UNNIVERSITY OF BUEA

FACULTY OF AGRICULTURE ANDVETERINARY MEDICINE

DEPARTMENT OF AGRICULTURAL ECONOMICS AND AGRIBUSINESS

MODELLING FARM-HOUSEHOLD LIVELIHOODS FOR ESTIMATING THE ADOPTION IMPACTS OF SELECTED POLICY INSTRUMENTS ON AGRICULTURE AND CLIMATE CHANGE IN SOUTH-EASTERN CAMEROON

By

Ngaiwi Mary Eyeniyeh

(AV16P035)

B.Ed. (Hons.) CST/Biology
M.Sc. (Botany)

A Thesis Submitted to the Department of Agricultural Economics and Agribusiness, Faculty of Agriculture and Veterinary Medicine of the University of Buea in Partial Fulfilment of the Requirements for the Award of the Degree of Doctor of Philosophy (Ph.D.) in Agricultural Economics

SUPERVISOR

Ernest L. Molua, PhD
(Associate Professor of Agricultural Economics. Department of Agricultural Economics and Agribusiness, University of Buea)

CO-SUPERVISOR

Justine E. Ayuk, Ph.D.
(Lecturer Women and Gender Studies. Department of Women and Gender Studies, University of Buea)

CO-SUPERVISOR

Denis Jean Sonwa, Ph.D.
(Senior Scientist, Center for International Forestry Research (CIFOR))

June 2023

DEDICATION

To God Almighty

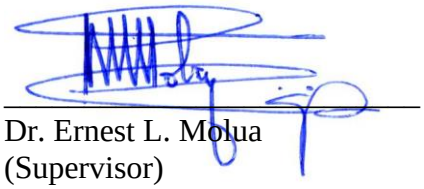
UNIVERSITY OF BUEA

FACULTY OF AGRICULTURE ANDVETERINARY MEDICINE

DEPARTMENT OF AGRICULTURAL ECONOMICS AND AGRIBUSINESS

CERTIFICATION

This is to certify that the thesis entitled '**Climate change adaptation in smallholder cropping systems: An Environmental Economic Analysis of Conservation Agriculture Adoption in Smallholder farms in the South and East Regions of Cameroon'** was carried out by **Ngaiwi Mary Eyeniyeh (AV16P035)** in the Department of Agricultural Economics and Agribusiness in partial fulfilment of the requirements for the award of the Doctor of Philosophy (Ph.D.) degree in Agricultural Economics under the supervision of:



Dr. Ernest L. Molua
(Supervisor)

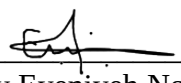
Date:16/06/2023

Dr. Justine E.Ayuk
(Co-supervisor)

Date:20/06/2023

Dr. Denis Jean Sonwa
(Co-supervisor)

Date:16/06/2023



Mary Eyeniyeh Ngaiwi
(Student)

Date:16/06/2023

AKNOWLEGEMENTS

I would like to express my sincere and heartfelt thanks to my supervisor Prof. Ernest L. Molua for providing me expert guidance, constructive criticism, timely support, encouragement, and supervision of this work. It is my good fortune to be his student and to do this work under his guidance. My sincere gratitude goes to my co-supervisors, Dr. Justine E. Ayuk and Dr. Denis Sonwa for their critical suggestions, positive comments, encouragement, and supervision of this work.

Furthermore, my appreciation goes to the University of Buea authorities in general and the entire staff of the Department of Agricultural Economics and Agribusiness in particular for putting me through whenever need arose. I also sincerely appreciate the African Economic Research Consortium (AERC) for partly funding this research. I am thankful to my classmates and friends with whom I shared my joys and sorrows throughout this period.

Also, my sincere gratitude to my lovely Mother Ngaiwi Regina Kifi and my lovely daughter Ngaiwi Shallom Riene, for encouragement, support, and care during my studies. My heart-felt thanks and appreciation also goes to my wonderful brothers and sisters- My lovely Dad Mr Tardzenyuy Emmanuel, Mr and Mrs Alemnge, Mr and Mrs Manjoh., Mathurin Miaffo for their prayers, love, support, encouragement and concern throughout this period.

Not leaving out a wonderful data collection team Eric Junior, Akamin Nkafu, Ivan Atemnkeng, Bikele Charles, Ebai Francis and Leonel for their immense efforts towards this research. To all whose names are not mentioned, I thank you all.

ABSTRACT

With climate change already compounding the socio-economic and biophysical constraints to development in Central Africa, the adoption of conservation agriculture (CA) is one mainstreamed opportunity to improve food and livelihood security in the region. Despite the rapid advancements in CA, research on CA has been superficially addressed in Cameroon. This study therefore seeks to ex ante estimate the adoption impacts of policy instruments (Reducing Emissions from Deforestation and Degradation REDD+ and CA) (REDD+) on the livelihood security of small holder farmers in the face of climate change in south-eastern Cameroon. To accomplish this herculean task, a multistage purposive random sampling technique was employed arriving at a sample of 351 respondents. Primary and secondary data were employed in this study. An impact analysis was conducted on smallholder farmers of this area, using a multinomial logit regression analysis with treatment effects. This research was grounded by the utility maximization theory and thus Heckman two-stage regression and the multivariate probit regression analysis were also employed for this study. The results from this analysis indicated that among the conservation practices employed by farmers, cover crops, mulching, minimum tillage, and crop rotation are the most used though agroforestry and intercropping have some conservation attributes and employed by most farmers. Furthermore, adoption of these policy instruments is determined by institutional, socio-demographic and farm level characteristics with gender playing a great significance. This therefore implies that adaptation to climate change is dependent on socio-demographic and plot level characteristics which should be paid thorough attention when formulating adaptation strategies and policies. Farmers of this area will greatly be positively affected in their livelihoods if they adopt mulching, intercropping, agroforestry, and cover crops. Thus, agroforestry and intercropping can be incorporated fully in conservation agriculture and scaled to attain climate change mitigation.

Keywords: Climate change, Conservation agriculture, Small-scale farms, livelihood security, Gender response, REDD+.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

AEZ	Agro Ecological Zones
AfDB	African Development Bank
AGRA	Alliance for a Green Revolution in Africa
AKIS	Agricultural Knowledge and Information System
AWG-LCA	Ad Hoc Work Group on Long-term Cooperative Action
CA	Conservation Agriculture
CAMACO	Climate Change, Agriculture and Food Security
CH_4	Methane
CO_2	Carbon dioxide
COP21	Paris Conference of Parties
CSA	Climate Smart Agriculture
DNA	Deoxyribonucleic acid
ENSO	El Niño Southern Oscillation
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	FAO Statistics
FAST	Feminist Agrifood Systems Theory
FPE	Feminist political ecology
GDP	Gross Domestic Product
GHGs	greenhouse gases
GISS	Goddard Institute for Space
ICCO	International Cocoa Organisation
IEA-CMR	International Environmental Agreements Cameroon
IFAD	International Fund for Agricultural Development
IFCBP	Interval fuzzy credibility-constraint bi-level programming
IFPRI	International Food Policy Research Institute
IITA	International Centre for Tropical Agriculture
IMF	International Monetary Fund
INDC	Intended Nationally Determined
IPAR	Institute of Policy Analysis and Research
IPCC	International Panel of Climate Change
LDCs	Least Developed Countries
MDGs	Millennium Development Goals
MNL	Multinomial Logistic regression model
N_2O	Nitrous Oxide
NARS	National Agricultural Research System
NGOs	Non-Governmental Organizations
NT	No Tillage
NTFP	Non-Timber Forest Products
O_3	Ozone
OECD	Organisation for Economic Co-operation and Development

PES	Payment for Ecosystem Services
PGIS	Participatory Geographic Information Systems
RED	Reducing Emissions from Deforestation
REDD+	Reducing Emissions from Deforestation and Forest degradation and others
SDG	Sustainable Development Goals
SIDA	Sweden International Development Cooperation Agency
SOM	Soil Organic Matter
SSA	Sub-Saharan Africa
STAT	Statistics
SWC	Soil and Water Conservation
TAR	Third Assessment Report
TPB	Theory of Planned Behaviour
UN	United Nations
UNDP	United Nations Development Program
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNISDR	United Nations International Strategy for Disaster Reduction
US	United States
USD	United States Dollars
USEPA	United states Environmental Protection Agency
WB	World Bank
WMO	World Meteorological Organization
ZT	Zero Tillage

CHAPTER ONE

Introduction

1.1 Background of Study

Conservation agriculture and livelihood security have risen to the top of today's international policy agenda, posing a serious challenge to governments all over the world (Sridhar et al., 2023). It is a difficult task to ensure a sustainable and equitable food supply in the face of climate variability and change, price volatility, the global financial crisis and demographic growth (Abbass et al., 2022). Despite significant and consistent increases in food availability overtime, both globally and in developing countries access to food remains limited, particularly in many low-income economies (Mhonyera et al., 2023).

According to the most recent estimates, approximately 795million people worldwide were undernourished in 2016, with 780 million of them living in developing countries (FAO et al.,2015). Although poverty is decreasing in many countries, significant progress remains to be made, particularly in sub–Saharan Africa's rural areas notably at the farm-household level, where 52% of the rural population is extremely poor and undernourished (FA0 *et al*.,2015). Therefore, understanding the interactions between policy instruments and how this impacts land use is critical for managing outcomes in Land-use, biodiversity, climate, and food systems nexus.

Various studies have explored different aspects of the problem of ensuring a sustainable and equitable food supply in the face of multiple challenges. One critical area of research has focused on the impact of climate change on food production(Arora, 2019; Aryal *et al*., 2020; Ortiz-Bobea *et al*., 2021; Ray *et al*., 2019), as changing weather patterns, and

extreme weather events can significantly affect crop yields, water availability, and agricultural ecosystems. These changes have a significant impact on food security and access, particularly in developing countries. Other studies have analyzed the effects of price volatility and the global financial crisis on food security and access (Ben Hassen & El Bilali, 2022; Erokhin & Gao, 2020; Kharroubi *et al*., 2021; Swinnen & Vos, 2021).

However, price increases can limit access to food, particularly for vulnerable populations already experiencing poverty and inequality. The global financial crisis also had a significant impact on food security, as it led to an increase in unemployment, poverty, and inequality. These challenges can further limit access to food for already vulnerable communities (Laborde *et al*., 2020). In addition to understanding the impact of climate change and other global events on food production and access, research has investigated the relationship between poverty and hunger. Studies have shown that poverty and inequality are significant contributors to food insecurity and malnutrition, with the poorest and most vulnerable individuals and communities facing the most significant impacts (Birkenmaier *et al*., 2016).

Finally, research has examined the role of policy instruments in addressing food security(Autio *et al*., 2021; Movilla-Pateiro *et al*., 2021). Policies can be instrumental in promoting sustainable land use practices, reducing food waste, and investing in agricultural research and development. International cooperation and partnerships among multiple stakeholders are necessary to develop and implement effective and sustainable solutions to ensure a sustainable and equitable food supply (Leisner, 2020). These studies have found that ensuring food security is a complex task that requires a multifaceted approach(Islam & Kieu, 2020). For example, addressing climate change and its impact on agricultural

productivity requires strategies such as developing drought-resistant crop varieties, improving irrigation systems, and promoting sustainable land use practices. Similarly, tackling the problem of poverty and hunger requires not only increasing food production but also ensuring equitable distribution of food and creating livelihood opportunities for the most vulnerable populations (Movilla-Pateiro *et al*., 2021).

The problem of limited access to food is caused by a range of factors, including inadequate food production, poor distribution networks, poverty and inequality, and environmental degradation (Hamid & Mir, 2021). Moreover, these factors are interconnected, and their effects are often compounded, leading to a vicious cycle of poverty and hunger. The global food system is also facing the challenge of demographic growth, with projections showing that the world's population will reach 9.7 billion by 2050, which will further increase pressure on the already strained food systems(Adeyeye *et al*., 2023).

Several solutions currently exist to address the problem of food security. These include investing in agricultural research and development, promoting sustainable land use practices, improving food distribution networks, creating social safety nets for vulnerable populations, and reducing food waste(Parven *et al*., 2022). Furthermore, international cooperation and partnerships are crucial for ensuring that these solutions are implemented effectively and sustainably (Madsen *et al*., 2021).

Despite the extensive research on food security and climate change there are still gaps in our knowledge that need to be addressed. One such gap is the limited understanding of the impacts of climate change on food production and food security in different regions of the world (Leisner, 2020). Climate change impacts may vary greatly depending on location,

and more research is needed to develop region-specific strategies for adapting to these impacts and mitigating their effects. There is also a loop in the understanding of the role of technology in improving food security and tackling climate change adaptation and mitigation (Hussain *et al*., 2020).

For example, emerging technologies such as conservation agriculture and vertical farming have the potential to enhance food production while minimizing environmental impacts. However, more research is needed to understand the effectiveness of these technologies in improving food security, particularly in developing countries. In addition, there is still a lack of clarity on the most effective policy instruments for addressing food security (Eriksson *et al*., 2020; Garske *et al*., 2020). While many policies (e.g REDD+) have been implemented at the national and international levels, it is still unclear which policies are most effective in promoting sustainable food production and reducing food waste.

Another gap in our knowledge is the limited understanding of the role of trade and globalization in shaping food systems(Hamilton *et al*., 2020). While trade can increase the availability and diversity of food products, it can also lead to increased price volatility and undermine local food systems(Baker *et al*., 2021). More research is needed to understand the complex relationships between trade, food security, and sustainability and develop policies that promote sustainable and equitable food systems. More research is needed to evaluate the impact of different policy instruments and identify the most effective strategies for addressing food insecurity. Finally, there is a lack of understanding of the social and cultural aspects of food security. Food is not just a basic need; it is also a social and cultural resource that shapes our identities and ways of life. More research is therefore needed to understand the cultural and social dimensions of food and the ways in which

food security and agriculture practices can reflect and contribute to local values and traditions.

1.2 Statement problem

In Cameroon, agriculture plays a crucial role, particularly for smallholder farmers who constitute 70% of the agrarian population (Howden *et al*., 2007). Alarmingly, these farmers, who produce 80% of the country's food crops (Epule & Bryant, 2016), often employ environmentally unsustainable farming practices and contribute to unsustainable changes in agricultural and forest land use (Beddington, 2010). As the population continues to grow(fig 3), there is increasing uncertainty and stagnation in food crop production rates (Epule *et al*., 2012). The slow growth rate of approximately 1% in crop production falls significantly short of meeting the demands of the expanding population, leading to a supply-demand imbalance (Abrams *et al*., 2018).

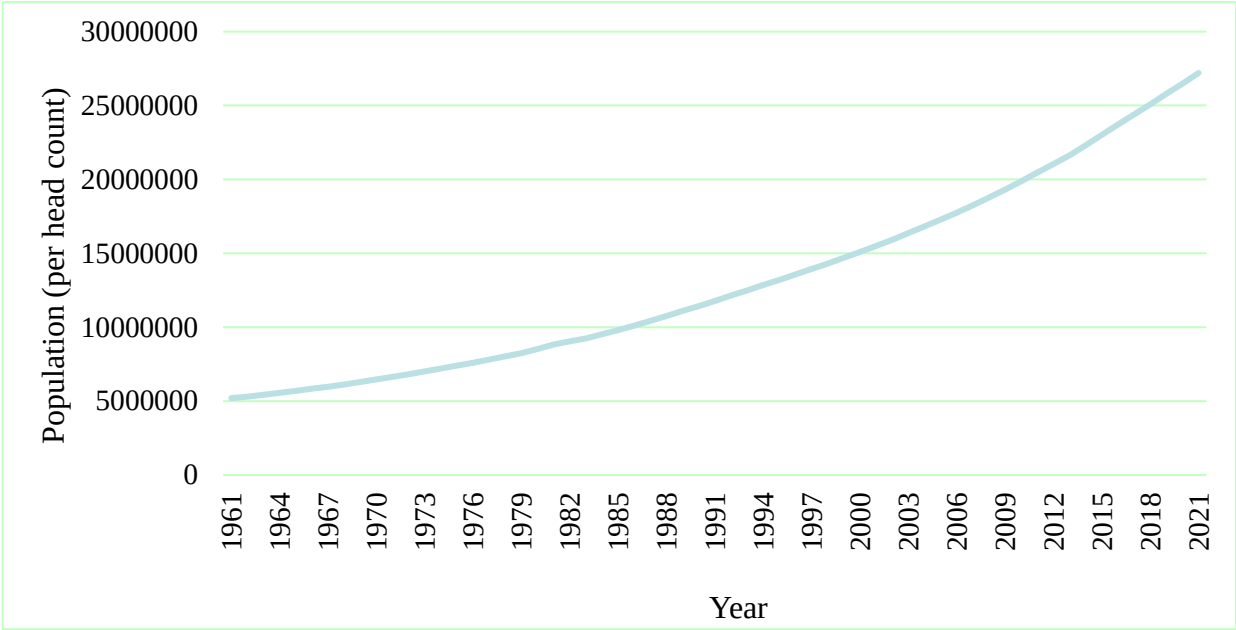


Figure 1. 1 Population growth rate in Cameroon 1961-2021

To compensate for the widening gap between demand and supply, there has been a surge in the search for cultivable land, resulting in rampant deforestation in Cameroon (Abrams *et al*., 2018). Deforestation, alongside unsustainable agricultural practices, contributes to the accumulation of greenhouse gases (GHGs) and exacerbates climate change (FAO, 2017). Consequently, Cameroon experiences fluctuations in temperature and rainfall patterns, as depicted in Figures 1.6 and 1.7.

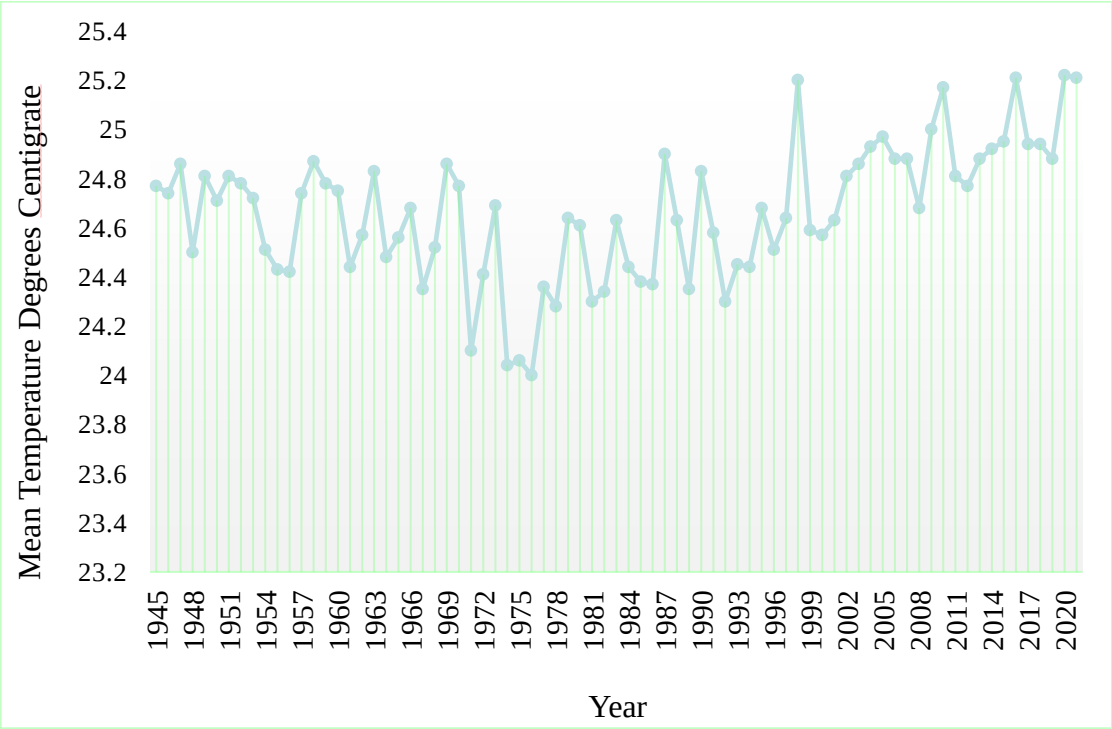


Figure 1. 2 Temperature variations in Cameroon 1945-2022

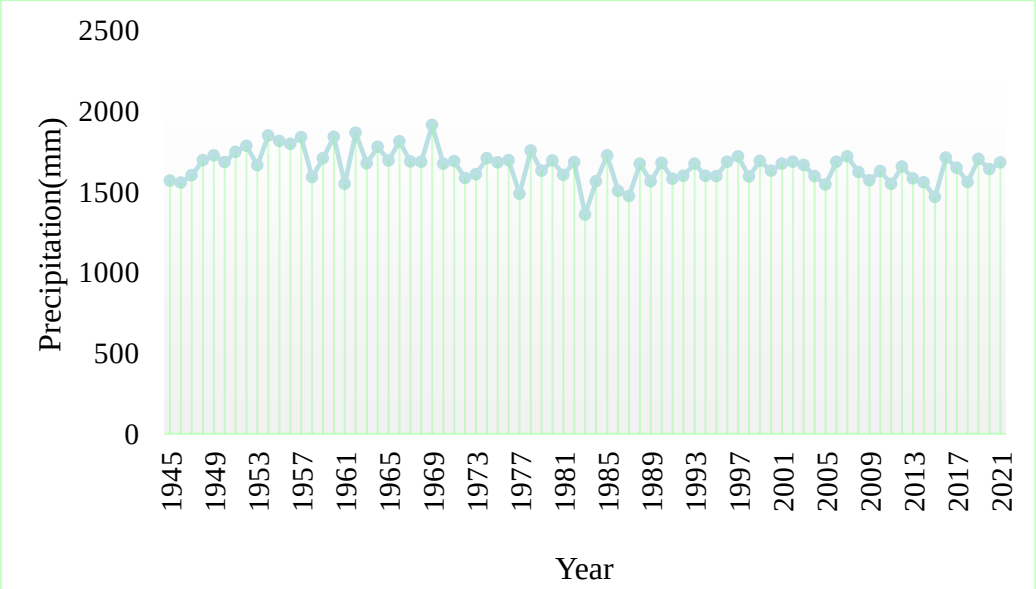


Figure 1. 3 Rainfall variations in Cameroon 1945-2022

These climate fluctuations pose severe challenges to the agricultural sector, which heavily relies on rain-fed systems (Awazi *et al*., 2019). Since agriculture is a significant contributor to the country's GDP and the livelihoods of its people, the increasing impacts of climate change and variability on agriculture have the potential to push a large portion of the population below the poverty line of less than one dollar per day. For instance, changes in precipitation patterns alone increase the likelihood of crop failures and production declines, particularly for crops like maize (Becker-reshef *et al*., 2020).

The adverse effects of temperature and rainfall fluctuations are evident in the fluctuating levels of crop production in Cameroon, as illustrated in Figures 3 and 1.5. Smallholder farmers, who heavily rely on agriculture for their livelihoods, face significant insecurity due to these fluctuations. This situation calls for urgent attention to address the challenges faced by smallholder farmers and mitigate the adverse impacts of climate change on their livelihoods and food security.

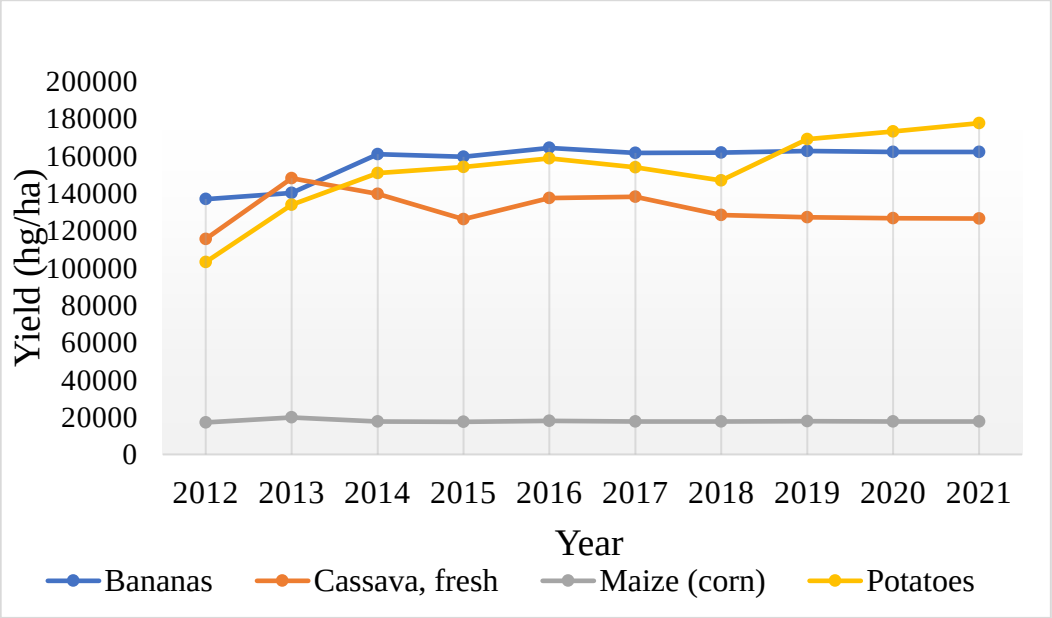


Figure 1. 4 Crop production levels in Cameroon 2012-2021

This study therefore aims to inform policy makers on how changes in climate and agricultural policies (conservation agriculture) might affect livelihood security of farm households that characterize the agricultural sector of Cameroon taking the south-eastern region as an example.

1.3 Research questions

The above research problem raises the question of how effective policy instruments are implemented to improve smallholder farmer livelihoods and environmental sustainability.

Specifically, this study seeks to answer the following research questions:

i) How do farmers in the East and South regions of Cameroon perceive climate variability?

ii) Which climate-smart adaptive strategies are used by the smallholder farmers in the South-eastern region of Cameroon to cope with the climate variability?

iii) What are the socioeconomic determinants of farmers' adoption of conservation agriculture (CA) in the South-eastern region of Cameroon?

iv) What are the effects of Conservation agriculture on the Livelihood security of smallholder farmers in South-eastern Cameroon?

1.4 Research Objectives

1.4.1 Main objective of the study

The main objective of this research is to ex ante estimate the effectiveness of selected policy instruments on sustainable land use in south-eastern Cameroon

1.4.2 Specific Objectives

Specifically, this study seeks to;

i) Assess farmers' perception of climate variability and change in the East and South Regions of Cameroon.

ii) Identify farm practices used in this area that are fulfil principles of conservation agriculture.

iii) Analyse the socioeconomic, Geographic and plot level determinants of farmers' adoption of Conservation agriculture in the South-eastern Cameroon.

iv) Evaluate the effects of CAs on the Livelihood of smallholder farmers in in the East and South Regions of Cameroon.

1.5 Research Hypotheses

The study statistically tests the null hypotheses;

H_{O1}: Smallholder farmers do not perceive any variations in the climate.

H_{O2}: Socioeconomic factors are not significant determinants of farmers' adoption of Conservation agriculture.

H_{O3}: Conservation agriculture have no effect on smallholder farmers' livelihood security.

1.6 Rational and Justification of the Research

There is an increasing demand for a micro-simulation tool capable of modelling farm-specific policies and capturing heterogeneity across farms. This stems from the recognition that the impact of a single policy can vary significantly depending on various factors. These factors include household location, resource endowment, land use, access to markets, economic status, and family composition. Thus, understanding the diverse effects of these factors on the adoption of policies on different farms is crucial for designing targeted and effective agricultural policies and ensuring equitable outcomes. However, farm-specific policies aim to address specific challenges faced by individual farms or farming communities.

Nonetheless, the impacts of such policies can differ widely due to the inherent heterogeneity among farms. Additionally, factors such as geographic location can influence the vulnerability of farms to specific risks, such as extreme weather events or market fluctuations. Furthermore, resource endowment, including access to land, water, and capital, can significantly affect a farm's productivity and resilience, also, farms with limited access to markets may face different constraints and opportunities compared to those with better connectivity.

Moreover, economic status and family composition play a role in determining a farm's capacity to adapt to policy changes. Small-scale and subsistence farmers may have

different needs and priorities compared to large commercial farms. Family farms with multiple household members involved in agricultural activities may have different labor dynamics and resource allocation strategies. Policies that fail to account for these differences can inadvertently exacerbate inequalities and have unintended consequences.

Therefore, there is a need for a micro-simulation tool which addresses these challenges by incorporating detailed data on individual farms, their characteristics, and their interactions with various policy scenarios. This will allow for the modelling of specific policy interventions, considering the diversity of farm-level factors and capturing the complexity of farming systems. Consequently, by simulating the impacts of policies on a farm-by-farm basis, the tool can identify the winners and losers of existing or alternative policies.

This level of granularity in policy analysis of this study enables policymakers to design more targeted interventions that consider the specific needs and constraints of different farms. It will help in understanding the distributional impacts of policies, including their effects on income distribution, food security, and social welfare. By identifying winners and losers, policymakers can adjust policies or implement complementary measures to ensure that the benefits are equitably distributed and that vulnerable farms receive adequate support.

1.7 Thesis Structure

This research is based on the premise that agriculture requires a multi-pronged approach to respond to climate change and socioeconomic challenges across different scales: adaptation, mitigation, food security (CA). The research sets out to address the research questions across five chapters that will be structured around a series of peer-reviewed journal papers, all of which will be published during the candidature. This introductory

chapter is followed by chapter 2 which provides a theoretical and empirical overview of CA adoption from an adoption lens it also examines the current literature through a systematic analysis of publications (e.g., journal articles, technical reports).

Furthermore, chapter 3 presents the overall methodological and analytical framework for the research investigation, arguing rational for an engaged scholarship approach to answering the research questions of this study. Chapter 4 will present the results from the study, and this will have 4 main sections. Objective one result will be presented in the first section followed by objective two to objective 4 respectively. The results from the study will be discussed and concluded in Chapter 5.

1.8 Chapter Summary

Chapter one puts Climate Smart Agriculture (CA) in a wider context of climate change, sustainable development, and climate-resilient transformation pathways. Several of the terms that are most important to this research are introduced, including adaptation, mitigation, climate smart agriculture and integration and reducing emissions from deforestation and forest degradation (REDD+). The chapter then provides an overview of the research aim and questions for this study, as well as the rationale and significance of this research, particularly how it contributes to emerging theories and discourses on climate change. To do so, this chapter commences by providing an overview on what CA is all about, the integration of mitigation and adaptation, followed by a description of the challenges in bringing the two approaches together in the agriculture sector. The chapter also explains the context of existing literature relating to the research problem, the geographic scope of the research, and how the research relates to current developments on CA. The chapter explains the implications for the research and outlines the structure of the

thesis.

CHAPTER TWO

Review of literature

2.1 Concepts and Issues

2.1.1 Conservation Agriculture

The issue of soil erosion was particularly severe in the Midwest region, where significant topsoil loss occurred due to various factors (Choudhary *et al*., 2016). In response, farmers began adopting practices such as cover cropping and crop rotation to protect the soil and preserve its fertility. The knowledge about these practices quickly spread, leading to a widespread adoption of Conservation Agriculture (CA) on approximately 60 million hectares of land globally by 2000 (Somasundaram *et al*., 2020). CA, as a concept, relies on three fundamental pillars: minimizing soil disturbance, maintaining complete soil cover, and implementing diverse crop rotations. The origins of Conservation Agriculture can be traced back to Kenya in the 1950s, where the focus was on preserving water reservoirs and preventing soil erosion (Kassam *et al*., 2009). Historical evidence suggests that conservation agriculture has proven to be one of the most robust and promising approaches to implementing sustainable agriculture worldwide (Strauss *et al*., 2021).

Therefore, conservation agriculture is defined as a sustainable farming approach that aims to enhance agricultural productivity, preserve natural resources, and improve the resilience of farming systems (Kassam *et al*., 2019). One of the foundational concepts of conservation agriculture is minimum soil disturbance, which involves reducing or eliminating tillage operations (Somasundaram *et al*., 2020). However, this principle draws inspiration from ancient agricultural practices such as zero-tillage and direct seeding, which have been documented in various cultures throughout history.

Notwithstanding, conservation agriculture encompasses three key principles: minimal soil disturbance, permanent soil cover, and crop rotation or diversification (FAO, 2017). These principles aim to enhance soil health, reduce erosion, conserve moisture, and promote biodiversity (Sharma & Biswas, 2022). Several studies have investigated the impacts of conservation agriculture on soil quality and productivity. For instance, Pittelkow *et al*. (2015) in their studies found that conservation agriculture practices, such as reduced tillage and crop residue retention, significantly improved soil organic matter content, water infiltration rates, and nutrient cycling. These improvements in soil quality contribute to enhanced soil fertility and long-term sustainability of agricultural systems.

Moreover, studies have demonstrated the positive effects of conservation agriculture on crop yields (Su *et al*., 2021). Myeni *et al*. (2019) conducted a global analysis reporting that conservation agriculture practices increased crop yields in various regions, particularly in rainfed agriculture dependent regions. Moreso, improved soil structure, moisture conservation, and reduced weed competition associated with conservation agriculture contribute to increased crop productivity (Kassam *et al*., 2016).

Conservation agriculture also offers environmental benefits by reducing the negative impacts of farming on natural resources. For instance, studies have shown that conservation agriculture practices significantly reduce soil erosion compared to conventional tillage (Lee & Gambiza, 2022). By preserving soil cover and structure, conservation agriculture mitigates the loss of topsoil, enhances water quality, and minimizes the release of greenhouse gases. Furthermore, conservation agriculture has socioeconomic advantages for farmers. For instance, studies have indicated that

conservation agriculture practices can lead to cost savings by reducing fuel, labor, and machinery requirements (Pittelkow *et al*., 2015).

Additionally, conservation agriculture contributes to increased resilience to climate variability and extreme weather events, reducing production risks and improving farmers' livelihoods (Kassam *et al*., 2015). However, the adoption of conservation agriculture can be influenced by various factors. Several studies have identified barriers to adoption, including the availability of appropriate machinery, access to credit, knowledge gaps, and social constraints (Choudhury *et al*., 2017; Thierfelder *et al*., 2017). Overcoming these barriers requires supportive policies, extension services, and farmer-to-farmer knowledge sharing. Therefore, a variety of CA practices deemed GHG reducing ought to be inspired (McCarthy *et al*., 2011). Among these:

a) Agronomic practices (promoting the use of perennial crops, which can be cultivated for longer periods, instead of annual crops, which require periodic turning of soil; extending crop rotations).

b) More careful land nutrient management.

c) Improved fallows.

d) Improved grazing land management.

e) Minimized tilling frequency.

f) Increased practice of agroforestry (i.e., crop production on land that also grows trees).

g) Restoration of degraded lands and organic soils through, for instance, re-vegetation.

h) Rewetting of cultivated organic soils.

i) Change in the composition of animal feed or change in stocking practices toward more intensive grazing methods to reduce enteric methane emissions from cows and other ruminants.

j) Improved manure management; and

k) Adoption of rice cultivation practices (such as mid-season drainage and shallow flooding) that reduce the amount of time that soils are submerged under water and by the same token the amount of gas produced (McCarthy *et al*., 2011).

CA reaching to contribute to sustainable landscapes and food systems likewise on resilience, ecosystem services, and price chains, involves a complex set of objectives and multiple transformative transitions. There has been completely different views to CA, for some, CA isn't a scientific or technical conception, however rather a "political" conception aiming at higher incorporating agriculture in climate negotiations (Conway, 2014). CA withal intends to mobilize science to realize necessary transitions, and needs bridging a diversity of disciplines in agricultural sciences and therefore the surroundings, and specifically, the utilization of temperature/rainfall change science information and models by the agricultural research community, like the Intergovernmental Panel on climate change (IPCC) projections, is very important (Rosenzweig *et al*., 2018).

2.1.2 Climate Variability and Climate Change

Climate is defined as long-term average weather conditions (usually taken for more than 30 years as defined by the World Meteorological Organization, WMO) of a region

including typical weather patterns such as the frequency and intensity of storms, cold spells, and heatwaves (Riedy, 2016).

Gutzler, (2015) defines climate variability as variations in the mean state and other statistics (e.g., standard deviations or the occurrence of extreme events) of the climate on all temporal and spatial scales beyond that of individual weather events or periodic fluctuations of average temperature, precipitation, which could result directly/indirectly from the yearly cycle of incoming solar radiation. Furthermore, Climatic variability is the types of changes (temperature, rainfall, the occurrence of extremes); magnitude and rate of the climate change that causes the impacts on the area of public health, agriculture, food security, forest hydrology, and water resources, coastal area, biodiversity, human settlement, energy, industry, and financial services (the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, 2017).

According to IPCC Climate change is, therefore, any change in climate over time, whether due to natural variability or from human activity. Climate change may be due to natural internal processes or external forcing or persistent anthropogenic changes in the composition of the atmosphere or land use (Xiao *et al*., 2020) (Potapowicz *et al*., 2019). Thus to better understand climate change (Campbell et al., 2014a) defined climate variability as "variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all geometric and temporal scales above that of individual weather events" (Campbell et al., 2014b).

Africa's climate is differentiated by seven zones which are: tropical rainforest, tropical wet and dry, tropical dry, mountain, Mediterranean, middle latitude, dry and humid sub-

tropical. And within the various zones, altitude, and other localized variables generate different regional climates (Bager *et al*., 2017). This led to (Hulme *et al*., 2001)'s description of Africa's climates to be both varied and varying. Fluctuated because, they reach out from moist central systems, through seasonally arid tropical systems, to sub-tropical Mediterranean-type climates. While shifting since every one of these climates shows various degrees of transient variability, particularly concerning precipitation.

Global mean surface temperatures have increased in a linear trend of 0.74 ^{0}C over the last 100 years with Africa being hot and dry with current trends showing warmer spells than it was 100 years ago (Agriculturae & Olorunfemi, 2013; Herrero *et al*., 2010; Kurukulasuriya *et al*., 2006). With these trends appearing to be widespread over the continent, the temperature changes are still not always uniform, for they vary considerably between and within regions and countries. An example, are countries lying around the Nile Basin witnessed an elevated temperature of between 0.2 and 0.3 ^{0}C per decade in the second half of the century, while in Rwanda, the temperature increased by 0.7 to 0.9 ^{0}C (Bager *et al*., 2017).

