$, FC $47.8 \pm 1.09\%$, AWHC $15.2 \pm 0.37\%$, pH 8.02 ± 0.07 , SOC $1.8 \pm 0.02\%$ and Sum of cations 68.2 ± 1.66 meq/100g. Test parameters indicated statistical significance ($P \leq 0.05$), which indicates a more efficient soil management strategy in CA than in CT.

Third, the study analyzed CA and CT benefits for crop productivity. In the Derashe area, smallholders cultivate annual + perennial crops using CA with *Targa-na-Potayta* mulching. All three CA principles, crop rotation, minimal tillage, and mulch were applied. In the nearby Arba Minch Zuriya district, smallholders practice CT to grow perennial + annual crops. In the area, some smallholders throw banana fruit tree leaves as a residues onto farmland. However, in order to say it CA, all three principles must be followed. Thus,

using the different tillage methods, production and gross income from dominantly cultivated *Moringa stenopetala* + sorghum/maize/teff in the Derashe area, and banana fruit + maize/teff in the Arba Minch Zuriya district were assessed.

Production and income data for two consecutive agricultural seasons were collected. CA practitioners generated significant production and income from annual crops. However production and gross income from banana fruit was higher under CT. The huge income differences were due to massive profits obtained from sole banana fruit production. Besides the extensive use of small-scale irrigation, mineral fertilizers application, and nationwide structured banana fruit marketing supported the high production and increased smallholders' profits. Lack access to irrigation water limit the Derashe smallholders from producing water demanding banana fruit tree.

Fourth, the study analyzed the various determinant factors that limit smallholders' CA adoption decisions; understanding the agronomic and economic benefits of CA. Nine independent variables i.e., age of the household head, formal education level, total family size, total land holding, total livestock holding, farming experience, net income from annual + perennial crops, extension service, and lack access to irrigation were used to explain the dependent variable CA adoption. The findings suggested that households with older age, higher formal education level, total livestock holdings, and net annual income were less likely to adopt CA. Increasing extension services and a lack of access to small-scale irrigation systems influenced the decision to practice CA. One of the principal factors preventing Arba Minch Zuriya district smallholders from adopting CA was the huge profit obtained from sole banana fruit production and marketing. Besides in the Derashe district, the availability of extension services and the lack of access to small-scale irrigation have led smallholders to continue practicing CA with *Targa-na-Potayta* mulching.

This study provides insight into the history of CA with *Targa-na-Potayta* mulching, and how smallholders design and implement the technology on their farmland. Appropriate technology application enhances soil quality and crop productivity. However, the adoption of CA with *Targa-na-Potayta* mulching was influenced by high crop yields, extension services, and lack of access to small-scale irrigation. The study revealed that with low agricultural input, CA with *Targa-na-Potayta* mulching increases soil fertility and productivity. However, there are several factors that limit smallholders to implementing the technology. Thus, the results of this study can be used as input to strategies and

policymakers to promote CA with *Targa-na-Potayta* mulching in similar agro-ecologies by first identifying the determinants of its adoption.

6.4 Contribution of the Study

6.4.1 Contributions for Knowledge

In the study area, we evaluated CA and CT benefits for soil management and crop productivity. Four broad research areas were explored: the history and benefits of CA with *Targa-na-Potayta* mulching, soil physicochemical properties under different CA and CT, production and income from annual and perennial crops, and factors affecting CA adoption. To collect appropriate data the study used a structured questionnaire, key informant interview, and transect walk. To complement the primary data, secondary data from published and unpublished scientific reports were analyzed.

To identify the physicochemical properties of the soil under CA and CT management, soil physical and chemical property indicators were used. Additionally, data were collected for two consecutive agricultural seasons using recall and crop harvest methods to assess major agricultural crop production and income. To get accurate estimates of production and income, quadrants were formed in the harvestable farm field. Therefore, both perennial and annual crops were harvested, measured, and converted to quintals per hectare. To assess the factors limiting CA adoption, 9 independent variables were used to explain the problem in the area. According to the analysis results, CA with *Targa-na-Potayta* mulching improved soil quality and crop productivity. Using this result, we can gain insight into smallholders' ability to come up with appropriate solutions to local problems. CA adoption, however, is positively influenced by a lack of access to small-scale irrigation and extension services and negatively influenced by receiving high profits from annual plus perennial crops.

