

**THE EFFECTS OF CLIMATE SMART AGRICULTURE ON SOIL
FERTILITY AND PRODUCTIVITY
THE CASE OF TULA-JANA WATERSHED, SNNPR ETHIOPIA.**

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JUNE 2018

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**A Thesis submitted to The Department of Environment and Sustainable
Development**

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**Presented in partial fulfilment for the requirements for the Degree of Master
of Arts (Environment and Sustainable development)**

Addis Ababa University

Addis Ababa, Ethiopia

June 2018

Addis Ababa University

School of Graduate Studies

This is to certify that the thesis prepared by Meron Tadesse, entitled: The effects of Climate Smart Agriculture on soil fertility and productivity: the case of Tula-Jana watershed, SNNPR Ethiopia submitted in partial fulfillment of the requirements for the Degree of Master of Arts (in Environment and Development Studies) complies with the regulations of the university and meets the accepted standards with respect to originality and quality.

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Abstract

The effects of Climate Smart Agriculture on soil fertility and productivity: the case of Tula-Jana watershed, SNNPR Ethiopia.

By Meron Tadesse

Adopting agricultural technologies such as climate smart agriculture (CSA) which aims to improve productivity and promote environmental sustainability remains the top agenda for international organizations. Yet, the impacts of these technologies on achieving the goal of food security and environmental sustainability has not been deeply explored. This study was conducted with the objective of assessing the effects of adopting climate smart technologies on soil fertility and productivity. The study employed a comparative analysis between CSA adopters and BAU with 0 year of intervention. Soil survey, HH survey, field observation and key informant interview was used to collect data. The soil survey was conducted to determine the impact of years of intervention on soil fertility as well as the fertility status of soil under CSA intervention when compared to other land uses. The result of the study revealed that CSA made improvements both on soil fertility and productivity. The SOM content of soil under CSA showed improvement both with intervention and time. Plant nutrients including nitrogen and phosphorus also showed improvement. Crop and livestock productivity of CSA adopters was found to be higher than BAU. The vegetation dynamics of the area also transformed significantly. The fertility of soil under CSA intervention however, was lower when compared to other land use systems like agroforestry and grassland. This indicates that CSA needs to be adopted at a landscape level integrating other land use systems for the overall ecological health of the area.

Key words: Adaptive capacity, Climate Smart Agriculture, mitigation, resilience, soil fertility

Acknowledgements

I would like to extend my deepest gratitude for my advisor Dr. Belay Simane for his unlimited support and encouragement throughout the thesis. His inspiration, enthusiasm, supervision, guidance, constructive comments and encouragement made this thesis happen. My deepest respect and gratitude goes to you. Dr. Dawit, CCAFS and Dr. Lulseged, CIAT thank you very much for co-advising me and for making this thesis possible. Dr. Wuletawu, CIAT, thank you for guiding me through the whole process down to the little details. Gebremedhin CCAFS, I really appreciate all the hard work you have put in while collecting the data. Dr. John Recha from CCAFS, I appreciate your constructive comments. Getamesay, Mesfin and Mesele from Inter Aide, thank you for opening your doors and letting me work on your incredible project site. You truly did an amazing job transforming the study area. I would also like to thank everyone who helped me and encouraged me while conducting this research paper. Thank you all!

Table of Contents

List of Figures	viii
List of Tables	ix
List of Acronyms	x
CHAPTER ONE	1
INTRODUCTION	1
1.1. Background	1
1.2. Statement of the problem	2
1.3. Research Objectives	4
1.4. Significance of the Study	4
1.5. Scope of the study	5
1.6. Limitations of the Study	5
1.7. Organization of the study	6
CHAPTER TWO	7
LITERATURE REVIEW	7
2.1. Definitions	7
2.2. Climate Change and Agriculture	8
2.3. The need to Adapt and Mitigate Climate Change	9
2.4. Climate Smart Agriculture (CSA) overview	10
2.5. CSA practices and technologies	11
2.6. Soil fertility	14
2.6.1. Soil properties in relation to fertility	14
2.7. Vegetation and biomass productivity indicator	19
2.8. Empirical Review	20
2.9. Conceptual Framework	21
CHAPTER THREE	23
RESEARCH METHODS	23
3.1. Description of Study Area	23
3.2. Research Design	24
3.3. Data Source	24

3.4. Data collection techniques and sample size	25
3.5. Data analysis	28
3.6. Ethical consideration.....	31
CHAPTER FOUR.....	32
RESULTS AND DISCUSSIONS.....	32
4.1. Demographic and Socio-economic characteristics of HH heads	32
4.2. Climate Smart technologies adopted.....	32
4.2.1. Crop Management.....	33
4.2.2. Sustainable Land Management (SLM)	34
4.2.3. Livestock Management.....	37
4.3. Effects of CSA on Soil fertility	38
4.4. Effects of CSA on Productivity	43
4.4.1. Crop productivity	43
4.4.2. Livestock Productivity	44
4.4.3. Vegetation and biomass productivity	46
4.5. Perception of farmers towards CSA.....	48
4.6. Climate Change Mitigation co-benefits	49
CHAPTER FIVE	53
CONCLUSION AND RECOMMENDATIONS.....	53
5.1. Conclusion	53
5.2. Recommendations.....	55
Reference	56
Appendices.....	59

List of Figures

Figure 1: Conceptual Framework of CSA	22
Figure 2: Map of Tula-Jana watershed.....	23
Figure 3: Sample pictures of soil profiles	26
Figure 4: CSA and BAU scenario at a glance	36
Figure 5: Restricted grazing practice at CSA intervention area.....	37
Figure 6: Change in selected soil fertility indicators for surface samples	39
Figure 7: Soil fertility status across other land uses for surface samples.....	41
Figure 8: Community forest at Tula-Jana watershed	42
Figure 9: SOC content at different depth	42
Figure 10: Time series NDVI analysis of Tula-Jana watershed.....	46
Figure 11: Vegetation change over time based on NDVI results.....	48
Figure 12: Picture of crop residue left on CSA intervention farmland	50
Figure 13: Mitigation potentials of CSA with introduction of cover crop and organic manure	51

List of Tables

Table 1: SOM content rating based on Metson (1961)	15
Table 2: Soil reaction (pH) rating kcl based on Metson (1961).....	17
Table 3: Total nitrogen rating (Kjeldahl) based on Metson (1961)	18
Table 4: Available phosphorus rating (Olsen) based on Metson (1961).....	18
Table 5: Potassium rating (Mehlich-3) based on Metson (1961).....	19
Table 6: Satellite image accusation information	29
Table 7: Crop management practices	33
Table 8: Constructed soil bunds with vegetative measures in Tula-Jana.....	35
Table 9: Independent samples t-test for mean difference	43
Table 10: Livestock distribution	44
Table 11: Area change of time series NDVI analysis	47
Table 12: Perceived benefits of CSA by adopting farmers	49

List of Acronyms

BAU	Business-as-usual
CCAFS	Climate Change, Agriculture and Food Security
CGIAR	Consultative Group on International Agricultural Research
CIAT	International Center for Tropical Agriculture
CRGE	Climate Resilient Green Economy
CSA	Climate Smart Agriculture
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
ILRI	International Livestock Research Institute
IPCC	Intergovernmental Panel on Climate Change
Mt CO ₂ e	Million metric tons of carbon dioxide equivalent
NDCs	Nationally Determined contributions
SLM	Sustainable Land Management
SNNPR	Southern Nations, Nationalities, and Peoples' Region
SWC	Soil and water conservation
UN	The United Nations
UNFCCC	The United Nations Framework Convention on Climate Change
USDA	United States Department of Agriculture

CHAPTER ONE

INTRODUCTION

1.1. Background

Agricultural production highly depends on natural resources and climatic conditions especially in developing countries which make it more sensitive to climate change and variability. Most African countries strongly depend on Agriculture for their economy and livelihoods. Sub-Saharan Africa countries are especially vulnerable to climate change due to various factors including, heavy dependence on small-scale rainfed agricultural economy, low income, lack of technology, high illiteracy rate and severe and widespread natural resource or ecological degradation. According to IPCC 2007 report, by 2020, in some African countries, yields from rainfed agriculture could be reduced by up to 50% in relation to climate change that will compromise the continent's food security.

Ethiopian agriculture contributes more than 40% of the country's GDP and accounts for 2.3 percent of the GDP growth in 2013/14 (UNDP, 2014). The sector also contributes to more than 90 percent of national export and serves as the main source of input to the industrial sector (Emerta, 2013). Ethiopia is no exception when it comes to climate change vulnerability. In Ethiopia, climate change is manifesting through recurrent drought, flooding, increase of mean annual temperature and changes in precipitation pattern. Being dependent on rainfed agriculture, these conditions threaten the country's economy and food security. Most of Ethiopian farmers are subsistence farmers that depend on rainfall and have less capacity to adapt to climate change. According to Emerta 2013, Ethiopia has lost a cumulative level of over 13 percent of its agricultural output between 1991 and 2008 in relation to climate change.

As climate change becomes a reality, it is a must to adapt to the changing climate and mitigate further change. To address the challenges of agricultural production, climate change adaptation and mitigation, a considerable attention is given to Climate Smart Agriculture (CSA). CSA aims to address issues of increasing food demand by the rapidly growing population while adapting to climate change and reduce GHG emissions (FAO, 2010; 2013).

Agriculture and climate change have a two ways relationship whereby agriculture is not only strongly affected by climate change but at the same time it is a significant contributor. About one third of global greenhouse emissions are directly or indirectly linked to agriculture (Worner *et al.*, 2012; GIZ, 2012). Ethiopia's annual GHG emissions were estimated at 150 Mt CO₂e in 2010, with 50 percent and 37 percent of these emissions resulting from agriculture and forestry sectors (mainly agriculture related deforestation), respectively (FAO, 2016). This fact coupled with the sector's high mitigation potentials form the basis to do agriculture differently. In this regard, the government of Ethiopia has embarked on the climate resilient green economy (CRGE) strategy to reduce GHG emissions by introducing CSA practices such as conservation agriculture, integrated watershed management, and nutrient and crop management that could reduce emissions by 40 Mt CO₂e in 2030 (CRGE, 2011).

In the study area, Tula-Jana watershed, climate smart practices like physical soil and water conservation structures integrated with biological measures, crop rotation, crop residue management, restricted grazing, agroforestry and community forest rehabilitation are being practiced under the guidance and support of Inter Aide France. Inter Aide has been leading the initiative of introducing climate smart practices in the area since 2006. Recently, the Consultative Group on International Agricultural Research (CGIAR) centers such as the International Center for Tropical Agriculture (CIAT), International Livestock Research Institute (ILRI) and Climate Change, Agriculture and Food Security (CCAFS) are partnering with Inter Aide to intensify and diversify farmers production while preserving the environment to maintain its productive capacity and build the resilience of farmers to cope with climate changes. In addition, the CGIAR centers support evidence generation and building capacity of Inter Aide staff and local communities. This study is part of the 'evidence generation' component, which focuses on investigating the effects of these climate smart practices on soil fertility and productivity.

1.2. Statement of the problem

Widespread land degradation has been one of the major challenges undermining agricultural production and productivity growth in Ethiopia. Land degradation has been exacerbated by agricultural land expansion to meet the increasing food demand, increasing energy demand causing deforestation, over grazing, low vegetative cover, long history of drought, unsustainable

use of natural resources and cultivation of marginal lands. It is also one of the factors that contribute for the vulnerability of the agriculture sector as well as rural populations to the adverse impacts of climate change. Land degradation results in environmental decline aggravating food insecurity and rural poverty which has further implications on weakening the adaptive capacity of farmers. As a result, both ecosystems and the rural community becomes less resilient to the adverse impacts of climate change.

Land degradation includes all process that diminishes the capacity of land resources to perform essential functions and services in ecosystems (Hurni *et al.*, 2010). Land degradation manifests itself through soil erosion, nutrient depletion and loss of organic matter, acidification and salination (Bewket and Teferi, 2009). According to Temesgen *et al.*, 2014, the most serious problem of Ethiopia's land resources is soil erosion.

In the study area, soil erosion and loss of soil fertility have been major challenges faced by the rural community. The area is characterized by steep topography and gets a high rainfall amount ranging from 1,000-1,400mm. The steep topography combined with high rainfall made the area highly vulnerable to soil erosion. Previous farming practices were aggravating the soil erosion problem. As a result, crop production was declining due to loss of soil fertility and some farmers were even forced to abandon part of their plots because it was no longer productive. In addition, land degradation caused shortage of fodder forcing farmers to buy fodder from their limited resources, put pressure on enset as farmers were resorting to feeding their cattle enset leaves and also put a burden on women and children who are mainly responsible for feeding and harvesting fodder. Lack of forage was also one of the constraining factor for breeding improved livestock varieties which have better productivity. To address these environmental and production challenges, CSA was introduced in the area by Inter Aide France. Various CSA interventions have been implemented for over a decade. However, very limited studies have been carried out regarding the effects of introduced CSA practices on soil fertility and productivity in the study area. As a result, there are no quantitative evidences related to the effects of CSA practices in the area which can undermine informed planning and decision making. Simeret (2014), conducted a related study in the Ambo district, Oromia region at farm level. However, since CSA was introduced recently at the time of her study, most results did not show a significant difference in soil quality compared to non-intervention areas.

Therefore, this study is conducted to fill the research gaps regarding CSA and its effects on soil fertility and productivity. To capture time effects of CSA on soil fertility, different intervention times were considered. The productivity aspect of CSA was assessed in terms of crop, livestock and vegetation cover. In addition, the mitigation co-benefits of the interventions are estimated using CCAFS-mitigation option tool (MOT).

1.3. Research Objectives

The main objectives of the study are to examine the effects of CSA practices on soil fertility and productivity.

Specific objectives

Having the above general objective, the study addresses the following specific objectives

- To analyze the effects of CSA practices on soil fertility
- To analyze the effects of CSA practices on productivity
- To assess the attitude of farmers towards CSA
- To assess the mitigation co-benefits of adopting CSA

Research Questions

In order to address the above stated objectives, this study attempt to answer the following research questions.

- Are the implemented CSA options having effects on soil fertility and productivity?
- Are there perceived benefits of adopting CSA by farmers?
- Does adopting CSA have mitigation co-benefits?

1.4. Significance of the Study

This study is expected to provide relevant information regarding the role CSA plays in improving soil fertility and productivity. The results related to the mitigation co-benefits of CSA practices can also give relevant information to effectively implement the Ethiopian CRGE strategy at micro-level. The information can be used by the public, organizations working in the study area as well as government institutions to assist policy formulation and frameworks. It can

also be used as an insight for further researches. The results of this study can also be used to scale approaches and methods to areas of similar agro-climatic zones and socio-economic backgrounds. Finally, the findings in this study will inform the sustainable land management program (SLMP), Inter Aide and CGIAR centers active in the area about the benefits of CSA practices to guide their planning and decision making.

1.5. Scope of the study

CSA is an integration of multiple technologies and interventions from farm to policy level. Different approaches can be used at different scale, different agro-ecological zone, different topography and different socio-economic characteristics. However, the scope of this study is limited to assessing the effects of specific climate smart technologies and practices being carried out in Tula-Jana watershed in Kembata Tembaro Zone, SNNPR, Ethiopia on soil fertility, productivity and potential mitigation co-benefits.