According to the Third Assessment Report (TAR) of the IPCC, the Earth's average surface temperature increased 0.6 ± 0.2 ^{0}C in the twentieth century. But with future expectations, these trends will persist, with a rise of 1.4 to 5.8 ^{0}C by 2100 (Masson-Delmotte *et al*., 2018). And concerning these future changes, the whole of Africa is expected to warm across all seasons throughout this century (Boko *et al*., 2007). Narrowing to the case of SSA, there will roughly be +2.0 to +4.5 ^{0}C of temperature rise by 2100, and this expected to be stronger than the global average (Engel & Muller, 2016). Furthermore, model results by (Meadows, 2006) revealed positive mean annual temperature anomalies in the future,

in the range of 2-3 ^{0}C for Southern Africa. Also, some of the Equatorial countries like Cameroon, Uganda, and Kenya, for example, will be about 1.4^{0}C warmer. Representing a rate of warming by 2050 to about 0.2 ^{0}C per decade.

As compared to rainfall, the temperature normally plays a significant role in driving year-to-year production changes but is less important in determining agricultural production in the tropics (Hertel & Lobell, 2014). Hence precipitation assumes a significant part in determining agricultural production levels and thus, the economic and social prosperity of rural communities (Hertel & Lobell, 2014). As cited in (Kotir, 2011) rainfall pattern in SSA is influenced by extensive intra-seasonal and inter-annual climate variability including intermittent El Nino-Southern Oscillation (ENSO) events in the tropical Pacific bringing about continuous outrageous climate events, for example, prolonged dry seasons and floods that decrease agricultural yields prompting serious food shortages. This ENSO (a key determinant of African rainfall variability) phenomenon is the climatic engine influencing rainfall on an inter-annual timescale and is often described as one of the important determinants of year-to-year climatic variability and serious effects far and wide (Gutzler, 2014).

Global warming has been figured to be the main driver of climate change in the same light, the IPCC in its fourth assessment report states that" Warming of the climate system is unequivocal as evidenced by observed increases in average air and ocean temperatures, widespread melting of snow and ice as well as rising global average sea level". Model-based predictions of future greenhouse gas-induced climate change for the continent also clearly suggest that this warming will continue and, in most scenarios, accelerate (Thornton *et al*., 2009). (Karimipour *et al*., 2019) therefore postulates, global warming to be a term

used to describe the overall atmospheric warming resulting from increased greenhouse gases produced by the human activities of petroleum derivative use, deforestation, changing land use, etc.

Furthermore, in early depictions, it was also referred to as the "greenhouse effect," quite literally because, like in a greenhouse, the increasing quantity of heat-trapping gases was resulting in an overall increase in atmospheric temperature. Rather than bringing about general warming overall earth systems, the general increment in atmospheric temperature converts into an interwoven of on-the-ground impacts, including a few territories being more sweltering and some colder, some wetter and some drier, and thus referred to as climate change (Karimipour *et al*., 2019).

Climate change has been identified by researchers, development practitioners governments as a threat and a hurdle to sustainable growth and development in the world (Bocchiola *et al*., 2019) This changes and variability in weather patterns have affected many developing countries with a resultant decline in national and household food security levels (G. C. Nelson *et al*., 2010). With these levels, these variations have been linked among other things to crop production fluctuation both in developed and developing countries (Wiebe *et al*., 2019a). It is expected that the increase in the frequency of climate fluctuations by the year 2030 will result in more food insecurity as compared to shifts in temperatures and rainfall patterns (Tulus *et al*., 2019).

The testament of climate change includes changes in terrestrial biological systems for example the shift towards earlier timing of events such as leaf unfolding and bird migration (Yu *et al*., 2019) and changes in types and abundance of plankton and fish (Grantham *et*

al., 2019) that have been observed at high latitudes. Global warming is mainly due to the presence of naturally occurring atmospheric greenhouse gases such as water vapor, carbon dioxide (CO_2) and methane (CH_4), ozone (O_3), and nitrous oxide (N_2O) which impede the escape of out-going long-wave radiation into space, thereby causing warming of the earth (Mann, 2009).

Furthermore, the warming is improved by human activities, for example, consuming carbon-based non-renewable energy sources and deforestation which radiate ozone-depleting substances into the atmosphere. (Touma *et al*., 2021), concluded that temperature increases are highly likely to be due to anthropogenic emissions of greenhouse gases. Changes in land use also contribute to global warming and together with deforestation, changes in land use contribute about 20% of the CO_2 emitted in a year (De Sy *et al*., 2015) while 80% is accounted for by the burning of carbon-based fossil fuels such as coal, oil and natural gas.

The highest emission scenario projects an increase of 2.4-6.4^{0}C in global average surface temperature, relative to the 1980-1999 base period, by the year 2100, while the rate of increase of temperature during the two decades, 2010-2030 is estimated at 0.2 ^{0}C per decade across all IPCC emission scenarios (M. R. Islam, 2019). The IPCC (2001; 2007) projects a high risk of extreme temperature events in future climates, warming is expected to cause a rise in sea level in the range 0.18-0.59 m during the period 2090-2099, relative to the 1980-1999 period, across all IPCC emission scenarios. For precipitation, there is less agreement among climate models on future projections than for temperature (PINIEwSkI *et al*., 2017), with projections over tropical regions being more uncertain than those at higher latitudes (Sanz & Cite, 2018). However, at high latitudes, there is a high probability

(95%) that precipitation will increase while in the sub-tropics, precipitation is likely to decrease by as much as 20% by 2100.

Projected sea-level rise also differs, with the lowest CO_2 emission scenario (B2 scenario) having the least rise of 1.80-3.81 m and the highest emission scenario (A1F1) having the greatest rise of 2.59-5.89 m over the period 2090-2099, relative to the 1980-1999 period (Table 2.1). The IPCC scenarios are based on projected future greenhouse gas emissions, particularly CO_2, which is in turn driven by factors such as social, economic, and technological changes. Thus, social, economic, and technological changes determine the level of vulnerability to climate change (Solomon, 2007).

Table 2. 1 Projected global average surface warming and sea-level rise at the end of the 21st century

	Temperature Change (°C at 2090-2099 relative to 1980-1999)		Sea-Level Rise (cm at 2090-2099 relative to 1980-1999)
Case	Best Estimate	Likely Range	Model-based range excluding future rapid dynamical changes in ice flow
Constant Year concentrations	0.6	0.3-0.9	NA
B1 scenario	1.8	1.1-2.9	18.0-38.1
A1T scenario	2.4	1.4-3.8	20.1-45.0
B2 scenario	2.4	1.4-3.8	20.1-42.9
A1B scenario	2.8	1.7-4.4	21.1-48.0
A2 scenario	3.4	2.0-5.4	23.1-51.1
A1Fl scenario	4.0	2.4-6.4	25.9-58.9

Source: (Solomon, 2007)

In the coming years, if greenhouse emissions are not lessened, the ambient temperature of Africa is likely to rise, and rainfall patterns are expected to change drastically (Amoo & Fagbenle, 2020). The predicted rise in temperatures could lead to an approximately 20% reduction in the growing seasons of key crops by the end of the century and increases in crop pest and disease incidence, for instance, production of beans is expected to fall by 50% (Ponce, 2020) (Yang et al., 2020). Thus, climate variability is likely to affect crop

production negatively and increase food insecurity particularly for people living in arid and semi-arid (ASAL) regions.

However, climate-related biotic and abiotic stresses have impacted poorly on harvests causing decreases in harvests, this has led to an increase in food insecurity (Nyantakyi-Frimpong *et al*., 2019). Amongst the abiotic factors that affect crop production are increasing temperature, high cost of inputs, unreliable rainfall, and decreasing water availability. On the other hand, biotic factors include pests and diseases, soil fertility (Marconi & Armengot, 2020). The reduced crop production in Africa has resulted in increased food prices especially in periods succeeding long spells of droughts and increased food demands(Rötter *et al*., 2018). FAO (2017) indicated that the food price spike of 2008 increased the number of hungry people from 800 million to 1.02 billion in the world. Notably, three-quarters of the affected during this period were in Africa.

2.1.3 Impacts Climate Change on Livelihood Security

Climate change affects agriculture and agriculture additionally affects global climate change. Higher temperatures, reduced rainfall and increased rainfall variability reduce crop yield and threaten food security in low income and agriculture-based economies. Thus, the impact of global climate change is damaging to countries that rely upon agriculture because the it is their main means of sustenance (Deressa et al., 2011). Vulnerability is that the degree to which a system (such as a social-ecological system) is probably going to be wounded or experience damage or stress within the natural or social surroundings (FAO, 2013). Vulnerability results from a mixture of processes that form the degrees of exposure to a hazard, sensitivity to its stress and impacts, and resilience within the face of these effects. it's additionally thought-about as a characteristic of all people, ecosystems, and regions confronting environmental or socioeconomic stresses, though the extent of vulnerability varies wide, it's usually higher among poorer people (Amare & Simane, 2017).

Additionally, climate change is one in all the foremost vital challenges of the present era. this is still very true for developing countries within the tropics and semitropics, that are expected to be hit hardest by global climate change (Hertel & Rosch, 2010). The potential negative implications of global climate change embody declining agricultural production (Buckley, 2010), lack of access to safe water, accumulated livelihood insecurity and downward spirals in varied human-development dimensions (Bandauko *et al*., 2022).

Moreover, most tropical developing countries have an outsized share of poor subsistence farmers (Harvey *et al*., 2014); the World Bank (2003) defines this cluster, as farmers who have low asset bases and who operate on less than 2 ha of cropland. Estimates indicate that people, small groups or households run a minimum of 90% of the over 570 million farms within the world (Mason-D'Croz *et al*., 2019). Roughly 2.5 billion of the three billion those that live in rural areas have confidence in farming as their main supply of finance (FAO, 2013), and smallholders comprise eighty four of that group (Mason-D'Croz *et al*., 2019).

However, global climate change is problematic for these smallholders as a result of their restricted resources stopping them from addressing climate-induced shocks (van den Heuvel *et al*., 2011), that adds to these farmers' vulnerability (Aggarwal et al., 2018). Furthermore, climate variability and ecological changes have consequently altered life and natural livelihood-sustaining systems resulting in socio-cultural, economic and environmental challenges and vulnerabilities (Thornton *et al*., 2014).

Nonetheless, the risk factors are terribly high and also the impacts can raise developmental impediments of safeguarding livelihood security and poverty eradication in Sub-Saharan Africa (Aniah *et al*., 2019). Global climate change and connected extreme events are therefore, negatively poignant on agricultural production wherever countless smallholder farmers rely on it. the chance of food insecurity is larger these days in developing countries as a result of livelihoods exposure and susceptibility to climate change (Conforti et al.,

2018). However, the extent of vulnerability of a system, household, and site is differentiated settled by environmental and socioeconomic factors, in Sub Sahara Africa, extreme events like drought already impede people's ability to grow crop and rear animal (Kebede *et al*., 2011).

Nonetheless, this can be principally attributable to Africa's poor socio-economic development standing and that successively affects the continent's aspiration towards sustainable development goals thus increasing farmer livelihood insecurity in this region (Dendir & Simane, 2019). However, in line with (Kurukulasuriya *et al*., 2006) most of the agricultural production is rain-fed, a scenario that makes it a lot more susceptible to global climate change and variability. The impacts of climate in agriculture embody reduction in production of various crops principally related to repeated droughts, floods, increasing crop pest and diseases and shift of growing seasons.

Agricultural growth has long been thought about as a very important step toward economic development and transformation in the developing world. This has so been the case in several Asian and Latin American countries wherever agriculture-led growth play a big role in economic transformation and livelihood of farmers (Banerjee *et al*., 2020). This transformation, however, has not occurred in Africa. In most low-income African countries the economy is essentially obsessed on agriculture (Clay & Zimmerer, 2020), with agricultural growth being predominate for the survival of the majority rural population directly reckoning on agriculture for his or her livelihoods (Hilson, 2016).

Most especially, Sub-Saharan African households rely upon subsistence agriculture for their livelihoods, and most agriculture in Africa, in turn, is carried out by subsistence households (Clay & Zimmerer, 2020). This remains true even after many decades of

growth in urban populations. As of 2010, the United Nations Food and Agriculture organization (FAO) reported that 58.8% of the entire sub-Saharan hands was in agriculture and a rather higher proportion (63.6 %) of the entire population was in rural areas. subsistence agriculture is additionally and significantly a supply of livelihoods for women (Wiebe et al., 2019). Although ladies form up very little quite 0.5 the agricultural force, women are in high probability to work in agriculture than in different sectors. Thus, agriculture is the main supply of employment for pretty much 2 thirds of economically active African women. only a few ladies add the wage labour market; the majority are operating in smallholder production (Broeck & Kilic, 2019).

Almost all the agricultural force is used in subsistence production systems instead of giant farms, though there's no conceptually clear way to outline ‘small farms’ or ‘smallholder agriculture’. on several measures wherever quantification is feasible, however, it's clear that almost all African agriculture takes place on a small scale. as an example, the overwhelming majority of crop farms are smaller than 5 hectares (Guido *et al*., 2020), and proof from various house surveys supports the concept that the median size of a crop farm is perhaps between one and 2 hectares in most of the countries with obtainable information.

Furthermore, the small acreage of those farms shouldn't obscure their importance in livelihood strategies. However, small farms don't seem to be solely sources of employment; they're additionally, maybe clearly, sources of food and sustenance (Meyfroidt, 2017). though there's monumental nonuniformity across SSA, several subsistence families produce an outsized fraction of the household’s food; and conversely, a lot of their agricultural output is consumed among the house (Janvry *et al*., 2017).

Household surveys from African countries typically show high rates of house consumption of agricultural produce. as an example, in Rwanda, solely 0.5 of the grain production enters market channels; the remainder is consumed among producing households. Similarly, households sell solely half of the roots and tubers made and fewer than ten per cent of the beans (republic of Rwandese Republic, national Institute of Statistics, 2010, p. 56). this is often not distinctive to Rwandese Republic, an equivalent pattern holds in African nation, as an example, wherever 2 thirds of the cookery bananas and 3 quarters of the cassava are consumed within the producing households (Uganda Bureau of Statistics, 2006, pp. 56-59). In northern Ghana, concerning eighty per cent of maize the only most significant crop is consumed by the households that produce it, together with 3 quarters of the sorghum and 0.5 the yams (Wiréhn, 2018).

As noted above, most African agriculture takes place in smallholder systems. only a few farms use large numbers of employed workers; the exceptions are large plantations that produce tea, rubber, and a couple of different export crops. As a result, most of the employees within the agricultural sector in continent are freelance or own-account workers; only a few are staff. though comparatively few countries report these information, the figures are striking in those countries that do (Liu *et al*., 2018). as an example, averaged over the amount from 2001 to 2010, only 1.2% of the agricultural force in Benin consisted of staff, as outlined by the International Labour organization (12,000 out of nearly one million).

Similarly, low proportions (less than two percent of the agricultural workforce) worked as staff in Guinea, Ethiopia, United Republic of Tanzania and Sierra Leon (Cleeve *et al*., 2015). In effect, this is often a live of the dominance of smallholder modes of production all told however, a couple of countries with large-scale production of plantation export crops. The exceptions to the present rule are revealing they're countries with comparatively small overall shares of agricultural employment (compared to total employment). Thus, large fractions of the agricultural force include ‘employees’ in Botswana (11.2%) and even

larger fractions in Republic of South Africa (59.1%) and Mauritius (55.3%)(Bryceson, 2019).

Although African smallholders rely on agriculture for sustenance additionally as for money financial gain, it's necessary to acknowledge that a lot of smallholder households pursue non-farm activities additionally to farming. The degree of dependence on agriculture varies considerably across and among countries with rural non-farm employment offering variety of advantages to agricultural households (Duker *et al*., 2020). It is a variety of diversification and risk coping, provides a vehicle for managing seasonal fluctuations in agricultural labour demand, and provides money financial gain to enrich and supplement the in-kind financial gain from farming (Bernier *et al*., 2015). there's vital spatial and economic nonuniformity in rural non-farm employment (Uk, 2007). In general, households that are in remote areas tend to devote all their labour hours to farming, and rural non-farm employment is correlate with proximity to markets.

However this correlation typically breaks down and it's in no way monotonic (Dzanku, 2019). In areas of proximity to cities and concrete markets, households might realize it worthy to focus on intensive production of high price agricultural outputs, like fruits and vegetables or dairy farm, aimed toward urban shoppers. Specialization might crop up at the extent of individuals; some household members may match in off-farm activities whereas others have involved full-time in farming activities (Camargo *et al*., 2017).

However, Fidèle *et al*. (2018) argue that rural non-farm employment is growing in importance in several developing countries, and lots of studies purpose to large, continued flows of population from rural to urban areas. Agriculture's share of total employment has been falling steadily in the majority countries within the region. As a result of rural populations still growing speedily, however, absolutely the variety of individuals operating in agriculture and living in rural areas appears probably to rise for consequent many decades in Africa (Hilson, 2016). what's clear is that in SSA, non-farm employment and urban employment are primarily in sectors like trading and informal services; there's very

little or no manufacturing employment in African towns and cities (Dercon & Gollin, 2014).

Urban employment opportunities seem to supply higher wages and standards of living than do rural jobs and it remains somewhat puzzling why rural-urban migration flows don't seem to be larger than presently. Possible explanations embrace the strength of informal insurance networks in rural areas; the potential loss of land rights and therefore the importance of holding title. In terms of long and external forces affecting smallholder agriculture in the African continent, maybe the foremost powerful are the availability of urban employment (Dhahri & Omri, 2020).

Consequently, if new urban employment opportunities emerge and barriers to movements fall, it looks doable that the pace of rural outmigration might dramatically increase. Subsistence agriculture dominates the agricultural sector in most desert African countries (Dhahri & Omri, 2020). Smallholder farms represent eightieth of all farms in Sub Sahara Africa (SSA) and contribute up to ninetieth of the production in some SSA countries (80% in total in Africa). Broad participation of smallholder farmers and their direct contribution to the expansion process is crucial for agricultural development (Vanlauwe *et al*., 2019).

In Cameroon within the Congo Basin, the bulk of rural households and an oversized proportion of urban households rely on plant and animal product from the forests to meet their nutritional, energy, cultural and healthful wants (Sonwa, 2017). Furthermore, Sonwa *et al*. (2012) in their paper explores the seemingly impacts of climate-induced changes on the provisioning of forest ecosystem goods and services and its result on the economic and social well-being of the society, together with the financial set-up and therefore the livelihoods of forest-dependent individuals. The analysis centred on four known vulnerable

sectors food (NTFPs), energy (fuelwood), health (medicinal plants) and water (freshwater) through a multi-stakeholder dialog at national and regional levels.

Additionally, they used a vulnerability assessment framework by combining the weather of exposure, sensitivity, and adaptive capability to conceive vulnerability in these sectors. The known sectors regarding the forest scheme were mentioned in sight of providing understanding of the sector's potential on adaptation capacities for policy intervention. Their analysis presented the possible implications of the vulnerability of these sectors for planning local and national adaptation ways. And their results showed that the local and national adaptive capacities to reply to climate impacts within the forest sectors includes reducing poverty, enhancing food security, water availability, combating land degradation and reducing loss of biological diversity.

2.1.4 Vulnerability to climate change

Vulnerability refers to the susceptibility of a system or community to harm from climate change (IPCC, 2014). It encompasses a wide range of factors, including exposure to climate hazards, sensitivity to those hazards, and the capacity to adapt and cope with the associated risks (Lecina-Diaz *et al*., 2021). By understanding vulnerability, policymakers and stakeholders can identify areas of high risk and develop targeted interventions to enhance resilience. Vulnerability, in the context of climate change, refers to the degree to which a system or community is susceptible to harm from the impacts of climate change(Birkmann *et al*., 2022). It is an integrated concept that includes exposure to climate hazards, sensitivity, or the degree of negative impact that the hazard causes, and the capacity to adapt and cope with the risks associated with the hazards(Birkmann *et al*., 2022).

Exposure refers to the presence or occurrence of the hazards in the area. It can be measured by the frequency, intensity, and duration of the climate hazards in the area. Sensitivity refers to the degree of negative impact of the hazard on the system or community(Pörtner & Roberts, 2022). Vulnerability is not just determined by natural and physical factors but also by social, economic, and political factors, as well as historical and cultural factors. Adaptive capacity refers to the ability of the system or community to adjust and cope with the risks associated with the hazards. It can be enhanced through measures such as improving infrastructure, access to technology, information, and resources, as well as social and institutional arrangements (Formetta & Feyen, 2019).

By understanding vulnerability, policymakers and stakeholders can identify areas of high risk and develop targeted interventions to enhance resilience. This can be achieved by implementing measures to reduce exposure to hazards, improve sensitivity, and increase adaptive capacity. For instance, building sea walls to reduce the impact of sea-level rise, improving irrigation systems to cope with droughts, or implementing early warning systems to reduce the impact of extreme weather events.

2.1.5 Climate change Mitigation

There has been a lot of concern on the increasing concentration of greenhouse gases, and carbon dioxide above all contributes to heating by tack long-wave radiation mirrored from the earth's surface. Over the past a hundred and fifty years, the quantity of carbon within the atmosphere has enhanced by 30%. Most scientists believe there's an instantaneous relationship between enhanced levels of carbon dioxide within the atmosphere and rising global temperatures (Cong *et al*., 2020; Pausata *et al*., 2020).

On mitigation, the forests have huge opportunities to contribute to the reducing emissions from deforestation and forest degradation (REDD) mechanism. But the forest itself and its multiple dependent societies and sectors got to adapt to potential climate risks. Hence, actors are debating the look of temperature change policy within the forest sector (Somorin *et al*., 2012).

Mitigation could be a human mediation to scale back the sources or heighten the sinks of greenhouse gases (Cordovil *et al*., 2020). Mitigation, alongside adaptation to climate change, contributes to the target expressed in Article two of the international organization Framework Convention on temperature change (UNFCCC). The ultimate objective of this Convention and any connected legal instruments that the Conference of the Parties might adopt is to realize, in accordance with the relevant provisions of the Convention, stabilization of gas concentrations within the atmosphere at a level that may forestall dangerous phylogeny interference with the climate system. Such a level ought to be achieved among a timeframe to permit ecosystems to adapt naturally to climate change, to confirm that food production isn't vulnerable and to alter economic development to proceed in a sustainable manner (IPCC ,2015:4).

Cameroon's per capita emission of 0.25 ton carbon dioxide that is well below the African average 0.92 t CO2/capita and really far from the Organisation for Economic Co-operation and Development(OECD) countries average 9.83 CO2/capital (Ahundjanov & Akhundjanov, 2019; Njoh *et al*., 2019). This is equally low compared to quite ten ton within the EU and twenty ton within the North American country and Australia. The country's total emissions of around 4.79Mt carbon dioxide represent but 0.1% of worldwide emissions (Hammed *et al*., 2018).

The agricultural sector is one among the foremost contributors of GHG (Green House Gas) emissions in Cameroon through the crop, livestock and natural resources carbon footprints (like as a result of soil degradation and land use amendment from forest land to agricultural land) (Martial *et al*., 2017). Cameroon intends to limit its GHG emissions in 2030 to by 25% or lower by 2035 (Belay *et al*., 2017; Weldegebriel & Gustavsson, 2017). GHG emission has compact the agriculture sector during a means that rainfall variability and associated yield reductions are calculable to cost Cameroon a good a part of its potential growth rate and increase poverty by 25% (Falchetta *et al*., 2019).

Since the country's main-stay and/or economy are supported agriculture, temperature change might negatively have an effect on agriculture (Tegegne *et al*., 2017). Moreover, increasing/decreasing rainfall related to climate change is damaging to (crop and livestock) agricultural activities. According to completely different studies (Bizikova *et al*., 2019; Rouzitalab *et al*., 2019), variety of mitigation methods to immune level of emissions significantly from the agriculture sector (i.e., from crop, mainly) Some of the known mitigation methods are: reducing expansion of cultivable land through agricultural intensification (increasing productivity by reducing GHG emission: conservation agriculture, compost, wise use of inorganic fertilizers, proper crop management)(Arya *et al*., 2019); improving animal productivity through breeding; feedlots practice by smallholder farmers; improving feed and feeding management; diversification toward lower emitting animal species (small ruminants)(Adegbeye *et al*., 2020); mechanization; manure management; afforestation/reforestation; agroforestry; soil and water conservation and land rehabilitation; and reducing rate of desertification (Adegbeye *et al*., 2020; Belay, 2016).

Africa is facing serious constraints exacerbated by temperature change. Several elements of its development are currently affected by this international environmental downside. More necessary is the indisputable fact that the poorest who are less contributors of climate change are the foremost vulnerable. Response to the present international threat has to address each the causes of the matter (i.e. mitigation actions) and therefore the consequences (known as adaptation to climate change) The twenty first Paris Conference of the Parties (COP 21) of the United Nations Framework Convention on climate change (UNFCCC) was a vital milestone that cause the event of supposed National Determined Contributions (INDCs) with commitments to mitigate climate change, however additionally to deal with vulnerability associated with this. These efforts in responding to climate change, notably his mitigation part, are to be drained in the context wherever the continent desires to enhance its development (Sonwa, 2017).

2.1.6 Climate change Adaptation

Discussions on adaptations especially in Africa is because the average climate is already being affected by the emitted anthropogenic greenhouse gas and aerosol emitted in the past and still being emitted (Le Quéré *et al*., 2020). Nowadays, adaptation has become a key focus of the scientific and political communities and may be a major space of dialogue within the triangular global climate change process. As global climate change is projected to hit the poorest the toughest, it's particularly necessary for developing countries to pay explicit attention to the management of natural resources and agricultural activities.

Adaptation is one in all the policy choices for reducing the negative impact of climate. Adaptation to global climate change refers to adjustment in natural or human systems in response to actual or expected environmental condition stimuli or their effects that moderates harm or exploits helpful opportunities. Common adaptation ways in agriculture embrace use of latest crop varieties and animal species that are highly suited to drier conditions, irrigation, crop diversification, adoption of mixed crop and livestock farming systems, and changing planting dates (Deressa *et al*., 2011). In most of these countries such as Cameroon, forest can play important role in achieving broader climate change adaptation goals (Bele *et al*., 2011). Facilitation of the adaptation measures arise from research and data collection which aim at highlighting the climate risks which requires urgent attention (Mabon & Shih, 2018; Mylonas *et al*., 2020).

In this light-weight, adaptive capability "is the power of a system to deal with global climate change (including climate variability and extremes) to moderate potential damages, to require advantage of opportunities, or to deal with the consequences" (Choden *et al*., 2020). We can so outline adaptation as "adjustment in natural or human systems in response to actual or expected climatical stimuli or their effects, that qualified damage or exploits helpful opportunities" Adaptation can be "anticipatory or reactive, private or public and autonomous or planned adaptation (Hughes, 2020).

Coping and adaptation are synonyms, with coping being the short-term measures aimed at dealing with immediate risks while an adaptation deals with tackling the effects of climate change. By 2050, it is predicted that the global population will be over 9 billion people, increasing the demand for food and other agricultural products (FAO, 2014). At an equivalent time, the globe faces challenges like land and water scarceness, accrued

urbanization, and temperature change and volatility. Agricultural production remains the most supply of financial gain for many rural communities (about eighty-six of rural individuals - 2.5 billion), who rely upon agriculture for their livelihood (the High-Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security, 2017).

Improving adaptation of the agricultural sector to the adverse effects of climate change are going to be imperative for safeguarding the livelihoods of the poor and making certain food security. In sensible terms, climate change adaptation needs quite merely maintaining current levels of performance of the agricultural sector; it needs developing a group of strong and however flexible responses that will improve the sector's performance even under the changing conditions brought about by climate change engenders (Bárcena *et al*., 2014).

According to Food and Agriculture Organization of the United Nations (2013), Main global climate change exposure for densely inhabited highlands and poor areas like the Himalaya, Andes, Central American highlands, rift valley, Ethiopian plateau, Southern Africa etc. They are vulnerable as a result of, rain-fed agriculture, marginal lands and poor soil wetness capability which is the very nature of the agricultural potential (Pauw & Ramasamy, 2019). The high prevalence of poverty, limited options, knowledge, social safety nets and resources drive to have low adaptive capacity.

Adapting to global climate change can entail changes and changes at each level from community to national and international. Communities should build their resilience, as well as adopting applicable technologies whereas creating the foremost of cognitive

content, and diversifying their livelihoods to deal with current and future climate stress (Chowdhooree, 2019; Musavengane & Kloppers, 2020).

Local coping ways and traditional knowledge ought to be employed in integrated with government and local interventions. To enforce effective adaptation measures, governments yet as nongovernment organizations, should think about group action climate change in their designing and budgeting at all levels of decision making process (Ananth *et al*., 2019). Decisions on the sort of adaptation typically created by people, teams inside society, organizations, and governments on behalf of society. Some adaptation measures are also taken at individual level, like fresh water gathering and investments, building dams, release new cultivars that are a lot more drought resistance need collective actions (Nw-egypt *et al*., 2019).

Congruently, societies have inherent capacities to adapt to global climate change and have developed completely different adaptation and mitigation methods to combat climate change. They have developed information, skills, technology, institutional arrangements and techniques that are necessary foundations for adapting to long-term global climate change (Muldoon-smith & Greenhalgh, 2019). Based on the sort of economic activities and social networks societies will access native coping methods against shocks. Communities have continually tailored to climate variations by creating preparations supported by their resources and knowledge accumulated through expertise of past weather pattern (Bagagnan *et al*., 2019).

Adaptation may be classified as autonomous or planned adaptation. Autonomous adaptation (also referred to as spontaneous adaptation) refers to “adaptation that doesn't

represent an acutely aware response to environmental stimuli, however is triggered by ecological changes in natural systems and by market or welfare changes in human systems" (Assefa & Laerhoven, 2018). It takes place without the directed intervention from a public or private agency (Assefa & Laerhoven, 2018 Planned adaptation on the opposite hand, is "the results of a deliberate policy call, supported by an awareness that conditions have been modified or are near to amendment and that action is required to return, maintain, or achieve a desired state" (Sherman *et al*., 2016).

A Study by Yazdanpanah *et al*. (2022) indicated that the vulnerabilities of climate change occur at various scales and successful adaptation depend on actions taken at different levels either at national or farm levels. The agricultural sector is particularly vulnerable to climatic variability and extreme weather events. Adaptation in this sector is most likely a reflection of these extreme weather events rather than the cumulative effects of climate change (Yazdanpanah *et al*., 2022). Some studies (Bhattacharya, 2019; Lybbert & Sumner, 2010) have outlined examples of national climate change adaptation measures used in agricultural sector to be:

1) Technological innovations: improved crop varieties, early warning systems, land and water management, integrated pest management, etc.
2) Government subsidies: agricultural subsidies among different farmers support services to cushion famers against the impacts of climate variability Farm production practices: farm production, land use, land topography, irrigation, and timing of operations

2.1.7 Reducing Emissions from Degradation and Deforestation and others (REDD+)

Reducing Emissions from Deforestation and Degradation (REDD) could be a framework most countries have come back to agree upon in otherwise beleaguered climate negotiations. It is modelled as an oversized scale Payment for ecosystem Services (PES) scheme wherever countries are paid per quantified amounts of avoided emissions and it's bestowed as a win-win solution for countries in both the global South and North (Awono *et al*., 2014).

REDD+ has garnered critics for being yet another homogenising top-down scheme for environmental governance (Karlsson & Thompson, n.d.), this time on a global scale. Managed not by one state however an opus of national and international actors, REDD offers a superb example of world governance, often delineated as, 'the collective capability to identify and solve issues on a worldwide scale' (Westholm & Arora-Jonsson, 2015) REDD activities initiated by the United Nations REDD programme (UN-REDD) and also the world bank expected to supply a cheap way of reducing emissions of greenhouse gases and to bring about transformations that mitigate climate change and reduce poverty, all these which are in climate smart agriculture.

However, the concession of the potential of reducing tropical deforestation and forest degradation in contributing to climate change mitigation came with the realization that tropical forests store up to 25% of all terrestrial carbon. Studies have indicated that the combined clear-cutting and logging in the 1990s could have accounted for 10 to 25 % of the global human-induced CO_2 emissions (Wood *et al*., 2014). The IPCC Fourth Assessment report elevated the debate on the role of REDD+ in climate change mitigation

when it confirmed that up to 20% of the total GHG emissions results from deforestation and forest degradation in developing countries (IPCC, 2007), and strengthened the position of REDD+ in international climate change policy negotiations.

The UNFCCC first gave official recognition to REDD+, through Decision 1/CP.13, it launched a comprehensive process to enable the full, effective, and sustained implementation of the Convention through long-term cooperative action, up to and beyond 2012, by addressing inter alia; reducing tropical deforestation and forest degradation, at its Thirteenth Session in 2007 in Bali, Indonesia. In recognizing REDD+, the COP mandated the AWG-LCA to assess: "Policy approaches and positive incentives on problems with reference to reducing emissions from deforestation and forest degradation in developing countries; and therefore, the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries" (UNFCCC, 2007).

The COP further mandated the Ad Hoc Work Group on Long-term Cooperative Action (AWG-LCA) to begin the process immediately, complete its work by 2009, and present the outcome to the COP for adoption at its Fifteenth Session. It also called on Parties, interested non-governmental and scientific organizations to develop, and advice on a possible Global Climate regime that would incorporate REDD+. Indeed, the Working Group lived up to its expectation and presented its work at the recently concluded Fifteenth Conference of the Parties to the UNFCCC.

These developments triggered a series of negotiations on the inclusion of REDD+ in a post-2012 Climate regime, starting with AD (Avoided Deforestation), to RED (Reducing Emission from Deforestation), then to REDD (Reducing Emission from Deforestation and

forest Degradation in Developing Countries), and to REDD (Reducing Emission from Deforestation and forest Degradation in Developing Countries; and also the role of conservation, sustainable management of forests and reinforcement of carbon stocks in developing countries). There have conjointly been deliberations and suggestions on the scope, funding choices, style and legal frameworks and institutional arrangements for a post-2012 global REDD mechanism (e.g., (Angelsen, 2009; Ballesteros *et al*., 2010), that play an informative role throughout the negotiations resulting in COP fifteen. Today, REDD+ forms part of the Copenhagen Accord adopted by the Parties at their 15th Session through Decision -/CP.15 in Copenhagen, Denmark (UNFCCC, 2009 Paragraph 6):

> "... we tend to acknowledge the crucial role of reducing emission from deforestation and forest degradation and also the have to be compelled to enhance removals of greenhouse emission by forests and agree on the requirement to supply positive incentives to such actions through the immediate institution of a mechanism as well as REDD-plus, to facilitate the mobilization of economic resources from developed countries...''

At the Oslo Climate and Forest Conference, over 50 countries launched and signed an Interim REDD+ Partnership (REDD+ Partnership, 2010). The FCPF and the UN-REDD Program will serve as the Secretariat for the Partnership. The Conference also increased the annual first-start funds from USD 3.5 billion to 4.5 billion for the 2010 – 2012 period. These developments demonstrate that prospects for REDD+ are high and that there is high political commitment to make REDD+ a reality (REDD+ Partnership, 2010).

Since 2007 several REDD+ pilot programs have been launched, notably the Forest Carbon Partnership Facility (FCPF) of the World Bank and the UN-REDD Program, to prepare selected developing countries for an international REDD+ regime. These Programs have

developed a set of requirements that participating countries must fulfil to ensure successful achievement of the overall goal of the Convention in general and the objective of REDD+. The two programs also require participating countries to ensure that the interests of different groups in society, particularly local and indigenous forest communities and civil society are catered for in national REDD+ strategies (see FCPF, 2009a; UN-REDD Program, 2009; World Bank, 2010).

The growing recognition of the importance of reducing emissions from deforestation and forest degradation in developing countries (REDD+) has created new momentum in the fight against deforestation. In 2010, over 190 countries supported the Cancun Agreements adopted under the UN Framework Convention on Climate Change (UNFCCC) recognizing the importance of tackling deforestation to mitigate climate change. So far, many developing countries have started to get "ready" for reducing forest-related emissions by building local capacities; strengthening institutions and land use emissions inventories; and designing national REDD+ strategies. While these efforts are essential for supporting the long-term protection of forests in developing countries, it is essential to also address the main drivers of deforestation many of which are outside the forest sector without further delay(Salvini, 2016). Agriculture is the main driver of deforestation in several countries and so as such connected to REDD+.

Therefore, the relationship of agriculture to global climate change is a topic of accelerating interest. Where, worldwide agricultural production is predicted to decrease underneath global climate change projections and poise a threat to international food security (IPCC, 2007). However, it's conjointly vital to notice that agriculture contributes a major quantity of world emissions annually, which might increase with the intensification or growth of

production to fulfil higher demand (Ministry of Agriculture Livestock and Fisheries, 2017).

In addition, estimates attribute as much as 80% of global deforestation to agriculture, a fact that is very relevant in the context of designing national strategies to implement the United Nations Framework Convention on global climate change (UNFCCC) policy framework for reducing emissions from deforestation and forest degradation and conservation, property management of forests and improvement of forest carbon stocks in developing countries (REDD+)(Cancun Decisions, 2010) 'Climate smart' agriculture may need the potential to supply ‘triple win’ advantages from inflated adaptation, productivity, and mitigation, providing a potential strategy to address each global climate change and food security issues (Cancun Decisions, 2010). Climate smart agriculture involves the employment of various ‘climate smart’ farming techniques to supply crops or livestock, that might facilitate cut back pressure on forests for agricultural use moreover as potentially maintain or enhance productivity, build resilience to global climate change, and mitigate the sector’s high emissions (Torquebiau *et al*., 2014).

However, land and forests have a high potential for both mitigation and adaptation, but their management is not always straightforward, due to trade-offs between land use options and the high stakes and diverging interests of multiple stakeholders (Friedmann *et al*., 2018). Finding land use strategies that merge land-based climate change mitigation and adaptation measures is therefore still an open issue in climate discourse. Adoption of such strategies can be encouraged by national and regional policies and concretized in land management approaches that are suitable to local contexts. Such strategies include payment for ecosystem services (PES) and integrated ecosystem management approaches, which provide incentives to local stakeholders to improve ecosystem management.

Examples of such approaches are numerous, among which Integrated Silvo-pastoral Approaches to Ecosystem Management facilitated by the World Bank in Latin America, where payment incentives were introduced to farmers for adopting integrated silvopastoral farming systems in degraded pasture lands (Pagiola *et al*., 2014).