To investigate the impact of CA with *Targa-na-Potayta* mulching on soil management and crop productivity at the community level, first, we studied the history and benefits of CA with *Targa-na-Potayta* mulching, as well as the technologies' contributions to improving soil quality and crop productivity. Using CA with *Targa-na-Potayta* mulching improved the soil's physical and chemical properties and enhanced income from annual crops by preventing long-term soil erosion and soil moisture stress. As a result, the study sheds light on the potential of technology to manage soil and crop production sustainably at the household level. In addition, it suggests various factors that limit CA adoption.

6.4.2 Contribution to Policy Implications

The problem of erratic and high rainfall intensities, long dry spells, and intensive CT aggravated the problem of soil erosion and soil moisture stress. This affected smallholders' crop production potential and exacerbated frequent droughts and famine. It also affected smallholders' survival in their origin. We should instead design and implement appropriate CA technologies based on observed issues in various agro-ecosystems, rather than providing them during a crisis. CA research at the household level has a positive implication for sustainable soil management and crop production. Providing up-to-date and scientific data on CA can help non-adopters to implement the technology and improve their livelihood sustainably.

In different regions, smallholders developed and implemented appropriate CA technologies to reduce soil erosion and increase crop production. In previous times, the study area was affected by prolonged drought and famine, primarily due to soil erosion and soil moisture stress. However, there was no technology recommended by the appropriate body to sustainably relieve the problem. As a result, local people developed CA with *Targa-na-Potayta* mulching to enhance soil quality and productivity. This research identified smallholders' role in inventing and implementing CA technologies. Therefore, to ensure effective policy formulation toward solving soil productivity problems, it is imperative to involve smallholders actively. Their experience, local knowledge, and indigenous practices are necessary resources that should be developed with scientific knowledge. The results of this study can help concerned bodies to gain a better understanding of the structure and benefits of CA with *Targa-na-Potayta* mulching. Moreover, the findings will also help appropriate stakeholders recognize local people's efforts in inventing appropriate technologies to minimize enduring problems of soil erosion and soil moisture stress in the area.

In Ethiopia smallholders employ CT and till the land with *maresha*, pulled majorly by oxen. As a result, soil physicochemical properties are degraded, and it becomes increasingly dependent on mineral fertilizers to artificially improve soil quality and crop productivity. Effective soil management, which integrates biological, chemical, and physical attributes, usually enhances soil quality. In many cases, farmers' CA practices directly affect soil quality. The study revealed that CA adopters practice crop rotation, minimum tillage, mulching with crop residue, and integration of agroforestry trees. As a result of this study, concerned bodies will better understand how CA with *Targa-na-*

Potayta mulching can sustainably improve soil quality and crop productivity. The results of this study will therefore be useful for intervening in similar areas where smallholders use CT dominantly and suffer from soil moisture stress and soil erosion problems as well. Besides, to modernize CA technology, the appropriate institution must disseminate affordable tilling technologies to smallholders. By doing so, they can minimize the time spent planting seeds in the ground counting their foot-steps.

Smallholders' CA technologies adoption decisions are influenced by socioeconomic, physical, and institutional factors. In order to simplify the promotion process, both positive and negative adoption limiting factors must be identified. The study revealed that ICA adoption increased with extension services and lack of access to small-scale irrigation. Shortage of rainwater coupled with lack of access to irrigation water made the progenitors invent fitting technology. The crop residue in the ICA can enhance soil moisture by reducing soil water evaporation. It also increases rainwater percolation into the soil. Furthermore, extensive extension services make it easier for younger smallholders to learn CA. Therefore, the results will be valuable input for concerned bodies to understand the factors limiting smallholders' adoption of cutting-edge technologies before scaling them out. It is also beneficial to train extension agents since they are well-informed about knowledge dissemination. To improve smallholders' productivity, the government should also build small-scale irrigation systems with extension services in areas with severe moisture stress.