1.6. Limitations of the Study

The Tula-Jana watershed contains different years of intervention time across the whole landscape. But due to limitation of time and resources, only certain years were selected for analysis. Also, the absence of baseline data made it difficult to make the best before and after comparison, instead baseline scenario/control has to be established for comparison that might challenge the representativeness of the control. Also, the political instability of the country delayed the data collection process.

1.7. Organization of the study

This study is organized into five parts. The first part deals with introduction, which encompasses background, statement of the problem, research objectives, research questions, significance, scope and limitation of the study. The second part focuses on review of related literature which covers definition of terms, concepts in relation to climate change and CSA, soil fertility parameters, empirical reviews and conceptual framework. The third part explains the research methods i.e., description of the study area, research design, data sources, data collection techniques and sampling methods, data analysis methods and ethical considerations. The fourth part deals with results and discussion. Finally, the last part focuses on conclusion and recommendation which derived from the findings of the study.

CHAPTER TWO

LITERATURE REVIEW

This section covers definitions of terms and concepts related to the study. Empirical review which depicts the measured benefits of CSA will also be demonstrated in this chapter. Conceptual framework of the study is developed based on concepts and reviews.

2.1. Definitions

Different definitions have been given for terms by different scholars and organizations. But for the purpose of this study, the following operational definitions have been used.

Climate change - a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods (UNFCCC, 2014).

Climate variability – is variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability) (IPCC, 2001).

Adaptation - is adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities (IPCC, 2001).

Adaptive capacity - is the ability or potential of a system to respond successfully to climate change, including climate variability and extremes and includes adjustment in both behavior and in resource and technologies (IPCC, 2007).

Resilience - is the ability of a system and its component parts to anticipate, absorb, accommodate or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration or improvement of its essential basic structures and functions (IPCC, 2012).

Mitigation - A human intervention to reduce the sources or enhance the sinks of greenhouse gases. Mitigation mostly targets to stabilize GHG emissions but might not in the short-term reduce the amount of GHG in the atmosphere nor reverse existing effects of climate warming.

Baseline scenario - Reference for measurable quantities from which an alternative outcome can be measured, e.g. a non-intervention scenario used as a reference in the analysis of intervention scenarios (IPCC, AR4).

“Business-as-usual”/BAU baseline scenario - a scenario which assumes that future development trends follow those of the past and no changes in policies will take place.

2.2. Climate Change and Agriculture

Climate change is strongly affecting agricultural production exacerbating poverty and food shortage. According to the FAO (2017) report, between 2005 and 2015, 26 percent of the total damage and loss caused by climate-related disasters in developing countries was in agriculture. Climate change is also expected to increase the frequency and magnitude of extreme weather events like droughts and floods. In areas where the temperature is already close to the physiological maxima for crops, warming will impact yields more immediately (IPCC, 2007). Higher temperatures will inevitably reduce yields of crops both in quality and quantity by affecting growth rates, moisture availability, photosynthesis and transpiration rates while encouraging weed and pest to spread. In general, climate change is expected to reduce cereal production by 1% to 7% by 2060 (Perry, 2007). Even though the impact of change in mean climate might occur in the long-run, the year to year production is being challenged by climate variability and extreme weather events. Historically, many of the largest falls in crop productivity have been attributed to anomalously low precipitation events (Kumar *et al.*, 2004; Amare, 2015). However, in recent years, extreme weather events, including untimely heavy rain and flooding have also been problems affecting agricultural productivity in countries like Ethiopia.

The change in climate affects the overall agroecological conditions. According to Rosegrant *et al.*, (2008), seasonal changes in rainfall and temperature could impact agroclimatic conditions, altering growing seasons, planting and harvesting calendars, water availability, pest, weed and disease populations. Climate change also alters the suitability of agricultural lands.

In some regions of the world, it is expected that there will be positive impact of climate change on crop production. However, looking at the overall impacts of climate change on agriculture, the negative outweighs the positive impacts, exacerbating global food insecurity.

2.3. The need to Adapt and Mitigate Climate Change

As described by the IPCC, warming of the climate system is unequivocal. Even with low to zero emission at present, further warming is expected due to the already existing GHG concentration in the atmosphere. Even though climate change is already affecting agricultural production, impacts are expected to worsen in the second half of the century (Easterling *et al.*, 2007). Therefore, short-term and long-term adaptation is a must to reduce the vulnerability of people to climate change. As many small-scale farmers have limited capacity to adapt to the changing climate, increasing the adaptive capacity of the vulnerable groups to cope with the adverse impacts of climate change has to be an important component of the adaptation process.

According to Smith *et al.*, (2007), mitigation options for agriculture, are generally divided into three broad categories of practices: 1. activities that increase carbon stocks above and below ground; 2. actions that reduce direct agricultural emissions (carbon dioxide, methane, nitrous oxides) anywhere in the life cycle of agricultural production; and 3. actions that prevent the deforestation and degradation of high-carbon ecosystems to establish new agricultural areas. Soils represent the largest reservoir of terrestrial carbon on the global scale and plays a critical role in carbon cycling (Solomon *et al.*, 2016). Improved farm management practices such as conservation agriculture and soil and water conservation that present minimum disturbance and reduced soil erosion significantly decrease carbon released from soils. Soil carbon sequestration is estimated to account for 89 percent of the technical mitigation potential in agriculture, compared to 11 percent for emissions abatement (Smith *et al.*, 2007).

Adaptation and mitigation efforts has to go hand in hand as only the combined effort can minimize and avoid the impacts of climate change. As attention is given to adaptation, mitigation efforts also have to be made to prevent climate change that exceeds the capacity of the natural and human systems to adapt.

2.4. Climate Smart Agriculture (CSA) overview

The idea of CSA emerged in the context of increasing concern over food security given rapidly changing demographics and climate (Mann *et al.*, 2009). Agricultural transformation was needed to sustainably improve productivity under changing climate. CSA emerged with the concept of integrating agricultural development with environmental responsiveness.

FAO (2010), defines CSA as agriculture that sustainably increases productivity, enhances resilience of livelihoods and ecosystems, reduces and/or removes greenhouse gases (GHGs) and enhances achievement of national food security and development goals. CSA is composed of three interlinked pillars: productivity, adaptation and mitigation.

2.4.1. Productivity

CSA aims to sustainably increasing agricultural productivity and incomes from agricultural productions with minimum to no adverse impacts on the environment. The main principle behind improving productivity is sustainable intensification which focuses on increasing production with efficient and optimum resource utilization and management. Improving productivity is a key factor in achieving food security especially for the poor and marginalized groups.

2.4.2. Adaptation

Through this pillar, CSA aims to reduce the vulnerability of farmers and ecosystems to climate change by stabilizing and enhancing ecosystems so that agricultural productivity will be maintained or improved as well as protect the biodiversity. By adapting to climate change, farmers will build their resilience to short and long-term stress of climate change.

2.4.3. Mitigation

CSA aims to reduce and/or remove GHG emissions where and whenever possible. It is also the aim of CSA to enhance carbon sequestration by enhancing the capacity of natural carbon sinks. As soils and trees are natural carbon sinks, CSA focuses on activities that reduce deforestation and soil management practices to maximize their ability to sequester carbon dioxide.

CSA targets to enhance adaptation to climate change and support efforts to reduce carbon emissions, while simultaneously increasing food security by promoting more synergies than

tradeoffs. Under these three common goals, CSA encompasses a wide range of practices based on crop production, livestock, forestry and fisheries (FAO, 2014).

2.5. CSA practices and technologies

Many CSA practices can improve soil fertility that will result in improved productivity that enhance resilience of farmers through improved adaptive capacity. It is also believed that CSA stabilize and enhance ecosystem services which is essential to build resilience and adapt to climate change. Soil management practices will also deliver a significant mitigation co-benefit through reduced GHG emission and enhanced carbon sequestration.

2.5.1. Conservation Agriculture

Conservation agriculture promotes soil quality through minimum soil disturbance, mulching and residue management which can increase soil fertility and the availability of nutrients to plants. Soil organic matter has been found to increase significantly over time in conservation agriculture systems, primarily due to the introduction of organic matter as crop residues or mulch and to the minimal disturbance of soil (FAO, 2016). Soil organic matter not only provides nutrients for the crop but is also a crucial element for the stabilization of soil structure. Presence of organic matter improves soil fertility and reduces soil erosion by improving the aggregate stability of soil. Minimum disturbance of soil results in less soil compaction which lowers the bulk density. High bulk density restricts root growth, movement of air and water through the soil resulting in poor plant growth that affects crop yield.

Conservation agriculture has beneficial effects on water management and water-use efficiency. Infiltration and water holding capacity improves with an increase in organic matter and low bulk density making water more available throughout the farming cycle. Mulching and crop residue management improves infiltration and the absorption capacity reducing the risk of erosion and flooding during heavy rains. Improved infiltration and absorption capacity contribute to aquifer recharge and make more water available for crops.

Conservation agriculture can also help mitigate climate change by reducing emission and sequestering carbon in soils and plant biomass (FAO, 2016). Conservation agriculture reduces erosion which prevents the release of carbon from the soil. Minimum disturbance of soil also

prevents the release of carbon. At the same time, improving organic matter and soil quality, promotes carbon sequestration by soil.

2.5.2. Agroforestry

Agroforestry is land use management system that involves the integration of trees and shrubs into farmland either through planting or natural regeneration. Agroforestry have a high potential for climate change mitigation, adaptation and crop productivity. Agroforestry enhances SOM, agriculture productivity, carbon sequestration, water retention, agro-biodiversity and farmers' income (Zomer *et al.*, 2016; Singh, 2017). Trees provide cover for soil that prevents erosion which is one of the main causes of soil degradation. Agroforestry improves agricultural yield by enhancing soil fertility through nutrient cycling, improved SOM and creation of favorable microclimate for certain crops.

Trees are also well-known carbon sinks. They fix carbon through the process of photosynthesis and store excess carbon as biomass (Nowak and Crane, 2002; Singh, 2017).

2.5.3. Integrated soil fertility management (ISFM)

Integrated Soil Fertility Management (ISFM) combines agronomic practices relating to crops, mineral fertilizers, organic inputs and other amendments that are tailored for different cropping systems, soil fertility status and socioeconomic profiles (Roobroeck *et al.*, 2016). ISFM improves fertilizer efficiency through enhanced nutrient uptake and retention of nitrate in soils reducing GHG emission from fertilizers. Combining fertilizers and organic inputs also enhances fertilizer uptake and retention by balancing immobilization and release processes (Chivenge *et al.*, 2009; Roobroeck *et al.*, 2016). Incorporating crop residue, compost and green manure enhances the efficiency of fertilizers and other agricultural inputs. It also replenishes lost soil nutrients.

2.5.4. Crop rotation and Intercropping

Intercropping is the simultaneous cultivation of more than one crop species on the same field while crop rotation is the practice of growing a sequence of plant species on the same land. Intercropping reduces the climate driven crop failure as variety of crops have different climatic adaptability (Shava *et al.*, 2009). Intercropping of cereals with leguminous crops facilitates

nitrogen fixation and improves yield. Inter-cropping with legumes reduce the amount of nitrogen fertilizer used.

Crop rotation diversifies soil nutrient utilization as different crops have different nutrient uptake. Crop rotation is a sustainable approach that increases yield and water use efficiency while reducing soil erosion (Huang *et al.*, 2003; Singh, 2017). Changing crop types helps controls weeds and reduces pest damage by interrupting their habits and lifecycles. Crop rotation is also an effective approach for carbon sequestration as compared to growing same type of crop continuously (Triberti *et al.*, 2016).

2.5.5. Soil and Water conservation (SWC)

SWC is the combination of the appropriate land use and management practices that promotes the productivity and reduce erosion and other forms of land degradation (Senders, 2004). SWC practices reduce soil erosion, enhances soil fertility, improves soil moisture and ultimately improves system productivity.

There are different types of SWC measures ranging from physical structures to agricultural conservation measures including strip cropping and cover cropping. Physical soil conservation structures are permanent features made of Earth, stones or masonry, designed to protect the soil from uncontrolled runoff and erosion and retain water where needed (SUSTAINET EA, 2010). Benefits can be significantly improved when physical measures are integrated with biological options.

Biological measures such as grass on SWC structures stabilize the physical SWC structure. It also increases nutrient retention and water infiltration that improve soil moisture. Covering SWC structures with palatable vegetative measure provides the opportunity to grow fodder for livestock.

2.5.6. Hedgerows

Hedgerow planting is an important component of the agricultural ecosystem. Hedgerows are lines or groups of trees, shrubs, perennial forbs, and grasses that are planted along the sideway of agricultural lands. Hedgerows have multiple functions. Hedgerows serve as habitat for beneficial insects, pest control, weed control, windbreaks, increase surface water infiltration and increase biodiversity (Earnshaw, 2004). But the most common functions of hedgerow in agricultural lands are erosion control and biomass production. Hedgerows reduce runoff by reducing the speed of water flow. They also improve soil structure around the root zone that improves water infiltration.

2.6. Soil fertility

Soil fertility refers to the ability of soil to provide essential plant nutrients in available forms and in a suitable balance to sustain plant growth and reproduction. Soil fertility is an important component of soil productivity. For optimum crop production both presence and availability of essential nutrients to plants is important. In this aspect, fertile soil combines soil physical, chemical and biological properties that are directly linked to nutrient provision and availability. A fertile soil is characterized by having adequate supply of nutrients essential for plant and provide favorable conditions for plant growth. Plants require both macro and micro nutrients for optimum growth. They also need balanced pH, good soil structure and soil organic matter for nutrients be available for plants and root growth. Soil fertility is one of the major factors that influence agricultural productivity.

2.6.1. Soil properties in relation to fertility

A soil is a combination of inherent and dynamic soil properties. Inherent soil property is associated with the soil formation and changes little with management practices. On the other hand, dynamic soil properties change over time in response to land management practices. There are several dynamic soil properties that are important for plant growth and productivity that can be used as indicators of soil fertility. Attributes of a good indicator are sensitivity to change, ease of measurement and interpretation, and repeatable methodology and reversibility so that improvement can be monitored (USDA, 2001).

Soil Organic Matter (SOM)

SOM comprises both living and nonliving components. It is considered as an important attribute of soil health due to the many functions it provides and support. It is even argued that organic matter management is soil health management and is critical for increasing agricultural resilience to climate change. SOM affects soil fertility, structure, stability, nutrient retention, soil erosion, and available water capacity. Soils with high organic matter tend to require lower farm inputs and be more resilient to drought and extreme rainfall (Moebius-Clune *et al.*, 2016). It is also an important carbon sink. Decreases in SOM can lead to a decrease in fertility and biodiversity, as well as a loss of soil structure, resulting in reduced water holding capacity, increased risk of erosion and increased bulk density and hence soil compaction (Weil and Magdoff, 2004).

Soil management practices like minimum tillage, mulching, crop residue management, Integrated Soil Fertility management, and agroforestry affect the organic matter content in the soil.