As cited in Salvini *et al*. (2016) in their work on REDD+ and Climate Smart agriculture in landscapes, there was an increasing attention on the United Nations' Reducing Emissions from Deforestation and Forest Degradation (REDD) programme, and the REDD+ scheme, which goes further to also include the role of conservation, sustainable management of forests and enhancement of carbon stocks. Moreover, REDD+ is a potentially powerful vehicle for stimulating developing countries to practise mitigation by reducing GHG emissions and to implement adaptation measures through sustainable forest management. Not ending there it also incorporates, safeguards as well, such as requirements for transparency, participation, protection of biodiversity and the rights of local people (UNFCCC, 2011). The United Nations Framework Convention on Climate Change (UNFCCC) emphasized that co-benefits should be promoted while implementing REDD+ and that 'the needs of local and indigenous communities should be addressed' (UNFCC, 2007).

However, REDD has remained forest-centred and powerfully double-geared to mitigation, stepping down adaptation to a second place (Karlsson & Thompson, 2011). Deforestation is driven by native stakeholders' wants and goals, that thus got to be taken under consideration and be satisfied. REDD policies that concentrate on forest protection while not promoting adaptation and development are doubtless to fail because of the underlying drivers of deforestation can persist(Elias *et al*., 2014). The Intergovernmental Panel on

Climate Change (Mbatu, 2016) has found that policies governing land use and REDD+ are more effective when they involve both mitigation and adaptation. Yet many REDD+ initiatives still overlook development goals and poverty alleviation and neglect benefit-sharing mechanisms for enhancing local livelihoods (Corbera and Schroeder, 2011). It remains crucial to identify an optimal policy mix that tackles synergistically all the above-mentioned goals at the various levels of governance (Kissinger, 2011).

Many climate change adaptation programmes centre on agriculture, because climate change related shocks and stresses in the natural environment are considered to require innovation towards adaptive agriculture, entailing higher production with fewer inputs. Despite this, agriculture continues to contribute to climate change (Tubiello *et al*., 2015) and particularly since agricultural expansion is the main driver of deforestation (Harris *et al*., 2012; Hosonuma *et al*., 2012). In this light we have conservation agriculture (CA) which aims at achieving the "triple wins" of food security, adaptation, and mitigation (FAO, 2010), enhancing adaptation and mitigation synergistically. Although CA represents a step forward towards greater integration of adaptation and mitigation, its prominence in practice has remained on agricultural goals and adaptation (Pears & Shields, 2017).

More than 10 years once REDD (Reducing Emissions from Deforestation and forest Degradation) entered the United Nation climate negotiations, its current state and future direction are still a matter of competition. Some observers argue that REDD+ has a poor track record of achieving what it is supposed to achieve i.e., reduce emissions as suggested by rising deforestation rates in REDD+ poster children like Brazil, Colombia, and Indonesia (Enrici & Hubacek, 2018). One main argument for explaining its poor track

record is that thus far REDD has been unable to tackle the foundation causes of deforestation, like the demand for agricultural commodities like vegetable oil, soy, cocoa and coffee (Sonwa *et al*., 2017; Karsenty and Ongolo, 2012).

Others claim that the restricted success of REDD is thanks to poor implementation at the national level, governance challenges and lack of progress within the wider global climate change negotiations(Brockhaus et al., 2021; Cadman et al., 2017). It is argued that the absence of an international carbon market and weak international emission reduction targets have hampered the implementation of REDD+ (Angelsen *et al*., 2017).

2.1.8 Nexus of Climate Change and Agriculture

Climate change and agriculture are reticular processes, each of which come about on a worldwide scale and their relationship is of explicit importance because the imbalance between world population and world food production will increase. Supported by some projections, changes in temperature, precipitation and severe weather events are expected to scale back crop yield in several regions of the developing world, significantly Black Africa and parts of Asia. The impact and consequences of climate change for agriculture tend to be additionally severe for countries with higher initial temperatures, areas with marginal or already degraded lands and lower levels of development with very little adaptation capability (Yohannes *et al*., 2015).

On the opposite hand, numerous studies indicate that current agricultural activities are a big supply of GHGs that worsen climate disruption. The practice of agriculture is incredibly completely different between developing and developed counties, which ends up in variation of agricultural contribution to climate change. In developing countries,

GHG emission from agriculture sector is way additional thanks to sizable amount of cattle and inadequate manure management, improper use of agro-chemicals and direction of the land. In turn, climate impact becomes additionally serious in developing countries because of their dependence on agriculture (Gebreegziabher *et al*., 2016).

On the opposite facet, agricultural sector has giant potential to mitigate and adapt climate change. Consistent with IPCC (2007), mitigation is an intervention to scale back the emissions sources or enhance the GHG sinks, whereas adaptation is the adjustment in natural or human systems in response to actual or expected environmental change amendment or their effects, to scale back damage or exploit helpful opportunities. Sustainable and organic agricultural systems will facilitate scale back agricultural GHG emissions through energy conservation, lower levels of carbon-based inputs, lower use of artificial fertiliser and different options that minimize GHG emissions and sequester carbon within the soil.

During mitigation and adaptation of climate change through completely different agricultural activities, there may be several challenges or barriers like monetary, policy and implementation barrier etc. In general, Agricultural activity may be a supply of GHGs moreover as a sink, notably through the storage of carbon within the soil organic matter and in biomass and influenced by climate change (Jost *et al*., 2016).

Agriculture's contribution to climate change is polemic because it could be a vital supply of greenhouse gases however conjointly a sink of carbon. Conferring with William Thornton and Lipper (2013), agriculture contributes 30-40% of manmade GHG emissions. Three-quarters of agricultural GHG emissions occur in developing countries, and this share

might rise on top of 80% by 2050. Conceding with FAO report in developing countries there's a big increase in GHGs emission from 2001-2011 (14%), the rise occurred, because of a rise in total agricultural outputs. As the world population and the demand for food still grow, total GHG emissions from the agricultural sector are projected to extend over time.

Agriculture produces direct and indirect emissions. Direct emissions return from fertilized agricultural soils and livestock manure. whereas indirect emissions return from runoff and natural action of fertilizers, emission from land-use changes, use of fossil fuels for mechanization, transport, and agro-chemical and fertilizer production. The foremost vital indirect emissions are changes in natural vegetation and ancient land use, together with deforestation and soil degradation. (Shafiq & Mahmood, 2022)found that deforestation (for agricultural growth and fuel wood) is the main explanation for climate change. Intensive tillage is additionally one in every of traditional land use practices that involve endlessly disturb the land. This practice will increase greenhouse gas emissions by inflicting decomposition of soil organic matter and soil erosion.

According to the World Bank (2008), agriculture contributes about 1/2 of the worldwide emissions of 2 of the foremost potent non-CO_2 GHG: Nitrous oxide (N_2O) and methane (CH_4). These non-carbon GHGs have powerful greenhouse effects and have larger longevity than CO_2. Globally, agriculture contributes to 58% of total N_2O emission. It emits 4.5 million tons of nitrous oxide annually. Numerous management practices within the agricultural land will cause production and emission of nitrous oxide, varying from fertiliser application to strategies of irrigation, tillage and cattle and feedlots.

Furthermore, the utilization of artificial fertiliser for agriculture could be a major supply of nitrous oxide emissions. except for this, giant quantities of fossil fuel are used to build artificial fertilizers as a result of its ingredient (Holka *et al*., 2022).The production method conjointly takes tons of energy thus their impact on climate change is truly larger once we issue this in industrial farming practices have worsened this loss and the result has been exaggerated emissions. Continuous cropping might lead to victimization of huge chemical fertiliser (Biernat *et al*., 2020).

Bestowing with (B. Bhattarai, 2022) study from Nepal, it was reported that farmers widely used immense quantities of chemical fertiliser to spice up their product and thought through as the prime activities to adapt climate change. The study conjointly reported that the farmers think about the negative result of agro chemicals just for their crops. This means that the farmers solely care as regarding their crop and choose appropriate condition to use not environmental facet result of fertilizers. The linkage between climate change and agriculture is clearly addressed directly in Article 2 of the Kyoto protocol that states: promotion of sustainable forms of agriculture in lightweight of climate change concerns (H. Clark *et al*., 2020).

In Article 3.4 of the Kyoto protocol conjointly mentioned about the carbon sink that will partially be accomplished with efficiency by organic agriculture. Article 10 of Kyoto protocol also stated the way to mitigate global climate change and measures to facilitate adequate adaptation to climate change by regarding completely different sectors together with agriculture (FAO, 2008).

2.1.9 Climate Change and Livelihood Security

Almost one billion people experienced hunger in 2010 (Otekunrin *et al*., 2019): The most vulnerable people cannot access enough of the major macronutrients (carbohydrates, fats and protein). Perhaps another billion are thought to suffer from 'hidden hunger', during which necessary micronutrients (such as vitamins and minerals) are missing from their diet, with resulting risks of physical and mental impairment (Gyasi *et al*., 2020).

Under-nutrition remains one of the world's most serious but least addressed socioeconomic and health problems (Lenaerts *et al*., 2019). The human and socioeconomic costs of under-nutrition are enormous, falling hardest on the poorest, especially on women and children (H. Clark *et al*., 2020; Delprato & Akyeampong, 2017). The millions of the world's people who have experienced under-nutrition early in life face many challenges as they grow up. They encounter associate raised risk of ill health and death once young, experience difficulties in class, and are typically unable to create a full contribution to the social and economic development of their households, communities, and nations after they become adults (Delprato & Akyeampong, 2017).

FAO estimates show that the share of malnourished people within the world population – the prevalence of malnourishment, seems to have been growing for 2 years in a row, and may have reached 10.9% in 2017, (Jumrani & Rai, 2020). Though absolutely the increase during this proportion could appear negligible from a historical perspective, considering continued increment in population, it implies that the number of individuals who are suffering from hunger has been growing over the past 3 years, returning to levels from virtually a decade ago (Owoeye *et al*., 2020). The absolute variety of malnourished people

within the world is currently calculable to be raised from around 804 million in 2016 to virtually 821 million in 2017. This trend sends a clear warning that, if efforts are not enhanced, the SDG target of hunger eradication will not be achieved by 2030 (Mary *et al*., 2018).

In Africa, as shown in Table 2.3, the situation is more pressing in the region of sub-Saharan Africa where an estimated 20-21.2 % of the population – or between one out of four and one out of five people in the region – may have suffered from chronic food deprivation in 2017 (Laborde et al., 2020). An increase within the prevalence of malnourishment has been discovered altogether in sub-regions of sub-Sahara Africa apart from east Africa. A further slight increase is seen in Southern Africa, while a significant uptick is seen in Western Africa, possibly reflecting factors such as droughts (Herrera *et al*., 2018), rising foods prices and a slowdown of real per capita Gross Domestic Product (GDP) (Grainger, 2010).

Table 2. 2 Prevalence of Undernourishment in Africa, 2005–2017

Prevalence of undernourishment (%)						
	2005	2010	2012	2014	2016	2017
WORLD	14.5	11.8	11.3	10.7	10.8	10.9
AFRICA	21.2	19.1	18.6	18.3	19.7	20.4
Northern Africa	6.2	5.0	8.3	8.1	8.5	8.5
Sub-Saharan Africa	24.3	21.7	21.0	20.7	22.3	23.2
Eastern Africa	34.3	31.3	30.9	30.2	31.6	31.4
Middle Africa	32.4	27.8	26.0	24.2	25.7	26.1
Southern Africa	6.5	7.1	6.9	7.4	8.2	8.4
Western Africa	12.3	10.4	10.4	10.7	12.8	15.1

Source: (Laborde et al., 2020)

The dynamics within the prevalence of malnourishment, combined with fast increment in population, have led to a dramatic increase within the total number of malnourished people.

This conjointly grounds one in all our problematic of this study that is increase rates of food insecurity.

Global modification has influenced food and water security in an important and extremely unsure ways that, and there are sturdy indications that developing countries bear the force of the adverse consequences, particularly from climate change. This is for the most part because of high poverty levels, and developing-country capability to adapt to global change is weak. Furthermore, the agricultural populations of developing countries for whom agricultural production is the primary supply of direct and indirect employment and financial gain are going to be most affected due to agriculture's vulnerability to global change processes (Ringler *et al*., 2010).

Climate change affects food security due to over-reliance on rain-fed agriculture, high levels of poverty, low levels of education, inadequate access to financial capital, and poor infrastructure, especially in sub-Saharan Africa. Kabubo-Mariara, (2016) in their research postulated that, climate variability and change can increase food insecurity which totally different food crops respond otherwise to climate change variables in African country. The results more indicated that food security responds completely too favourable agro-ecological zones, soil drain and depth, and high population density.

Climate change threatens to exacerbate existing threats to food security and livelihoods thanks to a mix of things that embrace the increasing frequency and intensity of climate hazards, decreasing agricultural yields and reduced production in vulnerable regions, rising health and sanitation risks, increasing water scarcity, and intensifying conflicts over scarce resources, which would lead to new humanitarian crises as well as increasing displacement

(Mulwa & Visser, 2020). Climate change occurs over a period of decades or centuries, what people experience in their daily life are climate variability and climate extremes (UN, 2016) regardless of whether these are driven by climate change. Similarly, all dimensions of food security and nutrition, together with food accessibility, access, utilization and stability, are doubtless affected even within the short term by climate variability and climate extremes (Fanzo *et al*., 2018).

Extreme weather effects disrupt the stability of food supply also people's livelihoods. An increase in extreme weather, such as floods and drought, because of climate change, would exacerbate this trend and could harm livelihoods that depend on climate-sensitive activities such as rain-fed agriculture and livestock rearing (Tanumihardjo *et al*., 2019). More than 60% of the population in Cameroon is dependent on the primary sector for a living. This explains that the livelihood of many rural and urban households stands in danger in case of frequent changes in the climate affecting agricultural productivity (FAO, 2017). The consequences of meteorological changes can be seen both in urban and rural areas leading to food insecurity and poverty. Variations in the climate have affected food productivity and water availability in Cameroon.

Also, as in the case of India, Rahman *et al*. (2019), mentions that 54% of the population faces a water shortage leading to 600 million people under the risk of acute shortage of water supply. (Harkness *et al*., 2020), states that wheat production can be adversely affected in case there is a rise in the temperature over 340 Celsius. Not solely will this earth science variation affect the productivity of crops and water resources; however, it additionally has serious repercussions on the economic and money resources of the poor and the small and landless farmers (Xiao *et al*., 2020)

Climate drivers relevant to food production and availability is also classified as modal climate changes (e.g., shifts in climate envelopes inflicting shifts in cropping varieties planted), seasonal changes (e.g., warming trends extending growing seasons), extreme events (e.g., high temperatures affecting critical growth periods, flooding/droughts), and atmospheric conditions (e.g., CO_2 concentrations, short-lived climate pollutants (SLCPs), and dust) (Christmas et al., 2020). Water resources for food production will also be affected through changing rates of precipitation and evaporation, groundwater levels, and dissolved oxygen content (Dinar *et al*., 2019)

Potential changes in major modes of climate variability can also have widespread impacts such as occurred during late 2015 to early 2016 when a strong El Niño contributed to regional shifts in precipitation in the Sahel region. In recent years, yields of staple crops such as maize, wheat, sorghum, and fruit crops, such as mangoes, have decreased across Africa, widening food insecurity gaps (Epule, 2021). In Nigeria, there have been reports of climate change having impacts on the livelihoods of arable crop farmers (Donkor *et al*., 2019). The Sahel region of Cameroon has experienced an increasing level of malnutrition, partially thanks to the impact of global climate change since harsh weather conditions resulting in extreme drought have a negative influence on agriculture (Hyland & Russ, 2019).

Farm households in the developing world often rely on a complex mix of crops, livestock, aquaculture, and non-agricultural activities for their livelihoods (Kabir *et al*., 2020; Shakhawat *et al*., 2019). Across the planet, smallholder farmers are thought about to be disproportionately at risk of climate change because of changes in temperature, rain, and

the frequency or intensity of maximum weather events directly affect their crop and animal productivity as well as their household's food security, income, and well-being (Chandra, 2017; Guido et al., 2020b). Smallholder farming systems have been recognized as highly vulnerable to climate change because they are highly dependent on agriculture and livestock for their livelihood (Chepkoech *et al*., 2019).

2.1.10 Climate change Adaptation and Agriculture

Adaptation to climate change involves changes in agricultural management practices in response to changes in climate conditions. It typically involves a mix of varied individual responses at the farm-level and assumes that farmers have access to different practices and technologies obtainable within the region (Nhemachena, 2008). The climate is ever-changing and mitigation efforts to scale back the sources or enhance the sinks of greenhouse gases can take time.

Adaptation is thus vital and of concern in developing countries, notably in Africa wherever vulnerability is high because of the power to adapt is low. climate change is anticipated to affect food and water resources that are vital for livelihoods in Africa wherever a lot of the population, particularly the poor, have faith in native supply systems that are sensitive to climate variation (Nhemachena, 2008). The global agriculture system is prone to climate change (Akinyemi & Mushunje, 2019; Dendir & Simane, 2019; Wiebe *et al*., 2019b). numerous world studies have indicated that progressive change is anticipated to negatively affect agricultural production (Kumar & Sharma, 2018). High temperatures and uncertainty in downfall patterns have important impacts on overall crop growth, development, and yield (Friedmann *et al*., 2018).

Adaptation may be a key issue that may cut back the severity of climate change on food production (Grafakos *et al*., 2019). Agriculture and food security are foretold to be considerably wedged by climate change, though the impact can vary by region and by crop. Combined with the increasing world population, there's an imperative would like for agriculture to adapt to ensure future food security for this growing population. Climate change imposes further stresses to the social and economic challenges that the poorest already face (IPCC, 2013), highlighting and accelerating their vulnerabilities, as their livelihoods rely on already overstrained climate-sensitive resources and their welfare systems are weak. By directly depleting the agricultural resources that poor people rely on for their livelihoods, the temperature change will increase their possibilities of falling into a cycle of poorness from which it's tough to flee (Nelson & Huyer, 2016).

Moreover, even the best success in global action towards mitigating climate change is going to be too little to create resilience and catch up on the harm price (Nelson & Huyer, 2016). In agriculture, adaptation to climate change is already happening (Cui, 2020). as farming communities have an extended record of coping and adapting to the impacts of weather and climate. a good framework of potential variations is crucial to eradicating the escalating poorness in developing countries (UNFCCC, 2015).

Within the agricultural sector of the many developing nations, farmers should create long-run choices to adapt to climate change impacts to produce food security and sustainable livelihoods (Ghanian *et al*., 2020). Agriculture sustains rural livelihoods and maybe a primary growth factor for several developing economies: contributing to poverty reduction, economic development, and the supply of environmental services (Halliday *et*

al., 2016). However, the agricultural sector is inherently sensitive to climate change (Ghoochani *et al*., 2017) through diversity loss, crop failure, water access loss, disease, and pest pressure (Altieri & Nicholls, 2017).

According to (Ayanlade *et al*., 2018), farmers have forever lived with ever-changing climate and have shown smart resilience to climate change and variability whereas (Ngin *et al*., 2020) signifies that adapting to current climate variability will increase resilience to future climate change. However, though some adaptation to current climate variability is happening, farmers might not essentially show an identical level of resilience in the future, notably, since in keeping with (Zhou *et al*., 2016) and (Gowdy & Baveye, 2019), future climate changes are seemingly to occur at a rate quicker than has been antecedental knowledgeable about in history. (Aryal *et al*., 2019) and (Verburg *et al*., 2019) conjointly note that farmers have developed innovative responses to environmental changes, as well as environmental condition variability to form a lot of property production systems.

However, extreme events like droughts that have occurred in Africa particularly in sub-Sahara Africa, within the last four decades, have shown that individual or community adaptation skills might not adequately handle these extremes (Gowdy, 2019). Crop management is altered during a range of how to deal with the effects of climate change (Kuntashula *et al*., 2017). Rojas-downing *et al*.(2017) and Kober *et al*. (2018) suggest crop management methods which will be used to deal with the effects of climate change including:

a) Planting mixtures of crops and cultivars tailored to totally different conditions as intercrops,

b) Using crop varieties that are a lot more tolerant to climate stresses,
c) Using mulch to hide the bare soil surface,
d) Altering amounts and times of irrigation and alternative water management practices,
e) Altering the temporal order or location of cropping activities,
f) Use of low-priced water-harvesting technologies wherever rainfall decreases and managing water to prevent waterlogging, erosion, and nutrient leach wherever rainfall will increase,
g) Diversifying income sources through integration with alternative farming activities like raising livestock and Planting mixtures of crops and cultivars adapted to different conditions as intercrops,
h) Using climate forecasting to reduce production risk.

In Cameroon, Akwen, (2017) identified adaptation strategies of smallholder farmers across the country to include dry and early planting, growing drought-resistant crops, changing planting dates, and using irrigation to cushion themselves against further anticipated adverse climatic conditions. According to Epule and Bryant, (2016) adaptation, strategies of smallholder farmers across the country include, expansion of farm size, help from relatives and dependents that live on the farm, Agroforestry, supplemental occupations, or livelihood diversification and usage of organic fertilizers.

2.1.11 Climate Change Mitigation and Agriculture

In the world nowadays, global climate change is at the center of most world debates. whereas the Intergovernmental Panel on global climate change (IPCC) attributes these environmental condition changes to anthropogenetic emissions of greenhouse gases (GHGs), a dynamical climate has and can still have adverse effects on agro-ecosystems

and societies in multiple ways in which, with negative consequences dominating (Rosenzweig *et al*., 2020). There is a lot of concern that the increasing concentration of greenhouse gases normally, and carbon dioxide especially contributes to heating by trappings long-wave radiation mirrored from the earth's surface (FAO, 2013).

Over the past a hundred and fifty years, the number of carbon within the atmosphere has multiplied by 30 (Ibid). Most scientists believe there's a right of way relationship between multiplied levels of carbon dioxide within the atmosphere and rising world temperatures (Stavins and Richards, 2005). Agriculture (excluding forestry and different land uses) contributes around twelve percent of world GHG emissions. Methane (CH_4) and nitrous oxide (N_2O) are the primary GHGs created by agricultural activities, comprising 55% and 45% of emissions from agriculture (FAO, 2017). the worldwide warming potentials of CH4 and N2O twenty-five and 298 times that of (CO2), (IPCC, 2007).

Global warming potential is a measure of how much energy the emissions of one ton of gas can absorb over a given amount of time (usually one hundred years), relative to the emissions of one ton of greenhouse emission. There are four primary sources of GHG emissions from agriculture: enteric fermentation, animal manures, fertilizers, and paddy rice. Enteric fermentation digestion of carbohydrates by ruminant is the largest contributor of CH4 from agricultural systems, contributing 40% of agricultural GHG emissions. The second-largest supply of agricultural GHG emissions (16% of agricultural GHG) is the management and storage of ruminant manure, that produces CH4 and N2O (FAO, 2015).

Artificial N fertilizers are the third-largest supply (13% of GHG emissions from agriculture) and the largest contributor of N2O, that is created once N not taken up by crops

undergoes microbial processes in soils. Organic nitrogen-containing fertilizers like manure and compost are sources of N2O emissions. Flooded (paddy) rice cultivation produces CH4 through anaerobic decomposition of organic materials (such as crop residues) in the rice paddy, contributively around 100% of total agricultural GHG emissions (S. Ali *et al*., 2019).

In addition to being sources of GHG emissions, farms even have the potential to act as "sinks" for greenhouse emission in different words, to take away carbon from the atmosphere and store it in soils or woody vegetation. The mitigation potential of carbon sequestration in agricultural soils is massive and has consequently been the main target of recent international attention like the "4 per 1000" initiative launched at the twenty-first Conference of the Parties (COP 21). The four per a thousand initiative is a global, voluntary collaboration to extend soil organic carbon (SOC) stocks by 0.4% annually, enough to halt the rise within the greenhouse emission concentration within the atmosphere associated with human activities ((Minasny *et al*., 2018; Soussana *et al*., 2017).

Measures that increase SOC even have robust potential synergies with food security (Frank *et al*., 2017). However, a variety of things make it hard to predict what quantity carbon often holds on during a specific soil and whether such carbon storage is permanent a very important thought for global climate change mitigation (Frank *et al*., 2017). The SOC mitigation potentials here ought to, therefore, be understood with caution; in most cases, they represent an edge of what may well be potential in practice. The biomass carbon mitigation potential of agroforestry the incorporation of woody perennials with crops and

ruminant mammal is additionally massive and, tho' additionally reversible, is a smaller amount subject to the uncertainties related to carbon sequestration in soils (Richards, 2019). The dataset used for this analysis was restricted to carbon stock changes in soils. To capture the complete mitigation potential of agroforestry interventions, values for carbon sequestration in biomass were taken from (Cardinael *et al*., 2018).

However, increases in SOC are related to multiplied crop yields (figure 2.1). Practices like reduced tillage and crop residue retention have the potential to buffer crop yields against weather extremes, particularly in drought-prone areas (Richards, 2019), additionally as increase average yields within the long run. However, improvement of soil structure and fertility may be a slow process; analysis on conservation agriculture has shown that farmers might have to attend 3 to seven years to experience yield increase (Richards, 2019).

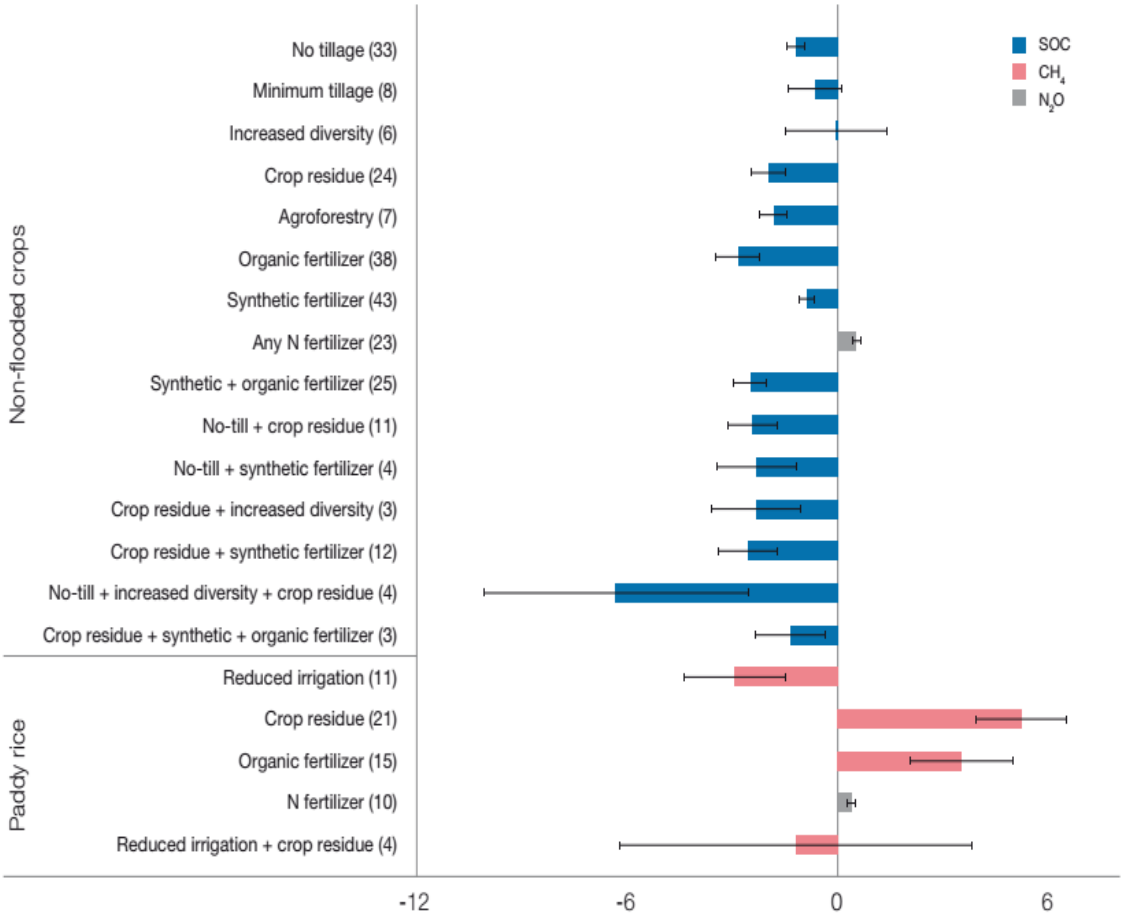


Figure 2. 1 Mitigation potential of climate-smart practices. (Source: (Richards, 2019))

Moreover, remodelling soil structure and fertility to boost yields depend on enough biomass production by crops, or additions of organic material like manure from off-field. In several cropping systems, particularly in SSA, the requirement for crop residues as stock feed constrains the effective use of mulching. Combining acceptable use of fertilizers with residue mulching will increase crop yields and therefore the obtainable amount of crop residues (Xiukang, 2018), chemical element inputs additionally facilitate the avoidance of yield penalties, as massive carbon inputs to the soil in the kind of mulch will promote chemical element immobilization by micro-organisms, making it inaccessible for crops. Water-saving interventions in paddy rice have very little result on rice yields once experienced properly (i.e., not permitting soil water levels to drop beyond 15 cm below the soil surface) and may scale back water use by over twenty percent (Carrijo *et al*., 2017).

the first advantage of such practices for the farmer is savings on fuel for water pump operation, or water itself wherever farmers pay per volume for irrigation water.

2.3 Theoretical Framework

2.3.1 Cobb-Douglas Functional Form

In economics, the Cobb-Douglas functional style of the production function is universally used to typify the link of output to input. It was proposed by Knut (1926) and tested against statistical proof by Charles Cobb and Paul Douglas(Biddle, 2012). In 1928, Charles Cobb and Paul Douglas (1928) revealed in a study in which they modelled the growth of the American economy during the period 1899 to 1922. They thought of a simplified eagle eye of the economy within which production output was buckled down by the amount of labour muddled and the amount of capital plunged in. Whereas several alternative factors are stirring economic performance, their model tested to be exceptionally scientific. The function they used to model production was of the form:

$P(L, K) = bL\alpha K\beta$……………………………………………………………..(1)

Where: P = Total production (the financial value of all goods produced in a year);

L = Labor input (the total number of person-hours worked in a year).

K = Capital input (the financial worth of all machinery, equipment, and buildings);

b = Total factor productivity; α and β are the output elasticities of labour and capital, in conjunction.

These values are constants strong-willed by handy technology. Output elasticity measures the receptiveness of output to a switch in levels of either labour or capital used in production. In agricultural production, the efficient allocation of farm resources helps

farmers to attain their objectives. It avails farmers the opportunity of improving their productivity and income. At the microeconomic level efficient allotment of farm resources (farmland, credit facilities, fertilizer, tractors, and labour, among others) assist farmers to contribute to food production, employment, industrial raw materials, and export product for foreign exchange earnings.

Acquiesce to (Olayide, n.d.), agricultural productivity is interchangeable with resource productivity which is the ratio of total output to the resource/inputs being considered. Consent to (Pesaran, 2015), the production function could be asserted in different functional forms such as Cobb Douglas, linear, quadratic, polynomials, and square root polynomials, semilog, and exponential functions. Nonetheless, the Cobb Douglas functional form is frequently used for its simplicity and flexibility conjugate with the empirical hold it has earned from data for various industries and countries. This theoretical model has been applied in existing literature including (Ekwere, 2016).

2.3.2 Decision Theory

Fundamentally, the objective of any theory of production must be to explain a process by which the rational entrepreneur may maximize his utility under the conditions of the environment set by the area of definition of the theory. This area of definition is, of course, described by the assumptions made, and is correspondingly narrower or broader, according as the assumptions are restrictive (Boutillier & Uzunidis, 2014). The wider the area of definition, the greater the number of relevant phenomena which will need to be incorporated within the theory, and to this extent the more complex the theory i s likely to become. Essentially, the objective of this theory is to explain the process by which the individual moves from a state of subjective uncertainty, to one of subjective risk

(Donaldson & Walsh, 2015). Once this position has been reached, the problem has been, in effect, converted into one of risk-trend, and the individual may choose from his "transformed" power set according to a von Neumann-Morgenstern preference ordering.

Thus, the importance of these theories to the economics of agricultural production depends upon the extent to which uncertainty exists in the economic environment of the agricultural entrepreneur. It is very well known that this environment is one of the most uncertain of all areas of production. Hence there is no need here to demonstrate this fact in detail, and we may assume any dynamic theory of production to be potentially very important to agriculture (Kramer & Porter, 2011).

Perhaps the most important causes of uncertainty in agriculture are price fluctuation, which arises as to the effects of the interaction between inelastic demand and variable production coefficients caused by variations in weather, disease effects, and so on. There are numerous examples where this point has been demonstrated. For example, Brown and Heady attributed the most importance to price fluctuations in causing income variability in livestock production. This income variation caused by fluctuating prices has various important effects or agricultural production. We may classify these effects into three broad groups: (a) Capital-rationing. (b) The choice of production methods. (c) Increasing the importance of management (Sandel, 2013).

In the field of economics, most of the model and theory is built on an assumption that all people are rational people, whose purpose is only to maximize personal benefits in production. Thus, as the owner of the cropland, farmers would theoretically adjust the crop planting area according to the expected crop price to maximize economic benefits. To

describe the influence of expected crop prices to the planting area, Nerlove proposed a supply response model in 1956 (Nerlove, 1956). At first, the relationship between the expected price and the real price is expressed as:

$$P_t^* - P_{t-1}^* = \beta(P_{t-1} - P_{t-1}^* \quad \text{.....(2)}$$

where t is the period; P^*_t and P^*_{t-1} is the expected price of period t and period t-1; b is named as the adjustment coefficient or expected price formation factor, which is a constant between 0 and 1. Zhang *et al*. (2019) in their work on the Agricultural production planning approach based on interval fuzzy credibility-constrained bi-level programming and Nerlove supply response theory. Developed a framework integrated Nerlove supply response model (Nerlove model) and interval fuzzy credibility-constraint bi-level programming (IFCBP) model for designing the agricultural production in arid and semi-arid regions.

Through the Nerlove model, the outlining process of crop planting area was characterized as an economic problem for forecasting farmers' behavior in place of an optimization problem for apportioning farmland resources, and the homogeneity between the crop planting area and market price can be obtained and further provide conceivable future crop planting area information. This developed model provides an effective trade-off between two decision-makers from different decision-making levels. The developed framework provides managers an effective way to plan the agricultural production in arid and semi-arid regions, and the developed model and related thinking may help solve similar problems (Stout, 2012). Thus, to this extent, we may regard the theory of decision- making as providing a device by which the theoretical problem of utility maximization under subjective uncertainty is transformed into one of subjective risk. However, this theory links us to the understanding that other factors like economic, institutional, and cultural factors

are an integral part in agricultural production. Though it fails to incorporate the farmer utility part when it comes to farm practice adoption.

2.3.3 Utility maximization theory

According to (Feder *et al*., 1985), the decision-making process is characterized by the choice of the excellent mix of the components of a technological package over time. The decision-maker is feigned to maximize the utility of asset use over time, subject to diverse resource constraints, usually assuming a concave utility function. This can be expressed by static models, or by dynamic, sequential models that take into consideration changing knowledge and conditions (Toborn & Harvesting, 2011).

If the decision to adopt zero tillage (ZT) is a two-staged process, the farmers will first choose whether to adopt zero tillage or not before they decide on how many expanses of available arable land to commit to zero tillage production. They do so by maximizing an underlying utility function from the production and consumption of farming activities. We assume that consumption and production decisions are integral because of fallibility in both product and factor markets. Consequently, a farmer's willingness to adopt zero tillage bet on the degree of the expected change in utility.

Yigezu *et al*. (2018)working on how increasing farmers' awareness and exposure to new agricultural technologies through the creation of systematic linkages in the research-to-development continuum affect adoption. They used the double hurdle and duration analysis models grounding the study on the Utility maximization theory. The results showed that heightened exposure and awareness of the zero-tillage technology through organized field days and demonstration trials, endorsed with providing free access to costly zero-tillage

seeders for first-time users, increases in propensity, speed, and intensity of adoption. The intensity of adoption is also positively inveigled by wheat acreage and farmers' access to credit. The findings of this study highlighted the gravity of facilitating farmers' initial exposure and ease of trying out new agricultural technologies, principally those requiring high initial investment, at low or no cost in ensuring fast and large-scale adoption.

Awotide *et al*. (2016), employed the utility maximization theory, to describe the responsiveness of farmers to new technology adoption. A farmer swaps from traditional to IRVs only if the utility achieved from the latter is higher than from the former. If U_{i0} is the utility gotten from the use of the traditional rice variety, while U_{i1} is the expected utility from the adoption of new IRVs, then, albeit not observed directly, the utility that a farmer *i* derived from adopting a given measure of the IRVs (*j*) can be expressed as:

$$U_{ij} = X_i\beta_j + \tau_{ij} \quad \text{.....(3)}$$

$j = 1, 0$; $i = 1, \ldots\ldots, n$

Where X_i is a farm-specific function, β_j is a parameter to be estimated, τ_{ij} is a disturbance term with mean zero and constant variance.

The adoption variable is a dummy, with 1 indicating adoption and 0 otherwise. A farmer adopts any of the new IRVs (j = 1), if $U_{i1} > U_{i0}$. Many of the studies that have appraised the adoption of improved agricultural technologies utilized either probit, logit, or Tobit model. The utility maximization theory therefore helps to explain farmers' decision-making processes in relation to the adoption of conservation agriculture practices. By considering the perceived costs and benefits associated with these practices, policymakers

can design targeted interventions to encourage adoption and enhance the overall utility of farmers.

2.3.4 Innovation and innovative capacity

The term ‘innovation’ has been used in various disciplinary contexts, for instance, industrial economics, agriculture, business, communication, management sciences, etc. where the approaches to conceptualization and ways of application are different. In a historical account of Schumpeter, 1939 cited in (Breschi & Malerba, 1997) the concept of innovation is defined as a way of setting up new production functions through technological and organizational reformation. He argued that innovations can only be promoted in the technological frontier. Schumpeter’s concept is more directed towards the concept of the invention rather than innovation (Mytelka, 2000).

Conferring to Rogers *et al*. (2015), innovation is ‘an idea, practice, or object that is anticipated as new by an individual or other group of adoption’. Rogers’s concept emphasizes the arrival of novelties in the existing condition. These novelties comprise different components which can be indicated by questions of what is new, how new, and new to whom (Johannessen *et al*., 2001).

In an account of Barnett, (2006) innovation is defined as the use of new ideas, technologies, and practices in particular places adopted by people who have not used previously. Predominantly, different theories and concepts of innovation have been elaborated on in a broad range of economic and industrial issues. Where innovation has been considered as a key element of business success, as a component of entrepreneurship, to create viable

competency or as an economic significance, etc. (Anandajayasekeram & Gebremedhin, 2009; Johannessen *et al*., 2001).