Currently, a shift in interest and practice from increasing short-term productivity at the expense of the environment to sustainable soil and crop productivity is highly required. The consequence of CT practice degrading the environment and smallholders' livelihoods is well documented. CA technology is aimed at long-term environmental sustainability, and its effects are realized over time. This research can help us better understand how soil erosion and soil moisture stress are reduced using the three principles of CA with *Targa-na-Potayta* mulching. Smallholders' livelihoods can be significantly changed using CA technology. As a result, our research contributes to the current literature on study fields while generating substantial scientific contributions. Providing research on the benefits of CA for soil management and crop productivity will help improve the current low adoption rate of the technology. Based on this finding, strategies and policymakers can recognize the benefits of CA with *Targa-na-Potayta* mulching and integrate it into the extension system to sustainably enhance smallholders' livelihoods.

6.5 Future Research Directions

Based on the findings of the current study, the following future research areas are recommended.

- With appropriate farming arrangements (small-scale irrigation, well-structured market) smallholders have short-term time horizons and future benefits do not adequately outweigh immediate needs. However, farmers' short-term needs must be balanced with environmental sustainability. Therefore the effect of short-term economic activities, CT, on the long-term productive potential of the soil needs to be investigated.
- The climate scientists now recognized that healthy soil play an important role in drawing down and sequestering carbon. The current study also found that the SOC was high under CA. Therefore, further research is required to assess *Targa-na-Potayta's* contribution to carbon sequestration, and the technology's benefit to climate-resilient agriculture.
- The current study use farmers' knowledge and experience to examine factors that affect the extent of farmland fertility. Further research is required to associate farmers' and scientific-based soil quality assessment.
- The role of women in home management and income generation is significant. Moreover, they are actively involved in farmland management under CA since draught animals are not required for tillage. Therefore, a study investigating the share of women in farmland management tasks compared to men under CA is required.
- In CT smallholders apply intensive mineral fertilizer and small-scale irrigation. Therefore, a study assessing the production, nutritional quality, and income of banana fruit under CA needs to be conducted.

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Appendices

Appendix 1 Household Survey Questionnaire

This questionnaire examines crop production, income, and determinant factors for conservation agriculture adoption in southwestern Ethiopia. The study is being conducted as part of a doctoral dissertation in Environment and Development by Lemlem Tajebe. The Woredas, Arba Minch Zuriya, and Derashe districts are identified for this research. A total of 392 households in 4 kebeles will be interviewed in each of the two study districts using direct house-to-house visits. Information given by individual household heads will remain confidential during the study and beyond. The study results will be reported based on aggregate data analyses. We believe that findings from this research will generate scientific information for policy-makers and rural development agencies that will guide them towards better and more informed decision-making for profitable and sustainable soil management and crop productivity. Your participation and candid response to the questions are highly appreciated.

General information about the Household

1. General Information

District _____

Kebele _____ Sub-kebele _____

Enumerator's Name _____

Date _____

2. Personal Information / Household Characteristics

2.1.Name of the household head: _____

2.2.Sex _____ Age: _____

2.3.Marital status: ____ (1) Single (2) Married (3) Divorced (4) Widowed

2.4.Are you native to the area? _____ (1) Yes (2) No

2.5.If not native, for how long have you lived in the area? _____ year(s)

2.6.Have you attended formal education? _____ (1) Yes (2) No

2.7.If yes, what is the highest *grade* attended? _____ grade

2.8.Details of the Household

2.8.1 Details of female household members

No.	Age	Educational level	Relation to the HHH (1=Wife; 2= daughter, 3. Nephew, 4. Cousin, 5. Aunt 6. Grand Mother	Role in the Farming system**	Total number of female in the family)
1.					
2.					
3.					
4.					
5.					
6.					
7.					
8.					
9.					