Table 1. SOM content rating based on Metson (1961)

SOM %	SOM rating
< 1	Very low
1 – 2	Low
2 – 4	Medium
4.2 – 6	High
> 6	Very high

Bulk Density (BD)

BD is an indicator of soil compaction. Bulk density is routinely assessed in agricultural systems to characterize the state of soil compactness in response to land use and management. Bulk density reflects the soil's ability to function for structural support, water and solute movement, and soil aeration. Bulk density is affected by land management practices. Lower bulk densities

have been generally observed in soils under less anthropogenic interferences like native forests (Bini *et al.*, 2013). On the other hand, anthropogenic activities like cultivation can result in compacted soil layers with increased bulk density. Cultivation destroys soil organic matter and weakens the natural stability of soil aggregates making them susceptible to damage caused by water and wind. When eroded soil particles fill pore space, porosity is reduced, and bulk density increases (USDA, 2001). Compaction also restricts root growth, movement of air and water through the soil resulting in poor plant growth that affects crop yield.

Soil Reaction (pH)

Soil pH generally refers to the degree of soil acidity or alkalinity. The pH scale ranges from 0 to 14; a pH value of 7 is considered neutral; pH value greater than 7 is considered basic or alkaline; and a pH value below 7, is considered acidic. pH affects nutrient availability by controlling the solubility and mobility of heavy metals, such as Aluminum Al, Iron Fe, Manganese Mn, Copper Cu, and Zinc Zn, and nutrients, such as phosphorus and at the same time controls the toxicity of many heavy metals. It also affects percent saturation, soil buffering capacity, cation-exchange capacity (CEC), and soil biological properties like microbial growth and diversity (USDA, 2001). Many crops prefer neutral pH value of 6.5 to 7.3. If pH is too high, nutrients such as phosphorus, iron, manganese, copper and boron become unavailable to the crop. If pH is too low, calcium, magnesium, phosphorus, potassium and molybdenum become unavailable (Moebius-Clune *et al.*, 2016). Too high or too low pH level therefore highly affects crop production by limiting nutrient availability to the plant. Management practices that increase SOM increase soil pH buffering capacity.

Table 2. Soil reaction (pH) rating (kcl) based on Metson (1961)

pH	pH class
< 4.5	Extremely acid
4.5 – 5.0	Very strongly acid
5.1 – 5.5	Strongly acid
5.6 – 6.0	Medium acid
6.1 – 6.5	Slightly acid
6.6 – 7.3	Neutral
7.4 – 7.8	Mildly alkaline
7.9 – 8.4	Moderately alkaline
8.5 – 9.0	Strongly alkaline
> 9.0	Very strongly alkaline

Total nitrogen (N)

Nitrogen is an important macronutrient which is essential for plants. N plays an important role in biochemical and physiological functions of plants that affect plant growth and development which influence productivity and yield. N is an essential constituent of protein in plants that build from amino acids. N is also a major part of the chlorophyll molecule and it is therefore necessary for photosynthesis. In addition to application of chemical fertilizers, N is derived from soil organic matter through mineralization. Management practices that enhance SOM and nitrogen fixation improves N in soil.

Table 3. Total nitrogen rating (Kjeldahl) based on Metson (1961)

Total nitrogen	Ranking
< 0.05	Very low
0.05 - 0.125	Low
0.125 - 0.225	Medium
0.225 - 0.30	High
> 0.30	Very high

Available phosphorus (P)

Phosphorus is one of the macro nutrients that are vital for plant growth. P is involved in several key plant functions, including energy transfer, photosynthesis and nutrient movement within the plant. Deficiency of phosphorus affects not only plant growth and crop yield, but also the quality of the formation of seeds. Phosphorus occurs in soil both in organic and inorganic forms. Management practices that reduce soil erosion prevents phosphorus loss.

Table 4. Available Phosphorus rating (Olsen) based on Metson (1961)

Available P (mg/kg)	Rating
< 5	Very low
5 - 10	Low
10 - 15	Moderate
15 – 20	High
> 20	Very high

Potassium (K)

Potassium is another macro nutrient that is essential to plant growth and development. K is associated with movement of water, nutrients, and carbohydrates in plant tissue. K also improves drought resistance of plants by improving root growth. K reduces water loss and wilting of plants by maintaining turgor pressure which is the force within plant cell that pushes the plasma membrane against the cell wall. Because K is needed in photosynthesis and the synthesis of proteins, plants lacking K will have slow and stunted growth that affects productivity.

Table 5. Potassium rating (Mehlich-3) based on Metson (1961)

Available K (mg/kg)	Rating
< 50	Very low
50 - 100	Low
100 - 250	Medium
250 – 450	High
> 450	Very high

2.7. Vegetation and biomass productivity indicator

Normalized difference vegetation index (NDVI) is one of the commonly used proxy indicator of biomass production and detect vegetation change. NDVI is conducted through analysis of satellite images using the Red and near-infrared (NIR) bands of the electromagnetic spectrum. NDVI is a measurement of the balance between energy received and energy emitted by plants. Plants have different reflectance nature on Red and NIR wavelength range. On the visible wavelength range, leaf pigments determine the reflective characteristics of the plant. If a plant is healthy, the chlorophyll present in the leaves will absorb the energy and hence the reflectance level will be low. Generally, healthy and dense vegetation will absorb most of the visible light that falls on it to use it in photosynthesis. The healthier leaves a plant has, the more visible wavelength of the electromagnetic spectrum will be absorbed by plants.

On the NIR wavelength range, cell/leaf structure determine the reflective characteristics of the plant. The internal structure of healthy leaves due to the presence of chlorophyll act as good reflectors of NIR wavelengths. Therefore, healthy vegetation reflects a large portion of NIR.

Based on these principles, NDVI is calculated as:

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)}$$

Where; NIR = Near Infrared

Red = Red band in the visible wavelength

NDVI values range between -1 and 1 where a value close to -1 corresponds to deep water and value close to 0 indicates absence of vegetation. NDVI value approaching 1 indicates temperate and tropical rainforests. The NDVI has shown consistent correlation with vegetation biomass and dynamics in various ecosystems worldwide (Pettorelli *et al.*, 2005).

2.8. Empirical Review

This section will provide empirical reviews on benefits gained from of adopting CSA practices.

A research done by CIMMYT in Malawi showed that conservation agriculture improves productivity and profitability of smallholder farmers while also enhancing their resilience to climate change. After years of trials on farmers' fields, it was found that maize yield showed 11-70% increase. It was also seen that the soil structure of experiment fields improved with less disturbance.

Between 1999 and 2003 at the Jima, Bako and Melkasa research centers, research done on maize, sorghum and teff showed that conservation tillage plots gave higher yields compared with the conventional tillage (Tesfa, 2001; FAO, 2016). The studies also indicated lower production costs for conservation agriculture fields. Baker *et al.*, (2007) estimated that the conversion of all croplands to conservation tillage globally could sequester 25 Gt C over the next 50 years. This is equivalent to 1 833 Mt CO₂-eq per year, making conservation tillage among the most significant opportunities from all sectors for stabilizing global GHG concentrations (FAO, 2016).

A 20-year study in south western Nigeria (Vanlauwe *et al.*, 2015) showed that When NPK fertilizers and organic inputs were combined maize grain yields were between 0.26 and 2.4 ton per hectare greater than as compared to when the same inputs were applied separately. This study also showed that in the ISFM system maize grain yields remained well above 2 ton per hectare after 10 years of cultivation displaying the role of ISFM in achieving sustainable intensification. In the same study, in trials where fertilizers and organic inputs were combined, the production of maize crops were significantly less impacted by oscillations in weather conditions strengthen the resilience of crops to climate change impacts.

A study conducted by Tadele *et al.*, (2014) about the combined effect of soil bund with biological SWC measures in the Northern West Ethiopia highlands revealed that soil bunds combined with elephant grass reduced soil loss and runoff by 63% and 40% respectively compared to untreated control plot. The same study also revealed that, SWC structures with elephant grass reduced soil loss and runoff by 43% and 28% respectively than soil bunds alone.

The reviews clearly showed that CSA is proven to be beneficial in terms of improving crop production and in some cases in building resilience. But there is the need to do more research to strengthen the existing knowledge base and to explore other dimensions of benefits.

2.9. Conceptual Framework

CSA is an integrative approach to address challenges of food security and environmental sustainability. CSA have three interlinked pillars of improving productivity, adaptation to building resilience and enhance carbon sequestration and reduce emission where possible. Addressing one pillar have co-benefit on the other. Improving productivity increases HH incomes that improves the adaptive capacity of farmers to climate risks. With improves adaptive capacity, farmers become more resilient. CSA also focuses on sustainable practices to maintain and enhance ecosystem services that would be resilient to climate change.

The mitigation pillar of CSA aims at reducing and/or removing GHG emission whenever and wherever possible. CSA involve practices that reduce deforestation and manage soils in ways that maximize their potential to act as carbon sinks. Reducing further emission and removing GHG from the atmosphere by enhancing carbon sinks, reduce and reverse the negative implications of climate change on ecosystems and productivity on the long run. Reducing GHG

emission is also relevant with the Nationally Determined Contributions (NDCs) adopted at Paris agreement in 2015. NDCs embody efforts by each country to reduce national emissions and adapt to the impacts of climate change.

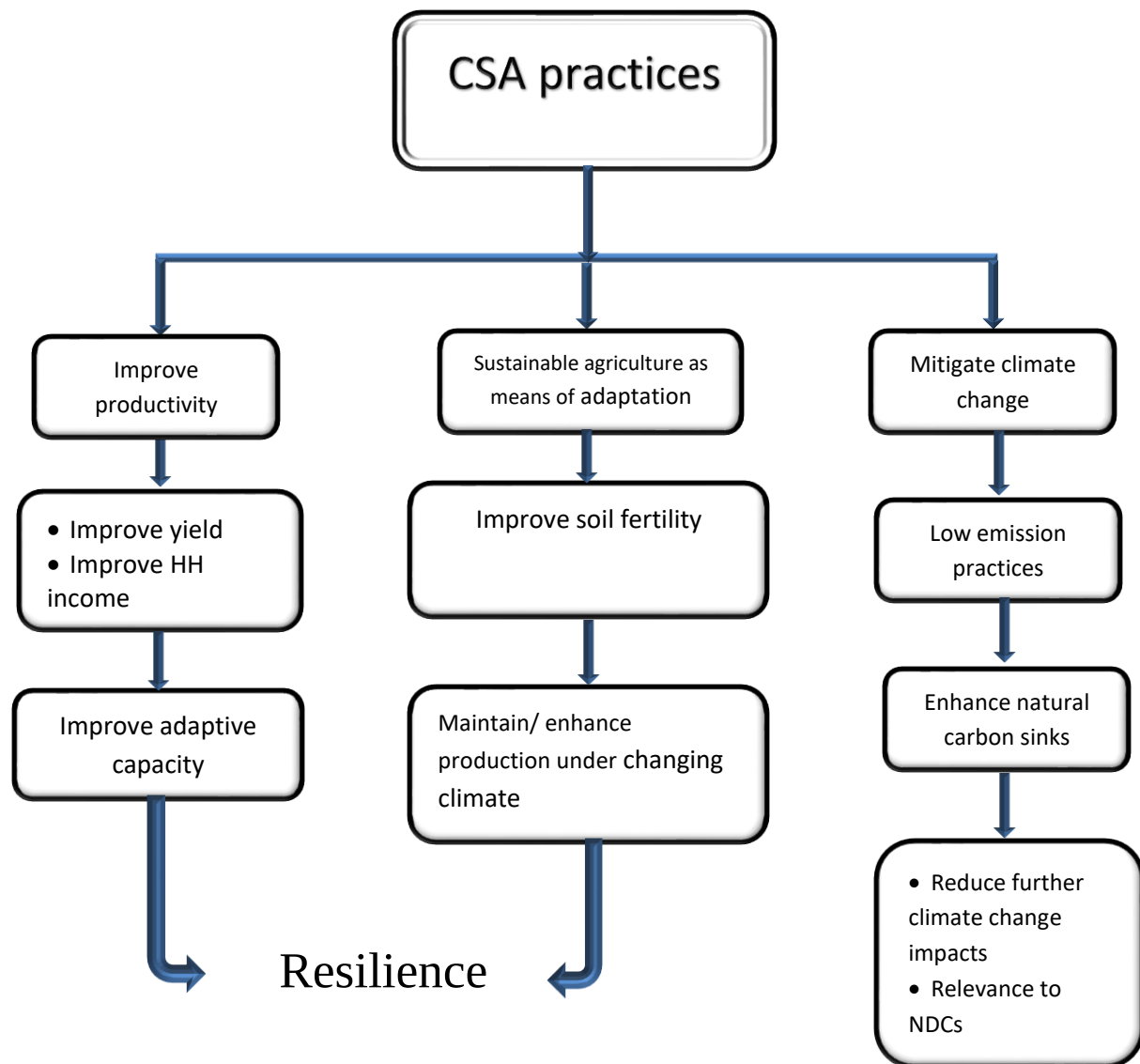


Figure 1. Conceptual framework of CSA (Modified from CSA manual to fit this study context)

CHAPTER THREE

RESEARCH METHODS

3.1. Description of the study area

3.1.1 Location

Tula-Jana watershed is located in Kembata Tembaro zone, SNNPR of Ethiopia. Geographically it is located at 7° 18' 14" north-latitude and 37° 46' 28" east- longitude. Tula-Jana watershed is about 270 km from Addis Ababa in the southern part of Ethiopia.

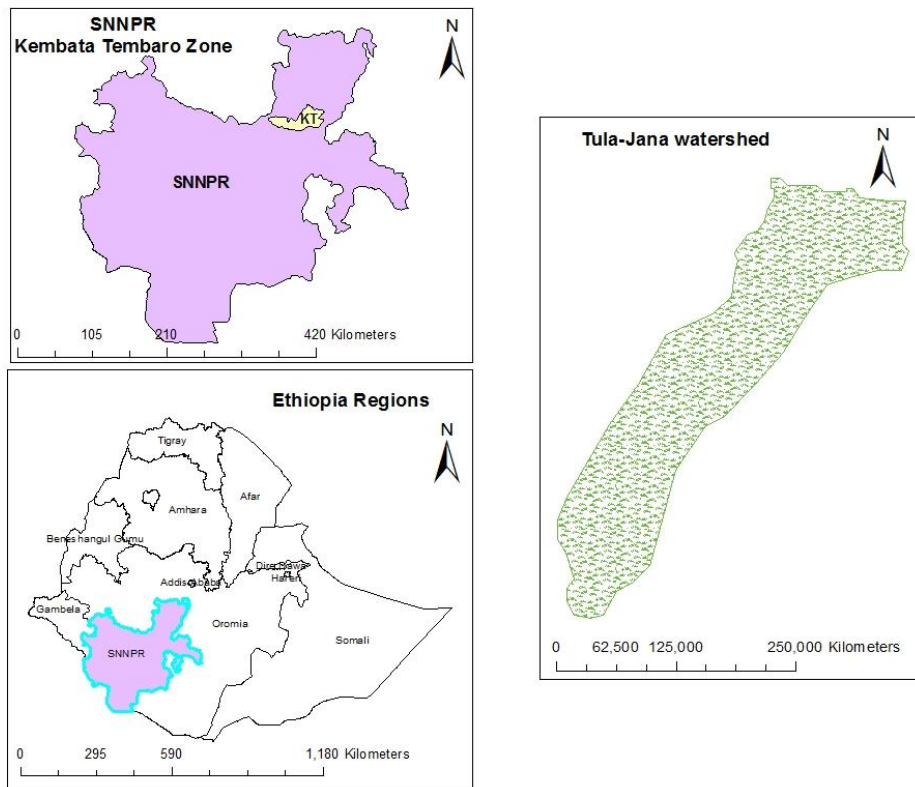


Figure 2. Map of Tula-Jana watershed, Kembata Tembaro Zone.