It is argued that innovation is a specific tool of entrepreneurship through which entrepreneurs can apply principles of innovation to achieve success (Drucker, 2014). Accordingly, it can be defined to the accomplishment of any products, processes, and firms. Concepts of innovation have also been used by different academic and non-academic (developmental agencies) agricultural research, organizational and policy documents such as (Clark, 2002; Engelhardt & Ritchie, 2001; Hall, 2011) in the various contexts of agriculture, for instance; crop production, livestock, agricultural goods processing and agribusiness.

However, the conceptual difference between "innovation" and "innovative capacity" is not well documented. This thesis is particularly concerned with the innovation in agricultural activities in a rural context in which innovation and innovative capacity are not used interchangeably. In the context of this thesis, the concept of innovation is defined as an initiation or adoption of new crops, cropping patterns, new breeds of livestock, and a new way of cultivation, etc. in a particular rural setting within a certain period.

The concept of 'innovative capacity is defined as the capacity to innovate new practices or improve their existing farming activities. In other words, innovative capacity can be defined as the capacity of farmers to help to be more innovative. Agricultural innovation is a newness that might have already taken place in other times and places but not in that time and place. In agricultural research mapping innovations and understanding, innovative capacity is important because it could provide better policy implications for

agricultural development and its progress. For many years, different theories and approaches have been appeared clarifying nature as well as the process of agricultural innovation. Notable innovation approach begins from the liner approaches.

The concept of innovative capacity is closely linked to the adoption of conservation agriculture practices. It encompasses farmers' ability to access, assimilate, and apply new knowledge, technologies, and approaches to their farming practices. By strengthening innovative capacity through improved access to information, technologies, support services, and conducive social and institutional environments, farmers can be empowered to adopt and successfully implement conservation agriculture practices, leading to improved agricultural sustainability and resilience.

2.3.5 Dynamics of CA Adoption

Specifically referring to CA farming, Ng'ombe *et al*. (2017) states, "usually farmers who are willing to follow the path to a more sustainable agriculture, embark on a long journey that takes them several years or even longer". This journey is assumed to consist of consecutive phases, each characterized by use of specific practices that increasingly incorporate practice and mastery of the three principles CA (minimum tillage, rotation, permanent soil cover) (Michler et al., 2019). He further emphasises that no journey towards adoption appears to be linear, and no journey seems to comprise the same sequence of phases, although some paths are more commonly followed than others. The authors illustrate their model with a graphical representation of four archetypes representing possible journeys, from a hypothesized entry point (current farmer practice) to a hypothetical end point (CA practice of some kind) as a function of time.

Contrary to other models, who adopts an innovation, to what degree and why, is not specified in Michler *et al*. (2019) graphic illustration. Another major difference of this theory, with that of Rogers (2003) or Hoffman (2006) is that an innovation is not assumed to be fixed, but on the contrary changes over time. In addition, the authors do not consider that there is necessarily one unique desirable target or end point in terms of technology adoption in Africa e.g., CA. Nevertheless, a major weakness of this concept is that there is no reference made to the "enabling environment', nor to the "individual factors" influencing adoption of innovation.

2.3.6 Theory of Behaviour Modification

As in Hruschka (1994), this theory refers to those forces facilitating the ambition acquisition as Driving forces (DF) whereas those negatively influential to focus on attainment he calls them Inhibiting forces (IF). Inhibiting forces for technology adoption (e.g., CA) may embrace for an example, lack of subsidies, limited liquidity (for labour hiring, buying herbicide, seeds of legumes for soil coverage, etc.), lack of machinery, and limited information. On the upper hand, driving forces or forces promotive to positive target might encompass, for example, financial assistance, technical advice, training, provision of inputs, linkage with market outlets, etc. Like Lewin (1943), Hruschka (1994) confirmed that behaviour (in this case adoption) results from the psychological field of inhibiting and driving forces. These forces are thus always present in a state of equilibrium or dis-equilibrium with varying degrees of tension between them. Bestowing to Hruschka (1994), an existing state of equilibrium maybe modified (for instance, from traditional farming to CA) by:

- The introduction of driving forces

- The removal of inhibiting forces or
- Combining these two processes. This implies: CB=+DF-IF

Where: CB=Change in Behaviour DF=Driving Forces IF=Inhibiting Forces

Once such forces are diagnosed in the farmers' decision-making process, the probabilities of diffusion can be measured and ramifications for promotion programs can be concluded (Bodnar *et al*., 2005; Rogers *et al*., 2015, p. 200). Situating within the context of CA promotion in Africa, the theory conceptualizes the seemingly image of farmers' change in behaviour from traditional farming to CA. A farmer practising traditional farming in Africa is at a state of equilibrium implying the driving and negative forces to his practice are equal. For such a farmer to adopt CA farming this may imply a modification in behaviour hence the previous state of equilibrium has to be disturbed. Achievable observed benefits that CA farmers enjoy by practising CA like increase yields; labour savings, etc., are the driving forces to encourage a disturbance of this equilibrium on the side of potential adopters.

On the opposite hand, lack of CA information, price of CA machineries, seeds, etc., in Africa are some of the inhibiting forces which may work against this alteration. Like Lewin (1943), for promotion of agricultural innovations in Africa to be effective, its however important to carefully establish these influential forces for each specific innovation and to design measures in re-enforcing the driving forces likewise as removing those forces thought of to be performing inhibiting roles. Nonetheless, same as (Lewin, 1943), Hruschka makes an excessive amount of generalisation on the problem of driving and obstructive forces while not specifically categorising them under environmental,

institutional, policy, individual or characteristics of the innovation concerned as is usually the case.

In summary, behavior modification techniques can play a significant role in promoting the adoption of conservation agriculture practices. By addressing farmers' beliefs, attitudes, perceived barriers, and social influences, behavior modification approaches can facilitate behavior change and increase the likelihood of adopting sustainable farming practices. By combining information dissemination, incentives, social learning, and habit formation strategies, policymakers, extension services, and agricultural organizations can effectively promote and support the widespread adoption of conservation agriculture practices.

2.3.7 Diffusion of Innovation Theory

Agricultural technology adoption is predicted on seminal work of Everett Rogers, in his theory of diffusion of innovations in 1962. The theory seeks to clarify however, why, and at what rate new perspectives and technology spread through cultures. Rogers distinguished five key characteristics that designate the rate of innovations adoption, these include: 1) The relative advantage reflective of however the innovation is subjectively perceived superior to the previous idea; 2) Compatibility reflective however the innovation is perceived “consistent with the prevailing values, past experiences, and desires of potential adopters”; 3) Complexness reflective of the perceived difficulty to grasp and use the innovation; 4) Trialability is “the degree to which an innovation could also be experimented with on a restricted basis”; and 5) Observability reflective of however the results of an innovation are visible to others (Toborn, 2011).

The diffusion of innovations in keeping with Rogers follow a logistic function reflective of the response of an individual in adopting a new idea compared to other members of society. Five classes of adopters each with its own characteristics are: 1) innovators, 2) early adopters, 3) early majority, 4) late majority, and 5) laggards. The rate of adoption is the relative speed with which an innovation is adopted. Rogers' work failed to give theoretical explanations of adoption decision process.

Mekonnen *et al*. (2019), studied Gendered Social Networks, Agricultural Innovations, and Farm Productivity in Ethiopia. the study was grounded on the Innovations diffusion theory, and detected that, shared kinship or membership in certain groups, informal varieties of mutual insurance and having frequent meetings with network members are all related to the next chance of forming an information link with a network member.

Furthermore, they found proof for a statistically important and positive relationship between networks and the adoption of row-planting likewise as yields for both male and female networks. Notwithstanding, the proof for an inverse U-shaped relationship of social learning, that is, between the number of adopters within the network and the adoption of row-planting, is strongest for feminine networks. their results, hence, suggest that extension services and alternative programs that promote agricultural innovations and explore yield improvement can profit from social networks though their success depends on determining the ''right" networks, like those of feminine household members in the case of row-planting.

In the same vein, Long *et al*. (2019), studying socio-economic barriers, in terms of supply and demand, that inhibit the adoption and diffusion of CA technological innovations in

Europe, made a theoretical framework based on the Innovations diffusion theory. This framework explored data from semi-structured interviews with CA technology providers and members of agricultural supply chains, like farmers associations and consumer goods producers (the end-users of the technology). Hence recommending a surge in the adoption and diffusion of CA technological innovations, likewise implications for the CA and innovation literature.

Diffusion of innovations theory posits that the characteristics of an innovation, like relative advantage and trialability can form its rate of adoption (Rogers, 2003). Importantly, technologies might not be entirely unaccustomed to meet the definition and dynamics of innovation, as even previous technologies can be repackaged and reintroduced (Rogers, 2003). CA programs, for instance, usually embrace a minimum of some antecedental ‘‘common” practices that are promoted, adapted, or boosted within farming system (Westermann *et al*., 2018).

Amadu *et al*. (2020) conducted a study in southern Malawi to understand the adoption of climate-smart agriculture (CA) practices. They identified a lack of clarity regarding the potential farm-level CA practices across different contexts, hindering the understanding of CA adoption in developing countries. Using the Innovations diffusion theory as a theoretical framework, they employed recursive bivariate probit regression to examine the impact of program participation on CA adoption across different classes. The study found a positive and statistically significant effect of program participation on the adoption of CA practices, particularly in the resource-intensive CA classes. These results highlight the potential applicability of the typology in enhancing knowledge about the effectiveness of CA promotion efforts in diverse social and environmental contexts. The findings also

emphasize the importance of external support for the adoption of resource-intensive CA practices among rural households and communities in Malawi and other developing regions.

Organizations and policymakers often utilize the Diffusion of Innovation Theory to develop strategies for technology adoption. They may focus on promoting the advantages and benefits of the technology, facilitating compatibility with existing systems, providing training and support to reduce complexity, and creating social proof through success stories and testimonials. Understanding the diffusion process helps to predict and influence the adoption of technology, leading to successful implementation and integration into various sectors and industries.

2.3.8 Theory of Planned Behaviour

According to (Ajzen, 1991), Ajzen's Theory of Planned Behaviour (TPB) helps understand how personal behaviour, such as adoption decisions, can be influenced. The theory focuses on behavioural beliefs, normative beliefs, and control beliefs as key considerations in guiding behaviour. Studies have successfully applied this theory, including research on farmers' intentions to adopt environmentally friendly agricultural practices. The TPB explains that attitudes, subjective norms, and perceived behavioural control contribute to intentions and behaviour. Additionally, the TPB has been extended to include factors like technology self-efficacy, originality, and expertise in predicting mobile shopping adoption. In the context of conservation agriculture (CA), farmers' adoption journeys are seen as nonlinear, with different phases and practices involved.

2.3.9 Summary outcome of reviewed theories and concepts

Different theories and concepts provide frameworks for studying the adoption processes of conservation agriculture (CA), but each has its strengths and limitations in capturing the complexity of the adoption and diffusion of innovations. Some theories focus on individual factors, while others overlook the institutional and policy dimensions. Factors such as agro-environmental circumstances, farmers' knowledge of technology, small-scale farmers' economic considerations, societal acceptance of innovations, resource availability, and security play a role in the adoption context of CA. Additionally, the stakeholders within the CA innovation system and the quality of linkages between them are important considerations. The Diffusion of Innovation Theory and the innovation systems approach offer comprehensive frameworks for analysing innovation systems in agriculture, including CA and fish farming. The utility maximization theory incorporates all the afore mentioned and thus this study is grounded by this theory.

2.4 Empirical Framework

2.4.1 Farmer Perceptions on Climate Variability

Martey & Kuwornu, (2021) in their research on perception of climate variability and soil fertility management choices among smallholder farmers in Northern Ghana employed the multivariate probit model. They found that farmers could combine different soil fertility management practices based on their perception or experience of drought, flood, awareness of climate change, long-term changes in temperature and rainfall. Thus, climate shocks and perception on climate variability have heterogenous effects on the soil fertility management options.

Talanow *et al*. (2021)in their investigation on farmer perceptions on climate change and adaptation strategies in South Africa's Western Cape used a completely descriptive statistical analysis. They found that most farmers perceive climate change and have experienced changes in temperature and rainfall and other extreme climate events.

Pandey & Choudhary, (2019) also in their investigation on climate variability and farmer perception in southern Ethiopia employed the binary logit regression model. Their results revealed that farmer perception on climate variability is strongly influenced by their access to climate and market information, education, agricultural inputs and the village market distance. Furthermore, (Makame & Shackleton, 2020) researched on perceptions of climate variability in Zanzibar, East Africa. they found that almost half of the farmers in this area perceived climate variability.

Cammarano *et al*. (2019)used the Heckman probit model to evaluate farmer perception on climate variability in North-West Ethiopia. They found that education level of household head, age of household head, changes in temperature and rainfall, crop failure in the past, frequency of drought in the past significantly increased farmers likelihood to perceive climate change. On the other hand, in the outcome model, income from livestock, gender of household head, extension advice and knowledge of adaptation measure strongly influenced the adaptation decision of these farmers.

Somboonsuke *et al*. (2018), in their study on Farmers' perceptions of impacts of climate variability on agriculture and adaptation strategies in Songkhla Lake basin. They sought to investigate the key problems of climate variability on the agricultural activities of farmers in this area. During this research, Data were collected using structured interviews from a

total sample of 271 farmers selected using the purposive and snowball techniques. The results from this study revealed that there was a drastic reduction in crop yield as a result of climate variability and also that, the negative impacts of this variability on para-rubber production, rice production, and oil palm production were at a high level.

Ayal & Leal Filho, (2017) also studied farmer perceptions on climate variability and its diverse on crop and livestock production in Ethiopia. They used the average aggregated mean score and MANOVER and their results revealed that, majority of farmers perceived changes in temperature and rainfall. Furthermore, they found that Sex, age, income and educational level are determinant factors of farmer perception to climate change.

Molua, (2007)study on evaluating the effect of climate variation and climate change on Cameroon's agriculture, he used a sample size of 800households from 50 out of the 58 administrative divisions in Cameroon. A Ricardian model was employed for the analysis in this study and both climate and household data were used. The results indicated that the effects of global warming and climate change on the agricultural sector are likely to threaten both the welfare of the population and the economic development of the country. In an older study on Climatic trends in Cameroon and implications for agricultural management which was aimed at estimating the relevance of climate issues for farmers' livelihoods, (Molua, 2022) indicate that locally increasing temperatures are linked to increasing dryness and drought and thus impacting negatively on agricultural production and crop yields.

2.4.2 Socio-economic determinants of conservation agriculture adoption

Ashraf *et al*. (2021) in identifying the coping and adaptation behaviour of farming households also examined the factors that influence farmers choice of drought induced adaptation strategy. They employed a multivariate probit model on 215 farm households from Parkistan. They found that land security, annual income, livestock ownership, credit access, extension services and Government/Non-governmental organization support influence the adaptation of farmers to agricultural conservation practices.

Deressa *et al*. (2011) in their study on determinants of farmers choice of adaptation methods to climate change in the Nile basin of Ethiopia. They used discrete choice models and found that level of education, gender, age, wealth of household head, access to extension, access to credit, information on climate, social capital, agroecological settings and temperature changes are the main determinants of farmer adoption of conservation agricultural practices.

Kwadzo & Quayson, (2021) in the same vein investigating factors influencing adoption of soil fertility management technologies by smallholder farmers in Ghana, used the logistic model and a multivariate probit model. They found that land ownership, distance from home to input market, access to credit and agroecological zone significantly influence farmer adoption of conservation agricultural practices.

Abegunde *et al*. (2019) researched on Determinants of the Adoption of Climate-Smart Agricultural Practices by Small-Scale Farming Households in King Cetshwayo District Municipality, South Africa. They used primary data for educational status, farm income, farming experience, size of farmland, contact with agricultural extension, exposure to

media, agricultural production activity, membership of an agricultural association or group, off farm income, distance from home to farm and the perception of the impact of climate change collected with the use of questionnaire from 327 farmers. They therefore employed both descriptive statistics and generalized ordered logit model to analyse data obtained. Their results portrayed that educational status, farm income, farming experience, size of farmland, contact with agricultural extension, exposure to media, agricultural production activity, membership of an agricultural association or group and the perception of the impact of climate change are significant and positive determinants of CA adoption. While off farm income and distance from home were significant but negative determinants.

Kurgat *et al*. (2020) assessed the determinants of adoption of five technologies that can help achieve some of the CA outcomes in smallholder farms in Tanzania. They used the multivariate probit model and found that household size, land size, land ownership, age of household head were positive determinants of farmer adoption of conservation agriculture. Chandio & Yuansheng, (2018), examined factors affecting adoption of improved rice varieties by smallholder farmers in Northern Sindh, Pakistan. The random sampling technique was used to collect data from 220 smallholder rice farmers through the face-to-face interview. Data were analysed using descriptive statistics and probit regression model. The empirical results showed that year of education, farming experience, soil quality, farm machinery ownership, access to market information and contact with extension agents had significantly positive influence on adoption of improved rice variety, while age had significantly negative effect.

Zulu-Mbata *et al*. (2016) examined the Determinants of Conservation Agriculture Adoption among Zambian Smallholder Farmers. The econometric analysis results on the determinants of CA adoption in this study show that social factors, to some extent, play an important role in a household's decision to adopt CA in Zambia. The results also show that availability of CA support services such as spraying services at community level had positive effects on the likelihood of smallholder households adopting CA. Surprising, the

availability of tractor hiring services in the community reduces the likelihood of CA adoption. Another striking finding relates to household farm size. Promoters of CA in Zambia have often focused on increasing CA adoption among households with small farms as compared to larger farmers. However, the results show that households cultivating larger pieces of land are more likely to adopt full CA than those cultivating smaller pieces of land, while landholding size did not seem to matter for the adoption of partial CA.

Syano *et al*. (2022), examined the factors influencing adoption of agroforestry practices among rural households in Kenya. The authors argue that when land ownership is extremely unequal, agroforestry activities and its growth deliver fewer paybacks for the poor rural households. Land tenure problems have been exacerbated by continuous fragmentation of land, land inheritance, gender imbalance in land ownership and the rights to land use. The paper concludes that the decision to adopt agroforestry was partly influenced by land and tree tenure, size of land and gender equity (women's rights to property and recognition of co-ownership). Additionally, rural households' investments in agroforestry increase with increasing in land tenure.

Maina *et al*. (2020) analyses the socio-economic determinants of adoption and the impact of adopting Brachiaria grass for feed sufficiency and increased milk production. Propensity Score Matching (PSM) method was used to assess the determinants and impact of the adoption of Brachiaria grass. Empirical results indicate that the adoption of Brachiaria grass led to a significant increase in milk production by 27.6% and feed sufficiency by 31.6%. The positive impact of Brachiaria grass is consistent with the role of agricultural technologies in improving the productivity, income, and welfare of smallholder farmers. They reported that the adoption of Brachiaria grass is influenced by age of farmer, tropical

livestock unit (TLU), type of animal breed, perceived benefits of the technology, access to extension, and farmer group membership.

Waaswa *et al*. (2022) in their research on understanding the socioeconomic determinants of adoption of climate-smart agricultural practices among smallholder potato farmers in Gilgil Sub-County, Kenya, used primary data collected using structured questionnaire and analysed their data using the Statistical Package for Social Sciences (SPSS) software, version 25.0. Descriptive analysis was used to compute the percentages and frequencies for some socioeconomic variables against the adoption of conservation agricultural practices (CAP). They also employed a binary logistic regression model was used to analyse the relationship between socioeconomic factors and the adoption of CAP. They used the following socio-economic variables: gender, age, education level, and off/on farm income. Their results showed that gender and farm income are significant determinants of adoption of CAP.

In another study carried out by Mogaka *et al*. (2021), on the socioeconomic factors influencing the choice of climate-smart soil practices among farmers in western Kenya, they used primary data with a sample size of 265farmers. They employed both descriptive statistics and the multinomial logit model where they presented marginal effects values. They used the following variables, education, gender, farm experience, age, farm size, land ownership status and number of plots. Their results showed that, farm experience and age were significant determinants of agroforestry adoption at 5% while farm experience and number of plots were significant determinants of organic farming adoption at 1% and 5% respectively. Furthermore, gender and rented land were significant at 1% and plot size, number of plots and owned land were at 5% significant in adoption of intercropping.

Belay *et al*. (2020), also investigated the Determinants of farmers choice of adaptation to climate variability in Dera woreda, south Gondar zone, Ethiopia. They employed descriptive statistics and Multi-Nominal Logit model (MNL) to analyse the data on household and demographic characteristics and the determinant factors that influences the choice of farmers adaptation, respectively. Results from the MNL model also found that the adaptation measures taken by the households are influenced by some predictor variables such as gender of the household head, age, access to extension services, agro-ecological location, farm size, family size and perception on temperature.

2.4.3 Effect of CA on Livelihood of smallholder farmers

Yatich *et al*. (2022), assessed the Effects of Climate Smart Agriculture Practices on Household Livelihoods in Soy Sub- County Kenya. Data was collected from two agro-ecological zones using a combination of structured household questionnaires (N-196) and key informant interviews (N-6). Analysis was performed using descriptive statistics. They used the data from key informants was used to verify the accuracy of survey results. Results showed that 88.7% of farm households who adopted CA practices saw increased yields, 73.46 % saw increased income, 7.65 % saw increased employment opportunities, 4.08% saw decreased pest and weed populations, and 0.06% saw increased soil quality. However, they suggest that implementing Climate Smart Agriculture practices is a viable strategy for reducing the negative impacts of climate variability, strengthening livelihoods, boosting food security, and reducing poverty.

Teklu *et al*. (2022) evaluated the effectiveness of Climate-Smart Agriculture Innovations in Smallholder Agriculture System in Ethiopia. Their study looked at how changes in CA have affected food security, climate adaptation, and greenhouse gas emissions. Using an

endogenous switching regression (ESR) model, data from a cross-sectional household survey was collected from a multi-stage sample of 424 smallholder farmers in the upper Blue Nile highlands of Ethiopia. They reported that farmers benefit from increased food security and adaptation to climate change thanks to CA innovations like improved variety, compost, row planting, and agroforestry, which also reduce greenhouse gas emissions from farm plots.

Furthermore, they stated that, while crop rotation improves farmers' food security and reduces their livelihoods' susceptibility to environmental disasters, sustainable wheat cultivation (SWC) accomplishes these aims while also lowering greenhouse gas emissions. However, they suggested that one of the CA practices in Ethiopia is crop residue management, but this approach falls short in at least two key areas. They therefore concluded that the best CA innovation portfolio for highland smallholder agriculture systems includes crop improvement, crop rotation, compost, row planting, soil and water conservation, and agroforestry.

Yamoah & Kaba, (2022), investigated integrating climate-smart agri-innovative technology adoption and agribusiness management skills to improve the livelihoods of smallholder female cocoa farmers in Ghana. Existing gender inequalities in Ghana's cocoa sector have been exacerbated by environmental and climate change issues. Women's economic security is threatened because they are currently underrepresented and have unequal access to opportunities in climate action initiatives. The goal of their study was to promote the use of shaded cocoa production in order to generate biomass (waste) for organic compost production by demonstrating how collecting cocoa waste can serve as the basis of a viable microenterprise. Methods for organic compost production and

agribusiness management were learned in accordance with a formal curriculum. To evaluate the efficacy of the training workshops and the overall progress of the project, the study analysed project notes and post-training community-visit observation records and interviews.

According to the findings, the recipients of this information were inspired to continue and increase their use of climate-smart agri-innovations in the form of shaded cocoa production. Positive social, environmental, cultural, and economic impacts, as well as promising prospects for improved livelihoods for women cocoa farmers, are also demonstrated by the findings. These findings suggest that SDG13, which urges immediate climate action, can be combined with SDG5, which prioritizes gender equity, to boost the implementation of cocoa agroforestry and the economic security of women working in Ghana's cocoa industry.

Abegunde *et al*. (2022) examined the impact of climate-smart agriculture (CSA) on household food security in South Africa's small-scale production systems. They collected data from 327 small-scale farmers and conducted statistical analysis to understand the relationships between CSA adoption, household characteristics, and food security. The study found that implementing CSA practices had a significant positive impact on family nutrition security. Gender was found to positively influence food security in the Mthonjaneni area but had no discernible effect in uMhlathuze. Factors such as farm income, non-farm income, farming experience, and household participation positively influenced food security in both areas. Conversely, household size and dependency ratio negatively affected food security. The authors argue that small-scale farmers can benefit greatly from adopting CSA practices to enhance productivity and ensure access to

nutritious food. They emphasize the importance of considering household characteristics when implementing CSA interventions to effectively address food security challenges in specific contexts.

Egeru *et al*. (2022) examined the adoption of climate-smart agriculture (CSA) and its impact on household food security in the Nakasongola District of Uganda. They conducted a cross-sectional household survey with 165 participants and used principal component analysis and an ordered logit model for analysis. The study found that households implemented various strategies to improve soil and water quality, livestock productivity, and disease prevention. The analysis classified the most frequent CSA practice combinations into six categories. Factors such as access to climate information, livestock units, non-livestock assets, and off-farm activities influenced CSA adoption. Adopters of CSA practices had a lower Food Consumption Score (FCS) compared to non-adopters, indicating better food security. The study emphasized the importance of integrated CSA practices and adapting them to regional production constraints. It suggested that marketing campaigns for CSA should focus on these aspects to encourage adoption and improve food security in semi-arid areas like Nakasongola District.

2.4.4 Determinants of CA adoption

Kifle *et al*. (2022) investigated factors influencing farmers' adoption of climate-smart agriculture in Siyadebrina Wayu District, Ethiopia. They found that crop diversification, crop rotation, intercropping, and integrated soil fertility management were widely practiced CSA techniques. Determinants of CSA adoption included farming system, farm size, access to irrigated farms, extension services, distance to marketplaces, and weather information. Despite a high response rate, the study revealed a low rate of CSA adoption.

The authors recommended prioritizing input provision, skill training, and context-specific technologies through extension programs. They also suggested policy and support initiatives to disseminate best practices to smallholder farmers in the region.

Furthermore, in the study on the adoption of forage crops in the rural municipality of Koumbia, Burkina Faso, Fayama *et al*. (n.d.) found that despite the potential benefits of forage crops in boosting animal productivity and farmer incomes, their adoption has been low. The study involved 73 agro-pastoralists in the Koumbia municipality and assessed a project focused on expanding fodder production. The research used a quantitative research strategy, collecting data through questionnaires and documents. The study revealed that forage crops were adopted at a rate of 88%, with education, land availability, income, forage seed availability, and familiarity with forage production techniques being significant factors influencing adoption. The decision to adopt forage crops among agro-pastoralists is influenced by these factors, and the perception of the viability of forage crops for meeting animal nutritional needs plays a crucial role. Negative attitudes towards forage production can deter farmers from cultivating these crops.

Also, in a study on adapting to climate change through conservation agriculture in Eastern Zambia by Umar (2021), both male and female smallholder farmers experienced the effects of climate change, such as a delayed rainy season, drought, and higher temperatures. Women highlighted lower crop yields, armyworm outbreaks, and decreased livestock fodder as major impacts, while men faced declining crop yields, rising livestock disease, and increased food insecurity. Both genders recognized the benefits of conservation agriculture (CA) in adapting to climate change, but their perspectives differed. Men valued high moisture holding capacity, increased crop yields, and reduced labor requirements,

while women emphasized increased soil fertility, lower costs, and drought resistance. The study concluded that adopting CA could benefit both male and female farmers in Eastern Zambia, but challenges such as weed pressure, labor demands, and limited access to inputs need to be addressed.

Muriithi *et al*. (2021), in their her study examined Smallholder farmers' adoption of climate smart agriculture (CSA) technologies. A total of 384 households were selected through a multi-stage sampling procedure. Analysis of the data was performed using both percentages and regression. According to the findings, 47.4% of farmers have adapted their practices to the effects of climate change by employing techniques like intercropping, crop rotation, and agroforestry. Adoption of the adaptation strategies was significantly influenced by sex (0.9%) and education level (9.2%). Further, mobile phones (0.9%) and neighbours/friends (0.2%) were found to have a negative impact on adaptation strategies. Greater emphasis in future policy should be placed on raising public understanding through a variety of media and facilitating access to local extension services.

Dagunga *et al*. (2021) in their her study examined conservation agricultural practices: determinants and effects on soil health for sustainable production in northern Ghana. A multivariate probit model was used to identify the determinants of conservation agricultural practices using cross-sectional data from 1284 households collected by the international food policy research institute, and an inverse probability weighted regression adjustment was used to determine the impact of conservation agricultural practices on soil health. The multivariate probit model's findings revealed that farmers' choices to implement conservation agricultural practices are influenced by a wide range of factors, including socioeconomic and institutional factors as well as different household-level

factors. Soil health can be improved by reducing its susceptibility to erosion by employing practices such as crop rotation, fallowing, contour ploughing or pit planting, and applying manure. Since conservation agricultural practices guarantee food production for current generations without compromising soil health for future productions, the study concludes that they will be useful in Ghana's pursuit of achieving zero hunger. And thus, recommended that order for Ghanaian families to increase their yields while preserving the quality of the soil, conservation agriculture should be a central component of the government's flagship program, "planting for food and jobs."

2.4.5 Framework linking major concepts

Figure 2.2 shows the study conceptual framework, showing the relationships among major concepts used in this study. The conceptual framework outlines the relationship among different farmer's assets and wealth as represented by the different forms of capital (Human, social, natural, physical and financial), transformation structures (e.g., conservation agriculture (CA)), policy, livelihood strategies and outcomes.

In this study's context the framework(fig 2.2) is applied to show the relationships when households try to respond to climate change and variability in Cameroon. However, the sustainable livelihood framework is a conceptual tool used to understand and analyze the various factors that influence livelihoods and their sustainability. It emphasizes the importance of different types of capital or assets that individuals or communities possess and can utilize to improve their livelihoods. Nonetheless, the framework typically incorporates five types of capital. Natural Capital refers to the natural resources available in the environment, such as land, forests, water, biodiversity, and other ecosystem services. In the context of conservation agriculture and REDD+, natural capital plays a crucial role.

Conservation agriculture practices aim to protect and enhance natural resources, such as soil fertility and water availability, by minimizing soil disturbance and promoting sustainable land management.

However, REDD+ focuses on conserving forests and their ecosystem services as a means to mitigate climate change and preserve natural capital. In addition, physical capital which includes infrastructure, equipment, tools, and other physical assets that individuals or communities possess. However on conservation agriculture, physical capital can involve the availability of farm machinery, irrigation systems, storage facilities, and access to inputs like seeds and fertilizers. Similarly, in the context of REDD+, physical capital may include infrastructure for forest monitoring, management, and carbon measurement.

Furthermore, human capital which refers to the knowledge, skills, education, and health of individuals, encompasses both formal education and practical knowledge gained through experience. In relation to conservation agriculture, human capital involves understanding and applying sustainable farming practices, such as intercropping, zero/minimum till, crop rotations, cover crops, mulching, etc. on the other hand, as regards to REDD+, human capital plays a role in capacity building efforts related to forest management, monitoring, and carbon accounting. Also, we have financial capital which refers to the financial resources available to individuals or communities to invest in their livelihoods. This can include savings, income, credit, and access to financial services. In conservation agriculture, financial capital is needed for acquiring inputs, equipment, and technologies that support sustainable farming practices. REDD+ initiatives often involve financial incentives or mechanisms to compensate communities for their efforts in forest conservation and carbon sequestration, thereby contributing to financial capital.

Moreso, there is another asset of sustainable livelihoods which social capital and relates to the relationships, networks, and social connections within a community or society. It encompasses social norms, trust, cooperation, and collective action. In the context of conservation agriculture, social capital plays a role in knowledge sharing, cooperation among farmers, and community-based resource management. While in the case of REDD+, social capital is essential for fostering community engagement, participation, and ownership in forest conservation efforts.

Therefore, by incorporating conservation agriculture and REDD+ into the sustainable livelihood framework, we recognize how these practices can influence and interact with the different capitals. Conservation agriculture contributes to the enhancement of natural capital, utilization of physical capital, development of human capital through knowledge and skills, and potentially financial capital through improved productivity. While REDD+ initiatives align with the preservation and sustainable use of natural capital, while also providing opportunities for financial capital through incentive mechanisms. Both conservation agriculture and REDD+ can benefit from social capital by fostering collaboration, knowledge sharing, and collective action within communities.

In summary, the sustainable livelihood framework incorporates the 5 capitals (natural, physical, human, financial, and social) to analyze how conservation agriculture and REDD+ influence livelihoods. These concepts highlight the importance of sustainable land and forest management, while considering the diverse assets and interactions that shape livelihood outcomes.

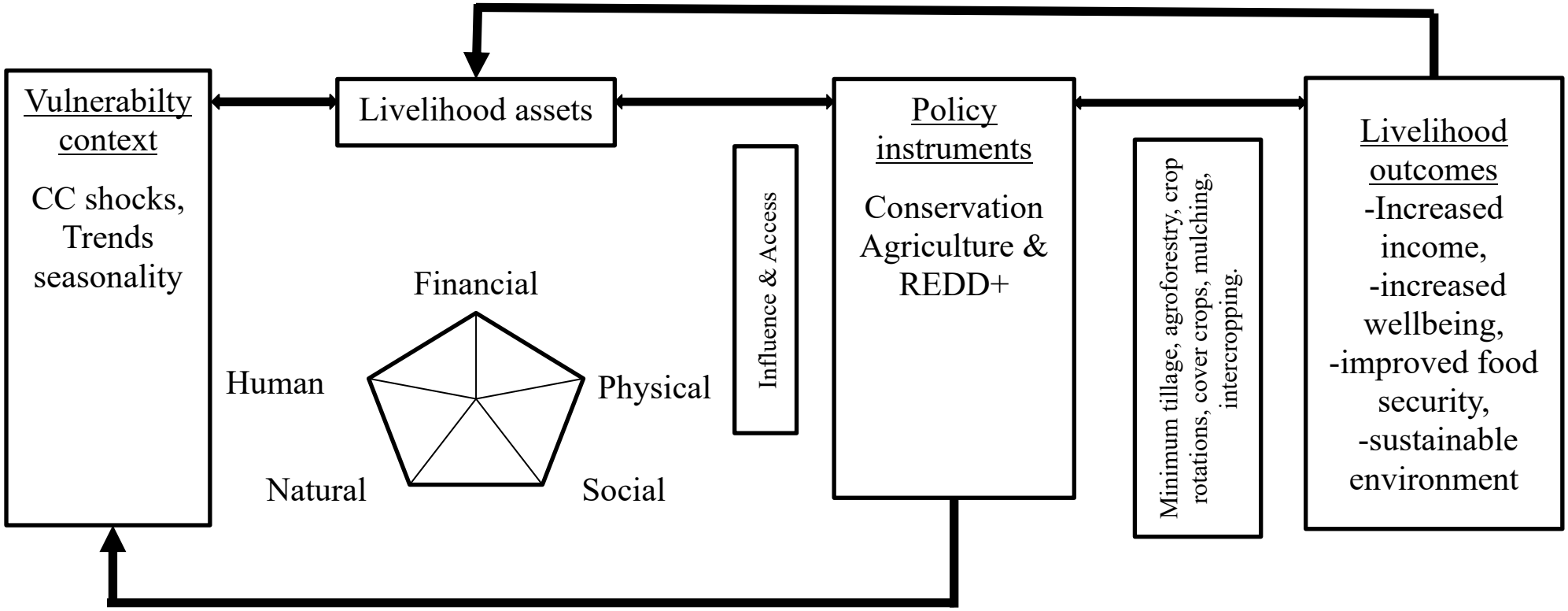


Figure 2. 2 Study conceptual framework showing the link between CA, REDD+, policy and livelihood outcomes

2.4.5 Gaps in Literature

A variety of literature covers the possible impacts of climate change on agricultural production and ways of adapting to climate change (Aryal *et al*., 2020; Fadina & Barjolle, 2018; C. A. Harvey *et al*., 2018; Raza *et al*., 2019). These studies generally indicate that farmers can overcome the adverse impact of climate change by implementing adaptation measures. Much of the literature review on agricultural adaptation to climate change has drawn attention to a range of factors affecting the adoption of such methods by small-scale farmers. A lot of these studies merely identify household, farm characteristics and institutional factors as the key determinants of adoption (Belay *et al*., 2020; Beyene *et al*., 2019; Chandra *et al*., 2017; Zulu-Mbata *et al*., 2016). However, there is a dearth of information on the drivers of choice and impact of specific CSA practices on livelihood status of small-scale farmers.

Studies have generally been done at the national level targeting major stakeholders in workshops. FAO has done studies to identify CA interventions that contribute to increased/sustained production of agricultural production systems amidst climate change and provide recommendations on the most appropriate interventions for increasing farmer's access to finance from micro-finance institutions to address these gaps in the value chain. In their report, FAO did not target rural households in their survey. Further still, the study did not assess the impact of CA practices on small scale farmer livelihood status.

Literature relating to crop yield shows that studies have been carried to estimate the impacts of climate change in the agricultural sector and more specifically the impacts on crop yield. Simulation methods and regression methods have largely been utilized. Studies using crop land or crop revenue models to determine the impact of climate change on agriculture show mixed results regarding the sign and magnitude of the impact. In this era

where there is increase in demand for agricultural products, there is a call for innovative methods to ensure constant supply. In this light this chapter has sought for literature on Conservation agricultural methods which were limiting because the practices a very few and researchers on looking at better or more methods to add came up with Climate smart agricultural methods which have other methods including conservation agriculture as one of its methods. This study therefore focuses on undertaking An ex-ante estimation of the effectiveness of selected policy instruments on sustainable land use in small farmer-households and farm level analysis of the effect on livelihood status of smallholder farmers to bridge the gap.

2.4.6 Chapter Summary

This chapter has reviewed studies in four main areas, those relating to. First the important concepts which ranged from climate change, conservation agriculture, Livelihood security and REDD+ have been thoroughly discussed bringing out the issues around these concepts. It has also looked at the nexus of climate change and agriculture how they interrelate with each other. This is followed by literature relating to importance and adoption of climate smart agriculture, and REDD+, followed by that relating to, the theories that have been applied in similar studies. Literature on crop output response shows that output response studies have been carried at the individual crop level and at the aggregate output level. Studies that incorporate weather variables reveal the importance of climate in influencing agricultural production decisions. Based on the idea that farmers have to simultaneously make crop production and input decisions, the realization of output will also depend on uncontrolled natural events. The utility maximization theory is adopted for this study because it allows for quantitative analysis, enabling researchers to construct models and test hypotheses based on empirical data. This approach helps in predicting adoption behavior, identifying influential factors, and designing effective strategies to promote technology adoption.