*Role give if

1. Living with the family and have strong contribution in the farm decision
2. Living with the family and have small contribution in the farm decision
3. Living with the family but doesn't have any contribution in the farm decision
4. Not living with the family members

2.8.2 Details of male household members

No.	Age	Educational level	Relation to the HHH (1=Husband; 2= Son, 3.Nephew, 4. Cousin, 5. Uncle, 6. Grand Father)	Role in the Farming system**	Total number of male in the family)
1.					
2.					
3.					
4.					
5.					
6.					
7.					
8.					
9.					

*Role give if

1. Living with the family and have strong contribution in the farm decision
2. Living with the family and have small contribution in the farm decision
3. Living with the family but doesn't have any contribution in the farm decision
4. Not living with the family members

2.9. What is your main source of income?

- a. Banana + Maize based agroforestry b. Crop production c. Livestock production d. off-farm income e. Other (specify) _____

2.9.1. What is your total farming experience? _____ Years.

Part I. Household Capital and Income

3. Do you have farm land a. Yes B. No

4. If the answer to the above is yes, how and when were your present landholding/plots acquired?

No.	Type of land acquisition	Since which year the plot has been acquired	Total area (ha or local unit)
1	Allocated by <i>kebele</i> PA		
2	Inherited		
3	Rented		
4	Sharecropping		
5	Other (specify		
6			
7			

5. What is your present land use distribution? By putting a (✓) mark in the appropriate column (s), indicate the distribution of your land use by category of land ownership.

No.	Major land use	Approx. Area (in local unit)	Land ownership category		
			Own land	Rented in land	Sharecropping land
1	Homestead area				
2	Main agricultural land				
3	Grazing land				
4	Woodlot				

6. If you are renting in and/or using other farmer's plot(s) on a sharecropping basis (as indicated in question 4 above), for how many years is your present contract period in each case?

Rented in		Sharecropping	
Since which year	Length of contract (years)	Since which year	Length of contract (years)

7. What kind of crops does your household grow in the main farmland and how much of each crop did you produce in the last year "***Meher***" season? Please indicate the estimated quantities of each crop produced for own household consumption and for sale.

Crops	Area	Total	Estimated	Distribution
-------	------	-------	-----------	--------------

		of land (ha)	production in Quintal	price per Kg	Consumed	Sold
Annual crops	Maize					
	<i>Teff</i>					
	Sorghum					
	Sweet potato					
	Seasam					
	Chicken pea					
	Cotton					
	Cassava					
Mixed Farming	Green Pea + Maize					
	Chicken pea + Sunflower + Sorghum					
Perennial Crops						
	Mango fruit					
	Papaya					

Banana Fruit Production in the Meher season of 2012 E.C.											
September		October		November		December		January		February	
Prod u (Qui)	Pric e per K.g	Produ (Qui)	Price per K.g	Produ (Qui)	Price per K.g	Produ (Qui)	Price per K.g	Produ (Qui)	Price per K.g	Produ (Qui)	Price per K.g

8. What kind of crops does your household grow in the main farmland and how much of each crop did you produce in the last year “**Belg**” season? Please indicate the estimated quantities of each crop produced for own household consumption and for sale.

Crops		Area of land (ha)	Total production in Quintal	Estimated price per Kg	Distribution	
					Consumed	Sold
Annual crops	Maize					
	Teff					
	Sorghum					

Crops		Area of land (ha)	Total production in Quintal	Estimated price per Kg	Distribution	
					Consumed	Sold
	Sweet potato					
	Seasam					
	Chicken pea					
	Cotton					
	Cassava					
Mixed Farming	Green Pea + Maize					
	Chicken pea + Sunflower + Sorghum					
Perennial Crops	Mango fruit					
	Papaya					

Banana Fruit Production in the “Belg” season of 2012 E.C.											
March		April		May		June		July		August	
Produ (Qui)	Price per K.g	Produ (Qui)	Price per K.g	Produ (Qui)	Price per K.g	Produ (Qui)	Price per K.g	Produ (Qui)	Price per K.g	Produ (Qui)	Price per K.g

9. What kind of crops does your household grow in the main farmland and how much of each crop did you produce in this year “*Meher*” season? Please indicate the estimated quantities of each crop produced for own household consumption and for sale.