3.1.2 Climate and Topography

The district where the Tula-Jana watershed is located has a mean annual minimum and maximum temperature of 12.6°C and 20°C respectively. The mean annual rainfall of the district ranges from 1,001 – 1,400mm. There are two rainfall seasons in the area; Belg (the short rainy season) from January to March and Meher (main rainy season) from June to October. Tula-Jana watershed is a highland with altitude ranging from 2420 - 2740 meters above sea level. The agroclimatic zone of the area falls in “dega” (cool zone) classification (source, SNNPR Bureau of Finance and Economic Development, 2017).

3.1.3. Farming and Livelihood Systems

The main economic activity in the study area involves mixed farming system with enset- cereal - livestock production. The main types of cereal crops grown in the area are wheat and barley. Legumes and vegetable like faba-bean and potato are also grown. Enset (*Ensete ventricosum*) which is an important source of food is grown in the area by almost all households. Livestock production includes cattle, sheep and poultry. Agriculture is the main means of livelihood for the community. The majority are subsistence farmers with an average land size of 0.5 ha. According to USAID livelihood profile 2005, the main source of income for the Kembata Tembaro zone is sale of wheat, pulses, potatoes, livestock & livestock products, and rural/urban laboring.

3.2. Research Design

This study employed both qualitative and quantitative research approaches with quasi experimental research design. The research engages a comparative analysis between CSA adopters and control/BAU baseline scenario where years of intervention is zero. Descriptive and inferential statistics were used to analyze and present the collected data.

3.3. Data Source

The study used both primary and secondary data. Primary data was collected through soil survey, household (HH) survey, key informant interviews and field observations to assess the effects of CSA practices on soil fertility and productivity.

Secondary data was collected from relevant governmental and non-governmental offices to obtain information about production trend, fertilizer recommendation and extent of CSA

adoption. In addition, different and relevant published and unpublished reports, bulletins and websites has been reviewed to strengthen the study.

Satellite images were downloaded from Landsat 4-5 Thematic Mapper (TM) Level 1 and Landsat-8 to driver NDVI and use it as a proxy to productivity.

3.4. Data collection techniques and sample size

3.4.1. Soil survey

Reconnaissance survey was conducted across the landscape to get an overview of the area and to select sampling sites. Purposive and random sampling methods were used while conducting the soil survey. Purposive sampling was used to identify the selected intervention times i.e. 0-year/BAU, 3 years, 6 years and 10 years of intervention. Random sampling was employed to collect samples from the selected intervention times based on the researcher and an expert judgement. As baseline data was not available, control has to be established for the comparative analysis. In this case, two types of control were established i.e. BAU, where land is managed in a conventional way and year of intervention is zero and initial scenario where the soil is undisturbed for many years. For BAU, samples were taken from nearby kebele of similar socio-economic and geographical characteristics with the study area but less CSA approach. For initial scenario, composite surface samples were taken from a church compound where the soil is undisturbed for more than forty years.

To further investigate the soil fertility and soil carbon status across different land cover types, samples were taken from agroforestry, grassland and community forest to analyze CSA soil fertility and soil carbon status compared to other land cover types.

For sampling, soil profiles were dug to take samples from 3 depth, 0-15cm, 15-45cm and 45-100cm. 1m width by 1m depth holes were dug to take the soil profile samples. The 0-15 cm range was used to represent the 'plough' layer.

To make the samples representative, 3 soil profiles were made, 1 from top slope, 1 from middle and 1 from foot slope. Composite surface samples were also taken in addition to the profile samples and therefore, a total of 76 samples were collected.

BAU



CSA intervention

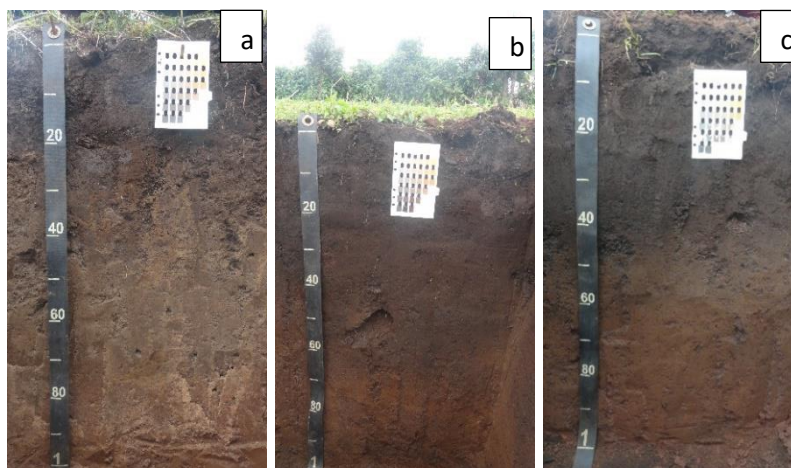


Figure 3. Sample pictures of soil profiles (a- 3 years intervention, b- 6 years intervention and c- 10 years intervention)

The collected samples were put into clean plastic bags and labeled before sending for laboratory analysis. The soil samples were analyzed in laboratory for Soil Organic Matter (SOM), Bulk density (BD), pH, Total nitrogen (N), available Phosphorus (P) and extractable plant nutrients.

3.4.2. Household survey

HH survey was conducted to assess the socio-economic characteristics of the study area and to assess if there is a significant difference in production between BAU and CSA adopters. The HH

survey was also used to assess sustainable agricultural practices undertaken in the area. Farmers' perception of CSA which is key for the sustainability of CSA practices beyond project years was also assessed by the survey.

The HH survey was also used as an input for the carbon tool used to estimate the mitigation potentials of adopting CSA. Random sampling method was employed in selecting HH for survey within the watersheds. Time of intervention was not considered in the socio-economic analysis as it was time and resource consuming. Semi-structured questionnaire was used to gather the relevant information from households.

In the two watersheds, Tula and Jana, there are a total of 470 HH. In Serara Bokata/BAU group, there are a total of 105 HH. Therefore, there are a total number of 575 households for this study.

Using Cochran's formula, the sample size was calculated as

$$n_o = \frac{z^2 pq}{d^2} \qquad n = \frac{n_o}{1 + \frac{n_o - 1}{N}}$$

Where;

n_o is the desired sample size when the population is greater than 10000

n is number of sample size when population is less than 10000

z is 95% confidence limit i.e. 1.96

P is 0.1 (proportion of the population to be included in the sample i.e. 10%)

q is 1-p i.e. (0.9)

N is total number of population

d is margin of error or degree of accuracy desired (0.05)

Using this formula, the sample size was calculated as

$$n_o = \frac{(1.96^2) * 0.1 * 0.9}{(0.05^2)} = 138$$

The sample size n was calculated for the two groups as;

$$n(csa) = \frac{138}{1 + \frac{138-1}{470}} \approx 110 \quad n(BAU) = \frac{138}{1 + \frac{138-1}{105}} = 59$$

A total of 200 sample size was taken considering 15% non-response rate; 140 CSA adopters and 60 BAU was considered for the HH survey.

3.4.3. Key Informant Interview

Key informant interview was conducted with the district Inter Aide Project coordinator and development agents. With the interview issues of main CSA practices undertaken in the area, seen improvements, recent CSA technologies being introduced, agricultural inputs and production challenges were discussed.

3.4.4. Field Observation

The field observation was used to observe and validate the collected information. With field observation physical and biological soil and water conservation measures and good practices like crop residue management and restricted grazing practice were observed and validated. The field observation was also beneficial in acquiring new information of hedgerow planting practiced by CSA adopters.

3.5. Data analysis

3.5.1. Descriptive and Inferential Statistics

The data obtained from soil survey, HH survey, key informant interviews, field observation, discussion with farmers and secondary data were analyzed and discussed using both qualitative and quantitative analysis methods. Descriptive and inferential statistics using statistical package for the social science (SPSS) version 23 was used to analyses the data from HH survey. The soil survey data was analyzed and presented with graphs and tables. The other data collected are discussed and narrated where fit. With descriptive statistics, percentage, standard deviation (SD) and mean values were analyzed. Independent samples t-test were conducted to determine if there is a significant difference in fertilizer use and yield between the two groups.

3.5.2. Time series NDVI analysis

Time series NDVI analysis was conducted to investigate the change in vegetation dynamics of the study area. For the analysis, high resolution satellite images were obtained from Landsat TM 4-5 and Landsat 8 for the year 2010, 2014 and 2017.

Table 6. Satellite image accusation information

Sensor	Sensor ID	WRS Path and row	No of bands	Pixel size	For year	Acquisition date
Landsat 4-5	TM	P 169 r 055	7	30m X 30m	2010	Dec 15, 2010
Landsat 8	OLI-TIRS	P 169 r 055	11	30m X 30m	2014	Dec 11, 2014
					2017	Dec 3, 2017

Source: Downloaded from <http://glovis.usgs.gov/>

In the study watersheds, there are two watersheds, Tula and Jana. At Jana watershed, CSA was introduced starting from 2006 but for most part of the watersheds, CSA was introduced starting from March 2012 and hence, the year 2010 was chosen to see the vegetation index before CSA intervention in most parts of the area. The image from 2014 represents two years after CSA and the 2017 image represents current condition and time effect of CSA. For satellite images obtained from Landsat TM 4-5, band 3 and band 4 were used as Red band and NIR band respectively. For images obtained from Landsat 8, band 4 and band 5 was used as Red band and NIR band respectively.

The NDVI values were categorized into four land cover types. Even though there is no distinct NDVI value boundary for each land cover type, the most likely classification made by Weier *et al.*, (2000) was used to make the classifications. Google earth and reference points taken from field were used to associate the classified categories with the ground truth. And therefore, for the purpose of this study, NDVI value of < 0.1 represent bare soil, $0.1 - 0.2$ - sparse vegetation, $0.2 - 0.4$ - grass and > 0.4 - dense vegetation.

3.5.3. Soil property analysis

The soil property analysis was conducted at Horticoop Ethiopia soil and water analysis laboratory. Different soil analysis standards were employed for the different soil parameters.

The pH of the soil was measured in the supernatant suspension of a 1:2.5 soil to liquid mixture. The liquid used for the analysis was 1 M KCl solution (unbuffered).

For Soil organic matter, Walkley-Black method was used which is based on the oxidation of organic matter by potassium dichromate ($K_2Cr_2O_7$)-sulfuric acid mixture followed by back titration of the excessive dichromate by ferrous ammonium sulfate ($Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$).

For bulk density, oven dry method was used. The moisture content and soil bulk density were calculated as:

$$\text{Moisture content (g/g)} = \frac{(\text{weight of moist soil} - \text{weight of oven dry soil})}{\text{weight of oven dry soil}}$$

$$\text{Soil bulk density (g/cm}^3\text{)} = \frac{\text{oven dry weight of soil}}{\text{volume of soil}}$$

Total nitrogen was analyzed using the Kjeldahl method which involves 3 procedures. **Digestion**, a process in which the sample is digested in boiling concentrated sulfuric acid, with the addition of a catalyst, until complete dissolution and oxidation. After this process, the nitrogen contained in the sample becomes Ammonium Sulfate.

Distillation, a process where excess sodium hydroxide solution is added to release the ammonium ion to ammonia form then distilled and received on a boric acid solution or a sulfuric or hydrochloric acid volumetric solution.

Titration, where the ammonia is determined with a volumetric acid solution or by back titration with sodium hydroxide solution of a known concentration if it was received on hydrochloric or sulfuric acid.

Available phosphorus was analyzed using Olsen method which involves extraction of P using alkaline sodium bicarbonate (pH 8.5) solution and determine the P concentration in the extraction.

Mehlich-3 method was used to determine extractable plant nutrients including sulfur (S), boron (B), potassium (K), calcium (Ca), magnesium (Mg) and sodium (Na).

3.5.4. Carbon analysis

To analyze GHG emissions and carbon sequestrations arising from adopting the introduced agricultural practices and to investigate the mitigation potentials of the study area, CCAFS-MOT (Climate Change, Agriculture and Food Security-Mitigation Options Tool) was used. CCAFS-MOT is an Excel based tool that estimates GHG emissions and sequestrations as well as calculates the mitigation potentials of an area if sustainable agricultural practice were to be adopted. The tool brings together several empirical models to estimate GHG emissions in rice, cropland and livestock systems, and provides information about the most effective mitigation options. In this tool, GHG emissions are estimated in terms of carbon dioxide equivalent per hectare ($\text{kg CO}_2\text{eq ha}^{-1}$) and carbon dioxide equivalent per unit of product ($\text{kg CO}_2\text{eq kg}^{-1}$).

3.6. Ethical consideration

While collecting data, the researcher explained the purpose of the study for respondents and also the community in general. The researcher under no circumstances gave false hope about the outcomes of the research. The culture and values of the community was respected while collecting data and any act that might provoke the cultures and values of the community was avoided. Also, the identity of respondents was and will be kept confidential.

CHAPTER FOUR

Results and Discussions

This chapter presents the analysis and discussions of the main findings of the study in relation to the research questions. The first section describes the demographic and socio-economic characteristics of the HH heads in the study area. This sub-section has been presented and discussed using descriptive statistics. The climate smart technologies adopted in the study area are covered in section two. Section three deals with the effects of CSA on soil fertility. In this section the laboratory results are analyzed and discussed. The effects of CSA on productivity is covered in the fourth section. Descriptive and inferential statistics are used to discuss the research findings. The perception of farmers towards CSA and the mitigation co-benefits are discussed in section five and six.

4.1. Demographic and Socio-economic characteristics of the HH heads

The basic demographic and socio-economic characteristics of HH heads including sex, age, education level and family size were analyzed. Agriculture is the main source of livelihood for the area. Some demographic characteristics like age of HH head and education level could have implications on land management and production but the analysis indicates that the two groups have similar characteristics. The average land holding size by both groups also shows no significant difference.

4.2. Climate Smart technologies adopted

Climate smart practices and technologies are essential components of climate change adaptation and mitigation. As the world food demand is growing, increasing food production is being conducted by expanding agricultural lands at the cost of forest and other land uses. Adoption of climate smart technologies provides opportunities to increase productivity while reducing adverse impacts on the environment. CSA incorporates not only conservation structures but also good practices that enhance the agricultural ecology to ensure the sustainability of agriculture for the next generation. The agricultural practices of CSA adopters and BAU in the study area was assessed in terms of crop management, SLM and livestock management.