CHAPTER THREE

Material and Methods

3.1 Description of Study Area

This study was carried out in some selected villages from the South and East regions of Cameroon (Fig. 3.1), based on the concentration of forests and active agricultural activities in this area. The South region is in the southwestern and south-central portion of the Republic of Cameroon. It shares borders with a portion of the Atlantic Ocean to the west, the Centre Region to the north, the Littoral Region to the northwest, the East region to the east, and Gabon, Congo, and Equatorial Guinea to the south. The South is the 4th largest region in the country, with a total area of 47,720km2 (Neba, 1999). The many Beti-Pahuin peoples, including the Ewondo, Fang, and Bulu, make up the principal ethnic groups. In addition, the South Region has a respectable amount of industry, with forestry, mining, and offshore oil drilling making up the bulk of its trade.

In the South, commercial agriculture is also significant, with cocoa and rubber as the two main cash crops. Additionally, fishing and raising cattle are important economic activities. Subsistence farmers make up a large portion of the population. The South region has a Guinea-type climate. In the interior, there is a lot of humidity, and the coastal area has 2000-3000mm of precipitation annually compared to 1500-2000mm in the interior. Rainfall along the coast from north of Kribi to the south of Ebodjé can reach 4,000 mm annually (Neba, 1999). Moreover, temperatures are high, averaging between 24 and 26°C from Kribi north along the coast. The Guinea-type climate offers alternating dry and wet periods in place of regular seasons. A protracted dry season that lasts from December to May ushers in the New Year. A brief dry season from July to October is followed by a

modest wet season from May to June. Around October, a prolonged wet season starts and lasts through November.

On the other hand, Cameroon's southeast corner is occupied by the East Region. It shares borders with the Central African Republic to the east, the Congo to the south, Adamawa to the north, and the Centre and South Regions to the west. It is the most sparsely inhabited and largest region in the country, covering 109,002km2. The Baka (or Babinga) pygmies were the original settlers, and the peoples of the East have been in Cameroon longer than any other ethnic group in the country's history. Also, the East region has virtually little industry; logging, wood, and mining make up much of its trade. Subsistence farmers make up most of the population instead. As a result, the region has minimal political significance and is frequently disregarded by Cameroonian politicians. This, together with the region's lack of growth, has earned it the nickname "the forgotten region." The South Cameroon Plateau, which makes up the country's southeast, contains almost the whole land of the East region. Except for the lower-lying plains of 200 to 500m in the extreme southeast centred on the Dja, Boumba, Sangha, and Ngoko rivers, the elevation thus fluctuates between 500 and 1000m above sea level (Neba, 1999; Fitzpatrick, 2002). The topography is mostly composed of monotonous, slightly sloping hills, labelled as "half-oranges" after the fruit they resemble.

Furthermore, the East has a wet equatorial climate, commonly referred to as a climate of Guinea type, which is characterised by high temperatures (24°C on average) and the absence of traditional seasons. Instead, there are four distinct seasons: a lengthy dry season (December to May), a light rainy season (May to June), a brief dry season (July to October), and a heavy wet season (October to November). Except for the extreme eastern and northern sections, where precipitation is slightly less, there is a fair amount of humidity,

cloud cover, and precipitation, averaging 1500-2000mm annually (Neba, 1999; Fitzpatrick, 2002).

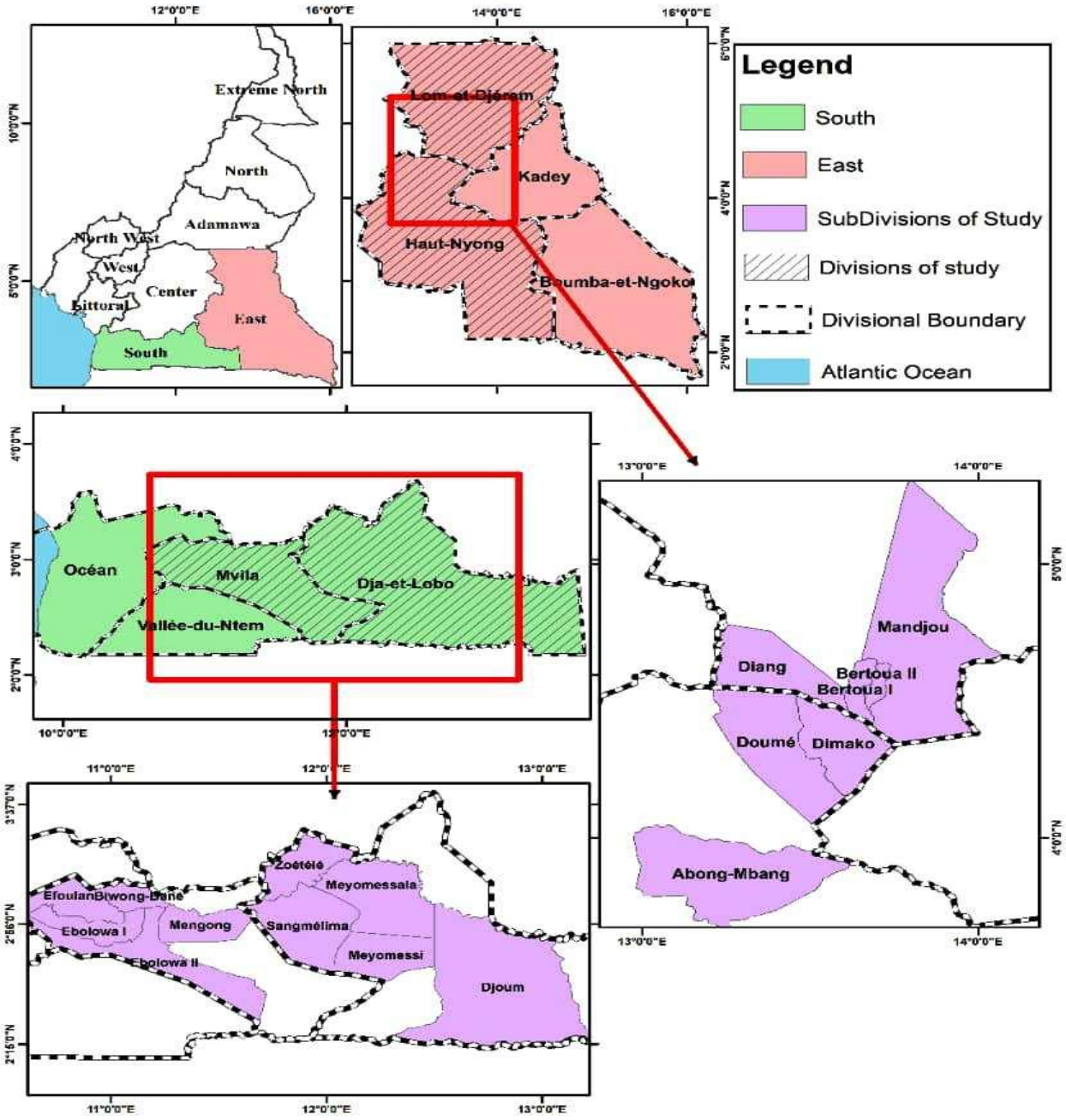


Figure 3.1 Map of Study Area(author 2021)

3.2 Research Design

This study adopts a mixed-methods research approach, combining both quantitative and qualitative data collection methods to gain a comprehensive understanding of the factors influencing the adoption of policy instruments for sustainable agriculture. Quantitative data collection methods involve the use of numerical data and statistical analysis. In the context of this study, quantitative methods were utilized to examine the extent of adoption of conservation agriculture and to quantify the impact of different factors on adoption rates. For instance, surveys and questionnaires may be administered to farmers to collect data on their current farming practices, including the use of conservation agriculture techniques. The data collected through these surveys can be analyzed using statistical techniques to identify correlations and associations between various factors and the adoption of conservation agriculture. This quantitative analysis can provide valuable insights into the prevalence and patterns of adoption, as well as the statistical significance of different influencing factors.

On the other hand, qualitative data collection methods aim to gather rich, in-depth information about the experiences, perceptions, and attitudes of individuals involved in the adoption process. Qualitative methods, such as interviews, focus group discussions, and observations, were employed to explore the contextual factors that influence farmers' decisions regarding the adoption of conservation agriculture. These methods allowed us to capture the complexity and nuances of the adoption process by delving into farmers' motivations, barriers, and challenges, as well as their perspectives on the benefits and drawbacks of conservation agriculture practices. Thus using qualitative data provided us with a deeper understanding of the underlying reasons behind adoption patterns and shed light on the socio-cultural, economic, and environmental dynamics at play.

By combining quantitative and qualitative data collection methods, the study can capitalize on the strengths of both approaches. The quantitative data can provide a broader overview and statistical evidence, while the qualitative data can provide a more nuanced and contextual understanding. Triangulating these different types of data can lead to a more comprehensive and robust analysis, enabling researchers to identify key factors that influence the adoption of conservation agriculture. Moreover, this mixed-methods approach allows for the validation and cross-verification of findings, enhancing the overall reliability and validity of the study's conclusions.

3.3 Sampling

The sampling frame considered the traditional typology of agro-ecological zones in the country. The sample was chosen through a purposive and multistage proportionate random sampling process. The procedure was employed to select villages from each division, and households from each village. In the first stage the two regions were purposively selected due to their dependence on forests for livelihood and dependence on rain-fed agriculture. In the second stage two divisions were selected due to their high involvement in agriculture, in these regions.

In the third stage, 10 villages were randomly selected from the list of villages gotten from the 4 divisions that is 5 villages from each division with a random pick of one village per subdivision. At a final stage, a systematic random sampling was employed to select 20 households from each village to arrive at a desired sample of 200 households per region. This was not fully accomplished in the east region because there were some villages that the population was smaller so at the end we reduced sample size to 15 households per village with one village having an extra questionnaire thus summing up to 151 households

in the east. This was not the same for the south region we surveyed 20households as initially stipulated, and thus arrived at a total of 351 households for the two regions.

Sample size determination is the act of choosing the number of observations or replicates to include in a statistical sample. The sample size is an important feature of any empirical study in which the goal is to make inferences about a population from a sample. If a sample is not a true representative of the target population, then it may lead to unreliable conclusions. Determination of sample size depends on several factors including the purpose of the study, population size, sampling error permitted, etc. The appropriate sample size can be determined using various formulae constructed in different aspects. The size of our sample dictates the amount of information we have and therefore, in part, determines our precision or level of confidence that we have in our sample estimates.

An estimate always has an associated level of uncertainty, which depends upon the underlying variability of the data as well as the sample size. The more the variables population, the greater the uncertainty in our estimate. Similarly, the larger the samples size the more information we have and so our uncertainty reduces. There are various approaches for computing sample size. To determine the appropriate sample size the following basic factors are to be considered the level of precision required by users, confidence level desired and degree of variability.

3.3.1 Level of Precision:

The sample size is to be determined according to some preassigned degree of precision. The degree of precision can be specified in terms of two criteria. The margin of permissible error between the estimated value, and the population value. In other words, it is the measure of how close an estimate is to the actual characters in the population. The level of precision may be termed as sampling error, which is the range in which the true value of

the precision is estimated to be. According to W.G.Cochran (1977) precision desired may be made by giving the amount of error that is willing to tolerate in the sample estimates.

The difference between the sample statistic and the related population parameter is called the sampling error. It depends on the amount of risk a researcher is willing to accept while using the data to make decisions. It is often expressed in percentage. If the sampling error or margin of error is ±5%, and 70% unit in the sample attribute some criteria then it can be concluded that between 65% to 75% of units in the population have attributed that criterion. High levels of precision require larger sample sizes and higher costs to achieve those samples.

3.3.2 Confidence level desired:

The confidence or risk level is ascertained through the well-established probability model called the normal distribution and an associated theorem called the Central Limit theorem. he probability density function (p.d.f) of the normal distribution with parameters μ and σ is given by

$$p(x) = \frac{1}{\sigma\sqrt{2\pi}^{e}} \quad -\frac{(x-\mu^2}{2\sigma^2}$$

where μ is the mean and σ is the standard deviation.

In general, the normal curve results whenever there are many independent small factors influencing the outcome. It is for this reason that many practical distributions, be it the distribution of annual rainfall, the weight at birth of babies, the heights of individuals, etc. are all normal, if a sufficiently large number of items are included in the population. The Z – value or Z – score corresponds with the confidence level (CL). That is, for CL of 90% the Z – value is 1.645, for 95% is 1.960 and 99% is 2.580.

3.3.3 Degree of variability:

The degree of variability in the attributes being measured refers to the distribution of attributes in the population. The more heterogeneous a population, the larger the sample size required to be, to obtain a given level of precision. For less variable (more homogeneous) population, smaller sample sizes work nicely. Note that a proportion of 50% indicates a greater level of variability than either 20% or 80%. This is because 20% and 80% indicate that a large majority do not or do, respectively, have the attribute of interest. Because a proportion of 0.5 indicates the maximum variability in a population, it is often used in determining more conservative sample size.

This study therefore, adopts Cochran (1977) formula to calculate a representative sample for proportions of a large population whose degree of variability is not known as on the formula below:

$$n_0 = \frac{z^2 pq}{e^2}$$

where, n_0 is the sample size, z is the selected critical value of desired confidence level, p is the estimated proportion of an attribute that is present in the population, q = 1- p, and e is the desired level of precision. Assuming the maximum variability which is equal to 50% (p =0.5) and taking 95% confidence level with ±5% precision, the calculation for required sample size will be as follows--

p =.5 and hence q =1-.5 =.5; e = .05; z =1.96

$$n_0 = \frac{(1.96)^2(0.5)(0.5)}{(0.5)^2} = 384.16$$

Which is approximately 384 participants to be considered for this study, with 192 of the participants from the South and 192 from the eastern regions of Cameroon.

.

Table 3. 1 Distribution of farmers studied

Region	Division	Sub-Division	Village	Number of HH
East	**Haut-Nyong**	Abong bang	Anzie	15
		Doume	Sibita	16
		Doume	Mbama III	15
		Dimako	Beul	15
		Dimako	Longtimbi	15
	Lom et Njerem	Mandjou	Kouba	15
		Bertoua I	Koume-goffi	15
		Ndiang	Ndoumbi	15
		Bertoua III	Adinkole	15
		Bertoua II	Gbakombo	15
South	**Dja Et Lobo**	Zoetele	Nkoumadjap II	20
		Djoum	Nkolafendek-Nkolatui	20
		Meyomessi	Melan	20
		Meyomessala	Elle	20
		Sangmelima	Monavebe	20
	Mvilla	Biwong-Bane	Melangue I	20
		Ebolowa II	Esinguili	20
		Efoulan	Akom	20
		Ebolowa I	Aka'ak	20
		Megong	Ke'eke	20

3.4 Research Instrument

Data for this study were collected using a pre-tested structured questionnaire on farm household head. This questionnaire was divided into five sections with each section further segregated into modules.

Section 1: was geared towards collecting data on Socio-demographic information which was made of three modules. Where module 1 captured data on household size and age, literacy (number of years of schooling), marital status, Religion, off-farm income, and gender of the household head. The category of information captured in Module 2 includes farmers' access to credit, farm size, Perception about the soil fertility, Distance from the residence to the nearest market in kilometres, Access to extension services, land ownership

status, Farm Terrain, hired labour hours, distance to farm, soil erosion, farming experience and category of crops cultivated. Module 3 of this section collated information on levels of production where we captured data on the various types of crops cultivated, their production quantities, percentage of home consumption, percentage of marketable surplus, the market price of these crops, usage of the surplus income, the main purpose of cultivation, perceptions on production quantities and the reason behind the changes. This section provided information that cut across responding to all research questions.

Section 2 has just one module (Module 04). This section assessed climate change and climate change vulnerability from the farmers' perspective. The information used for this category includes farmers' apprehension on changes in temperature and rainfall patterns, the nature of this changes, the number of years farmers experience these changes, sectors most affected by these changes, months with greatest hits, types of crops lost due to these changes, different ways these changes have affected farmer health and significant effects identified in their communities typical of these changes. This section responded to the research question on farmers' perception of climate variability and change.

Section 3 captured farmers' adaptation measures towards a changing climate. It has two modules 05A and 05B. Here the category of information gotten from module 05A was on if farmers change their activities due to changing climate, what type of measures they take to align with this changing climate, their awareness of these measures, and the decision-maker towards adopting this measure and if they acquired training on these measures. Module 05B was designed to capture information on the adoption of the selected adaptive strategies that were termed climate-smart agricultural practices. Also, the difficulties faced in adoption were captured. This section provided information for responding to the

research question which focused on analysing the socioeconomic, Geographic and plot level determinants of farmers' adoption of Conservation agriculture.

Information on Gender relations was collated in section 4 of the questionnaire. Information on gender roles in the household and at the level of adoption of climate-smart practices was gotten, gender roles on-farm preparation, crop management, transportation, and marketing were also captured in this section. Also, the aspect of decision making in gender roles was not left out where information was captured on who as per gender takes decisions on some farm level activities.

The last section which is section 5 was on livelihood and food security. Where farmer welfare was captured and livelihood and food security indicators like health, income, nutrition was captured, and others. This section provided information for responding to the research question on estimating effect of conservation agriculture on smallholder farmer livelihood security.

3.5 Data Collection

A research permit from the Department of agricultural Economics and Agribusiness, Regional delegations of Agriculture in both East and South regions, to conduct research was sought, after which data collection began. Data collection for this study took place within the months of January, February, and March .The questionnaires were administered individually to all the sampled smallholder farmers in the study area. Data collection was done by reading out the questions and helping the respondent to understand and then respond. Caution was exercised in order to ensure all questionnaires issued to the respondents are received back and numbered for reference. A register of all questionnaires

was adhered to, and each questionnaire was given a reference number for tracking purposes. The data to be collected was quantitative and qualitative in nature comprising of numeric and non-numeric types. Before analysis, data was checked for accuracy and then entered into a computer. The raw data was properly coded to prepare for analysis to coordinate it and offer a way of interpreting to quantitative techniques. This involved the reading of the data and demarcating segments within it. Every segment was identified by a code that suggested how the linked data relate with the research aims. Moreover, Stata, excel and word computer packages played a crucial role in analyzing data.

3.6 Data Analysis

3.6.1 Objective 1 Assess farmers' perception of climate variability and change in the East and South Regions of Cameroon.

Based on (Heckman, n.d.), when a farmer's decision process about the adoption of a new technology requires more than one step, models with two-step regressions, such as Heckman's sample selection, are appropriate to correct for selection bias generated during the decision-making processes. The Heckman's sample selection model is based on the farmer's utility or profit maximizing behaviour, and the assumption is that a farmer uses a new technology only when the perceived utility or profit from using the new technology is significantly greater than the traditional or the old method.

Like technology adoption, adaptation to climate change is a two-step process that involves perceiving that climate is changing and then responding to the change through adaptation measures (Asrat & Simane, 2018; Deressa *et al*., 2011). Therefore, the Heckman probit selection model is employed in this study to investigate the determinants of perception and

adaptation to climate change. The first stage of the model (the selection model) considers whether a farmer perceived a change in the climate, and the second stage of the model (outcome model) explores whether the farmer adapted to climate change conditional on the first stage.

In the two-stage process, the second stage of adaptation is a sub-sample of the first. Thus, it is likely that the second stage sub-sample (those who responded to change) is non-random and necessarily different from the first (which included those who did not perceive climate change), and this creates a sample selection bias (Asrat and Simane 2017a; Deresa *et al*. 2011). Therefore, the Heckman two-step maximum likelihood procedure was used to correct for this selection bias. The underlying relationship in the Heckman's sample selection model consists of a latent equation given by:

$$Y_j = x_j\beta + u_{ij} \qquad (1)$$

Such that, we observe only the binary outcome given by the probit model as

$$y_i^{probit} = (y > 0) \qquad (2)$$

The dependent variable is observed only if *j* is observed in the selection equation

$$y_i^{select} = z_i\delta + u_{2j} > 0 \qquad (3)$$

$$u_1 \sim N(0,1)$$

$$u_2 \sim N(0,1)$$

$$Corr(u_1, u_2) = \rho$$

where y_i^{select} is whether a farmer has perceived climate change or not, z is an m vector of regressors, which include different factors hypothesized to affect perception; δ is the parameter estimate, u_{2j} is an error term and u_1 and u_2 are error terms, which are normally distributed with mean zero and variance one. Thus, Eq. 3 is the first stage of Heckman's two-step model which represents the farmers' perception of changes in climate.

Equation 1 is the outcome model which represents whether the farmer adapted to climate change and is conditional upon the perception model. When the error terms from the selection and the outcome equations are correlated ($\rho \neq 0$), the standard probit techniques yield biased results (Asrat and Simane 2017; Deresa *et al*. 2011). Thus, the Heckman probit (heckprob) provides consistent and asymptotically efficient estimates for all parameters in such model. The dependent variable for the selection equation is whether a farmer has or has not perceived climate change. The explanatory variables include sociodemographic, environmental, and institutional factors selected based on hypothesized relationships described in literature on factors affecting the awareness of farmers to climate change or their risk perceptions (Asrat and Simane 2017a; Deresa *et al*. 2011) and field observations made in the study area. In the case of the outcome model, the dependent variable is whether a farmer has adapted or not to climate change. The explanatory variables are chosen based on the climate change adaptation literature (Asrat and Simane 2017; Deresa *et al*. 2011; Deresa *et al*. 2009; Hassan and Nhemachena 2008) and field observations made in the study locations. The hypothesized explanatory variables for the Heckman's two-step model used in this study are described in the section that presents the empirical model results.

3.6.2 Objective 2 Identify farm practices used in this area that are fulfil principles of conservation agriculture.

CA practices used in the South and East were identified and grouped into heterogeneous principal clusters using Multiple component analysis (MCA). This is a upgraded Principal component Analysis. Where two kinds of components are extracted for monitoring. Firstly, it applies PCA transformation to obtain the principal components of normal operating data, after which it then uses the non-local preservation projection to extract the fault discriminant components between normal and faulty operating data. The first kind of component, principal component is necessary for fault detection and cannot be omitted. The second kind of component, fault discriminant component is optional which is available only when some prior fault data are collected.

The components will be rotated using orthogonal rotation (varimax method) (Chatterjee *et al*., 2015) so that a smaller number of highly correlated practices were put under each component for easy interpretation and a generalization about a group. A principal component analysis is useful in reducing the dimensionality of data without loss of much information. This is important as it allows determination of the relationship between practices based on usage and subsequent analysis by fitting the groups into the model and reaching conclusions. The approach is superior to the use of a convenient grouping of practices which would make it difficult to conclude about a group in cases where few practices could represent the entire group. The practices were then grouped using principal component analysis with iteration and varimax rotation in the model represented below:

$$Y_1 = a_{11}x_{12} + a_{12}x_2 + \ldots + a_{1n}x_n \quad (4)$$

$$Y_j = a_{j1}x_{j1} + a_{j2}x_2 + \ldots + a_{jn}x_n \quad (5)$$

where $Y_1,\ldots Y_j$ = principal components which are uncorrelated, a_1- a_n = correlation coefficient, $X_1,\ldots X_j$ = factors influencing choice of a particular strategy. The selection of these practices before the field study was guided by the successful CA practices established by a previous study from the (FAO, 2015).

3.6.3 Objective 3 Analyse the socioeconomic, Geographic and plot level determinants of farmers' adoption of Conservation agriculture in the South-eastern Cameroon.

We employ the MVP to assess the determinants of CAP adoption since it is attractive for analyzing choice behaviour as it permits a flexible correlation structure for the unobservable covariates (Huguenin & Fischer, 2020). Furthermore, Teklewold *et al*. (2019) revealed that estimates from the MVP vastly contrasted across all equations estimated. However, indicating the appropriateness of differentiating between practices as heterogeneity in adopting agricultural practices and analysis of each separate practice is supported rather than grouping the practices into a single variable (Teklewold *et al*., 2017).

In a single-equation statistical model, information on a farmer's adoption of one agricultural conservation practice (CAP) does not alter the likelihood of adopting another CAP. However, the MVP approach simultaneously models the influence of the set of explanatory variables on each of the different practices while allowing for the potential correlation between unobserved disturbances and the relationship between the adoption of different practices. A source of correlation, in this case, is either complementarity or substitutability between different methods. The interrelationship between adopters' decisions with unobserved factors must be captured to avoid bias and inefficient estimates (Greene, 2000).

The observed outcome of CAP adoption is modelled following a random utility formulation. Consider the i^{th} farm household (i = 1, ……, N) facing a decision on whether or not to adopt the available CAP on plot p (p = 1,.., P). the benefits farmers get from traditional farm methods is represented by U_0, while the benefits they get from adopting the kth CAP is denoted as Uk: where k denotes choice of agroforestry (A), intercropping (I), cover crop (C), crop rotation (R), mulching(M), minimum/zero tillage (T). The farmer adopts the kth CAP on plot p if $Y_{ipk}^{*} = U_K^{*} - U_0 > 0$. The net benefit (Y_{ipk}^{*}) that the farmer derives from the adoption of k^{th} CAP is a latent variable determined by observed household, plot, and location characteristics (X_{if}) and the error term (ε_{ip}):

$$Y_{ipk}^{*} = X_{ip}'\beta_k + \varepsilon_{ip} \quad (6)$$

When we used the indicator function, the unobserved preferences in equation (6) were translated to the observed binary equation for each choice as follows:

$$Y_{ipk} = \begin{cases} 1 \; if \;\; Y_{ipk}^{*} > 0 \\ 0 \; otherwise \end{cases} \quad (k = A, I, C, R, M, Z) \quad (7)$$

In the multivariate model, where the adoption of several CAP is probable, the error terms mutually follow a multivariate normal distribution with zero mean and variance normalized to unity (Kassaw *et al*., 2019).

Where: µA, µI, µC, µR, µM, µZ ~: MVN (0, Ω) and the symmetric covariance matrix X is given by:

$$\Omega = \begin{bmatrix} 1 & \rho AI & \rho AC & \rho AR & \rho AM & \rho AZ \\ \rho IA & 1 & \rho IC & \rho IR & \rho IM & \rho IZ \\ \rho CA & \rho CI & 1 & \rho CR & \rho CM & \rho CZ \\ \rho RA & \rho RI & \rho RC & 1 & \rho RM & \rho RZ \\ \rho MA & \rho MI & \rho MC & \rho MR & 1 & \rho MZ \\ \rho ZA & \rho ZI & \rho ZC & \rho ZR & \rho ZM & 1 \end{bmatrix} \quad (8)$$

The off-diagonal elements in the covariance matrix are of particular interest, representing the unobserved correlation between the stochastic components of the different types of CAP. This assumption means that equation (6) generates an MVP model that jointly represents decisions to adopt a particular farming practice. The use of non-zero off-diagonal elements in this specification allows for cross-correlation. The error terms of several latent equations, which represent unobserved characteristics that affect the choice of alternative CAP. When analyzing the determinants of adoption, we consider the influence of non-observable household characteristics on adoption decisions. For instance, there may be a correlation between plot-invariant characteristics (managerial ability) and the decision to adopt a particular CA technology. A pooled MVP model is consistent because unobserved heterogeneity is uncorrelated with observed explanatory variables. We exploited the multiple plot observations nature of our data and estimated equation (6) with and without Mundlak's (1978) approach. However, this was to control for unobserved heterogeneity, including the means of plot-varying explanatory variables (e.g. average of plot characteristics, plot distance to the home of a farmer) as additional covariates in the regression model.

From our MVP model above, we conceptualized that before adopting one or more CAP, a farm household compares the net benefit of adopting and not adopting and only chooses to adopt the new CAP if the net benefit is more significant than non-adoption. Farm households tend to adopt more CAP if the household derives higher utility from the previous adoption. However, the MVP model is limited to estimating the intensity of the adoption of CAP. We, therefore, adopted the ordered probit model to evaluate the intensity of adoption. In addition, we considered assessing the extent of adoption by the numbers of CAP adopted at the household levels. This concept is related to a Poisson count distribution

model; however, a Poisson distribution contradicts our assumption of the interdependence of CAP which renders it inappropriate. Usually, a standard analytical process of assessing the intensity of adoption considers the proportion of land area stipulated by some adoption studies (Awazi *et al*., 2019). As a result of data limitation on variables related to this, we treated our dependent variable as an ordinal variable that follows categories of ordered outcomes, for example, households that adopt one, two, or more CAP. Following Cameron & Trivedi (2010), our ordered outcomes are modelled sequentially as a latent variable y^*, where y^* is an underlying unobserved measure of households' adoption of CAP in numbers, and it is specified as follows:

$$y_i^* = X_I' B + u_i \quad (9)$$

For a j^{th} farm household where normalization is that the regressors x do not include an intercept, for a low y^*, adoption of CAP is low, for $y^* > 1$, the number of CAP increases, for $y^* > 2$, adoption increases further, and this continues further. For m categories following a standard ordered probability model, the probability of observing outcome i corresponds to the following:

$$\Pr(outcome_{j=i} = \Pr(K_{i-1} < X_i'\beta + \mu_i \leq \alpha_i) \quad (10)$$

Where μ_i is assumed to be normally distributed with a standard normal cumulative distribution function. The coefficients $\beta_1 \ldots\ldots\ldots \beta_k$ is jointly estimated with the cutpoints $\alpha_1, \alpha_2, \ldots\ldots \alpha_{k-1}$, where k is the number of possible outcomes.

3.6.4 Objective 4 Evaluate the effects of CAs on the Livelihood of smallholder farmers in in the East and South Regions of Cameroon.

To ensure accurate estimation of the impacts, methods that account for self-selection and unobserved heterogeneity need to be employed. These methods can help identify the causal effects of CSA adoption on welfare outcomes by appropriately addressing the biases arising from the non-random nature of adoption decisions and the presence of unobserved factors. By considering these challenges, we can obtain more reliable and robust estimates of the impacts of CSA practices on farmers' welfare.

Therefore, to address the issue of selection bias in our study, we employ the multinomial endogenous switching regression (MESR) method, considering both observed and unobserved heterogeneity. This approach has several advantages compared to other methods commonly used in similar studies. Firstly, the MESR corrects selection bias by incorporating the inverse Mills ratio (IMR) based on the theory of truncated normal distribution (Malikov and Kumbhakar, 2014; Bourguignon *et al*., 2007). This helps address the issue of potential selection bias arising from both observed and unobserved factors. Secondly, the MESR allows us to construct counterfactuals based on returns to the characteristics of both CSA adopters and non-adopters (Kassie *et al*., 2017). By comparing these counterfactuals, we can estimate the impact of CSA adoption on various outcome variables of interest. Thirdly, the MESR permits the interaction between the choice set of CSA technologies and the explanatory variables, capturing the effect of CSA on both the intercept and slope of the outcome equation (Abdoulaye *et al*., 2018; Kassie *et al*., 2017; Di Falco and Veronesi, 2013). This allows us to examine how the choice of specific CSA practices influences the outcome variable. Finally, the MESR identifies the specific choice of CSA practices that yields the highest outcome effect (Wu and Babcock, 1998). This

information is valuable in determining the most effective CSA practices for enhancing the desired outcome.

The MESR is a two-stage simultaneous estimation technique. In the first stage, we model farmers' choice of CSA practices using a multinomial logit selection (MNLS) equation, accounting for unobserved heterogeneity. The IMRs calculated from the first stage are then included as additional covariates in the outcome equation to account for selection bias resulting from time-varying unobserved heterogeneity. The outcome equation is estimated using Ordinary Least Squares (OLS) regression.

First stage: Multinomial logit selection model

As previously mentioned, the initial stage of estimating the factors that impact the adoption of climate-smart agriculture (CSA) is modeled within the framework of random utility. In this framework, a farmer i at time t selects a CSA technology set (j = 1, ……, 3) that maximizes their expected utility (U_{jit}). If the expected utility of choosing a CSA technology set j is relatively higher than other technology sets k, the farm household will choose the former (i.e. $\rho_{1it} = \max_{k \neq j}(U^*_{kit} - U_{jit}) < 0$ (11)

We assume that the utility of selecting a CSA technology set *j* can be represented by the latent variable U^*_{jit}. To describe farmers' adoption behavior regarding CSA, we follow the approach taken by Khonje *et al*. (2018) and specify the following latent model:

U^*_{jit} *=β1 Household sizeit + β2 Ageit + β3 Land sizeit + β4 Farm experienceit + β5 Extension accessit + β6 Land ownershipit + β7 Number of farmlandsit + β8 Educationit + β9 Distance from home to farmit + β10 Farm incomeit + εitj* (12)

Where $\varepsilon_{jit} = c_i + \eta_{jit}$

$$Y\begin{cases}1\ if\ U_{jit}^{*} > \underset{k\neq 1}{max}(U_{kit}^{*})\ or\ \rho_{1it} < 0 \\ \cdots \\ \cdots \\ \cdots \\ \cdots \\ j\ if\ U_{jit}^{*} > \underset{k\neq j}{max}(U_{kit}^{*})\ or\ \rho_{jit} < 0\end{cases} \quad \forall k \neq j \qquad (13)$$

where β1-β10 represent the coefficients for the independent variables, εitj is the error term, and *i* represents the farm household. The error term captures unobserved variables that may affect farmers' CSA adoption behavior. The variables included in the model are household size, age, land size, farm experience, access to extension, land ownership, number of farmlands, education, distance from home to farm, and farm income. The model estimates the impact of each of these variables on farmers' expected utility in selecting a specific CSA technology set, with the aim of identifying the factors that influence the adoption of CSA.

The terms c_i and η_{jit} represent household-specific heterogeneity and time-varying unobserved factors or idiosyncratic errors, respectively. If there is a correlation between the unobserved factors and explanatory variables, the estimates of the multinomial logit selection (MNLS) model may be inconsistent. However, assuming that η_{jit} is independently and identically Gumbel distributed across all CSA choice sets, following the independence of irrelevant alternatives (IIA) hypothesis (Bourguignon *et al*., 2007). From Eq 6 we can derive a multinomial logit model. This model allows us to express the probability (P_{jit}) that a farmer *i* at time *t* will choose technology *j* out of *J* options as follows:

$$P_{jit} = pr\left(\rho_{1it} < 0 X_{jit}\right) \frac{\exp(\delta_j X_{jit} + \varphi_j \overline{X}_{ji})}{\sum_{k\neq j}^{J} \exp\left(\delta_k X_{kit} + \varphi_k \overline{X}_{ki}\right)} \qquad (14)$$

To account for unobserved heterogeneity, we employ a pooled Multinomial Logit Selection (MNLS) model with correction based on the Mundlak (1978) and Wooldridge (2010) approach. In this model, the time-invariant unobserved effect (c_i) is represented as a linear projection of the means of all time-varying observed explanatory variables (X_{ji}) as follows: $c_i = X_{ji} + i$. By incorporating this correction, we aim to capture the influence of unobserved factors on the estimation of Eq. (11) and improve the accuracy of our results.

Second stage: Multinomial endogenous switching regression model(MESR)

In this study, we employed the endogenous switching regression (ESR) approach to examine the effects of different response packages on farmer welfare. To account for potential selection bias, we utilized a correction model. The analysis considered a total of seven regimes, with regime j = 1 serving as the reference category representing non-responsive households. The farmer welfare status equation was formulated for each potential regime, and its impact was evaluated accordingly.

$$\begin{aligned} Regime\ 1 \quad Q_{i1} &= z_i \propto_1 + \mu_{i1} \; if \; i = 1 \\ &\ldots \\ &\ldots \\ &\ldots \\ &\ldots \\ Regime\ j \quad Q_{ij} &= z_i \propto_j + \mu_{ij} \; if \; i = j \end{aligned} \tag{14}$$

In the equation presented above, Q_{ij} represents the farmer welfare status, while z_i represents a set of exogenous variables encompassing household, plot, location characteristics, institutional variables, and climate shocks. The subscript "ij" denotes the i^{th} farmer in regime j, and the error terms μ_{ij} follow a distribution with E($\mu_{ij}|x, z$) = 0 and var(μ_{ij} $|x, z$) = σ_j^2. The variable Q_{ij} is observed if and only if CSA strategy j is employed, which occurs when $U_{jit}^* > \max_{k \neq j}(U_{kit}^*)$. If there is a dependence between the error terms in

equations (3) and (4), ordinary least squares (OLS) estimates for equation (4) may be biased. Therefore, to achieve consistent estimation of $\propto_j$, it is necessary to incorporate selection correction terms for the alternative choices in equation (3).

The multinomial endogenous switching regression (MNLESR) assumes a linearity assumption as follows: E(μ_{ij} $|\varepsilon_{i1} \ldots \varepsilon_{ij}$) = σ_j $\sum_{k\neq j}^{J} r_j(\varepsilon_{ik} - E(\varepsilon_{ik}))$. Importantly, the construction of the model ensures a zero correlation between the error terms in equations (3) and (4). By considering these assumptions and accounting for the interdependence of the error terms, the MNLESR provides a robust framework for estimating the effects of different CSA strategies on food security outcomes.

Based on the aforementioned assumption, the equation (3) can be represented in the following manner:

$$\begin{aligned} Regime\ 1\ \ Q_{i1} &= z_i \propto_1 + \sigma_{1\lambda_1} + \omega_{i1}\ if\ i = 1 \\ &\ldots \\ &\ldots \\ &\ldots \\ &\ldots \\ Regime\ j\ \ Q_{ij} &= z_i \propto_j + \sigma_{j\lambda_j} + \omega_{ij}\ if\ i = j \end{aligned} \tag{15}$$

σ_j represents the covariance between ε's and μ's, while λ_j denotes the inverse Mills ratio derived from the estimated probabilities in Equation (5) in the following manner:

$$\lambda_j = \sum_{k\neq j}^{j} \rho_j \left[\frac{P_{ik} ln(P_{ik})}{1-P_{ik}} + \ln(P_{ij})\right] \tag{16}$$

The correlation coefficient (ρ) in the equation above represents the relationship between the error terms (ε) and the unobserved factors (μ). The error terms (ω_{ij}) in the multinomial choice setting, as previously mentioned, have an expected value of zero. Specifically, there are j - 1 selection correction terms, with each term corresponding to a specific alternative CSA practice.