Crops		Area of land (ha)	Total production in Quintal	Estimated price per Kg	Distribution	
					Consumed	Sold
Annual crops	Maize					
	Teff					
	Sorghum					
	Sweet					

Crops		Area of land (ha)	Total production in Quintal	Estimated price per Kg	Distribution	
					Consumed	Sold
	potato					
	Seasam					
	Chicken pea					
	Cotton					
	Cassava					
Mixed Farming	Green Pea + Maize					
	Chicken pea + Sunflower + Sorghum					
Perennial Crops	Mango fruit					
	Papaya					

Banana Fruit Production in the “Meher “ season of 2013 E.C.											
March		April		May		June		July		August	
Produ (Qui)	Price per K.g	Produ (Qui)	Price per K.g	Produ (Qui)	Price per K.g	Produ (Qui)	Price per K.g	Produ (Qui)	Price per K.g	Produ (Qui)	Price per K.g

10. Do you think lack of land ownership prevent tree planting in the main farmland?

A. Yes B. No

11. Are you the owner of the main farmland? If **No** go to question **12** and If **Yes** skip to **question No. 14**

A. Yes B. No

12. If you were the owner of the land do you think you will plant trees with annual crops?

A. Yes B. No

13. If the answer to question 12 is “No” why?

14. The government has introduced a system of land certification for farmers.

14.1. Have you received the certification book for your land? A. Yes B. No

(If “Yes”, continue to Q. 14.2.)

14.2. When did you receive the certification (year)? _____

15. In what way has the introduction of land certification changed your attitude with respect to growing trees on your farm? a) It has changed my attitude positively (increased interest to integrate trees in the main farmland) b) It has not changed my attitude in any way c) It has changed my attitude negatively (decreased interest to grow trees)

16. What other changes, if any, have you made on your land use/land management investment following the provisions of land certification?

17. Do you believe that land certification will give you more security

17.1. Over ownership of your land? A. Yes B. No

17.2. Over ownership of your tree property? A. Yes B. No

18. How many heads of the livestock does your household own?

No.	Livestock type	Number
1	Oxen	
2	Cows	
3	Heifers (<i>gider</i>)	
4	Youngbulls (<i>woyfen</i>)	
5	Calves	
6	Sheep	
7	Goats	
8	Donkeys	
9	Chicken	
10	Horse	
11	Mule	
12	Bee hives	

19. What is the main feed source for livestock?

A. Crop residue

B. Natural grazing (open access)

C. Private grazing land

D. Cut and carry system from perennial plant (*Moringa stenopetala*, Banana, Mango)

E. Others (specify) _____

20. Do you sell any of these animals as part of generating cash income for your household during 2012 and 2013 E.C.? (If “Yes”, continue to question 21. If “No”, go to question No. 22)

A. Yes

B. No

21. Please specify the number of livestock sold with the respective price;

No.	Livestock type	Number of animals sold	Income earned (in birr)
1	Oxen		
2	Cows		
3	Heifers (<i>gider</i>)		
4	Youngbulls (<i>woyfen</i>)		
5	Calves		
6	Sheep		
7	Goats		
8	Donkeys		
9	Chicken		
10	Horse		
11	Mule		
12	Bee hives		

22. Do you sell any animal product to generate cash income for your household?

A. Yes

B. No

(If “Yes”, continue to question 23. If “No”, go to question 24.)

23. How much animal product did you sell last year on average per week?

No.	Animal product	Unit	Estimated quantity sold per week	Unit price	Annual income earned (in birr)
1	Milk	Liter			
2	Butter	Kg			
3	Egg	No.			
4	Honey	Kg			
5	Others (specify)				

24. Does any member of your household work on any off-farm income source activities?

A. Yes

B. No

25. If the answer for the above answer is “Yes”, please indicate which off-farm activity your household members do and the estimated average annual income earned annually?

No.	Off-farm activity	Estimated annual income (Birr)
1.	Daily laborer	
2	Permanent Employee	
3	Petty trade	
	Other (specify)	

26. Does your household receive income from the following sources? If “Yes”, please give the estimated average income (Birr) earned per year. (If none, write “0” in the space provided.)