4.2.1. Crop Management

As crop management practices, fertilizer and pesticide use, use of improved seed varieties, row planting and crop rotation were analyzed. The result of the analysis is summarized in Table 7.

Table 7. Crop management practices

<i>Crop management</i>	<i>CSA</i>	<i>BAU</i>
	n = 140	n = 60
<i>Fertilizer use</i>	100%	100%
<i>Pesticide use</i>	98.5%	95.9%
<i>Improved seed varieties</i>	97.9%	89.8%
<i>Row planting</i>	100%	98%
<i>Crop rotation</i>	99%	98%

From the table, the percentage of fertilizer and pesticide use by both groups is similar. To determine if there is a change in the amount of fertilizer used (DAP and UREA), independent samples t-test was conducted but the result did not show a significant difference between the two groups. Regarding the type of fertilizer used, 90.8% of CSA adopters and 95.9% of BAU use synthetic fertilizers while 9.2% of CSA and 4.1% of BAU responded use both synthetic and organic fertilizers. Even though the use of organic fertilizer is low by both groups, CSA adopters tend to use relatively more organic fertilizer than BAU.

Regarding the use of improved seed varieties, the survey indicates that 97.8% farmers in intervention area and 89.8% of BAU use improved seed varieties. This figure shows that there is 8.73% difference in improved seed use that might have implications in crop yield.

Crop rotation which is an important element of sustainable agriculture is exercised by both groups. Further investigation was conducted to discover which crops farmers rotate. The most commonly rotated crops by both groups is wheat with potato. However, 35.2% and 29.8% of

CSA adopters responded to rotate wheat with faba bean and barley with faba bean respectively while none of the farmers from BAU responded to rotate these crops. legumes fix nitrogen through their symbiotic association with nitrogen fixing bacteria that improve N content in the soil. Therefore, use of legumes in crop rotation like wheat/barley with faba bean will have positive implications on soil fertility and crop productivity.

4.2.2. Sustainable Land Management (SLM)

SLM technologies being practiced in the area were analyzed from collected questionnaires and field observation. The mainly identified SLM practices include soil and water conservation structures, biological measures on SWC structures, crop residue management and hedgerow planting.

Soil and Water conservation structures with biological measure

Soil and water conservation is crucial in areas with steep topography and high rainfall like Tula-Jana watershed to control and reduce land degradation and maintain the productive capacity of the area. Integrating physical SWC structures with biological measures provides multiple benefits including reduce soil erosion, improve water absorption and fodder production. In this regard, almost all farmers in intervention area, 97.4% have physical SWC structure of which 95.9% are covered with vegetation/grass. Soil bunds are the main types of SWC structure adopted in the area. Soil bunds are embankment and ditch structures that are constructed along a contour to slow down the speed of rainwater and catch sediment that has been eroded uphill.

Desho grass (*Pennisetum pedicellatum*) and elephant grass (*Pennisetum purpureum*) are the main types of grass grown on soil bunds. Desho is an indigenous perennial grass that is highly palatable and nutritious for livestock. It has a high biomass production capacity 30 - 109 t/ha (Ecocrop, 2010). Desho is also praised for its extensive rooting system that stabilizes SWC structures. The characteristics of Elephant grass including rapid growth, stress tolerance and high biomass yield made it favorable for adoption.

In addition to stabilizing SWC structures and providing fodder for livestock, Desho and elephant grass provides small business opportunity for farmers. From discussion with farmers, grass from 4 meters soil bund is sold for 50 birr on average.

The project document in the study area reveals that until 2015, a total of 1896 km of soil bunds covered with vegetation has been constructed.

Table 8. Constructed soil bunds with vegetative measures in the Tula and Jana

Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Km	454	603	780	986	1159	1239	1443	1594	1884	1896

Source: Inter Aide site report (2015)

To ensure the sustainability of adoption, micro nurseries to propagate vegetative materials by farmers has been established at farmer's backyards. This address the limitation of having access to fodder grass seed. It also ensures the survival and renewal of grass on soil bunds. The project document indicates that 95.4 % of farmers in the specific study area have farm-based micro nurseries.

At BAU 57.1% have SWC structures on their cropland. However, the SWC structures are not properly maintained and only 4.1% have biological measures.

Crop residue

Crop residue management is one of the key components of sustainable agriculture essential to enhance SOM. The result of the survey indicates that 67.9% CSA adopters and 18.4% of BAU leave crop residue on their farm. The crop residue is latter incorporated with the soil while cultivating the land. The availability of fodder for livestock from SWC structures provided the opportunity for farmers in CSA intervention area to leave more crop residue on their croplands.

Hedgerow planting

During field observation, which was later confirmed by key informant interview, it was observed that farmers practice hedgerow planting during production seasons. "Sinar" (oat grass) and Vetch grass is planted at the sideway of the cropland. The main purpose of the hedgerow planting is to reduce soil erosion and biomass production for livestock.

Cover crop

The survey reveals that 11.2% of CSA adopters use cover crop on their farm. Cover crop introduction is being carried out as a pilot project with vetch and lupin varieties. So far 13.6 ha

has been covered with cover crops and the project is working to significantly increase this number by the next project year. As the number of users and area covered is small, cover crop introduction might not have significant implication by the current number. However, when the pilot project is scaled, it will bring multiple benefits including improve soil organic matter, improve soil structure and add nutrients to the soil. Shortage of organic matter was one of the constraining factors mentioned by farmers for using organic fertilizers. The introduction of cover crops will add better green manure to the soil in the near future. The general overview of BAU and CSA is shown in figure 4.

BAU



CSA



Figure 4. CSA and BAU scenario at a glance

4.2.3. Livestock Management

The main type of livestock in the area include, ox, cow and sheep. In addition, donkey and horses are also owned by farmers. Farmers rear these livestock for the purpose of draught power, milk, meat, transportation and for market as a means of getting additional income.

The main source of livestock feed in CSA intervention area is cut-and-carry system. 94.4% of farmers in CSA intervention area use grass from SWC structures to feed their cattle. Farmers also use straw and enset leaves as feed during dry seasons and in between fodder harvest period. Also, during milk production periods, 20.9% of farmers buy wheat bran “fureshka” as a supplement for their cows. The survey indicates that 4.6% of the farmers still use free grazing as means of feeding their livestock.

Restricted grazing is one of climate smart technology being adopted in CSA intervention area. During field observation, it was observed that, the cattle spend the day in a house compound or in private grazing area tied (see figure 5).



Figure 5. Restricted grazing practice at CSA intervention area

Idir, which is a social institution is playing a vital role in enforcing the restricted grazing rule. Social institutions like, Idir are established laws, customs or practices by the local society. The IPCC on the Fourth assessment report pointed the importance of social institutions as a regulatory body for effective interventions. Idir has social legitimacy and respect by the community in the study area. This social institution plays mediating role and provide enabling environment for implementing CSA technologies. Not only free grazing is banned, but also farmers are expected to report to Idir if they see free grazing especially in croplands. This act of social sanction is enabling the effective implementation restricted grazing.

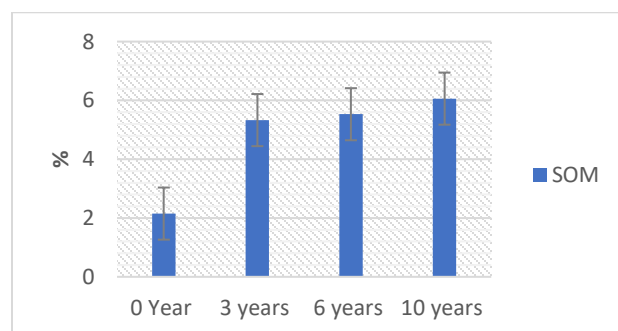
The above figures are entirely different at BAU. Free grazing is the means of feeding livestock by 40.1 % of farmers. Only 4.1% use cut and carry system and there is also heavy dependence on straw and ensiled leaves as source of food for livestock. The high dependency on straw weakened crop residue left on crop fields. It also puts pressure on ensiled potentially reducing its productivity and the ecological benefits including soil fertility and carbon sequestration. 22.4% of the farmers also buy wheat bran “fureshka” to feed their cattle.

4.3. Effects of CSA on Soil fertility

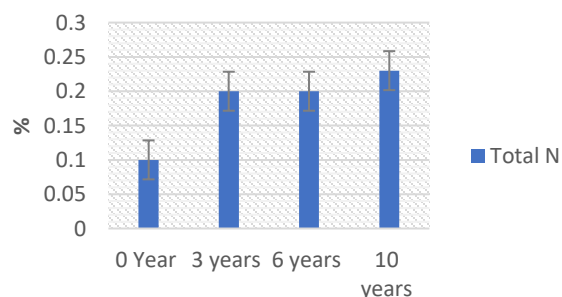
The soil fertility status of CSA intervention area was analyzed with regards to intervention time and in comparison, with other land use types.

Four intervention times i.e. 0 year (BAU), 3 years, 6 years and 10 years were under consideration for the time analysis.

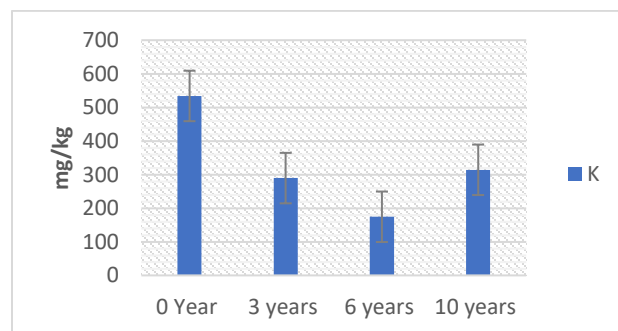
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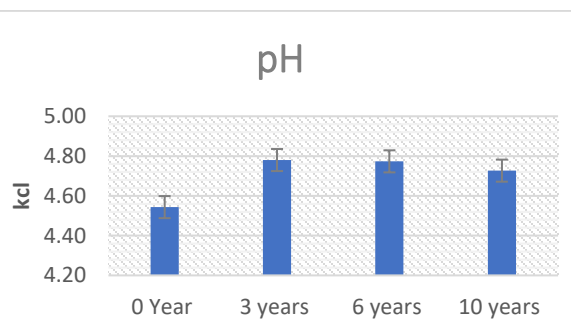
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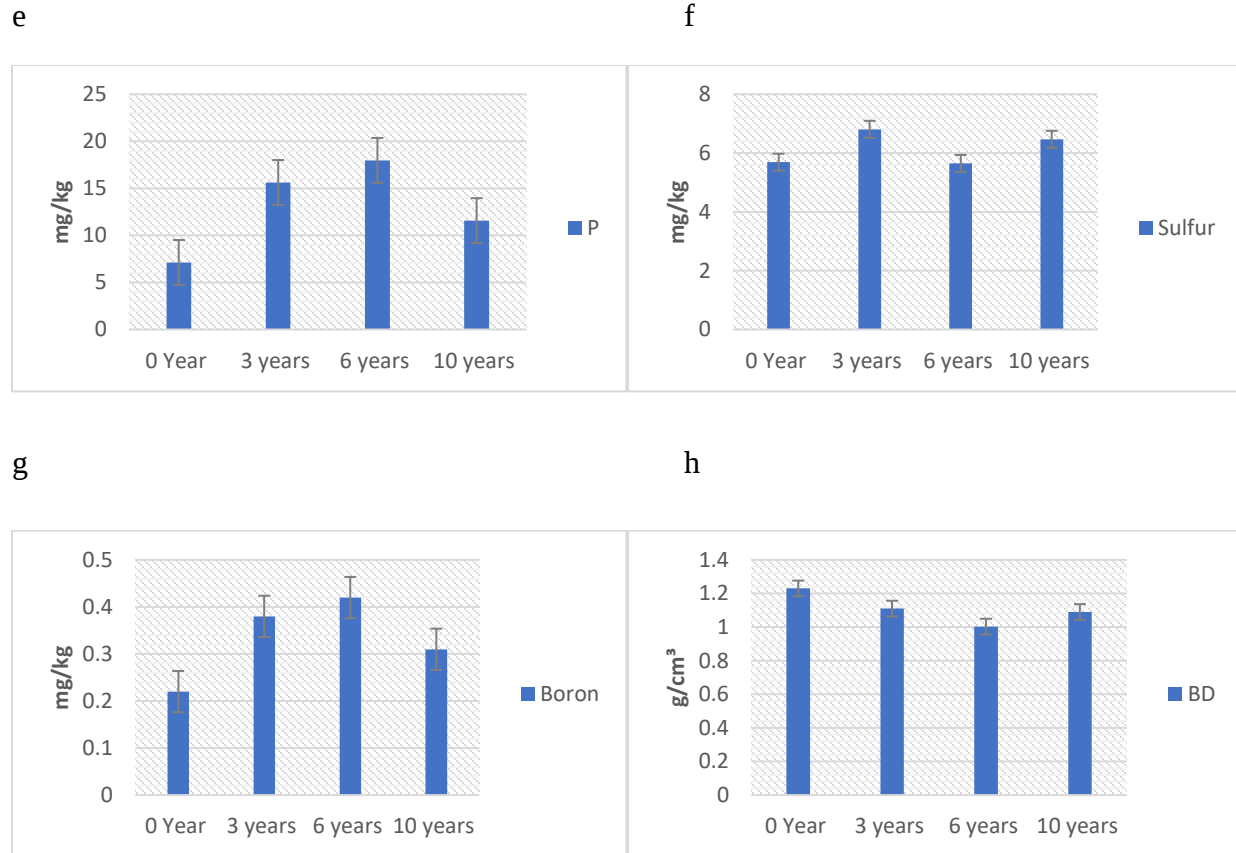


Figure 6. Change in selected soil fertility indicators for surface samples (a. SOM, b. total nitrogen, c. potassium, d. pH, e. phosphorus, f. sulfur, g. boron, h. bulk density)

The result of the analysis indicates that, the implemented CSA technologies have positive effects mainly on bulk density, pH, SOM and total nitrogen. For instance, the soil under CSA intervention have more than double the amount of SOM than BAU. The result also indicates that SOM tends to slightly improve over time. The SOM in soil under BAU is low (2%) while the soil under CSA intervention is rated high for 3 years and 6 years of intervention (5.33% and 5.53% respectively) and very high for 10 years of intervention (6.06%).

SOM is closely associated with soil fertility and bulk density. Organic matter is one of the natural sources of plant nutrients. In addition to nutrient provision, organic matter also promotes better aggregate stability and water holding capacity. In general, soils with high SOM have lower BD. As a result, the bulk density of the soil showed improvement over intervention. Soil with lower BD will have better root growth, aeration and water movement that will have impact on

crop yield. BD also improves water infiltration that reduce runoff and erosion in slopping areas similar to the study area.

The result also shows that plant nutrients such as nitrogen, phosphorus and boron and extractable plant nutrients including calcium (Ca), Magnesium (Mg) and Iron (Fe) that are essential for plant growth and productivity showed improvement with intervention. Nitrogen which is one of the most essential nutrient for plant growth shows improvement over intervention and time. This may be attributed to CSA practices including ISFM and crop rotation with Faba bean.