To address the issue of heteroskedasticity arising from the generated regressors (λ_j), bootstrapping was employed to estimate the standard errors in Equation (5). This resampling technique helps account for the variability in the data and provides robust standard errors in the presence of heteroskedasticity.

Estimating average treatment effects

The calculation of the treatment effect on the treated resulting from the adoption of CSA involves comparing the anticipated outcomes of CSA adopters and non-adopters in both actual and counterfactual scenarios. The expected outcomes of CSA adopters in the actual scenario can be represented as:

$$E(Y_{jit}|U = j,\ M_{jit,}\overline{M}_{ji,}\hat{\lambda}_{jit}) = \beta_j M_{jit} + \ \vartheta\overline{M}_{ji} + \ \sigma_j\hat{\lambda}_{jit} \quad (17)$$

The expected outcomes of adopters had they decided not to adopt(counterfactual)

$$E(Y_{1it}|U = j,\ M_{jit,}\overline{M}_{ji,}\hat{\lambda}_{jit}) = \beta_1 M_{jit} + \ \vartheta_1\overline{M}_{ji} + \ \sigma_1\hat{\lambda}_{jit} \quad (18)$$

Equation (7b) represents the counterfactual outcome for CSA adopters, assuming that their characteristics ($M_{jit,}\overline{M}_{ji,}\hat{\lambda}_{jit}$) have the same coefficients as the characteristics of non-adopters (Khonje *et al*., 2018; Kassie *et al*., 2017; Teklewold *et al*., 2013). The Average Treatment Effect on the Treated (ATT) is calculated as the difference between Equation (7a) and Equation (7b) (Khonje *et al*., 2018; Kassie *et al*., 2017), given by the following formula:

$$ATT = E(Y_{jit}|U = j,\ M_{jit,}\overline{M}_{ji,}\hat{\lambda}_{jit}) - E(Y_{1it}|U = j,\ M_{jit,}\overline{M}_{ji,}\hat{\lambda}_{jit})$$

$$= M_{jit}(\beta_j - \beta_1) + \hat{\lambda}_{jit}(\sigma_j - \sigma_1) + \overline{M}_{ji}(\vartheta_j - \vartheta_1) \quad (19)$$

The right-hand side of the equation represents the anticipated change in the average food security status of adopters, assuming that adopters had the same returns as non-adopters, thereby having similar characteristics. The term $\hat{\lambda}_{jit}$ represents the selection component that accounts for any potential impact resulting from variations in unobserved variables (Khonje *et al*., 2018).

3.7 Ethical considerations

Confidentiality and privacy of information collected was communicated to the respondents before the start of the interviewing process. The questionnaires did not indicate the identity of interviewees, because the disclosure of confidential information might stigmatize the respondent. The other ethical issue to be considered is the physical and psychological harm ethics. This was achieved through designing the questionnaire in a user friendly manner in order to ensure that there was no physical or psychological harm caused.

Enumerators were trained and sensitized on need to avoid physical and psychological harm to the respondents and even to oneself. To ensure informed consent, the questionnaires were only administered to respondents who gave their consent and were willing to participate in the interview. The purpose of the study was clearly explained to the interviewees. The enumerators' ensured permission sought as per the cultural values and practices of the target population. It was also the duty of the enumerators to ensure that the respondents are protected from harm and discomfort during the entire interview process.

3.8 Operational definition of Variables

Table 3. 2 Operational definition of Variables

Objective	Variable	Indicators	Measurements	Measurement Scales	Type of Analysis
To Assess farmers' perception of climate variability and change in the East and South Regions of Cameroon	Climate factors	Rainfall , Temperature, Soil erosion, Wind/thunderstorm Drought	Too much, early or late rains Increase heat, decrease humidity Frequency of floods, Frequency of wind/thunder stoms, Loss of water bodies	Nominal Interval	Descriptive And regression
Identify farm practices used in this area that are fulfil principles of conservation agriculture.	Climate smart agriculture techniques	Agroforestry, Intercropping Cover Crop , Crop Rotation Mulching Zero/minimum Tillage, bush fallow, integrated, crop/livestock, water management, nutrient management, organic fertilizer, stress tolerant variety, woodash application.	Use or no use	Nominal	Descriptive statistics and Multiple component analysis

To Analyze the socioeconomic, and plot level determinants of farmers' adoption of Conservation agriculture in the South-eastern Cameroon.	Demographic factors Social factors Economic factors Institutional factors	Gender, Age, Education level, Farm size , Landownership status Access to credit, Access to extension advise, Access to subsidies , Farm income, Distance from home to farm , Distance from farm to market, Labour hours	Either male or female, No. of years since birth, Level of education attained, Land size in ha, Purchased land, Leased land, Family land, Receive agricultural loans, Receive extension advise, Receive government subvention Quantity of produce sold, Price of sales, Time use to reach the farm , Time used to reach the market, Hired labour, Family labour	Nominal Interval	Descriptive Statistics and Regression
To evaluate the effects of CAs on the Livelihood of smallholder farmers in in the East and South Regions of Cameroon	Farm income Health services Sanitation Household assets	Major source of income, Access to hospitals, Access to modern toilets Access to household basic assets	Sales of farm outputs, Type of treatment received when sick, Types of toilets, Ownership of tv, mobile phones, radio, Type of water sources	Nominal Interval	Descriptive statistics & Regression
	Dependent Variable CA Adoption	CA practice Non-practice of CA	Conservation agriculture practice in farms	Ordinal	Descriptive statistics & Regression

3.9 Chapter Summary

This study was carried out in South-eastern Cameroon during the months of January, February, and March. A cross sectional survey was carried out with a questionnaire divided into 5 sections used as the data collection tool for the study. The sample size of the study was 351 and descriptive statistics and regression analysis using multinomial logit models, multivariate probit models, Heckman two-stage model and multiple component analysis. Excel and Stata 17 were used as the statistical packages for data analysis.

CHAPTER FOUR

Results and Discussion

4.1 Farm Household Characteristics

4.1.1 Socioeconomic profiles of farmers

A breakdown of socioeconomic profiles of farmers is provided on figure 4.1. This shows that, both male and female farmers are well represented in the sample though males are more than the female with proportion of 52.32% against 47.68% in the East and 57.5% against 42.5% and for the pooled sample 55.27% as against 44.73% for the male and female respectively. Gender was taken into consideration since the work was on farming methods and both sexes are usually very actively involved in farming. In some areas the number of women involved in agriculture often outweigh the male population probably because male often have more off farm activities, they are involved in. This is proven by the percentage representation from the statistics above thus showing clearly our study made sure each gender is fairly represented to ensure for no bias on our results.

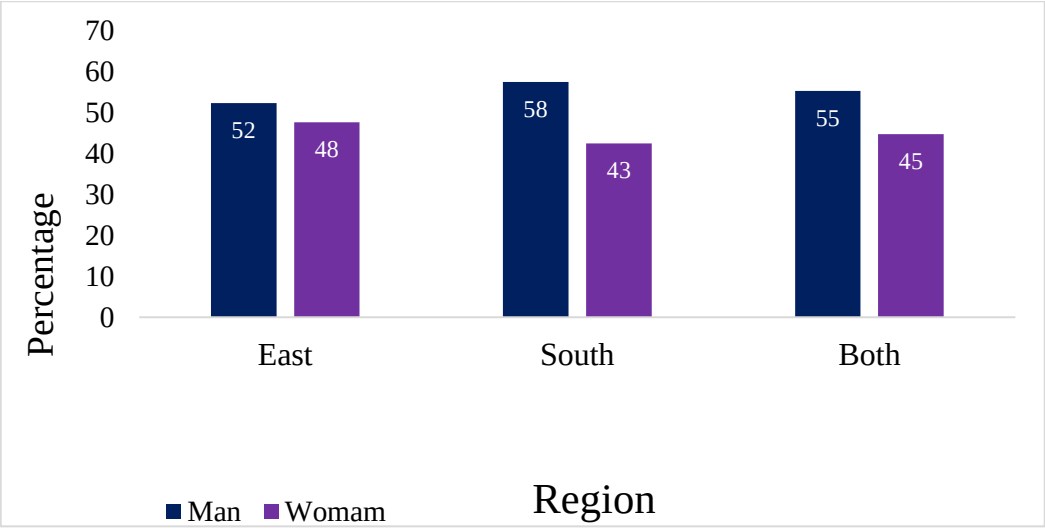


Figure 4. 1 Gender representation in the Study area (Source: Analysis from field survey, 2020)

This result could also be explained by the fact that, agriculture and food security are characterized by gendered dimensions in that women play a key role in agricultural production, food processing and marketing. They also play a decisive role in dietary diversity, being also responsible for nutrition at the level of the household. Furthermore, women are actively involved in the production and domestication of plants and animals; also, they are knowledgeable in seed selection and vegetative propagation because they understand how plants and animals grow and reproduce none the less, they also involve in tree planting. Adding flesh to all these women comprise 20 to 50% of the agricultural labor force in developing countries (McCarthy *et al*., 2011) and 79% of them are economically active and has reported that agriculture is their primary economic activity as stated by (Doss & Morris, 2001).

In the case of Cameroon, women have proven in different time periods to be the most actively involved in agriculture reaching up to 79% above the rank as compared to other SSA countries McCarthy *et al*. (2011). Because of this over reliance of women on agriculture in a highly climate- sensitive sector, any stress on the sector, including those related to climate change are likely to hit hard on their livelihoods. Also, men in their contributed role to food production face fewer constraints than women because they have more access to productive resources such as land, credit, and extension services.

In addition, in the case of crop failure due to harsh climatic conditions, cultural traditions often make it easier for men to leave their farms in search of employment elsewhere, leaving women behind to struggle to feed their families and make ends meet. In this light, just as different countries and societies have varying degrees of susceptibility to adverse

impacts of climate change, men and women also have different coping and adaptive capacities and consequently disparate vulnerabilities to the impacts of a changing climate.

It therefore becomes very imperative to include gender in studies of adoption of conservation practices especially in this era of changing climates, for not everyone has the capability to properly adopt farm technologies for improved food security and livelihoods. Keeping in mind that gender relations also determine household security, wellbeing of family, planning, agricultural productivity and others. Tsige *et al.* (2020) carried out similar research where both genders were fairly represented to reduce the levels of bias in the analysis.

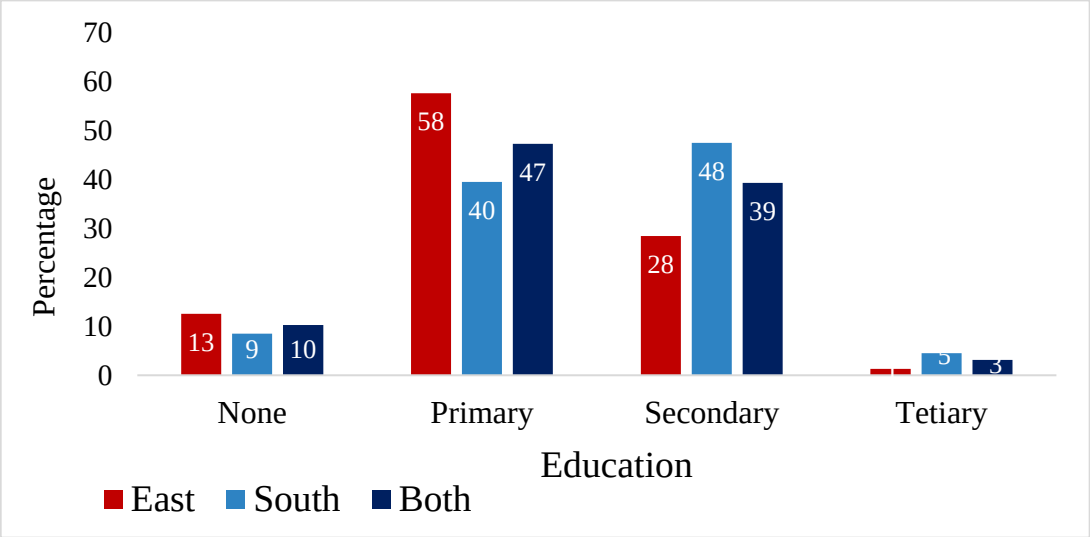


Figure 4. 2 Educational levels of Farmers in the Study area (Source: Analysis from field survey, 2020)

As educational level increases, farm output increase and specifically output increases with secondary school education which has a very high return on agricultural productivity. Furthermore, education is important to the improvement of agricultural productivity as such formal education opens the minds of farmers to knowledge (Oduro-ofori *et al.*, 2014). The World Bank confirms this in its survey of 1992 in low income countries which stated that farmers with basic education are 8.7% more productive than farmers with no

education. Also, education enhances agricultural productivity primarily by improving farmers decision-making ability and at the second place by alleviating ttechnical efficiency that is, improves the farmers capability to make better choices in terms of input and make better economically rational decisions.

Futher, there are positive externalities from schooling in the form of higher agricultural productivity where farmers benefit by adopting technology and practices used by one educated farmer. This is confirmed in the work of Appleton and Balihuta (1996). Furthermore, productive value of education on agriculture can also be divided into two "worker effect" and "allocative effect" where the worker effect is a situation whereby ann educated farmer, given the same number of input can produce a greater output, in other words, better use of current resources. Thus increased output per unit change in education with all other factors being constant.

On the otherside, allocative effect is where a worker os able to acquire information about cost and charcteristics of inputs and interpret the information to make decisions that will promote output, here, there maybe a change in input and the farmer adopts methods which will otherwise not have been used. Thus a key way education influences agricultural productivity is by improving the ability of farmers to take decisions concerning the selection for better output.

In a nutshell, education has three princial ways it raises or could raise agricultural productivity especially in rural areas among small holder farmers. These are; improvement in farmers skills, enhancement of farmers' ability to obtain, understand and utilize new input, and improvement in overall managerial ability. The mode level of school attainment

is primary education with proportion of 57.62, 39.5 in the east and south respectively and generally 47.29%, followed by secondary 28.48%, 47.5% for the east and south respectively and generally 39.32%, those that have never been to school were 12.58%, 8.5% for the East and South regions respectively and in general, 10.26%9.7% while those that had attained higher education were 21.32%, 4.5% respectively for the East and South regions and in general 3.13%, being the least represented.

Cumulatively, about 57.55% of farmers have not gone beyond primary level. Educational level is very important in adoption studies for level of education is considered to affect adoption of farming practices especially the new farming technologies. Some studies equally considered education levels in adoption like that of Mantey *et al*. (2020), Vecchio *et al*. (2020) and Li *et al*. (2020)

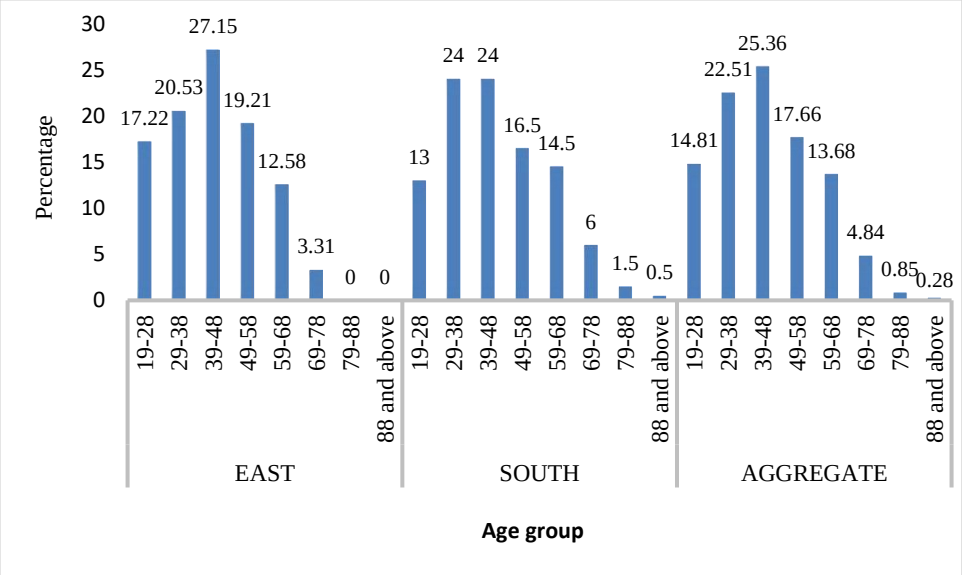


Figure 4. 3 Age groupings of Farmers in the Study area(Source: Analysis from field survey, 2020)

Age is assumed to be a determinant of adoption of new technology. Older farmers are assumed to have gained knowledge and experience over time and are better able to evaluate technology information than younger farmers (Kariyasa & Dewi, 2013; Mignouna *et al*., 2011). The mode age is 39-48 years with proportion of 29.36%, followed by those aged

29-38 years 22.5%, 19-28 years 14.81%, 59-68years 13.68%, 69-78years 4.84%, 79-88years 0.85% then 88+ years 0.28%. Adoption decisions require maturity and adventure. Age therefore is a fundamental facet for adoption unless you categorize the age of the sample population there will be unanswered questions when it comes to adoption of farming strategies for if majority farmers do not fall under the active age group then this will distort adoption for, they can't adopt if they are not actively involved in farming.

Additionally, age has equally been found to have a negative relationship with adoption of technology. This relationship has been explained by (Zeng *et al*., 2018) that as farmers grow older, there is an increase in risk aversion and a decreased interest in long term investment in the farm. On the other hand, younger farmers are typically less risk-averse and are more willing to try new technologies. Thus, our sample populations proved to us that majority of farmers were in their active age where they have more energy to dispense. These results were in line with those of (Wekesa *et al*., 2018)

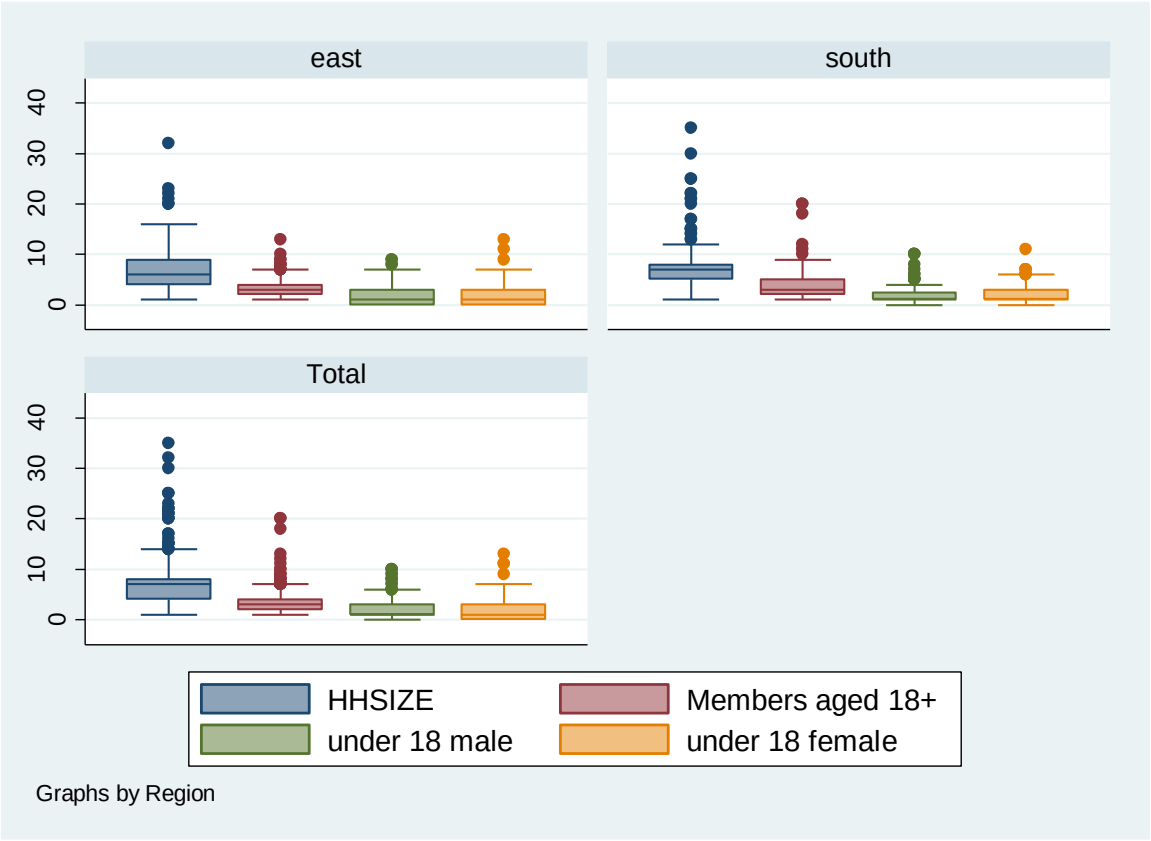


Figure 4. 4 household size and Household age differentiation of Farmers in the Study area (Source: Analysis from field survey, 2020)

Household size is displayed in figure 4.4. The fact that most of the conservation agricultural practices are labour intensive compared to the other types supports the results. Larger family size may enable one to provide additional labour needed in use of the organic fertilizer (Ajewole, 2010). The results of this study are nearly in accord with those of Wang (2016), which revealed that farmers had higher ages and lower education levels in developing countries. And also agreed with studies conducted in Ethiopia by (Meskerem & Degefa, 2015).

Table 4. 1 Farm size distribution among farmers in the study area

Region	Farm size	Frequency	Percentage
EAST	0.25-2.25	105	69.54
	2.50-4.50	30	19.87
	5.00-6.75	9	5.96
	7 and above	7	4.64

	Total	**151**	**100**
SOUTH	0.25-2.25	221	60.50
	2.50-4.50	62	31.00
	5.00-6.75	10	5.00
	7 and above	7	3.50
	Total	**200**	**100**
AGGREGATE	0.25-2.25	226	64.39
	2.50-4.50	92	26.21
	5.00-6.75	19	5.41
	7 and above	14	3.99
	Total	**351**	**100**

(Source: Analysis from field survey, 2020)

Farm size plays an important role in adoption process of new technology. Many authors have analysed farm size as one important determinant of technology adoption. Some technologies are termed scale-dependent because of the great importance of farm size in their adoption (Bonabana-wabbi & Taylor, 2002). Farmers with large farm size are likely to adopt a new technology as they can afford to devote part of their lad to try new technology unlike those with less farm size (Uaiene *et al*., 2009).

To explain this, small farm size may provide an incentive to adopt a technology especially in the case of an input-intensive innovation such as a labour -intensive or land-saving technology. The mode land area cultivated is from 0.25-2.25ha 64.39% farmers used plot size of this range and 26.21% of farmers used plot sizes between 2.50-4.50ha, with the least population (3.99%) using plot sizes of at 7ha and above. The average land cultivated was significantly higher for male with an average of 3.4ha as against 1.6 ha for females.

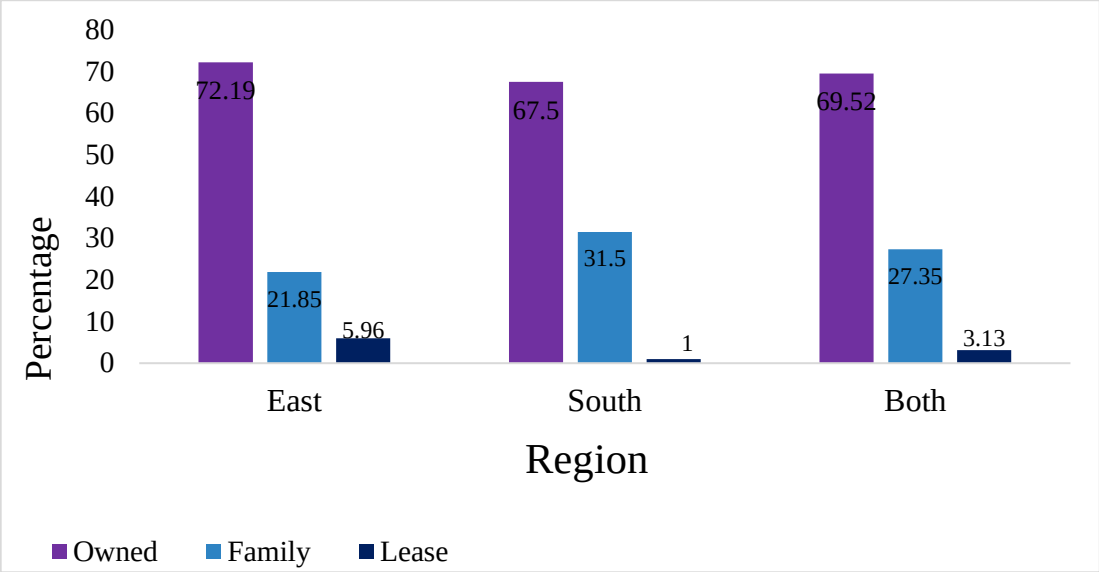


Figure 4. 5 Land ownership status of Farmers in the Study area (Source: Analysis from field survey, 2020)

Land is an indispensable resource in agricultural production and thus land access is fundamentally crucial to efficient agricultural production, food security and poverty alleviation in SSA. Lands vital role in food production is inked to the social, political and economic life of most African countries, where agriculture, natural resources and other related land-based activities are critical to livelihoods, food security, income and employment (Akinyemi & Mushunje, 2019).

Furthermore, secure land tenure is widely assumed to be important for good agricultural land management. Thus, farmers who engage in long term soil conservation may sacrifice immediate income for the promise of better soil fertility and enhance production in the future. Since there are no guarantees that farmers who rent or work on family land will reap the benefits of long-term soil conservation, tenant farmers are expected to use management strategies that maximize short term production even if this compromises future soil fertility. An overall, 69.52% of farmers in this area owned the land they cultivated while 27.35% work on family land and 3.13% on leased land(fig 4.5). Our results corroborated with those of (Mugure *et al*., 2013) and (Zeng *et al*., 2018).

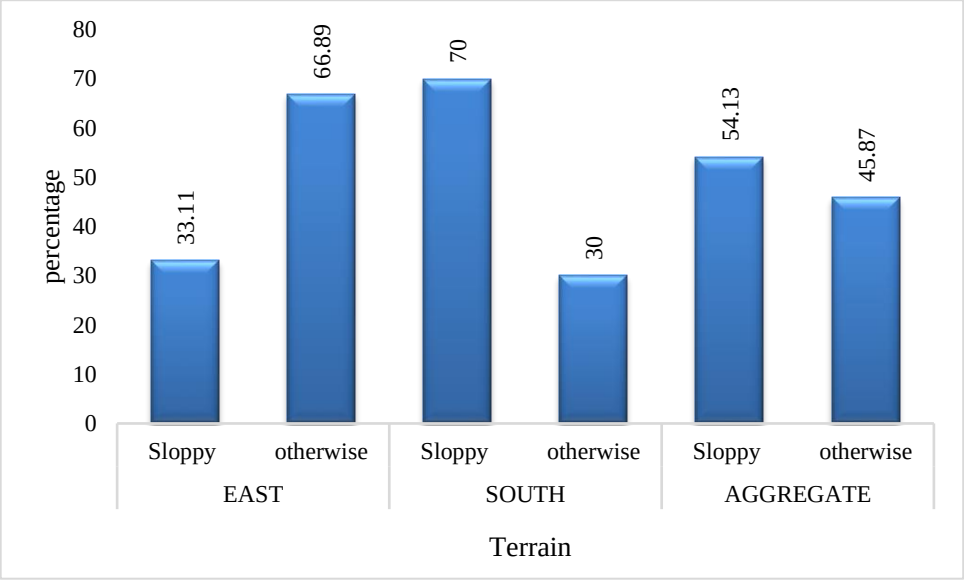


Figure 4. 6 Terrain of Farms in the Study area (Source: Analysis from field survey, 2020)

Also, farmers mostly cultivated on sloppy land 57.9%, approximately 40.4% cultivate on flat land while 1.7% cultivate on undulated land.(fig 4.6) Farm terrain as a strong role in adoption because it either affects erosion, wind speed and also type of plant thus determining the kind of method a farmer can easily adopt (Diwakar *et al*., 2019).

Table 4. 2 Farm experience in study area

Region	Observations	Mean	Std deviation	min	max
East	151	16.76	12.48	1	50
South	200	18.57	15.41	1	70
Aggregate	351	17.79	14.23	1	70

Farming experience is a big facet to the adoption of farm technologies. Farm experience is one of the household characteristics, which a farmer acquired in his life by undertaking farming activities. Farmers can observe success and failure in crop production or otherwise. Therefore, this could help them to weight between the performance of a modern and a traditional technology, and to develop more confidence to take risks related to

farming. It is also an important factor for success in farming. This is because; as farming age increases farmers can gain more information about farming.

Also, experienced farmers tend to be more versed with environmental degradation and crop failure problems. This contributes to their decisions of whether to adopt a new technology or not. Though some of these farmers because of their experience might be so conversant with these issues and tend to take them as part of farming rather than sorting for solutions, or they may have tried and failed to solve the problems and so just decide to live with them like that.

Experience of the farmers is likely to have a range of influences on adoption because with increase in working year the farmer gets more understanding about the farming system. Experience is expected to improve farmers' involvement in seed production. A more experienced grower may have a lower level of uncertainty about the technology's performance (Yirga et al., 2023). Farmers with higher experience appear to have often full information and better knowledge and were able to evaluate the advantage of a technology. Most farmers have 1-10 years farming experience 44.0%, 32.3% have 21 years and above while 23.7% have 11-20 years(table 4.2).

4.1.2 Institutional factors

As seen on table 4.3 below, on average, farmers spend about 0.92hr to reach their farms. Male and female farmers spend almost the same amount of time moving on foot from their homes to the farm, with an average of 0.89hr, 0.97hr respectively. Probably because the farms in theses villages where noticed to be located in the same area

Table 4. 3: Distance from Home to farm/ input/output market

Region	Variable	Gender	obs	Mean	Min	Max	Std dev
EAST	Distance to input/output market	Male	79	103.25	2	420	75.59
		Female	72	102.94	3	420	89.56
	Distance from home to farm	Male	79	66.26	1	260	49.52
		Female	72	72.47	5	250	65.11
SOUTH	Distance to input/output market	Male	115	132.12	0	800	128.79
		Female	85	109.91	0	800	130.11
	Distance from home to farm	Male	115	47.41	1	240	42.96
		Female	85	45.72	1	250	41.13
AGGREGATE	Distance to input/output market	Male	194	120.37	0	800	110.94
		Female	157	106.32	0	800	46.56
	Distance from home to farm	Male	194	55.09	1	260	113.14
		Female	157	57.99	1	250	54.95

(Source: Analysis from field survey, 2020)

As a farmers land get closer to the market center or farm plots, they can have access to transportation facilities and relatively better support from concerned bodies to their seed multiplication which might increase the use of technology. Also, as a farm household is closer to the market it is expected to be more likely to participating in intensive farming activities that demands adoption of new agricultural technologies because it may decrease cost of transportation both for input and outputs. The distance to input and output markets reflects the transaction costs associated with buying inputs and taking produce to the market. result in a detrimental impact on the level of technology adoption. As the plot area and the nearest input market is far from the homestead, farmers will face higher transportation cost given poor infrastructure and thereby accessibility of new technology

becomes difficult. Similar results were found by other studies (Kassie *et al*., 2018; Tang & Hailu, 2020).

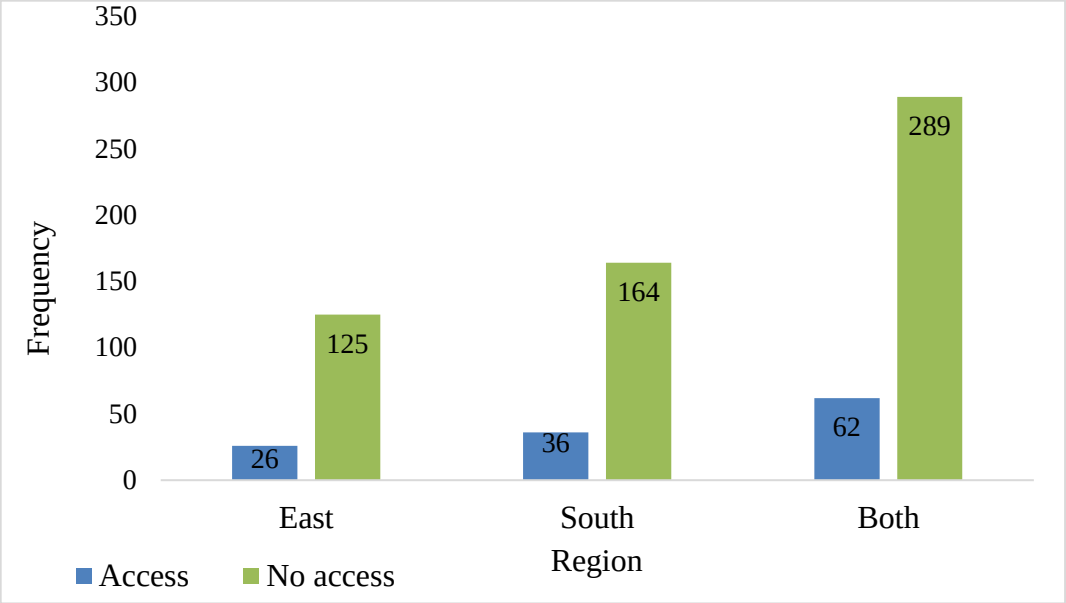


Figure 4. 7 Access to extension service layered by gender (Source: Analysis from field survey, 2020)

More frequent extension visit, using different extension teaching methods like attending demonstrations and field day can help farmers to adopt a new technology. If farmers get better access to extension services they are expected to adopt new technologies than others (Maiangwa *et al*., 2007). Extension is an important source of knowledge for farmers that significantly inpluence adoption of conservation agricutural technologies. 66% of the sampled farmers reported to have no access to extension services(fig. 4.7). With the earliar mention positive effect of extension on adoption and as also reported by other studies like (Workineh *et al*., 2020) & (Mantey *et al*., 2020).

Extension systems must therefore be strengthened to increase farmer knowledge and understanding on new agricultural technological options in a timely an accurate manner using the most appropriate commuication and training methods and eliciting information about farmers' concerns and problems with these technologies and also conveying them to

research and technolgy centers. This results were inline with the results of (Awotide *et al*., 2016) and (Muchangi, 2016). Comparing between male and female, though male slightly have more access to extension services (38.3%), while approximately 32.5% female farmers have access to extension services.

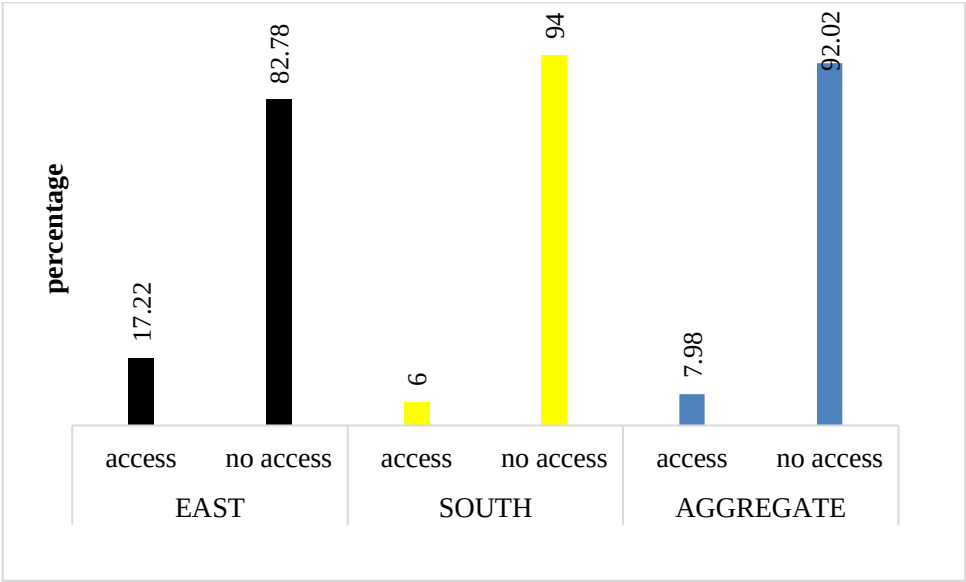


Figure 4. 8 Government Subsidies (Source: Analysis from field survey, 2020)

Rural households are risk averse, lack access to capital markets and are unable to borrow in other to finance the adoption of an improved agricultural technology. Thus a subsidy on the price of technology can move some no adopting households to adopt the new technoogy this is because subsidies provide incentives to enable changes that cannot otherwise happen (Skreli *et al*., 2015). Also, Huang & Drescher, (2015) reported that input subsidies appear to be non-distorting in terms of producer decisions but Bojnec and Latruffe (2013) porstulated that subsidies are negatively associated with the farms' technical efficeincy but increases farmers profitability.

Government subsidy has had a clear impact on production levels because of reduction in costs of procution and also more fascilities to employ more labour hours for production. As shown on fig 4.8, majority of farmers (89%) in the East region did not receive any government subsidy thus could negatively affect the adoption for many farmers compalined of the expensive nature of some of these technologies. This results did not

tarry with those of Skreli *et al*. (2015) who reported a maority of farmers receiving government subsidies.