- a) Remittance ----- birr/Year
b) Retirement benefit ----- birr/year
c) Other source of income -----birr/year

Part II. Household Production Expenditures

27. System Input Expenditure (Cost estimation are solely for the main farmland only) “Meher” Season

No.	Items	Hectare of land	No. of person	No. of days	Price/person/day(s)	Total	
1.	Land preparation cost						
1.1.	Land cleaning cost						
1.2.	Cultivation 1						
1.3.	Cultivation 2						
1.4.							
1.5.							
1.6.							
2.	Seed cost	Hectare of land	Required seed in K.g	Price per K.g	Total price		
2.1.	Maize						
	teff						
	Sorghum						
	Chicken pea						
	Green pea						
	Seasam						
	Cotton						

3	Fertilizer cost	Hectare of land	Required fertilizer in K.g	Price per K.g	Total price		
3.1.	Urea						
3.2.	DAP						
3.3.	NPSB						
4	Land management cost	Hectare of land	No. of person	No. of days	Price/person/day(s)	Total	
4.1	Planting cost						
4.2	Digging cost						
4.3	Weeding Cost						
4.4	Watering cost						
4.5	Harvesting Cost						
4.6	Transportation cost						
6.	Food for daily laborers	Required amount in K.g	Price per K.g	Total price			
6.1	Maize						
6.2	<i>Moringa stenopetala</i> leaf						
6.3	Kale						
6.4	Salt						
6.5	Firewood						

28. System Input Expenditure (Cost estimation are solely for the main farmland only) “Belg” Season

No.	Items	Hectare of land	Price per units	Total cost
1.	Land preparation cost			
2.	Cost of seeds			
3.	Cost of Seedling			
4.	Planting cost			
5.	Watering cost			
6.	Fertilizer cost	Inorganic		
		Organic		
7.	Pesticide cost	Locally produced		
		Fabricated		
8.	Herbicide	Locally		

		produced			
		Fabricated			
9.	Weeding cost				
10.	Harvesting cost				
11.	Transportation cost				
12.	Specify if other cost				

Part III. Community Perception on Soil Fertility and Land Management

29. Do you use chemical fertilizer to improve the land productivity? If the answer is

No please skip to question No. 36

- a. Yes B. No

30. If yes, for how long did you use? _____ years

31. How much chemical fertilizer in average do you apply in the main farmland?
_____ K.g.

32. Which chemical fertilizer do you use most of the time?

- A. DAP B. UREA C.NPSB d.Other
(specify)_____

33. What are the impacts of chemical fertilizer for the sustainable productivity of land?

- a. Increase the per annum productivity of the land
b. Decrease the productivity of land in time
c. Other (specify) _____

34. Do you have a plan to switch the application of chemical fertilizer to the organic one?

- a. Yes B. No

35. If Yes, what methods do you plan to manage the soil fertility?

- a. Put crop residues
b. Use animal dung
c. Other (specify) _____

36. If you are applying organic fertilizer, do you have a plan to use chemical fertilizer?

- a. Yes b. No

37. If the answer is **yes**, what are the reasons?

- a. The soil loss its fertility
b. I need to use the residue and the dung for fuel-wood

c. Other (Specify) _____

38. How do you categorize the fertility of your land? (Indicate the estimated area that falls under each fertility category.)

	Fertility category		
	1=poor 2=intermediate 3=fertile	1=poor 2=intermediate 3=fertile	1=poor 2=intermediate 3=fertile
Estimated area (specify the unit in hectare)			

Part IV. Land Use Decision

39. What was the previous land use before the integration of Banana/Mango fruit trees in the main farmland? By putting a (√) mark in the appropriate column (s),

Monocropping	Mark (√)	Year of the practice
Maize		
Teff		
Sorghum		
Cotton		
Sweet potato		
Bare land		
Natural forest		
Mixed farming		

40. What were the advantage and disadvantages of the prior land use? Use the previous land use (s) from the above question No. 38.

Land use	Advantage	Disadvantage

41. What are the top three reasons that cause to change the previous land use? Select options from the table below. If the option is not listed please specify it.