The above result is in agreement with farmers perception of soil erosion and loss of soil fertility as production constraints. 80.6% and 66.3% of the farmers responded that soil erosion and loss of soil fertility is not a production constraint in their farmland. The implemented CSA technologies including SWC structures with biological measures, crop residue management, hedgerow planting etc. reduced the soil erosion and added organic matter to the soil that is having positive implications on the soil fertility.

The fertility status of soil under CSA intervention was compared with other land uses using initial scenario as a baseline with surface samples. This analysis was used to determine SOM content of soil under the management of cropland, agroforestry, grassland and community forest. The different land use managements were compared to an initial scenario where the soil is undisturbed for a long period, in this case forty years. The result shows that agroforestry have the highest amount of SOM (9.1%) even better than the initial scenario (7.8%) while BAU have the lowest SOM.

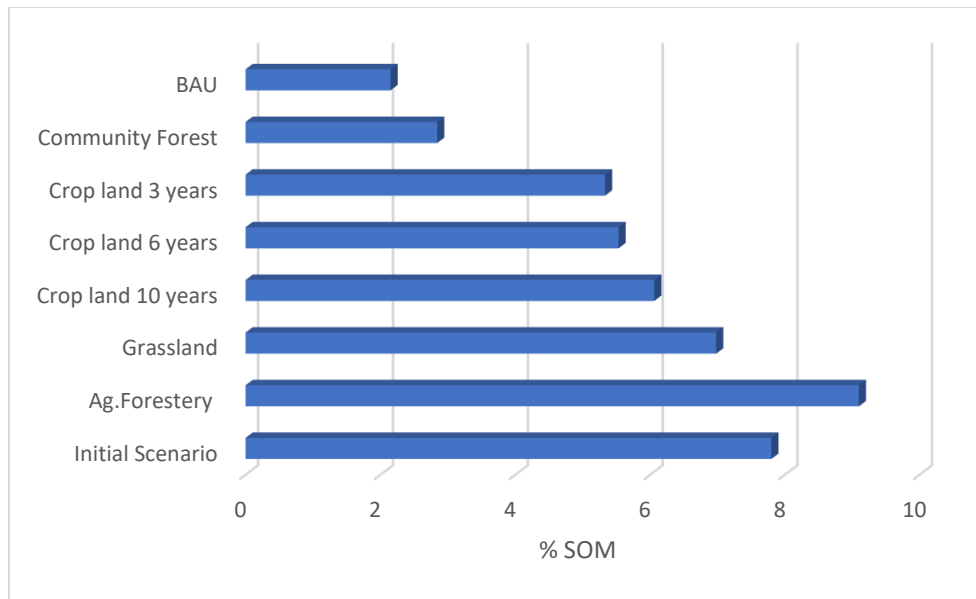


Figure 7. Soil fertility status across other land uses for surface samples

The agroforestry system in the study area mainly involve enset plantations with vegetables like potato, cabbage, carrot, beetroot and garlic. enset is a multipurpose perennial crop with high biomass production. enset have highly decomposable parts like the leaf, pseudo stem and the core that add organic matter to the soil. Also, enset benefits from organic matter addition from livestock manure and domestic waste.

Next to the agroforestry system, the initial scenario presented the highest SOM content. When soil remains undisturbed and enclosed, the SOM and hence the SOC improves and release of carbon from soils will be significantly reduced. Soils are the largest carbon sinks and play a vital role in the global carbon cycling. The carbon stock in soils is highly vulnerable to human activity and disturbance. Land use systems such as agro-forestry, grassland and community forest that enhance the SOM and present minimum disturbance are important measures in reducing carbon release from soils and improve the soil carbon stock. So therefore, enhancing carbon sequestration by soils and storing it as SOC is a key element in climate change mitigation.

The community forest shows relatively low surface SOM content compared to other land uses. This is because the area was highly degraded until restoration started. The community forest was established in 2004 to rehabilitate the degraded land. The community forest is mainly covered with grass and young *Grevillea* trees (Figure 8).



Figure 8. Community forest at Tula-Jana watershed

The forest is located on a steep slope with no SWC work. The fact that the community forest is young, lack of SWC structures and lack of biodiversity as it is mainly dominated by one tree species could have contributed for the lower surface SOM content than usually expected. Regardless of these shortcomings, it presented a better SOM than BAU.

The SOC content of the soil at three depth, i.e. 0-15cm, 15-45cm and 45-100cm were analyzed for the different land use systems. The result indicates that the SOC content of crop land and agro-forestry are mostly concentrated at surface and sub-surface depth which makes it highly susceptible to human activity and disturbance. The amount of SOC for these land uses significantly reduces at 45-100 cm depth.

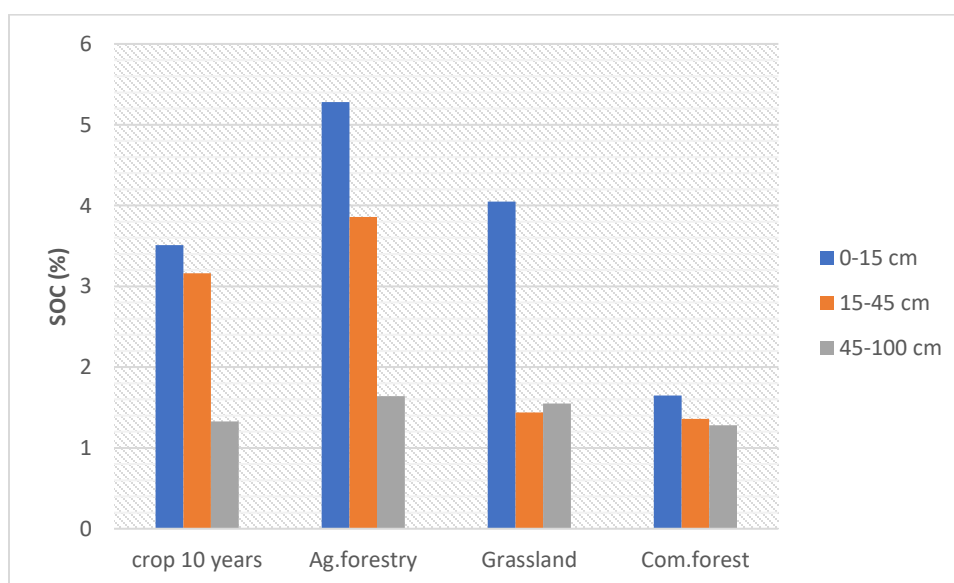


Figure 9. SOC content at different depth

On the other hand, the community forest stored a proportional amount of SOC at the different depth. Forests are important carbon sinks that sequester carbon and store it in the forest biomass and soils. The result indicates that forest are important deep carbon pools which stores carbon at higher depth that reduce soil carbon loss from surface disturbance. Soil carbon stock is rapidly decreasing due to land use change and unsustainable forest management. The result reveals that integration of trees and forest with agricultural land use system will improve the soil carbon stock.

4.4. Effects of CSA on Productivity

4.4.1. Crop productivity

The main and commonly grown crops in the study area are wheat, barley and potato. In addition, Faba bean is grown by farmers in CSA intervention area. To determine if there is a significant difference in crop yield between the two groups, independent samples t-test for the mean difference at 5% was conducted.

Table 9. Independent samples t-test for the mean difference

Crop type	Mean Value		t-value	df	p-value
	CSA (kg/ha)	BAU (kg/ha)			
Wheat	1297.88	820.00	6.65	148	0.000
Barley	933.56	632.26	4.32	110	0.000
Potato	4128.3	2288.26	7.66	141	0.000
Faba-bean	640.45	0	-	-	-

The p-values (< 0.001) for all crop types shows that there is a significant difference in crop yield between the two groups. From the mean values, it can be concluded that CSA adopters are 45.13%, 38.48% and 57.35% more productive compared to BAU for wheat, barley and potato, respectively. This comparative advantage has multidimensional benefits. Farmers can generate

more income by selling more for market that improves their adaptive capacity. For instance, on average, farmers at CSA produce 477.88 kg more wheat per hectare than BAU. At the nearest market to the study area, wheat is sold for 13 birr/kg. Therefore, CSA adopters get additional 6,212.44 birr for wheat per hectare than BAU. More production also improves their HH food status. The additional income generated can also be invested back to the production system which further improves productivity of the following season.

The two groups have similar utilization of agricultural inputs. However, CSA adopters practice better SLM which is having significant effects on crop yield. In addition to reducing soil erosion and improving soil fertility, SLM also improved the efficiency of agricultural inputs. The first pillar of CSA which is improving productivity to increase yield and HH incomes has been realized with the adopted practices in the study area.

4.4.2. Livestock Productivity

The types of livestock analyzed to compare productivity were oxen, cow and sheep. Table 10 indicates that 66.9% and 69.4% of farmers in CSA and BAU own ox. Ox is an important component of the farming system for both groups as tillage is still conducted by a pair of ox which explains the similar extent of ox ownership by both groups.

Table 10. Livestock distribution

<i>Livestock distribution</i>	<i>CSA</i>		<i>BAU</i>	
	n = 140	SD	n = 60	SD
<i>OX</i>	66.9%	0.37	69.4%	0.36
<i>Cow</i>	94.9%	0.76	59.2%	0.74
<i>sheep</i>	51.02%	1.05	24.5%	0.71

Source: own survey, 2018

To compare the livestock size of the two groups, conversion was made to Tropical livestock units (TLU) based on Storck *et al.*, (1991). Accordingly, the average livestock size at BAU is 1.21 TLU while it is 2.65 TLU at CSA intervention. This indicates that, CSA adopters are engaged with more cattle breeding compared to BAU. This is mainly attributed to the availability of forage from SWC structures with biological measures. Farmer's engagement with livestock production diversifies their livelihood options that improves resilience. Livelihood diversification, which is one component of sustainable livelihood framework, improves resilience by bringing additional income, spreading risks and strengthening recovery capacity. With this regard, CSA adopters have better adaptive capacity and resilience compared to BAU farmers.

The survey also revealed that 51.5% of CSA adopters have improved cow varieties while this figure is 14.3% at BAU. The average liters of milk per cow per day was also assessed and the result shows that CSA adopters get 2.16 lt/cow/day while BAU farmers get 1.23 lt/cow/day on average. The liters of milk per cow shows a significant difference ($t(53.26) = 4.455, p < 0.001$). Farmers explained that having an improved cow variety used to be a burden because of their high feed demand even though this varieties have better productivity. The availability of fodder encouraged farmers to breed improved varieties which mainly presented the difference in milk production as compared to BAU farmers.

Most of the livestock waste is used for home gardening and enset plantation. The survey revealed that 98% of CSA adopters that own livestock (132 respondents) use the livestock waste for homestead where vegetables and enset are grown. At BAU, this figure is not too far from CSA. The main difference emerges from the number of livestock owned. The above figures show that, on average CSA adopters own more livestock than BAU farmers. This indicates that more organic fertilizer is applied to homestead than BAU. This will have significant effects on the productivity of enset plantation and SOM of the soil as seen from soil analysis results. Even though CSA adopters have a relative advantage, farmers also revealed that they still do not have enough livestock waste to use on their croplands.

There is also a difference in animal fattening between CSA and BAU farmers. From the survey, 31.1% of CSA adopters are engaged with animal fattening while this figure is 14.3% at BAU.

Mainly oxen and sheep are fattened for market. On average CSA adopters sell 7.24 TLU per year while BAU farmers sell 2.19 TLU per year.

4.4.3. Vegetation and biomass productivity

To investigate vegetation cover change of the study area, NDVI analysis was conducted to assess the vegetation dynamics of the study area before and after CSA intervention. The analysis was conducted for 2010, two years before CSA intervention, 2014, two years after intervention and 2017 to assess the current status. The result clearly shows that there is a significant shift in the vegetation index towards green which indicate improvement in vegetation and biomass.

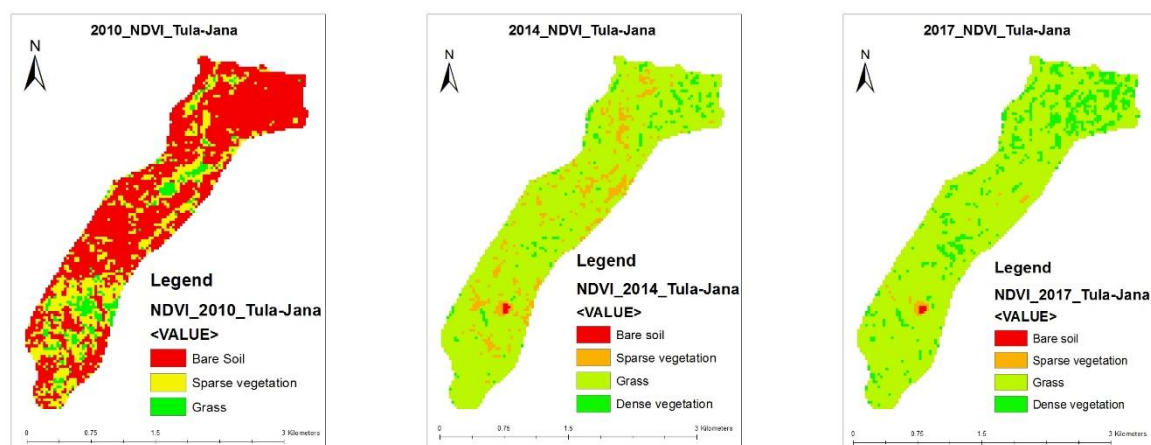


Figure 10. Time series NDVI analysis of Tula-Jana watershed

The number of pixels (1 pixel=30m X 30m) under each category was used to determine area of each category. The area and percentage of each land cover type was computed and compared for the year 2010, 2014 and 2017 to determine the change in vegetation cover. The details of the analysis are summarized in table 11.

Table 11. Area change of time series NDVI analysis

Land cover type	2010		2014		2017	
	Area (ha)	%	Area (ha)	%	Area (ha)	%
Bare soil	253.08	63.12	0.81	0.2	0.72	0.18
Sparse vegetation	98.55	24.59	35.82	8.94	3.24	0.81
Grass	49.14	12.26	347.13	86.6	343.08	85.6
Dense vegetation cover	0		17.01	4.24	53.73	13.4

In 2010, 63.12% of the area had no vegetation cover. This area reduced significantly to 0.2% in 2014. This indicates that most of the vegetation cover change occurred between 2010 and 2014. From the table, it can be seen that 86.6% of the landcover type in 2014 was shrub/grass. This is mainly attributed to the introduction of SWC structures that have biological measures. In 2010, there was no dense vegetation cover in the study area which changed to 4.24% in 2014 and 13.4% in 2017. enset planting is a longtime tradition in the study area. The land degradation and loss of soil fertility in the area was affecting the productivity of enset. Also, the lack of forage was putting pressure on enset plantation. During field survey and discussion, Farmers reported that their enset plantation is more productive and healthier which could be associated with increase in dense vegetation cover. enset is also the main beneficiary of livestock waste that enhanced the productivity. Also, from discussions with farmers, they are practicing planting of trees on cropland boundaries with tree specious like juniper, red hot poker tree (*Erythrina abyssinica*) and eucalyptus.