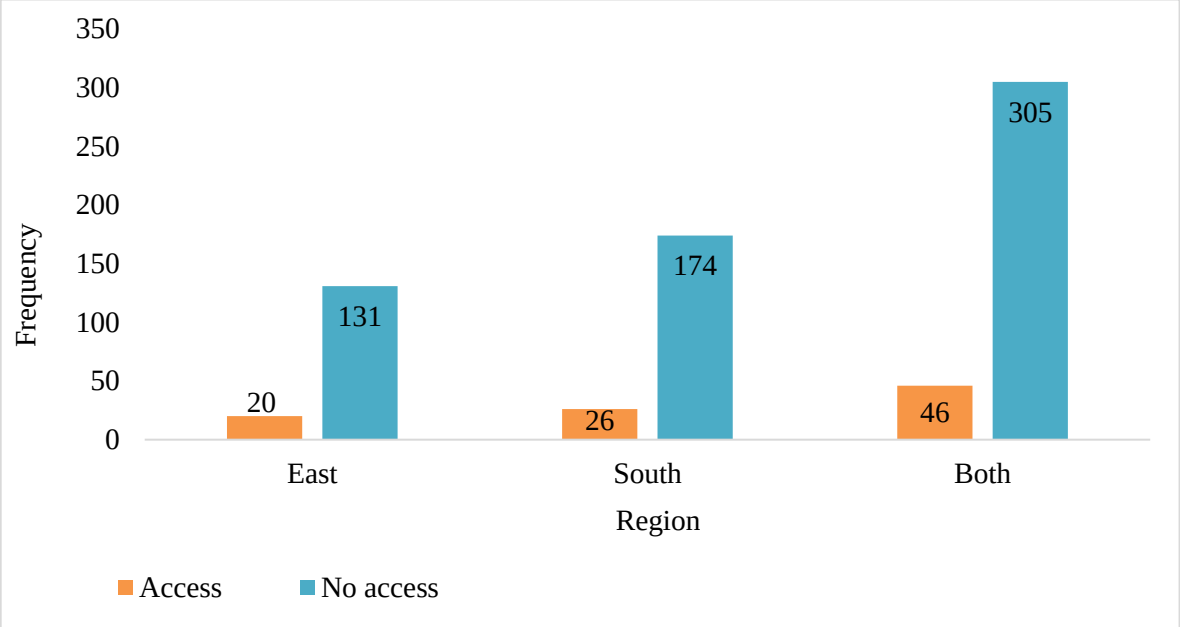


Figure 4. 9 Access to agricultural credit (Source: Analysis from field survey, 2020)

Lack of access to cash or credit may hamper smallholder farmers from adoptiong new technologies that require initial investments(Doss, 2004) and therefore its access is assumed to be positively associated with adoption. And also can ease liquidity constraints, alleviate household risk-bearing conditions, and thus the adoption chances of a new technology. There is a great difference in farmers who have access to credit and those who don't in the East region. Their access to agricultural credit was appalling as only 17% could access farm credit(fig 4.9), corroborating with the findings of Zakaria *et al*.(2020). This is not fair to the agricultural sector of this area because there will be very little investments in the farm and thus low production levels which subsequently impacts negatively of smallholder farmer livelihood security. The South region was not any different but even worser where just 6% farmers reported to have access to credit which is a determinant in enhancing the productivity of the farming sector through enabling farmers to purchase new varieties and additional farmland in some cases(fig 4.9).

In general, just 7.9% of farmers in the two regions had access to agricultural credit this is disheartening because access to credit is a source of finance to invest in physical capital. This study therefore finds that access to credit is limiting for farming in this rural community since many households have no access to credit. Access to credit is among key elements for improving agricultural production and poverty reduction. Credit can facilitate farm households to purchase the needed agricultural inputs and enhance their capacity to effect long-term investment in their farms. Improving credit access often regarded as the key element for increasing agricultural productivity and has been an effective strategy to increase smallholder productivity and alleviate poverty (Adugna and Heidhues, 2000).

The proportion of male that had access to agricultural credit is 42%, significantly higher than that of female 20%(fig 4.9). This might be so since male farmers often have more assets than female and can use for collateral and also for most of the male farmers, food production is often geared for the market unlike women whom their main purpose is for house consumption and only sells the marketable surplus. Thus, male farmers will even move to town or next villages to seek for agricultural credit.

"I have just my small piece of land to work and feed my children who will want to lend me money that I have nothing to show for. At times I even want to lend money from my neighbors to complete my children school fee and they are not secured to give before much money for my farm?" Mama nkengfack

4.1.3 Crop production levels

The most cultivated crop in both regions is cassava (fig 4.10). Even though the results reveal that 78% of farmers in the South region cultivate cassava slightly more than those in the East regions (72.65) by 5.45%. This is because it is a key component in their traditional meal and hence it is a delicacy. Their ancestors as well as parents equally cultivated cassava, meaning they grew up cultivating cassava as their main crop. Also, the climatic conditions favour the growth of the crop and given their farm practices such as zero tillage, which suites cassava cultivation since little or no-tillage is needed.

Additionally, the by-products from cassava such as garri act as a source of revenue to the farm households thereby improving on their income level and hence, rescuing them from the poverty trap. As reported by most family heads, the surplus income is then spent on by food stuff, children's education, housing, clothing, health, energy, transport, leisure, reinvestments in the farm, and family ceremonies, among others. This is supported by work of (Mvodo & Liang, 2012), who mentioned that cassava is one of the major staple food I cameroon and also serves as a raw material for moe than 80 industrial products worldwide and represents a delicacy, enabling the processing of many culturally appreciated recipes.

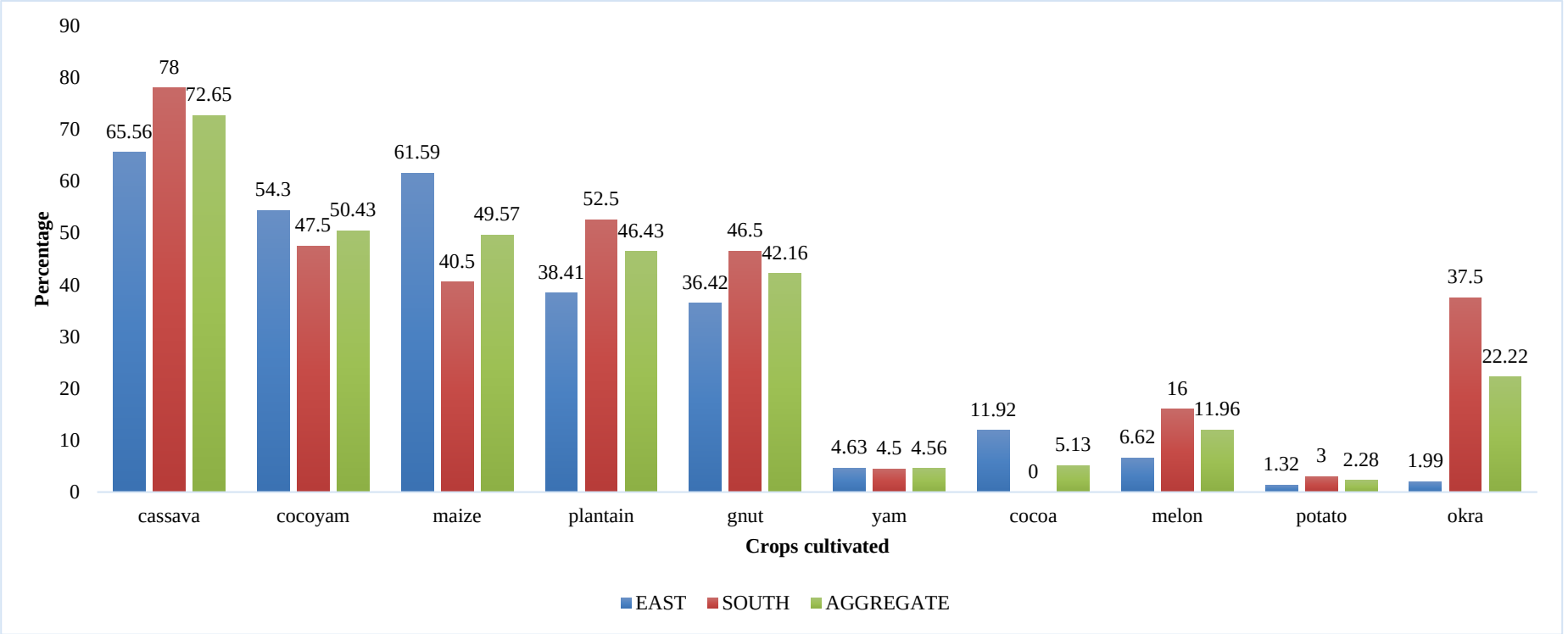


Figure 4. 10 Main crops cultivated in the study area (Source: Analysis from field survey, 2020)

Table 4. 4: percentage crops cultivated in the study area stratified by gender

Main Crops cultivated	Gender	
	Male	Female
Cassava	19.3	80.7
Cocoyam	56.5	43.5
Maize	51.4	48.6
Plantain	55.6	44.4
Groundnut	43.5	56.5
Cocoa	81.7	18.3
Other crops	62.5	37.5
N	193	157

Table 4.4 further presents that female farmers are more involved in cassava production (80.9%) which is significantly different from male farmers (65.8%). Since cassava is the main staple food crop consumed in this area and female farmers mostly produce for house consumption, they tend to be the ones more involved in its production, for men will prefer to involve themselves in crops they will only sell more and that have a high market value. In concordance with this, the cassava sector in Cameroon has been reported to be primarily occupied by women who have generated for the past years an important share of family income (Moma *et al*., 2014).

However, it appears that for men the family is not always a priority, unlike women. Thus estimating demand functions, Lachaud (1998) argues that the share of female income significantly and positively influences food and energy costs and negatively expenditures on cigarettes, tobacco etc. Engle (2001), also confirm that women's income has a stronger association with children's nutrition than men. This explains why female are more involved in cassava production since it directly impacts on their share income for the family. This study is in line with that of Igwacho *et al*. (2016).

On the other hand, groundnut and Cocoa cultivation have a very high significance between the two gender categories where female farmers where more involved in Groundnut cultivation, 52.9% against 33.2% and male for Cocoa, 39.4% against 10.8% (table 4.4). The soups of the rural community in this area is mainly made of groundnut thus follows the same trend with cassava production. There was no significant difference in cocoyam, maize, plantain cultivation among male and female farmers. This is probably because these crops are produced in this area mainly for commercial purpose.

Furthermore, women's triple role in development has been classified into reproductive, productive and community management surfaces in this case thou in many societies in the developing world, only the domestic and community roles of women have been emphasized (Mosses, 1993). Thus women get actively involved in production of this crops for marketing and their importance in expenditure on children either on their health, education etc can be explained as part of their triple roles.

4.2. Assessment of smallholder perceptions on climate change and variability

4.2.1 Descriptive statistics

In adoption of farm technolgy in a changing climate, the first step is to perceive these changes. If a farmer is not able to perceive any change in climate change, this means that there is no issue and also even if they experincing a drop in crop yield they might not know the possible changes or ammeliorations to make on their farms.

Table 4. 5: Perception of climate change, stratified by gender

Region	**Gender**	**Stats**	**Perceived change in climate**			**Total**
			Yes	**No**		
EAST	Male	n	75	4	79	151
		%	94.93	5.07	100	
	Female	n	70	2	72	
		%	97.2	2.7	100	
SOUTH	Male	n	113	2	115	200
		%	98.2	1.71	100	
	Female		80	5	85	
		%	94.11	5.88	100	
AGGREGATE	Male	n	188	6	194	351
		%	96.9	3.09	100	
	Female	n	150	7	157	
		%	95.54	4.46	100	

(Source: Analysis from field survey, 2020)

This therefore bring perception a very important part of adoption of farm technology. Asrat and Simane (2017) and Deresa *et al*. (2009) portulated that adaptation at farm level involves two stages: perceiving a change in climate and deciding whether to adopt or not(inncluding which adaptation strategy to use). Almost all the farmers (99%) indicated to perceive climate change (table 4.5). This results are in line with those of Asrat and Simane, (2018).

Both perception and knowledge guide decision making and consequently, farmers' action on climate change adaptation. In an inquiry into social limitations to climate change adaptation, Prober *et al*. (2019) argued that, in addition to limitations presented by availability of technology and the capacity for learning, other elements including perceptions and knowledge considerations within society fundamentally limit climate change adaptation.

Mortoja & Yigitcanlar, (2022), also noted that public perceptions/opi- nions are critical components of the socio-political context within which policymakers operate, and can fundamentally compel or constrain political, economic, and social action to address a particular risk, such as climate change. Thus, a first step toward enabling more communities and individuals to adapt to climate change could be to make explicit the underlying values shaping preferences and decisions (Prober *et al*., 2019).

Men and women are more likely to perceive climate related changes that more directly affect their social roles/ activities probably due to their struggles to fulfil their responsibilities/obligations in society. In this regard, women's traditional role of ensuring food availability in the household makes them keener on hindrances to achieving this goal. For instance, women are responsible for preserving (drying) of foodstuffs such as cassava, maize, and groundnuts. Decreases in temperature can portray their plight of having to dry foodstuffs for longer periods of time under the sun; while the consequences of increased temperature, flood frequency, changes in seasons, drought severity and frequency present multiple constraints to achieving their role as homemakers.

In addition, men being major owners of livestock such as cattle normally kept outdoors in kraals would be more affected by strong winds which reportedly stirred animals into

stampedes leading to straying and death of animals. More specifically, from our results on table 4.5, there was a great disparity in perception between the male (94.93%), and female (97.2%) headed households in the East region. Meanwhile, in the South region, there a slide difference between the female and male headed households which recorded (94.11%) while 98.2% respectively. This results are in conformity with those of (Gorettie *et al*., 2019).

Farmers also observed that afternoons were hotter, the onset of wet season was delayed, dry season had become shorter, incidences of flood increased, and rainfall had become erratic. This implies the shorter wet season and increased temperature. It means that the farmers recognized the changes in climate factors. This finding is congruent with (H. P. Bhattarai, 2021), who also found that the people in Chituen village in Nepal experienced hotter dry seasons, shortening wet seasons, drought, floods and erratic pattern of rainfall. Zegeye *et al*. (2022), in their study in Ethiopia and South Africa also observed increased temperature and decreased rainfall.

However, Abid *et al*. (2019), reported that farmers perceived long term changes in temperature and decrease in precipitation. Gbetibouo (2009) also observed that farmers' perceptions appear to be in accordance with the statistical record in the Limpopo River Basin which was his study area. (Chiputwa *et al*., 2020; Diouf *et al*., 2019), found that farmers in Senegal are aware of climate change. Smallholder farmer in study area generally perceived late rains and increased temperatures as a major cause of the of the decrease in production levels.

Furthermore, research has reported that majority of smallholder farmers perceived same trends in temperature and rainfall. When rains delay coming with the incidence of increased in temperatures, this changes the agricultural calendar thus obstructing the lifecycle of plants which consequently results in low crop output (A.i *et al*., 2016; Gadédjisso-Tossou, 2015).

Also, Farmers' perception of the effects of climate change included changes in timing and length of growing season, reduced crop yield, increased pest and disease outbreak, stunted growth of crops, decreased feed intake by livestock, reduced growth rate of livestock, reduced egg production, inadequate pasture, and reduced birth rate and size (Fig 4.11).

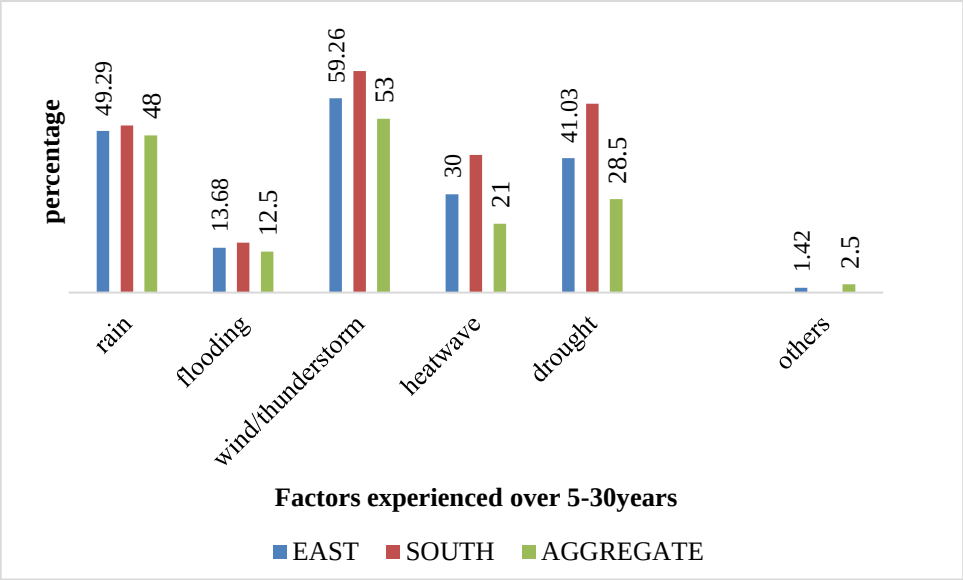


Figure 4. 11 Factors of climate change experienced (Source: Analysis from field survey, 2020)

These effects of climate cannot seriously threat to agriculture because of rising temperatures, changes in rainfall patterns or increased drought. However, Singh, (2020), argued that this is directly linked to reduced soil productivity and high incidence of pests and diseases. This is also directly linked to reduced performance of livestock. These effects have serious implications for food security for the study area, especially the rural communities which also rely on agriculture to meet their subsistence needs. These findings

support Mertz *et al*. (2009) who observed that farmers attribute these challenges to changes in climate. A climate change impact potentially significant to small farm production is loss of soil organic matter due to soil warming. Higher air temperatures are likely to speed the natural decomposition of organic matter and to increase the rates of other soil processes that affect fertility.

Furthermore, conditions are usually more favourable for the proliferation of insect pests in warmer climates. Longer growing seasons may enable several insect pest species to complete a greater number of reproductive cycles. However, on Figure 4.11, farmers reported that they experienced more of wind/thhunderstorm(67.11%). This was followed by instable rains and third by drought and the complain about rains here was mostly that it comes late ad no longer rains as much as it use to. Wind has a very strong impact on crops because when these crops sprout and are approaching maturity with the occurrence of strong winds and thunderstorm, these plants are pushed to the floor which distorts their growth causing low outputs. In the aspect of late rains, smallholder agriculture is predominantly dependent on rain and when these rains come late it alters the agricultural calendar causing the abortion of some crops and those that survive with late planting do not produce well.

Figure 4.12 shows that farmers generally perceived that they have lost crops due to change in rainfall with proportion of 76.3%. Water is a very vital component in a plants life for plants need water especially for breaking dormancy to ease germination. As it is agriculture in sub-Sahara Africa is basically rainfed, thus variations in rainfall pattern will greatly affect the reproductive lifecycle of crops. Farmers in the study.

The trend of maize yield is the same with the trend of rainfall (Okeowo *et al.*, 2015), furthermore they explained that except when rainfall declines while maize yield increases which could be that rainfall variability might have reduced and also in amount during the growing season which could increase maize yield (Rowhani *et al.*, 2011). Our positive relationship between rainfall and maize yield is in line with Epule *et al.*(2021)who reported that maize yields were better when rainfall pattern is normal. Also, the planting date of maize could have fluctuated due to rainfall variability experienced during that period. Thus, leading to the loss of maize with the south region reporting 34.44%, East 22.5% and generally 27.64% (fig 4.12).

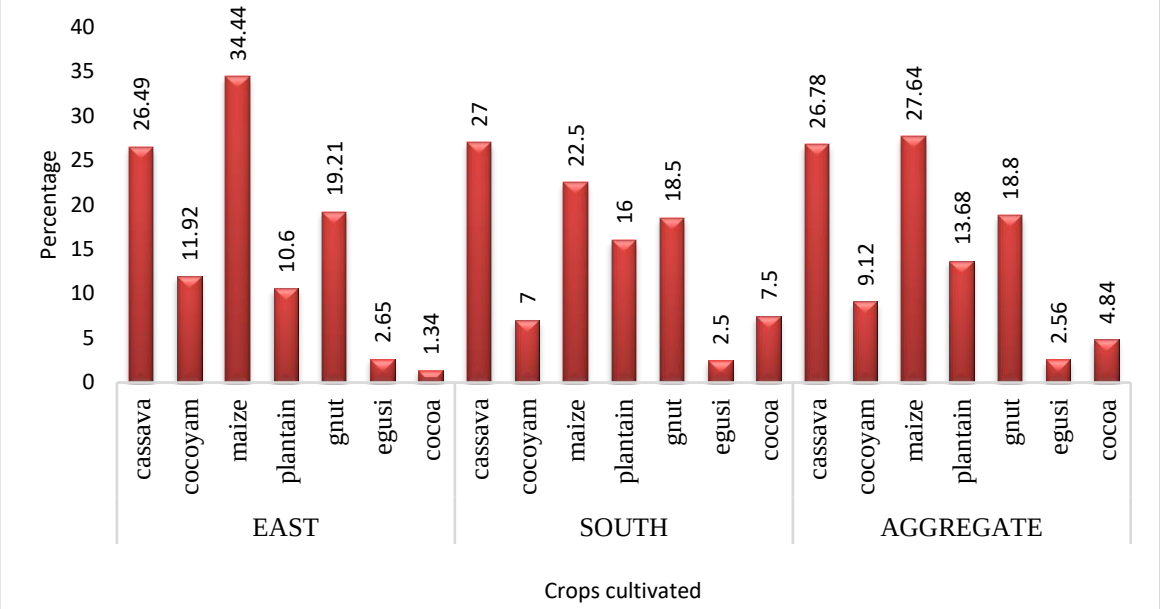


Figure 4. 12 Perception on Crops affected by change in rainfall . (Source: Analysis from field survey, 2020)

Furthermore, Farmers generally perceived that they have lost crops due to change in temperature with proportion of 80% farmers as against 20% for those that said no. farmer perceptions on crop affected by change in temperature as showed that maize was the most affected (27.64%) seconded by Cassava (26.78) and the least affected was egusi about 2.56%.

Cassava was one of the crops most hit by temperature, this might sound strange but when they do the planting and there are no rains normally the seedlings die off and very few survive also cassava is in species, we have those due in 6months and after tis six months if not harvested the tubers begin to rotten because of over heat. Even when the cassava has sprouted it needs a little rain to survive and when there are no rains and high temperatures the cassava dries off. Maize is equally affected by high temperatures especially when the first rains come and planting is done then the rains just disappear and takes long periods before falling again the seedlings dry off/ rots in the soil and also as maize grows it requires rain if there are little rains the cones produced will not be healthy thus affecting its production.

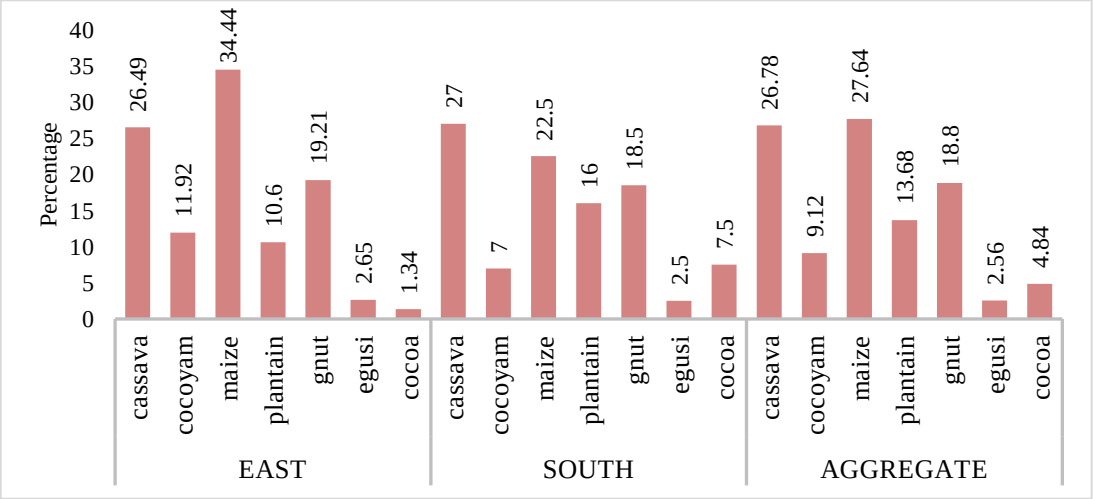


Figure 4. 13 Perception on Crops affected by change in temperature (Source: Analysis from field survey, 2020)

4.2.2 Inferential statistics

Results of the selection and outcome models are presented in Tables 4.6, 4.7 and 4.8, for the Aggregate, South and the East, respectively. In both models, some of the explanatory variables and their respective marginal values are statistically significant in determining perception and adaptation in a direction that would be expected. The calculated marginal

effects measure the expected changes in the probability of perception and adaptation with respect to a unit change in an explanatory variable.

Table 4. 6 Determinants of perception and adaptation to climate variability in the Study area (aggregate)

Explanatory variables	Outcome model (Adaptation)				Selection model (Perception<$^{1}_{0}$)			
	Regression		Marginal effects		Regression		Marginal effects	
	Coef	P value	Coef	P value	Coef	Pvalue	Coef	P value
Age	0.00	0.586	0.00	0.586	.004	0.666	.004	0.666
Gender	0.03	0.390	0.03	0.390				
Hhsize	0.01	0.108	0.01	0.108				
Farm experience	0.00	0.287	0.00	0.287				
Distance home/farm	0.00	0.504	0.00	0.504				
Secondary education	-0.01	0.805	-0.01	0.805				
Farm revenue	-0.27	0.000***	-0.27	0.000***				
Exp flood	-0.10	0.061*	-0.10	0.061*				
Access to extension	0.24	0.001**	0.24	0.001**				
wind/thunder frequency	0.12	0.005**	0.12	0.005**	.38	0.183	.38	0.183
Land ownership	-0.10	0.035*	-0.10	0.035*				
Terrain of farm	-0.05	0.177	-0.05	0.177				
Changes in rainfall					0.29	0.312	0.29	0.312
Soil erosion					-4.43	0.000	-4.43	0.000***
Heatwave					-0.01	0.966	-0.01	0.966
Soil fertility					-4.53	0.000	-4.53	0.000***
Drought					0.36	0.224	0.36	0.224
Cons.	1.39	0.000			1.15	0.017		
Total observations				351				
Censored				337				
Uncensored				14				
Wald chi-squared				(13)=51.64				
Prob>chi-squared				0.000				

***Significant at 1% level **Significant at 5% level *Significant at 10% level

Results of the selection model for the south region (4.7) indicate that severe soil erosion and moderate soil fertility significantly increase the likelihood of farmers' perception of

climate change ($P < 0.01$). Likewise, frequency of wind/thunderstorm and changes in rainfall is statistically significant in enhancing farmer's perception of climate change ($P < 0.05$). Also, results of the outcome model for the south region are also portrayed in 4.7. Accordingly, revenue from farm, frequency of wind/thunderstorm, extension services, and land ownership strongly influenced farmers' adaptation decision ($P < 0.001$). Moreover, household size is significant in determining farmers' adaptation decision ($P < 0.05$).

Table 4. 7 Determinants of perception and adaptation to climate variability in the South Region

Explanatory variables	Outcome model (Adaptation)				Selection model (Perception<$^{1}_{0}$)			
	Regression		Marginal effects		Regression		Marginal effects	
	Coef	P values	Coef	P values	Coef	Pvalue	Coef	Pvalues
Age	-.0003	0.911	-.0003	0.911	.0026	0.835	.0026	0.835
Gender	.0377	0.510	.0377	0.510				
HH size	.0119	0.042	.0119	0.042*				
Farm experience	.0039	0.149	.0039	0.149				
Distance home/farm	-.0009	0.179	-.0009	0.179				
Education	.0697	0.220	.0697	0.220				
Farm revenue	-.3389	0.000***	-.3389	0.000***				
Exp flood	-.1383	0.093*	-.1383	0.093*				
Access to extension	.2637	0.025**	.2637	0.025*				
Wind/thunder	.1797	0.005**	.1797	0.005**	.8974	0.043*	.8974	0.043
Land ownership	-.2034	0.001***	-.2034	0.001***				
Terrain	.0190	0.722	.0191	0.722				
Changes in rainfall					.9048	0.045*	.9048	0.045
Soil erosion					-4.861	0.000***	-4.861	0.000
Heatwave					.4742	0.355	.4742	0.355
Soil fertility					-4.910	0.000***	-4.910	0.000
Drought					.4072	0.401	.4072	0.401
Constant	5.518	0.000			.7079	0.000		
Total observations		200						
Censored		192						
Uncensored		8						
Wald chi-squared		(13) =56.75						
Prob>chi-squared		0.000						

***Significant at 1% level **Significant at 5% level *Significant at 10% level

On the other hand, Results of the selection model for the East region (Table 4.8) indicate that severe soil erosion and moderate soil fertility significantly increase the likelihood of farmers' perception of climate change ($P < 0.01$). Likewise, education is statistically significant in enhancing farmer's perception of climate change ($P < 0.05$). Also, results of the outcome model for the East region are also portrayed in Table 4.8. Accordingly, revenue from farm, frequency of flood and extension services strongly influenced farmers'

adaptation decision ($P < 0.05$). Moreover, educational level of household head is significant in determining farmers' adaptation decision (10%).

Table 4. 8 Determinants of perception and adaptation to climate variability in the East Region

Explanatory variables	Outcome model (Adaptation)				Selection model (Perception<$^{1}_{0}$)			
	Regression		Marginal effects		Regression		Marginal effects	
	Coef	Pvalues	Coef	Pvalues	Coef	Pvalue	Coef	Pvalues
age	-.002	0.385	-.002	0.385	.012	0.502	.012	0.502
gender	-.044	0.314	-.044	0.314	-.119	0.811	-.119	0.811
HH size	-.001	0.839	-.001	0.839				
Education	-.084	0.082*	-.084	0.082*	-2.54	0.017	-2.54	0.017
Terrain of plot	.048	0.319	.048	0.319	-.520	0.374	-.520	0.374
Farm Revenue	.146	0.012***	.146	0.012***				
Flood frequency	-.142	0.023***	-.142	0.023***				
Access to extension	.181	0.017***	.181	0.017***				
Wind/thunder	-.018	0.700	-.018	0.700				
Land ownership	.047	0.356	.047	0.356				
Changes in rainfall					-.135	0.797	-.135	0.797
Soil erosion					-.4.73	0.000***	-.4.73	0.000***
heatwave					-.356	0.495	-.356	0.495
Flood					.347	0.680	.347	0.680
Soil fertility					-4.58	0.000***	-4.58	0.000***
drought					.761	0.187	.761	0.187
Constant	6.10	0.000			.7079	0.000		
Total observations		151						
Censored		145						
Uncensored		6						
Wald chi-squared		(10) =17.99						
Prob>chi-squared		0.055						

***Significant at 1% level **Significant at 5% level *Significant at 10% level

Generally, from the results of the outcome model (Table 4.6) revenue from farm, access to extension advise and frequency of wind/thunderstorm strongly influenced farmers adaptation decision ($P < 0.01$). while landownership is significant in determining farmers'

adaptation decision ($P < 0.05$). on the other side results from the selection model depicted that soil erosion and fertility strongly influenced farmers perception to climate change ($P < 0.01$).

4.3 Climate smart agricultural practices in South -eastern Cameroon

4.3.1 Descriptive statistics

As observed in all the region's most farmers did not take any measures to protect their farm though this difference is not wide with only 48.3% and 35.5% farmers from the East and South respectively taking measures to protect their farms (table 4.9). Generally, a majority (59%) of farmers did not take any measures. Farmer being sensitive to changes in their farms quickly start thinking of how to ameliorate these changes to ensure their high yields for profit maximization while ensuring for food security and thus secured livelihoods. The greater issues that affected farmers not to take measures was because they were not even aware of the existence of these measure (table 4.9).

Table 4. 9 Take measures to protect farms from climate change

Region	Take measures to protect the farm		Total
	Yes	No	
East	73	78	151
%	48.3	51.7	100
South	71	129	200
%	35.5	64.5	100
Aggregate	144	207	351
%	41	59	100

(Source: Analysis from field survey, 2020)

Furthermore, we can see from the plot below that these farmers only learnt from their friend farmers, there was very little intervention from the government agencies like the extension workers and from NGOs. Farmers that got information and shared with their peers where those who travelled out of the village, learnt new techniques from family or friends out of

the village. Also they could have relative working for agricultural government agencies that will enlighten them in these aspects so when they return to the village they share these ideas with their friends. Thus, making farmers to rely on each other, for those who travel and learn other methods from other regions they come back and teach their friends.

This might be advantageous and not, not in that this particular method might not be best fitting in their context since it might be from a different agroecological zone. However, this awareness on adaptive measures leads to reduction in crop loses and subsequently improve on farmer's productivity. This results are in line with those of Asrat & Simane, (2018) who reported that the more the farmers awareness on adaptive strategy the more their productivity increased.

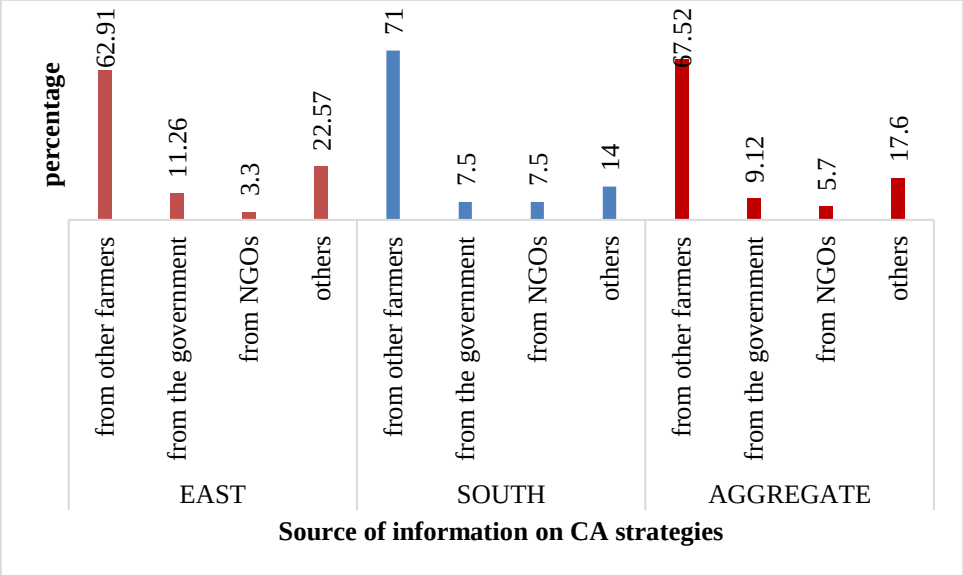


Figure 4. 14 Source of awareness of CSA strategies (Source: Analysis from field survey, 2020)

However, adapting to climate change entails usually taking the right measures to reduce the negative effects of climate change (or exploit the positive ones) by making the appropriate adjustments and changes. The Intergovernmental Panel on Climate Change (2007) defines adaptation as adjustments in natural or human systems in response to actual or expected climatic stimuli or effects, which moderates harm or exploits beneficial

opportunities. It also refers to actions that people, countries, and societies take to adjust to climate change that has occurred.

Nonetheless, adaptation has three possible objectives: to reduce exposure to the risk of damage; to develop the capacity to cope with unavoidable damages; and to take advantage of new opportunities. Thus to protect their farms from climate change, farmers in this area mostly protect their crops 63.8%, protect soil 58.8%, while some protect water sources 10.2%(fig 4.15). This is a reality for smallholder farmers when they realize there are issues concerning their crops they first look at how to help the crop survive the adversity before thinking of other methods. This is in line with what most of the farmers shared during face to face interviews, they complained of late rains during planting season and so they have to wait till the rains fall before they can plant their crop if not whatever crop they plant to wait for the rain will not produce well and thus low yields. So, they prefer to protect their crops by waiting till the first rains fall (fig 4.15).

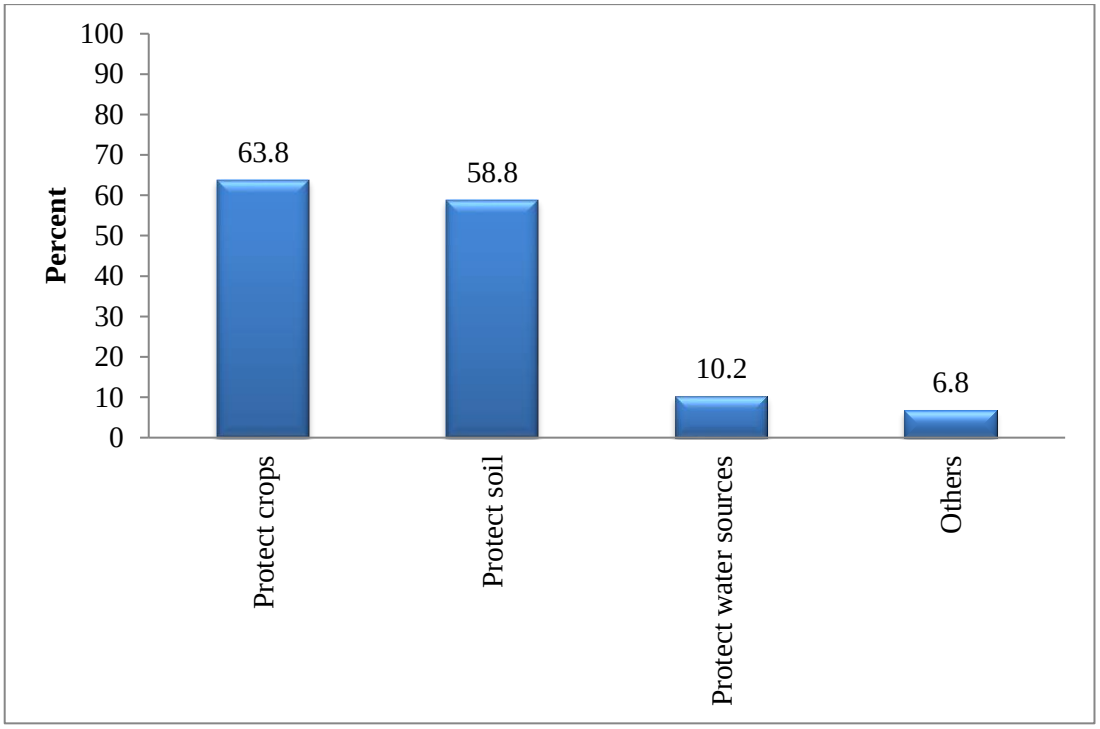


Figure 4. 15 Dimensions of Adaptive measures to protect farm from climate change effects

(Source: Analysis from field survey, 2020)

Additionally, climate smart agriculture strategies used by these smallholder farmers is displayed in figure 4.16. This result shows that the most employed strategy was agroforestry (61.54%) and the least employed strategy was water management (0.57%). This could be because a higher percentage of the cultivable land in the study area is self-owned. Land in this area is easily acquired paving a way for farmers to own more than one parcel of land making it easier for them to allow a parcel that no longer produces well to fallow. This results is in line with the findings of (Sonwa, 2017), who reported that agroforestry is the most practiced conservation agriculture method in Cameroon and central Africa.