1. _____
2. _____
3. _____

No.	Causes of change
1.	Land degradation
2.	Food insecurity
3.	Recurrent drought
4.	Erratic rainfall
5.	Soil erosion
6.	Lose soil fertility
7.	Market disincentive

42. For how long have you been growing Banana/mango fruit trees? _____ years.

43. Please indicate the number and specify the primary objective of planting Banana/mango fruit trees by putting a (✓) mark.

No.	Tree name	Estimated no of trees	Primary objectives of growing the trees							
1.	Banana fruit trees		1	2	3	4	5	6	7	8
2.	Mango fruit tree									

Key to primary objectives 1= Cash income; 2=Household consumption; 3=Erosion control/Soil improvement 4=animal fodder; 5=shade; 6=Medicinal value 7 = water purification 8) Others _____

44. What are the advantages and disadvantages of the current land use?

Land use	Advantage	Disadvantage

45. How has your overall annual rate of planting Banana/mango fruit trees with Maize/sorghum in the main farmland varied over the last 5years?

a) declined b) increased c) remained the same

46. If declined, what is the most, second, and third important factor for the decline?

-----Most important factor

1. Shortage of labor

2. Shortage of seedlings
3. Shortage of land
4. Negative effects on food crops
5. Market disincentive

6. Low survival rate/productivity
7. Self-sufficient for own consumption
8. Prohibitive government regulation

-----Most important factor

1. Increased availability of labor
2. Increased supply of seedlings
3. Increased size of land
4. Positive prospect of tenure security
5. Market incentive (high market demand)

6. Increasing scarcity of wood from other sources
7. Improved information/knowledge on the nutritional and medicinal value
8. Improved information/knowledge for SWC

A. Yes B. No

A. Options for the land use change a) No market access b) couldn't make the family food secure c) The soil fertility is declining d) Other (specify)

Planned land use	Reason for change

50. What is the reason behind fruit tree plantation?

- A. Give high respect for trees
- B. Planting trees with annual crops is the culture of the area
- C. Specify if other _____

Part V. Marketing and Extension Service

51. How far is your household/farmland located from the nearest all-weather road? -----

----- k.m and to nearest town _____ km

52. How far is the nearby market distance _____ km

53. Do you have an established access to marketing? A. Yes B. No

54. Where have you mostly sold these products? a) inside your village b) In the nearest market c) to cooperatives (specify) _____

55. Who help you in the management and delivery of updated information?

- a) GO's b) NGO's c) private institutions d) research institutes e) Universities
- a) Other specify

56. What is the role of DA's in the management of the land uses?

- A. Actively inform us land management techniques
- B. Deliver agricultural inputs
- C. Help us to practice beneficial land use
- D. Create awareness to integrate multipurpose tree on the main farmland
- E. Other (specify) _____

Appendix 2 Key Informant Interview Questionnaire

1. Discuss the problem of soil erosion and moisture stress in the past and present in area?
2. How the progenitors survived from the problem of soil erosion and moisture stress?
3. What motivates progenitors to invent CA with Targa-na-Potayta mulching?
4. Discuss about the invented technology and its benefit for soil erosion and moisture stress?

5. What benefit did the progenitors and the current generation obtained from implementing the technology?
6. What are the major crops before the plantation of the current crops?
7. How do you explain the production and income from banana fruit?
8. How do you compare you life before and after banana plantations?

Appendix 3 Market Prices of Crops and Fruits in the Study Area

Crops	Unit of measurement	Crop and Fruit Market price		
		Zeyise Elgo and Zeyise Wezeqa		
		2020/2021 Meher	2019/20 Meher	2020 Belig
Maize	Kg	16	10	6
Sorghum	Kg	22	12	9
Chickpea	Kg	36	15	22
Teff	Kg	50	30	25
Boloke	Kg	24	12	12
Green Pea	Kg	15	6	7
Cotton	Kg	28	28	28
Mango	Kg	1.5	1.5	1.5
Sweet Potato	Kg	3	1	1
Mitimita	Kg	200	120	120

Source: Market survey result (2021).