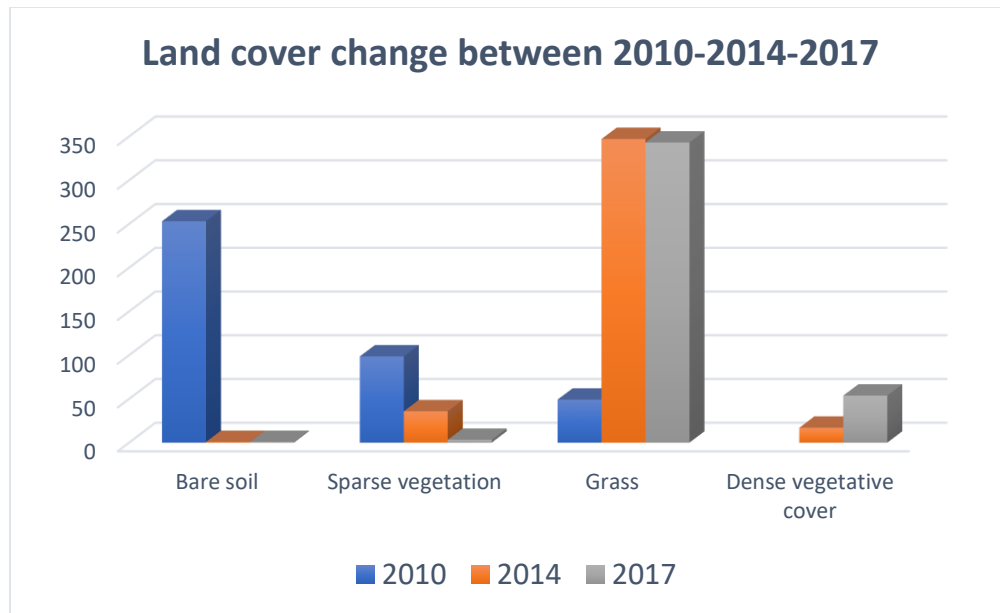


Figure 11. Vegetation change over time based on NDVI results

The above figure indicates that the biological measures on SWC structures are maintained between 2014 and 2017 as the graph does not show a significant change for grass category.

The overall vegetation dynamics of the area significantly transformed towards green which indicates that there is more vegetation and biomass which have positive implications on soil carbon stock.

4.5. Attitude of farmers towards CSA

The survey results revealed that most farmers (96.4%) have positive attitude towards CSA. Farmers perceived that CSA is making improvements on crop and livestock productivity, improve income, diversify livelihood options, HH food status and soil fertility.

Table 12. Perceived benefits of CSA by adopting farmers

<i>Perceived benefits</i>	<i>Frequency</i>	<i>Percentage</i>
<i>Improved crop productivity</i>	119	85%
<i>Improved Livestock productivity</i>	90	64.3%
<i>Improve HH income</i>	82	58.6%
<i>Diversify livelihood options</i>	80	57.1%
<i>Improve HH food status</i>	113	80.7%
<i>Improve soil fertility</i>	119	85%
<i>No improvement</i>	2	1.4%

Source: own survey, 2018

Attitude of farmers is an important element for the sustainability of adoption of CSA technologies. Perceived and measures benefits of CSA will encourage farmers to continue practicing CSA technologies beyond project years. Good perception and attitude also motivates peer learning for the adoption of technologies by other farmers.

4.6. Climate Change Mitigation co-benefits

CCAFS-MOT tool was used to estimate GHG emissions and sequestrations arising from agricultural practices in the study area. The tool requires inputs including regional information country and climate, soil information texture, soil organic carbon, nitrogen content, pH and bulk density. There is also a simplified input option for soil data requirement where default values will be used depending on soil type chosen. But since the detailed inputs required were available and to represent the study area well to its specific values, the detailed input options were used. For the tool, it is considered that there is no land use change since 89.8% of the respondents replied their land has been crop land for more than 20 years. On the second section of data input, crop for this case, there are different data requirements including crop type, crop yield (kg/ha),

crop residue management, soil management including tillage and cover crop, organic fertilizer use and synthetic fertilizer use. On the soil management practice, under tillage there are options of conventional tillage, reduced tillage and no tillage. For the analysis, reduced tillage was considered appropriate as the farmers in the area use a pair of oxen to till the land even though the land might be tilled two to three times depending on the crop type. The justification behind is, this traditional system of tillage is by no means comparable to mechanized tillage which falls under the conventional tillage category. No tillage is not practiced in the area either.

The analysis was conducted with the two groups; CSA and BAU. To quantify the amount of crop residue left and incorporated, the residue production calculator developed by Washington State University was used which calculates average residue dry yield based on grain yield. Accordingly, the amount of crop residue for wheat was calculated from the average yield which equals 3188.71 kg/ha. Based on the researcher and other expert's judgement, it is considered that 5 to 10 % of this residue is left on the cropland (figure 12). For BAU, as only 18.4% of farmers responded to leave crop residue, it was not considered in the tool. Production information including average yield (kg/ha) and average fertilizer use kg/ha (DAP and UREA) were used as an input for the tool.



Figure 12. Picture of crop residue left on CSA intervention farmland

The tool estimates the carbon emission from fertilizer use, soil mining, land use change and burning residue. Then it estimates the carbon offset arising from good agricultural practices. The net emission is then calculated per area and per yield.

The net emission was estimated for wheat and the result indicates that the net GHG emission per area is 358.1 kg Co₂ eq ha⁻¹ and 435.4 kg Co₂ eq ha⁻¹ for CSA and BAU and the net emission per yield for the two groups are 0.276 kg Co₂ eq kg⁻¹ and 0.531 kg Co₂ eq kg⁻¹ for CSA and BAU respectively. The fact that CSA adopters adopted soil management practices that enhanced carbon sequestration by soil reduced their net GHG emission per hectare. Also, the comparative advantage of CSA adopters over BAU in crop production lowered their net GHG emission per yield as they produce more for similar agricultural inputs. The tool indicates that BAU is mainly an emitter as there is no soil management practice adopted to enhance carbon sequestration.

The tool also estimated that CSA intervention area have the potential of offsetting 2039.30 kg Co₂ eq per hectare per year with the introduction of cover crops and 1313.31 kg Co₂ eq per hectare per year with organic manure addition. The above figure is lower for BAU with 1056.96 kg Co₂ eq per hectare per year for cover crop introduction and 826.07 kg Co₂ eq per hectare per year for organic manure addition. This indicates, that CSA have higher mitigation potential than BAU with the introduction of additional climate smart technologies.

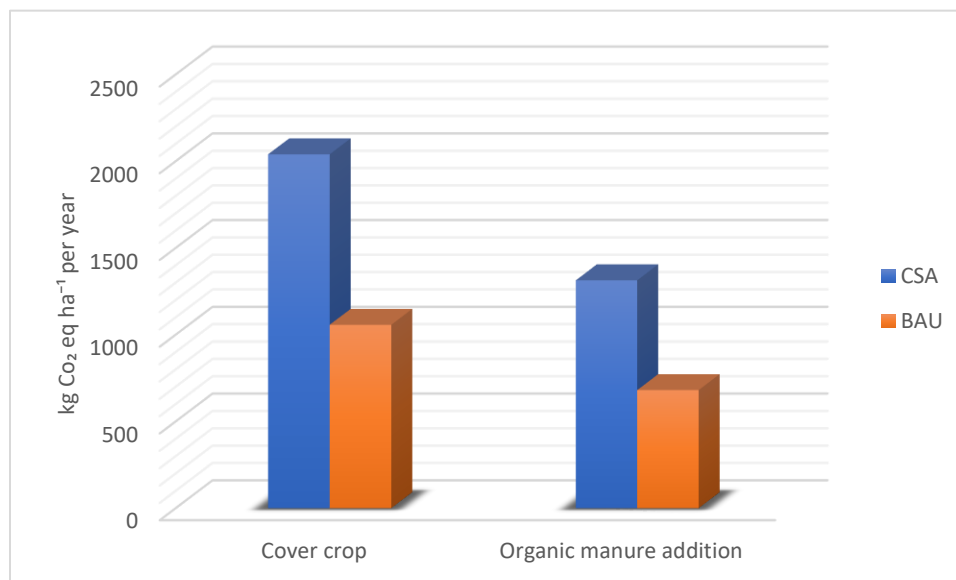


Figure 13. Mitigation potentials of CSA with introduction of cover crop and organic manure

The carbon offset and the further mitigation potentials of CSA practices presents a good opportunity for NDCs and future international climate finance opportunities. COP 21 Paris made an agreement that involves flows of funds from developed to developing nations for climate change mitigation and adaptation projects and programs. In this regard, CSA have the potential to obtain payment opportunities that will support the sustainability of adopted practices.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

Agriculture is the main source of economy and means of livelihood for many African countries including Ethiopia. The sector faces many challenges from environmental degradation to climate change which is undermining agricultural production and productivity. Adopting agricultural practices and technologies such as CSA that address these issues remains the way forward. This study tried to investigate the effects of adopting CSA on soil fertility and productivity.

The main types of CSA technologies adopted in the study area are crop management including use of improved seed varieties and crop rotation, SWC structures with biological measures, crop residue management, hedgerow planting and livestock management including restricted grazing. Backyard nurseries are established to address the problem of shortage of vegetative materials for the SWC structures which is an important factor for the sustainability of the practice.

From the results it can be concluded that CSA is making plausible improvements both in soil fertility and productivity. The SOM content of soil under CSA intervention shows a substantial improvement as compared to BAU. Some plant nutrients also showed improvements with CSA intervention. Maintaining and enhancing soil ecosystem services ensures food security and reduce rural vulnerability to the adverse impacts of climate change. Also, reducing soil erosion and improving SOM, enhance soil carbon stock as a mitigation co-benefit which has relevance to NDCs. The result shows that, forest is an important carbon pool that store SOC at higher depth. And therefore, trees have to be an integral component of an agricultural landscape to enhance carbon sequestration.

The result also revealed that soil fertility improves over time that indicates the sustainability of adopted technologies has to be safeguarded in order to exploit the long-term benefits. Intervention projects are usually short lived. Long term benefits of adopting CSA can only be realized when adopted technologies are properly maintained. This is the case at BAU where SWC structures were once introduced but the sustainability of practice deteriorated overtime.

Therefore, a system has to be in place that assures the continuity of practices after projects phaseout.

The study also revealed that CSA have positive implication both on crop and livestock productivity. CSA adopters produce more per hectare than BAU farmers with similar utilization of agricultural inputs. This is an indicator that CSA technologies such as SLM enhance the efficiency of agricultural inputs. The productive advantages of CSA adopters will enhance their adaptive capacity through improved incomes. In this regard, CSA adopters will have better resilience to the adverse impacts of climate change.

In relation to mitigation co-benefits, the result of the study revealed that adopting CSA practices reduce the net GHG emissions both per area and per yield. CSA also presents a better carbon offsetting potential compared to BAU that might present an opportunity in future carbon trading.

In general, CSA presents a good opportunity to improve soil fertility and productivity. However, when compared to other land uses, the organic matter of soil under CSA intervention falls behind. Agro-forestry presented the highest amount of SOM followed by initial scenario where the soil is undisturbed then followed by grassland. This is an indicator that CSA needs to be adopted at a landscape level integrating crop and other land use systems to guarantee the overall ecological health of the area. Through climate smart landscape approach, both agricultural production as well as environmental sustainability objectives can be addressed.

5.2. Recommendations

Adopted CSA practice supported building resilience through improved incomes and by maintaining and enhancing soil ecosystem services. As seen in the study, adopting further CSA practices such as cover crop and organic manure addition will place additional benefits with regards to soil fertility and carbon sequestration. The pilot project of introducing cover crops needs scaling up to further improve the impacts of CSA.

Adopted practices has to be sustained in order to attain the long-term benefits of CSA. For this, inclusive systems and institutional arrangements needs to be in place to assure the continuity of CSA practices beyond project years. Technology and knowledge transfer also has to the objectives of Projects.

A landscape approach that integrates CSA with other land use systems such as agroforestry, grassland and forest needs to be considered to attain the objective of agricultural and environmental sustainability.

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Appendices

Appendix 1. HH survey questionnaire

Code _____

Questionnaire

Dear Respondent,

My name is Meron Tadesse and I am currently pursuing a master's degree in Environment and sustainable development at Addis Ababa University. I am conducting a research on Climate Smart Agriculture and its effects on soil fertility and productivity in Kembata Tembaro zone, SNNPR. Your honest response is very crucial to the success of the study and hence I kindly ask your sincere response. The information you provide will only be used for academic purposes and your personal information will be kept confidential.

Date _____ Time _____

Enumerator's Name _____ Signature _____

Part I. Household survey

I. Socio-economic characteristics

1. Woreda _____ Kebele _____ 1=Tula 2=Jane 3= _____

2. Household (HH) head's Name: _____

Sex: 1=Male 2=Female

3. Age of HH head 1. 18-30years 2. 31-40 years 3. 41-50 years

4. 51-60 years 5. 61-70 years 6. above 70

4. Education level of HH head 1=No formal education 2=1-8th grade

3=9-12th grade 4=Vocational training 5=Diploma 6=Degree and above

5. Is respondent HH head? 1=Yes 2=No

6. If no, respondent Name: _____

Sex:1=Male 2=Female

7. Relationship of respondent to HH head. 1=Spouse 2=Child 3=Relative

8. Family size Male _____ Female _____

9. No. of family members below 18 Male _____ Female _____

10. No. of family members above 18 Male _____ Female _____

11. Sources of livelihood? (multiple answers) 1=Crop production 2=Poultry
3=Livestock production 4=Rural/urban laboring 5=Trade
other _____

12. How much is your estimated annual income in birr? _____

II. Agricultural Productivity

Crop productivity

1. Status of land ownership 1=Own 2=Rented Other _____

2. Size of farm (ha) _____

3. Is your land converted to cropland in the past 20 years? 1=Yes 2=No (it's
been crop land for more than 20 years)

4. If yes, from what land use system? 1=Forest 2=Grassland other _____

5. Do you use fertilizer? 1=Yes 2=No

6. If yes, what type of fertilizers? 1=Chemical 2=Organic 3=Both

7. How do you rate your chemical fertilizer use than before?

1=Decreasing 2=The Same 3=Increasing

8. The reason for answer # 5 _____

9. Do you use chemical pesticides? 1=Yes 2=No

10. Do you use improved seed varieties? 1=Yes 2=No

11. Do you grow crops during the “Belg” season? 1=Yes 2=No

12. If yes, which crops? 1=Potato 2=Cabbage 3=Beetroot

Other _____

13. If no #11, why? _____

14. How do you rate your production trend since 2012 (for the last 5 years)?

1=Declining 2=The Same 3=Increasing

15. Yield of main crop varieties this harvest year (2010 E.C.)

Crop type	Cultivated area (ha)	Yield (qt)	Fertilizer used (kg) 1=DAP 2=UREA
1.			1=_____ 2=_____
2.			1=_____ 2=_____
3.			1=_____ 2=_____
4.			1=_____ 2=_____
5.			1=_____ 2=_____

16. What are the main challenges in relation to agricultural production and how do you rate it?

No.	Constraints	Rank 1= High 2=Medium 3=Low 4=Not a problem
1.	Rise in temperature	
2.	Low Rainfall	
3.	High Rainfall	
4.	Climate variability	
5.	Soil Erosion	
6.	loss of soil fertility	
7.	Water shortage	
8.	Pests and diseases	
9.	Lack of improved varieties	
10.	Lack of access to inputs*	
11.	High cost of inputs	
12.		

* Inputs – Fertilizer, pesticides and herbicides

17. Do you get weather forecast information? 1=Yes 2=No

18. If yes, how do you get it? _____

Livestock productivity

1. How many livestock do you have?

Cattles _____ sheep _____ Goats _____

Other _____

2. How many of your livestock are local breeds and improved breeds?

Livestock type	Local breeds	Improved	Remark
Cattles			
sheep			
Goats			

3. Where do you get the feed for your livestock?

1=Open grazing in common areas

2=Open grazing on crop lands

3=Cut and carry from SWC structures

4=enset Leaves

5= Straw Other _____

4. Where do your livestock spend the day?

5. How many liters of milk do you get a day? _____

6. Do you fatten livestock for market? 1=Yes 2=No

7. If yes, what types 1=Oxen 2=Sheep 3=Goat

other _____

8. How many fattened livestock do you sell a year?

Oxen _____ Sheep _____ Goat _____

Other _____

9. What is the average selling price? Oxen _____ Sheep _____ Goat _____

Other _____

10. How do you rate your livestock productivity?

1=Declining

2=The Same

3=Increasing

11. What do you do with your livestock waste? 1=Fertilizer for farm homestead farming 2=fertilizer for 3=Use for fuel 4=Store it in a pit other _____

III. SLM practices

1. Is there physical soil and water conservation structures on your farmland? 1=Yes 2=No
2. If yes, are these structures covered with vegetation? 1=Yes 2=No
3. If yes, what type of vegetation?
1=Trees 2=Shrubs 3=Grass other _____
4. Do you use a traditional or improved plow? 1=traditional 2=improved
5. If use improved plow, what type is it? _____
6. How many times do you plough your land while preparing for cropping?

Crop type	Plough	Remark

7. Do you sow in rows? 1=Yes 2=No
8. If yes, do you grow any crop/grass (cover crop) between rows? 1= Yes 2=No
9. Do you rotate crops in consecutive cropping seasons? 1=Yes 2=No
10. If yes, which crops do you rotate? 1= wheat and barley 2=wheat and potato
3=wheat and Faba bean 4= Barley and potato 5=Barley and Faba bean
6= potato and Faba bean Other _____
11. Do you practice intercropping? 1=Yes 2=No
12. If yes, which crops do you intercrop? _____

13. Do you leave the crop residue on the field? 1=Yes 2=No
14. Do you have trees on your plots? 1=Yes 2=No
15. Do you plant trees on plot boundaries? 1=Yes 2=No
16. If yes # 14 & 15, what tree species? 1= Eucalyptus 2=" Korech"
3=Juniper (tside) 4=Enset other _____

17. How many trees do you have on your cropland? 1= Eucalyptus _____
 2= “korch” _____ 3= Juniper (tsede) _____
 Other _____
18. Do you have enset plantation? 1=Yes 2=No
19. If yes, where? 1=On crop lands 2=Homestead other _____
20. How much is the size of your enset plantation (ha)? _____
21. Do you plant other crops/vegetable with the enset? 1= Yes 2= No
22. If yes, which crops/vegetables? 1= Potato 2= Cabbage 3= Beetroot
 Other _____

IV. Perception of CSA

1. Are you CSA adopter/under intervention by Inter Aide? 1=Yes 2=No
2. If yes, for how long? _____
3. In what aspects CSA is improving your life? (multiple answers)
- | | |
|------------------------------|-----------------------------------|
| 1= Improve crop productivity | 2= Improve livestock productivity |
| 3= Improve Income | 4= Improve HH food status |
| 5= Improve soil fertility | 6= Diversifying livelihood option |
| 7= Reduce soil erosion | 8= provide weather information |
| 9=No improvement | |
| Other _____ | |
4. What aspects do you expect improvements from CSA options? _____

5. Are you finding CSA beneficial and recommend to others?
- | | |
|---------------------|---------------------|
| 1= Highly recommend | 2= Recommend |
| 3= Not sure yet | 4= Do not recommend |

Thank you!

Appendix 2. Key informant interview discussion points

Key informant interview – Discussion points

1. Work title
2. How many households are there in Tula and Jane watersheds?
3. How many households are CSA adopters?
4. Total area and total area under intervention?
5. What types of CSA/SWC works have been done in the area?
6. Production trend for the last 10 years? If there is also evidence
7. Types and quantities of fertilizers recommended per ha per crop type?
8. Do you give recommendations of fertilizer use for farmers?
9. Do they apply the recommended amount of fertilizer? If not, why?
10. Is there enough supply of fertilizers?
11. Do all farmers use fertilizers? If not, why?
12. Is fertilizer use increasing/decreasing/the same? What's the reason?
13. Do all farmers use improved seeds? If not what percentage use? What are the reasons not to use improved seeds?
14. Is there enough supply of improved seeds?
15. Do farmers get weather forecast information? How do they get it?
16. What are the main challenges of the community in relation to production?
17. How is CSA working to address the challenges?
18. Is CSA introducing other livelihood options for the farmers?
19. Is CSA making an impact on the overall livelihoods of the community? In what aspects? If there is evidence, please provide?
20. What is the attitude towards adopting CSA by farmers?
21. Is CSA the way forward to address climate issues? Why?

Appendix 3. Demographic and socio-economic characteristics of HH heads

		CSA n=140	BAU n=60
Sex	Male	89.8%	91.8%
	Female	10.2%	8.2%
Age	18-30	11.7%	10.2%
	31-40	35.2%	34.3%
	41-50	30.6%	38.8%
	51-60	13.8%	6.1%
	61-70	7.7%	10.2%
	>70	1%	0
Education Level			
	No education	34.7%	36.7 %
	1-8th grade	57.7%	59.2%
	9-12th grade	7.7%	4.1%
Family size			
	<3	0	0
	3-4	13.3%	14.3%
	5-7	45.4%	36.7%
	8-10	32.1%	32.7%
	>10	8.7%	16.3%
Average land size (ha)		0.58	0.55
Source of livelihood			
	Agriculture	100%	100%
	Rural/urban laboring	19.9%	20.4%
	Trade	18.4%	10.2%

Appendix 4. Independent samples t-test for fertilizer use

Crop type		Mean Value		t-value	p-value	Std. Error Mean
		CSA (kg/ha)	BAU (kg/ha)			
Wheat	DAP	132.02	117.2	1.75	0.082	8.467
	UREA	115.65	114.27	0.145	0.885	1.385
Barley	DAP	98.32	88.44	1.026	0.307	9.879
	UREA	72.19	65	0.852	0.396	8.442
Potato	DAP	198.32	206.52	0.647	0.518	12.683
	UREA	153.57	148.7	0.478	0.633	10.2

Appendix 5. Soil laboratory analysis results

Horticoop Ethiopia (Horticulture) PLC								
Soil and Water Analysis Laboratory								
Soil Analysis Certificate								
Information about sample								
Sampled By	Client			Order Number			18 - 00 - 52	
Location	SNNPR			Date Sampled			-	
Report Date	Friday, May 25, 2018			Date Received			April 24/2018	
Lab.Code	PH-Kcl	Olson	Mehlich-3			OC	OM	Total Nitrogen
		P	S	B	K			
		mg/kg	mg/kg	mg/kg	mg/kg			
18HM0335	4.97	6.26	7.16	0.10	728.13	4.05	6.98	0.26
18HM0336	4.87	9.24	6.45	0.39	954.39	1.93	3.33	0.15
18HM0337	4.78	5.41	11.64	0.60	546.45	1.15	1.98	0.12
18HM0338	6.20	34.02	28.70	0.93	2137.52	5.45	9.40	0.33
18HM0339	6.80	44.37	30.73	1.35	2259.46	5.40	9.31	0.36
18HM0340	4.64	14.28	5.38	0.37	255.05	2.77	4.78	0.18
18HM0341	4.49	32.55	6.42	0.30	195.22	2.88	4.97	0.17
18HM0342	4.40	12.39	7.65	0.48	325.47	3.17	5.47	0.21
18HM0343	4.51	18.27	7.37	0.37	300.98	3.45	5.95	0.21
18HM0344	4.79	8.06	3.86	0.46	221.57	3.00	5.17	0.18
18HM0345	4.60	13.10	6.10	0.36	313.81	3.14	5.41	0.20
18HM0346	4.77	6.66	3.10	0.40	201.01	2.70	4.65	0.18
18HM0347	4.99	4.99	1.87	0.63	205.64	1.49	2.57	0.09
18HM0348	4.31	16.85	8.42	0.40	288.57	3.00	5.17	0.22
18HM0349	4.78	5.88	4.02	0.41	230.65	2.73	4.71	0.18
18HM0350	5.15	5.82	1.96	0.60	216.55	0.97	1.67	0.09

18HM0351	4.39	23.92	7.73	0.45	260.16	3.30	5.69	0.20
18HM0352	4.78	10.92	4.41	0.28	179.04	3.02	5.21	0.18
18HM0353	4.39	4.20	5.56	0.51	437.72	1.39	2.40	0.11
18HM0354	4.64	8.19	4.31	0.41	134.50	3.32	5.72	0.20
18HM0355	4.74	6.15	3.94	0.33	98.45	4.14	7.13	0.26
18HM0356	4.64	5.77	1.93	0.70	124.65	0.46	0.80	0.05
18HM0357	4.54	7.28	4.13	0.53	108.10	3.34	5.75	0.21
18HM0358	4.80	5.09	2.26	0.67	98.90	2.00	3.45	0.12
18HM0359	4.78	6.26	1.50	0.20	352.15	1.26	2.18	0.08
18HM0360	4.24	11.55	5.08	0.32	376.38	3.32	5.72	0.22
18HM0361	4.72	5.14	2.36	0.24	307.19	3.40	5.86	0.19
18HM0362	4.73	5.14	1.15	0.12	411.75	1.25	2.15	0.10
18HM0363	4.47	10.81	4.69	0.16	238.74	2.89	4.99	0.19
18HM0364	4.73	3.85	2.06	0.10	252.68	2.34	4.03	0.16
18HM0365	4.33	4.97	4.20	0.06	326.36	0.87	1.50	0.09
18HM0366	4.28	11.56	8.45	0.29	316.40	4.67	8.06	0.30
18HM0367	4.73	12.21	4.64	0.34	296.59	3.74	6.45	0.25
18HM0368	4.64	8.56	2.39	0.03	425.40	1.88	3.24	0.10
18HM0369	5.55	66.14	17.55	1.04	932.60	5.46	9.41	0.37
18HM0370	5.37	16.64	7.80	0.58	636.86	4.14	7.14	0.27
18HM0371	4.71	8.61	4.26	0.03	275.36	2.28	3.93	0.13
18HM0372	4.91	81.41	22.03	0.86	1263.03	4.96	8.55	0.32
18HM0373	4.62	18.23	9.86	0.26	710.48	3.51	6.06	0.20
18HM0374	4.16	10.37	9.18	0.06	912.30	1.12	1.92	0.09
18HM0375	5.85	24.18	18.58	0.81	1421.00	5.42	9.35	0.31
18HM0376	4.43	11.98	16.32	0.11	494.82	3.92	6.76	0.23

18HM0377	4.17	8.48	5.06	0.05	383.16	1.53	2.64	0.10
18HM0378	6.35	57.54	27.79	1.33	1217.33	5.22	8.99	0.31
18HM0379	4.68	10.81	5.74	0.22	358.74	3.00	5.17	0.21
18HM0380	4.70	12.39	4.18	0.10	338.28	2.78	4.79	0.15
18HM0381	5.83	47.72	11.81	1.05	1208.46	5.48	9.45	0.33
18HM0382	4.62	11.88	21.72	0.21	784.13	4.29	7.40	0.31
18HM0383	4.61	10.81	35.18	0.10	242.64	2.37	4.09	0.12
18HM0384	4.71	13.44	4.16	0.11	358.40	3.08	5.31	0.16
18HM0385	4.56	11.34	2.57	0.06	236.22	1.09	1.88	0.15
18HM0386	3.96	13.36	3.01	0.04	170.91	1.06	1.83	0.19
18HM0387	5.20	9.42	6.25	0.59	1209.33	3.10	5.34	0.33
18HM0388	5.08	6.91	4.80	0.27	891.62	1.92	3.31	0.17
18HM0389	4.88	7.14	1.67	0.07	518.08	1.31	2.26	0.09
18HM0390	5.27	8.48	7.80	0.71	1036.68	5.97	10.30	0.35
18HM0391	4.95	7.98	1.01	0.03	615.54	1.31	2.26	0.09
18HM0392	5.26	7.14	1.93	0.07	929.01	2.29	3.94	0.13
18HM0393	4.81	8.85	3.50	0.08	492.22	1.44	2.48	0.10
18HM0394	4.09	7.48	2.09	0.19	207.02	0.47	0.81	0.03
18HM0395	4.45	13.52	0.76	0.26	60.75	0.14	0.24	0.01
18HM0396	5.40	8.61	7.38	0.06	832.90	1.95	3.36	0.13
18HM0397	5.06	8.19	4.66	0.09	429.07	2.23	3.84	0.13
18HM0398	4.55	5.67	0.26	0.14	268.03	0.45	0.78	0.04
18HM0399	4.48	6.16	0.31	0.15	285.95	0.44	0.76	0.04
18HM0400	4.09	4.44	4.74	0.21	239.42	0.34	0.59	0.04
18HM0401	4.61	9.59	3.05	0.07	666.76	1.69	2.91	0.10
18HM0402	4.36	9.41	2.03	0.12	591.97	1.29	2.22	0.07

18HM0403	4.55	9.32	5.78	0.10	539.78	0.97	1.67	0.07
18HM0404	4.76	9.77	4.52	0.02	640.18	0.90	1.55	0.12
18HM0405	4.85	11.34	1.16	0.06	450.83	1.25	2.16	0.10
18HM0406	4.85	8.77	2.29	0.06	531.71	1.25	2.16	0.10
18HM0407	4.88	10.56	5.37	0.12	807.92	2.36	4.07	0.18
18HM0408	4.48	9.59	2.56	0.08	398.08	1.54	2.65	0.12
18HM0409	4.80	10.15	2.04	0.03	377.90	1.63	2.81	0.13
18HM0410	5.05	9.24	2.35	0.07	198.21	1.39	2.40	0.10
18HM0489	4.40	8.06	8.32	0.27	312.62	4.52	7.80	0.33
	Zufan Gikidan 							
					Lab Head			
	T: +251 11 652 55 89 P.O.BOX: 1646 Debre Zeit, Ethiopia E-mail: Laboratory.horticoop@gmail.com							

Appendix 6. Graphs of change in extractable plant nutrients