Appendix 4 Banana Market Price

Banana Market price							
Crops	Unit of measurement	Zeyise Eligo			Zeyise Wezeqa		
		2020/2021 Meher	2019/20 Meher	2020 Belig	2020/2021 Meher	2019/20 Meher	2020 Belig
Banana	Kg	10	6	6	13	8	8

Source: Market survey result (2021).

Appendix 5 Moringa stenopetala Leaves Market Price

Moringa Market price							
Crops	Unit of measurement	Walessa			Holte		
		2020/2021	2019/20	2020	2020/2021	2019/20	2020

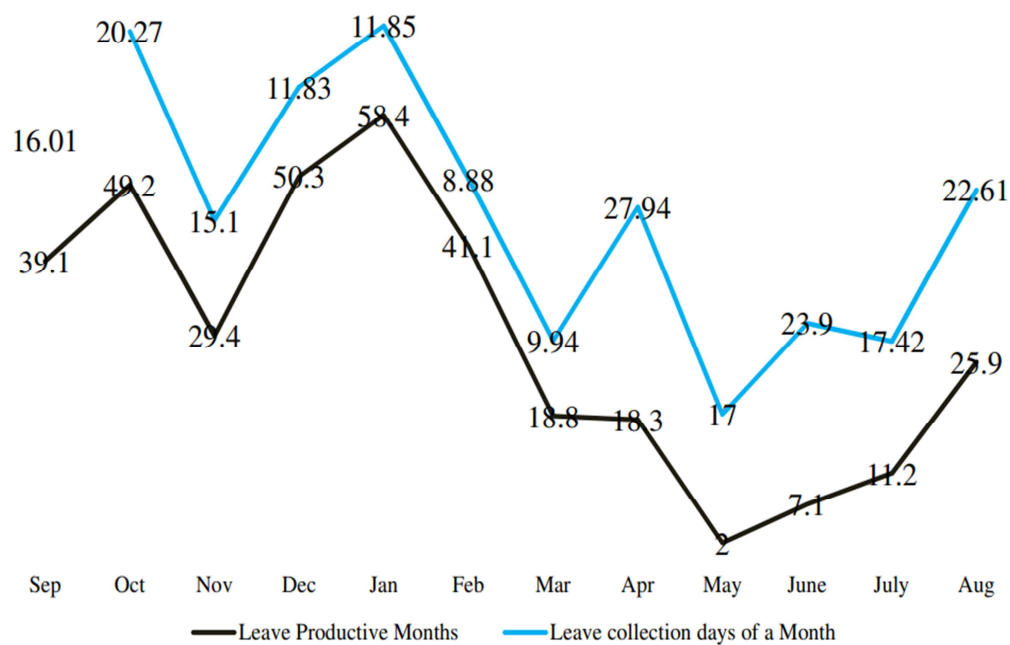
		Meher	Meher	Belig	Meher	Meher	Belig
Moringa	Kg	15	15	15	15	15	15

Appendix 6 Conversion Factor for Livestock Number into TLU

Animals	TLU
Ox/ Cows	1.0
Young Bulls/ Heifers	0.75
Calves	0.25
Sheep/ Goat	0.13
Horse/ Donkey	1.1
Chicken	00.13

Source: Strock *et al.* (1991)

Frequently stated Highly Productive Months with Total Days of Leave Collection in each Month



Moringa stenopetala Leaves Collection Days in the Productive Months of the Year

Appendix 7 Field Pictures



A tiny thatched roof made by the Derashe people to manage their farmland staying in the field (Picture by the Author)



Marketing of Moringa stenopetala Leaves at Gumayde Area (Picture by the Author)



Interviewing Derashe and Arba Minch Zuria District Smallholders (Picture by the Author)



Derashe Women Weeding the Land (Picture by the Author)



A River water that Border Arba Minch Zuriya and Derashe Districts (Picture by the Author)



Air Drying of the Soil Samples Under Shade on Spread Sheet (Picture by the Author)



Grinding and sieving the air dried soil samples for further soil physicochemical analysis
(Picture by the Author)