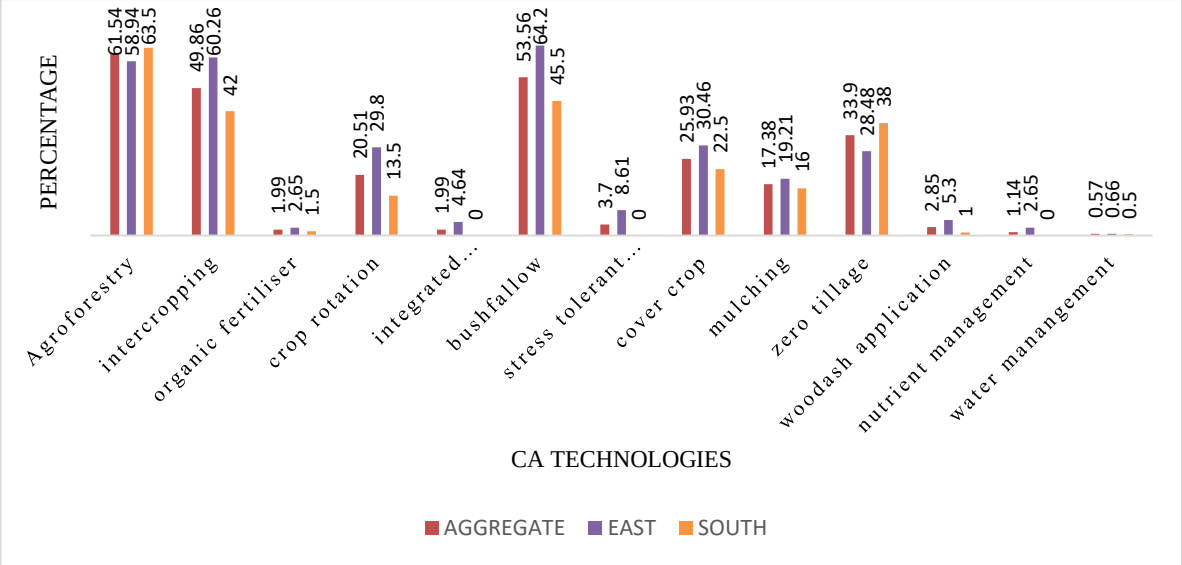


Figure 4. 16 Conservation Agriculture Adaptive Strategies Used (Source: Analysis from field survey, 2020)

4.3.2 Conservation agriculture strategies as adaptive methods to climate change.

Table 4. 10 Dimensions per principal inertia and percentage

Dimension	Principal inertia	Percent	Cum percent
dim 1	.1306291	13.06	13.06
dim 2	.1122932	11.23	24.29
dim 3	.095344	9.53	33.83
dim 4	.0902547	9.03	42.85
dim 5	.0842627	8.43	51.28
dim 6	.0789935	7.90	59.18
dim 7	.0731272	7.31	66.49
dim 8	.0692271	6.92	73.41
dim 9	.068854	6.89	80.30
dim 10	.0587199	5.87	86.17
dim 11	.0506242	5.06	91.23
dim 12	.044547	4.45	95.69
dim 13	.0431231	4.31	100.00
Total	1	100.00	

From table 4.10 above we choose dimension one since it presents the highest inertia and percentage, thus giving more information on the individual contributions of each practice as a conservation agriculture practice.

Table 4. 11 Contributions of various practices as a conservation Agricultural practice

Categories	**Overall**				**Dimension 1**			**Dimension 2**		
		mass	**quality**	**%inert**	**coord**	**sqcorr**	**contrib**	**coord**	**sqcorr**	**contrib**
Agroforestry	0	0.030	0.043	0.047	0.411	0.014	0.002	0.649	0.030	0.004
	1	0.047	0.043	0.030	-0.257	0.014	0.001	-0.406	0.030	0.003
Intercropping	0	0.039	0.190	0.038	0.770	0.078	0.008	0.997	0.112	0.013
	1	0.038	0.190	0.039	-0.774	0.078	0.008	-1.003	0.112	0.013
Organic fertilizer	0	0.075	0.287	0.002	0.042	0.011	0.000	0.224	0.276	0.001
	1	0.002	0.287	0.075	-2.058	0.011	0.002	-10.994	0.276	0.062
Crop rotations	0	0.061	0.395	0.016	0.883	0.395	0.017	0.039	0.001	0.000
	1	0.016	0.395	0.061	-3.421	0.395	0.067	-0.153	0.001	0.000
Integrated Crop/Livestock	0	0.075	0.030	0.002	0.023	0.004	0.000	0.069	0.026	0.000
	1	0.002	0.030	0.075	-1.151	0.004	0.001	-3.380	0.026	0.006
Bush fallow	0	0.036	0.474	0.041	1.942	0.427	0.049	-0.696	0.047	0.006
	1	0.041	0.474	0.036	-1.684	0.427	0.042	0.603	0.047	0.005
Stress tolerant crops	0	0.074	0.028	0.003	0.086	0.025	0.000	0.031	0.003	0.000
	1	0.003	0.028	0.074	-2.225	0.025	0.005	-0.799	0.003	0.001
Cover crops	0	0.057	0.316	0.020	0.919	0.316	0.017	0.049	0.001	0.000
	1	0.020	0.316	0.057	-2.627	0.316	0.050	-0.141	0.001	0.000
Mulching	0	0.064	0.429	0.013	-0.198	0.024	0.001	0.871	0.405	0.016
	1	0.013	0.429	0.064	0.942	0.024	0.004	-4.138	0.405	0.077
Zero/min till	0	0.051	0.397	0.026	1.150	0.337	0.024	-0.523	0.060	0.005
	1	0.026	0.397	0.051	-2.243	0.337	0.047	1.019	0.060	0.009
Woodash application	0	0.075	0.151	0.002	0.097	0.042	0.000	0.169	0.109	0.001
	1	0.002	0.151	0.075	-3.312	0.042	0.009	-5.751	0.109	0.024
Nutrient management	0	0.076	0.415	0.001	0.046	0.024	0.000	0.200	0.390	0.001
	1	0.001	0.415	0.076	-4.025	0.024	0.005	-17.361	0.390	0.089
Water mananagment	0	0.076	0.003	0.000	0.009	0.002	0.000	-0.007	0.001	0.000
	1	0.000	0.003	0.076	-1.591	0.002	0.000	1.168	0.001	0.000

Agroforestry contributes 0.3% as a conservation agricultural practice(table 4.11). This farming practice could play a greater role as a mitigative practice rather than a conservative practice that is why it only contributed very little as a conservation practice. Intercropping contributed 1.6% (table 4.11) as a conservation agricultural practice. Intercropping most often is considered in the same class with agroforestry as mitigative practices instead of conservation practice though it exhibits a reasonable contribution as a conservation practice far more than agroforestry. Cover crops also contributed 6.7% as a conservation agricultural practice, this is because cover crop is one of the main practices as far as conservation agriculture is concerned and acts basically as a soil conservation practice by preventing or protecting the soil against soil erosion. This corroborates with the results of Dunn *et al*. (2016).

Furthermore, Zero/minimum tillage contributes greatly (7.1%) as a conservation agricultural practice. This is one of the core practices in conservation agriculture because it embodies one of the principles of conservation agriculture. This agrees with Kassam and Friedrich, 2009 who affirms that minimizing soil disturbance maintains proper aeration in rooting zone, oxidation of organic matter, water movement in soil. Crop rotation contributes 8.4% as a CA strategy (table 4.11). While bush fallow contributed the highest (9.1%) as a conservation agricultural strategy. Mulching which is one of the core practices of CA contributed very small in this area probably because they do not practice it much. Mulching is practiced more in the Northwest because of their soil type.

Table 4. 12 List of conservation agricultural strategies

Group	Percentage of users	Components
Crop management practices(C)	62.4%	Intercropping Cover crops
General field management practices(F)	58.69%	Crop rotations Bush fallow
Soil management practices(S)	48.44%	Mulching Zero/minimum tillage

4.3.3 REDD+ Potentials in smallholder farmers livelihood security

Agroforestry and other tree-based systems contribute to Reducing Emissions from Deforestation and Forest Degradation as part of REDD+ under certain definitions and as a part of a strategy for achieving REDD+ landscapes. In the context of REDD+, agroforestry has the potential to provide environmental services like fuel wood (that would otherwise be sourced from adjacent or distant forests) supply and biodiversity. In fact, Agroforestry has been used in several protected area landscape buffer zones and within conservation as one way of alleviating pressure on forests, thereby reducing deforestation. Fig. 4.16 therefore portrays the potentials of REDD+ on small holder farmers, where in involving towards the achievement of REDD+ experience benefits ranging from more sources and increments in income, environmental services, increase yields, better soil fertility and structure while also ensuring for food security.

Agroforestry systems, a set of sustainable land-use management practices centred around planned and managed interactions between trees, shrubs, crops, livestock, and other factors of agricultural production (Bishaw, 2012), have become a potential vehicle to transform the capacities of subsistence farmers to achieve food security.

However, agroforestry has the potential to address Africa's contemporary agricultural crisis. Adding trees to farms can restore soil fertility, produce animal feed, facilitate the integration of livestock into croplands, secure organic fertilizer in the form of manure, alleviate the fuel wood shortage, mitigate deforestation and climate change, and above all, improve agricultural yields and incomes, ensuring more secure livelihood for Africa's poorest.

Furthermore, in the East we had more adopters (58.94%) of agroforestry than nonadopters (41.09%) (fig 4.16), though there was more adoption of this farming method in the south (63.5%) as compared to the latter, generally more (61.54%) as to 38.46 smallholder farmers in this study regions adopted the agroforestry system of agriculture. This could imply the farmers of the study area had a level of awareness of this method and because most of them valued fruit trees and the income they get from it thus decided to cultivate crops amongst trees. These findings are in agreement with those of Mogaka *et al*. (2021) and Franzel *et al*. (2001) who reported that adoption rates of agroforestry in Sub Sahara Africa where high , but are in disagreement with the findings of Ajayi, (2007).

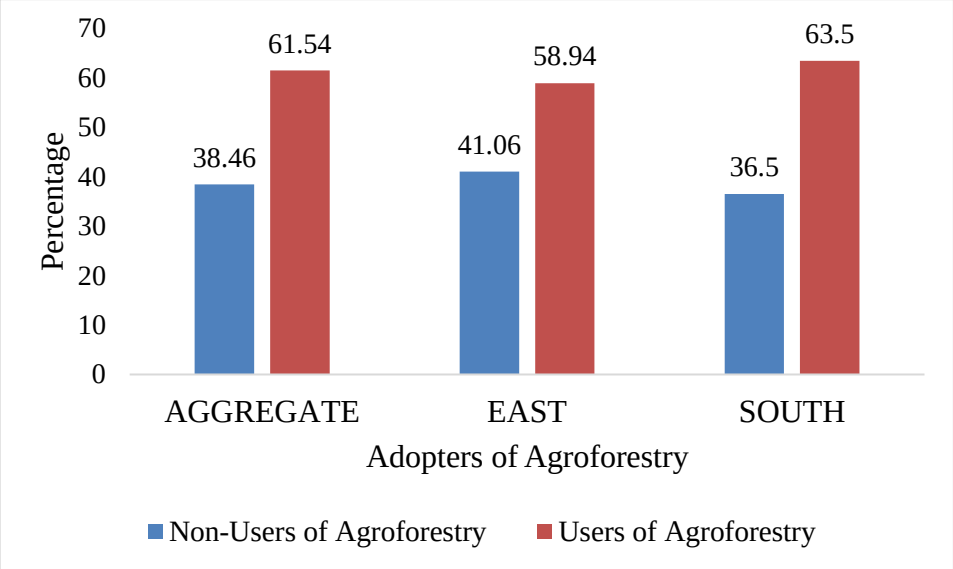


Figure 4. 17 Adoption of Agroforestry as a mitigative wing to climate change (Source: Analysis from field survey, 2020)

4.3.3.1 Agroforestry adoption per land ownership status

As shown on fig 4.17, agroforestry generates adaptation benefits through its impact on reducing soil and water erosion, improving water management and in reducing crop output variability (Ajayi *et al*. 2009, 2007; Mercer 2004; Franzel and Scherr 2002).

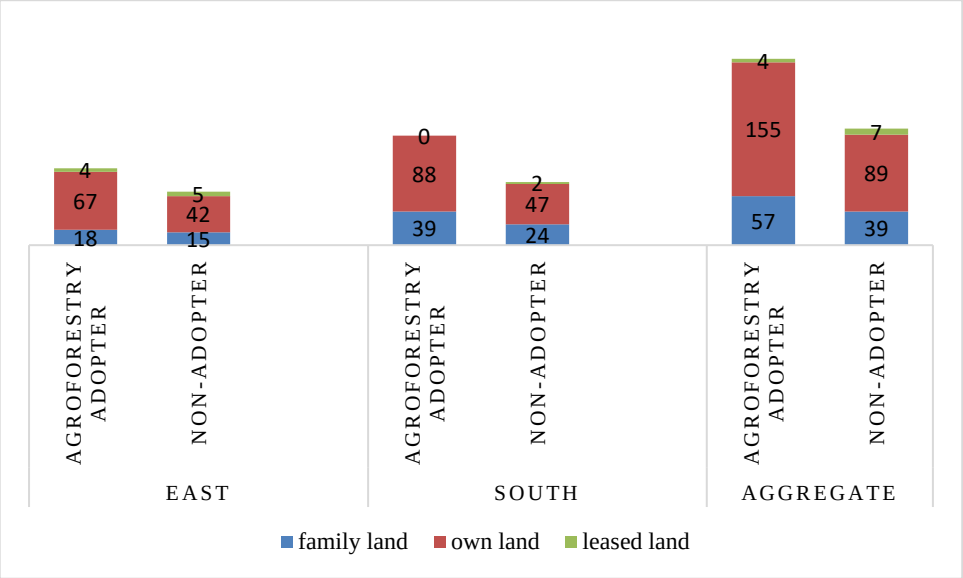


Figure 4. 18 Adoption of Agroforestry per land ownership status as a mitigative wing to climate change (Source: Analysis from field survey, 2020)

Trees and bushes may also yield products that can either be used for food consumption (fruits), fodder, fuel, building materials, firewood, or sold for cash, leading to greater average household income, and contributing to household risk management via reduced income variability (Ajayi *et al*. 2009; Franzel *et al*. 2004). Planting trees and bushes also increases carbon sequestered both above and below ground, thereby contributing to GHG mitigation (Verchot *et al*. 2007).

Adoption of agroforestry can lead to improved crop and livestock production because agro-forestry practices are less costly, more affordable and because inputs for fodder and soil amendments are readily available to small-holder farmers (Parwada & Gadzirayi**,** 2010) In the East region a greater number of smallholder farmers who owned 67 (44.4%) their land are the ones that adopted agroforestry, followed by those working on family land 18 (11.9%) and just very few 5 (3.3%) who worked on leased lands adopted this system (Fig 4.17). The few who worked on leased land that adopted this system might have met these trees on the farm and are not even allowed to cut them down since they are working on the land only for a period. The case of the farmers in the South region is not very different but

none of the smallholder farmers who worked on leased land attempted to adopt this system of conservation agriculture.

Looking at it at a general scale, most adopters of agroforestry are smallholder farmers that owned their lands (44.2%) followed by those working on family land (16.8%). This increase in adoption as per land ownership can be explained with the necessity of high investments in agroforestry systems which take longer periods for the benefits to manifest. Farmers will not want to invest on what their benefits are not secured and thus farmers who own their lands will readily adopt agroforestry because no matter the time lapse it takes for them to achieve their benefits, they are secured they will achieve. This is in congruence with Mogaka *et al*. (2021), who found that land ownerships is likely to influence adoption and tenants are less likely to adopt technologies that require long term high investment on land.

4.3.3.2 Perceived Benefits of farmers using Agroforestry systems

Smallholder farmers in the study area generally perceived agroforestry to be more beneficial (Figure 4.18) in that it increases crop yield, seconded by less soil erosion, environmentally friendly, improves food security (12.1%), an increases sources of income (9.68%), better soil fertility (4.03%), respectively. This corroborated with the findings of Sollen-Norrlin *et al*. (2020) who reported that crop and tree yields produced in agroforestry required 14–34% less land or fewer resources in terms of light, water, nutrients, compared to monoculture. This is a significant advantage and provides avenues for ecological intensification to produce more with fewer inputs. This finding was also in line with some authors who reported agroforestry to be one such potentially sustainable way of achieving healthier soils for increased agricultural production (Mbow *et al*., 2014) and environmental performance. And that besides provisioning services like food, fodder, fibre, and fuelwood production, agroforestry also provides several other ecosystem services, including

regulation of nutrient cycling, carbon sequestration, habitat for biodiversity, erosion control, fire and flood control, and recreational and cultural services (Seddon *et al*., 2020).

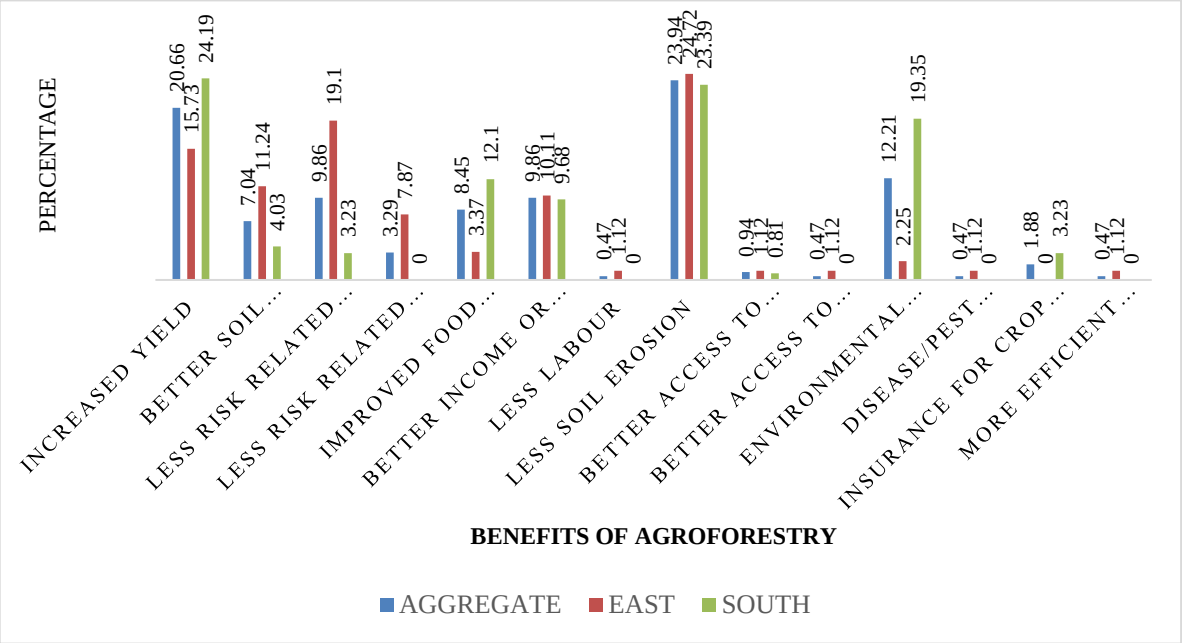


Figure 4. 19 Associated benefits of Agroforestry systems to Adopters (Source: Analysis from field survey, 2020)

4.3.3.3 Perceived Constraints of farmers using Agroforestry systems

Majority of smallholder who adopted agroforestry generally observed a decrease in crop yield (25.78%), (Fig 4.19) this could be due to poor management of the agroforestry systems they adopted. Despite numerous studies (Lehmann *et al*., 2018; Xu *et al*., 2019) demonstrating the higher productivity of agroforestry, some authors (Jones-Garcia & Krishna, 2021) got findings of smallholder farmers who see agroforestry as unproductive and thus as financially unviable which are in line with our findings of farmers observing agroforestry to decrease crop yields. A reasonable percentage (17.19%) of farmers amongst the adopters also associated agroforestry with high initial investment, reduction in arable crop area and the aspect of no ready market for their products since the distances from farm to market are very far in this area.

Comparing with figure 4.18 , a greater percentage of farmers who adopted agroforestry experienced increase in pest/disease in their plots. This increase can be associated with less knowledge on management of agroforestry fields and the type of cops and trees to plant on these plots since their access to extension services are very low thus no knowledge on management strategies. This is better explained by the results of Pumariño *et al*. (2015), which stated that pest abundance and plant damage were lower in agroforestry treatments for perennial crops, but annuals were unaffected. The findings of this study on pest and disease increase is contradicted by those of Sollen-Norrlin *et al*. (2020) who reported a decrease in pest/disease due to agroforestry systems and further explained that when agroforestry is used in form of hedges, boundary plantations, and windbreaks they create a physical barrier, especially if pests or pathogens are transported by wind.

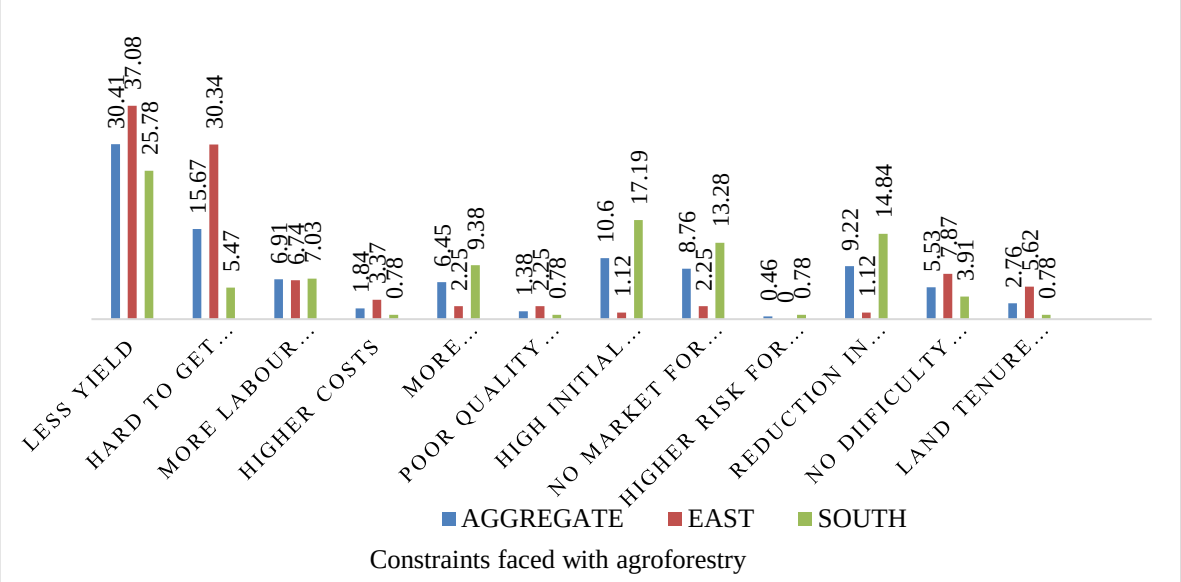


Figure 4. 20 Associated constraints of Agroforestry systems to Adopters (Source: Analysis from field survey, 2020)

4.4 Socio-economic determinants of farmers' adoption of conservation agricultural (CA) strategies

4.4.1 Household gender differentials in farm activities

Gender relates to socially assigned roles and behaviors attributable to men and women; it refers to the social meaning of biological sex differences. Gender roles are roles that are

played by both women and men, which are not determined by biological factors but by the socioeconomic and cultural environment or situation. Gender affects the distribution of resources, wealth, work, decision-making, political power as well as the enjoyment of rights and entitlements within the family and in public life. Women are twice as likely as men to be involved in agriculture related activities (Agamile *et al*., 2021). Whatever the culturally ideal position of men and women may be, major economic and social transformations taking place in the globalized world are rapidly and substantially changing household formations and patterns of obligations. From our results on fig 4.20, men (251) are more involved in clearing than women(100).

These results corroborate with those of Gebre *et al*. (2021) which states that the responsibility of land preparation and planting has traditionally been assigned to men, whereas women typically collaborate with men in other agricultural tasks, including weeding, harvesting, and gathering. Women dominate in farm activities like ploughing(209), ridging(220), manure application(281), harvesting(216), crop handling(279) and selling of farm produce (242). This dominance could be because, women are more involved in farm activities that requires time and care. This can be further explained as women often get attached to nature the more, they interact with nature and thus tend to have more interest in non-monetary aspect of agriculture but more of conserving nature.

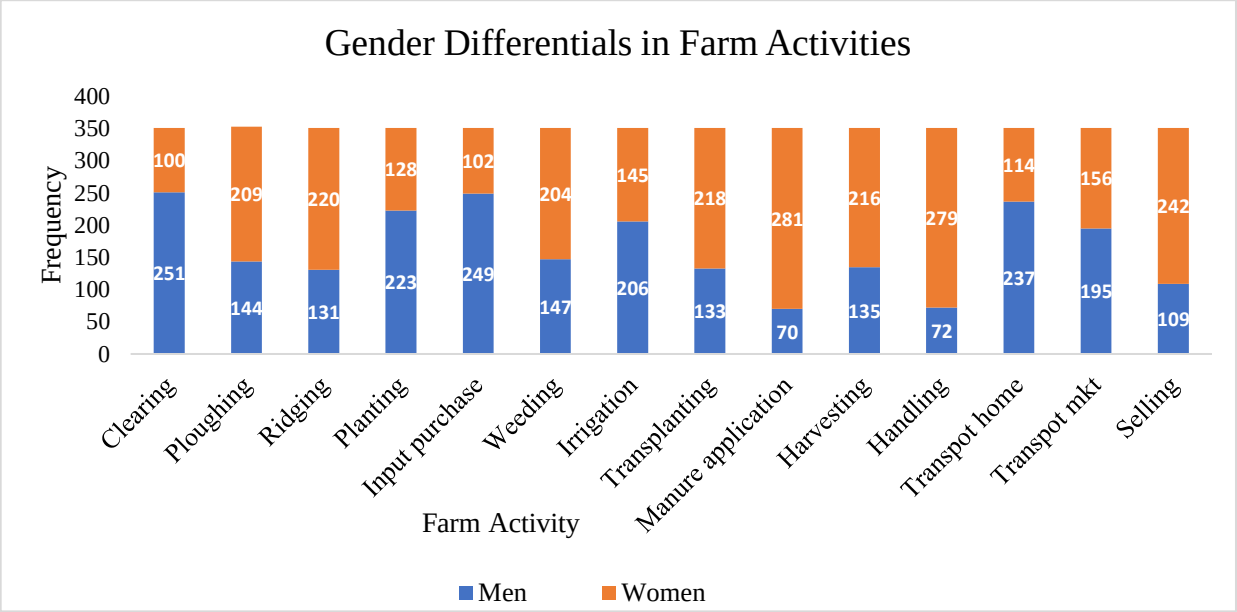


Figure 4. 21 Gender differentials in household farm activities

These results agree with Nyukuri. (2006) who reported that, farming activities were characterized by a distinct division of labor between men and women. Where, men predominantly engaged in land clearing, land preparation, and planting cash crops while other activities like irrigation, handling crops, storage and food processing were carried out by women. Furthermore, women have a greater participation than men in certain farm activities such as sowing, transplanting, weeding, irrigation, (as seen on figure 4.20) winnowing, storing, and in dairy activities such as fodder collection and milking(Paul & Rani, 2017).

Therefore, women often have to work for longer hours than men in these tasks. However, it is worth noting that these differences are not universal and may vary depending on a variety of factors, including culture, education, and individual experiences. Ultimately, it's important to recognize that both men and women have valuable perspectives and contributions to make when it comes to environmental issues, and that effective solutions

will likely require collaboration and cooperation across genders and other demographic groups(Ndiritu *et al*., 2014).

Furthermore, figure 4.21 shows gender differentials in household decision making. Decisions based on crop variety, input purchase, farm technology, and proceed use are taken by male in households headed by men. While decision on most of the technical household farming activities is taken by women: farm activity(245), planting periods(230), harvest period(205), weeding(241), price (210) and sales(305) of farm output as seen on figure 2 bellow. This is because women are plot managers in both female and male headed households as reported by Ndiritu *et al*. (2014). The inequalities in household decision making are a result of traditional and cultural factors, the uneven distribution of productive resources such as land, improved seed varieties, fertilizers, farm machinery, labor, training, and information between genders results in disparities in agricultural output(Gebre *et al*., 2019).

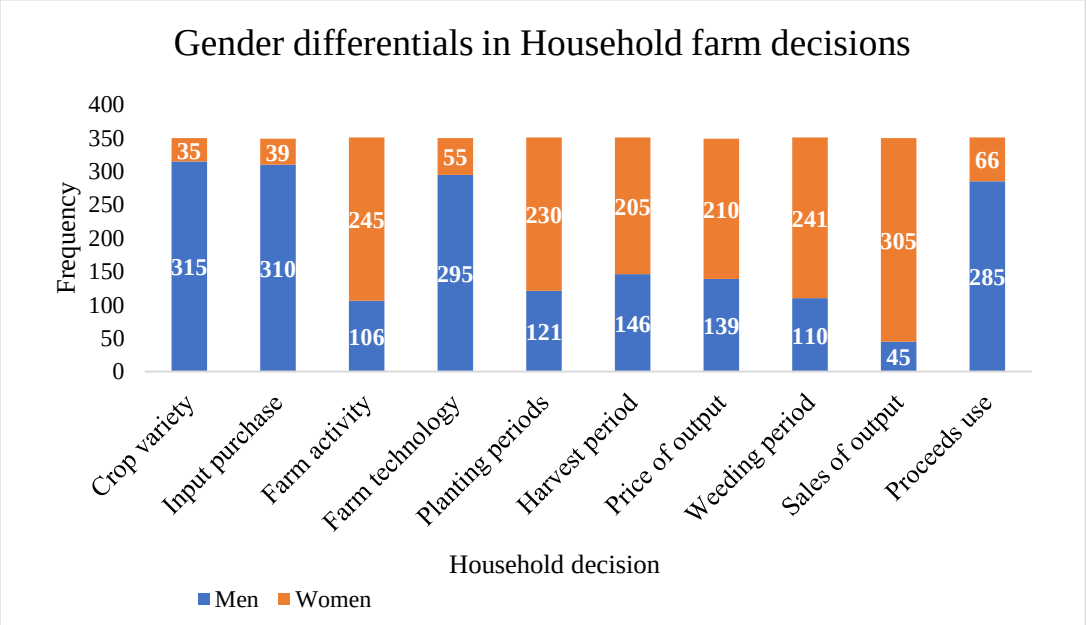


Figure 4. 22 Gender differentials in Household farm decisions

4.4.2 Inferential Statistics

4.4.2.1 Socio economic factors are not determinants of adoption of CA by small holder farmers.

The average age of agricultural household heads is estimated at 44 years, with 18 years of farming experience (table 4.13), thus indicating that the heads of these households are still in their productive agriculture years. Age plays a vital role in driving household decisions to embrace agricultural novelties in many adoption studies since it might represent experience in farming methods and use. However, age is said to have a diverse outcome on CAP acceptance (Nigussie *et al*., 2017). Furthermore, many homes (about 45 %) are headed by a woman. While this suggests that females play an important role in farming, it does not diminish the significance of male heads, who may be land administrators impacting adoption preferences.

The average home size in the study area is seven, which implies a typical large family environment. Most agricultural settings in developing nations have large family sizes, signifying the potential for family labour use. The average farm size cultivated by many farmers is 2.42 hectares, demonstrating that the mainstream of farmers in this area is typically rural farmers. The size of a farm influences technological adoption. Larger farm size holders are more inclined to accept new methods because they can devote a section of their land to testing emerging innovations, whereas farmers with smaller farmlands are far less willing to do so (Gebremariam &Tesfaye, 2018).

Table 4. 13 Description of Socioeconomic Variables

Variables	Description	Average	Std Dev.	Min	Max
Household Factors					
Age	Age of house head (years)	44.52	14.31	19	90
Farmhouse Size	Number of members in the house (count)	7.26	4.79	1	35
Gender	Gender of house head (Dummy, female=1, male=0)	0.55	0.50	0	1
Marital Status	1 = not married; 2 = common-law; 3 = married monogamy; 4 = married polygamy; 5 = widow; 6 = Divorce	2.71	1.34	1	6
Education	Years of education of household head (count)	1.39	0.80	0	7
Economic Profile					
Farm Size	Farmland size(hectares)	2.42	2.64	1	28
Farms Cultivated	Number of farms cultivated (in numbers)	2.28	1.51	0	10
Land Ownership	Land ownership status (1= family, 2= owned land, 3= leased land	0.50	1.76	1	3
Farm Experience	Household head farming experience (Years)	17.79	14.23	1	70
Distance from Home to Farm	Distance from farm households to farmland (in kilometres)	56.39	50.43	1	260
Access to Extension	Contact with extension worker (Dummy, yes=1, No= 0)	0.36	0.48	0	1
Access to Credit	Available agricultural finance (Dummy, yes=1, No= 0)	0.18	0.38	0	1
Received Government Subsidies	Farmers who received government subvention (dummy, yes=1, No=0)	0.08	0.27	0	1
Use of sustainable Farm Tech	Modern farm technology (dummy, 1=yes, No =0)	0.63	0.48	0	1
Perception of Soil Fertility	Perception on fertility of soil (1=very fertile, 2=moderately fertile, 3= not fertile	1.27	0.67	0	3
Perception of climate Variability	If farmers perceive variability in climate (Dummy, yes=1, No=0)	1.03	0.19	0	1

(Source: Analysis from Survey data, 2022)

Also, household size is a determining factor of CAP adoption, especially at the household level for family farms lands (Oyetunde-Usman *et al*., 2021). The size of the household, for example, is very necessary for adopting soil and water-saving technologies, because they demand additional labour requirements (Gebremariam & Tesfaye, 2018). Household statistics revealed that 80% of household heads had at least one year of formal training, implying that most household heads are uninformed and unable to understand the best farming techniques and technology knowledge uptake (table 4.13).

The survey also reveals that about half of household heads are tenure secured, which is ascribed to difficulties in transferring tenure rights, as in most Central African countries (Mugumaarhahama *et al*., 2021). While the role of extension service remains paramount to promoting modern agriculture, only approximately 36% and 18% of farmers had contact with an extension worker and financing, respectively. Contacts with extension advisers are critical for raising awareness and showcasing farm practical trials and techniques while prompting sustained adoption. Paradoxically, access to extension services remains low, indicating a significant alleged risk of CAP adoption among farmers. Nevertheless, research has proven that farmer contacts with extension advisers have a favourable stimulus on the uptake of innovative agricultural practices (Wekesa *et al*., 2018).

According to Wekesa *et al*. (2018), agricultural finance is a major driver of technological adoption. This study affirms this for only very few farmers had access to agricultural loans, a possible explanation for low adoption rates in this area. The average years of farming expertise in this area are 18 years. This knowledge allows them to compare the performance of new and old farming technologies and gain confidence in taking farming risks which is a critical aspect of agricultural success.

Furthermore, table 4.14 displays the multivariate probit model's coefficient estimations. The correlation of CAP error terms suggests our six CAPs under consideration are interdependent. The findings showed that the model's log-likelihood ratio (LR) of -1058.61 and the Wald2 (114) = 252.23 is significant at (P0.00), indicating that the model is well-fitting. The significance of LR also implies that the decision to use several conservation farming strategies is interconnected. This relevance level is derived from the fact that

identical unobserved home factors can influence the adoption of various CAP (Oyetunde-Usman *et al*., 2021). The gender of the house head has a beneficial consequence on agroforestry uptake.

According to findings from this research, men were more likely than women to use agroforestry. This prediction backs up prior research that males control farming resources and, as a result, easily embrace practices that require more resources (Negera *et al*., 2022; Oyetunde-Usman *et al*., 2021). However, it contradicts Musafiri *et al*. (2020), who showed that females are more likely to pursue agroforestry. The findings showed that old farmers use agroforestry, cover crops, and zero tillage more, whereas young farmers use more intercropping, crop rotation, and mulching.

The disparities in these practices could be attributed to young farmers' capacity to recognize the value of sustainable farming practices such as intercropping and mulching. These results conformed with those of Negera *et al*. (2022) who explained that older farmers prefer to stick to the practices they already know than indulge in new exploits.
Farm size is significant (p= 0.01) only for driving cover cropping adoption, meaning that an increase in farm size enhances the household's chances of adopting cover crops as a conservation farming approach. As a result, a farmer with a larger farm size has more financial resources and a greater area to devote to enhancing technology adoption. They can also purchase more advanced and sophisticated technologies, as well as the ability to bear the risk if the equipment fails to function properly.

Furthermore, Deininger & Castagnini, (2006) found that farm size was substantially connected to the likelihood of investing in conserving soil and water. However, as well as

contrast with such findings and further explained land size as a relative measure that is specific to the context and thus cannot be generalized.

Correspondingly, Khonje *et al*. (2018), found that farm size was associated with the adoption of numerous CAP methods since it mirrors capital, which alleviates liquidity limitations in applying the practices. They discovered that farmhouses with large farms have greater chances to use current technology than farmers with smaller farm sizes.
Contact with extension agents had a considerable beneficial influence on cover crop uptake, whereas mulching had a negative influence.

Extension agents are critical in raising knowledge of and showcasing new CAP technology. Fundamentally, the more contacts made, the more knowledge gained, because sustainable farming necessitates new abilities such as observation, monitoring, and risk assessment. The results relate to the necessity of knowledge on applying cover crop strategies rather than mulching. These results are in support of those of Daniso, (2022), who postulate that extension advice is for developing institutional frameworks that facilitate the propagation and transfer of information. However, our findings, agree with Anang & Asante, (2020), who emphasized the vitality of extension advice in increasing new farm method acceptance.

The availability of loans for farming has a negative impact on zero tillage adoption this is contradictory to the results of Lee & Gambiza, (2022). Farmers with access to agricultural financing no longer see the need to use zero-till since they have more money to spend on inputs for other techniques. Furthermore, the distance between home and farm encourages the use of agroforestry, intercropping, and zero tillage. Shorter distances encourage farmers to adopt these strategies. The number of farmlands a farmer owns has a favourable

influence on zero tillage adoption, and a farmer with more cultivable farms has the comfort of experimenting with various farming techniques on one of the farms. In contrast, marital status had a strongly negative relationship with zero tillage adoption. Marriage generates family labour, and because women and children can assist in crop production, processing, and marketing, the household can engage in more complex agricultural practices such as intercropping.

Land ownership also facilitates the household decision to implement innovative farm methods. According to findings from this study, land security played a substantial role in increasing the use of cover crops. Selahkwe *et al*. (2021) also reported land ownership to be a major factor in the adoption of compost in the western regions of Cameroon. As a result, farmers who own their farms may employ intricate and demanding conservation methods. This consequence could be because land security permits farmers to explore complicated technologies, impacting cover crop use. Also, soil fertility had a considerable impact on zero tillage adoption but had a negative impact on mulching adoption. This can be clarified further by stating that soil fertility is said to impact the uptake of recovery methods, and zero tillage is a soil fertility recovery practice. As a result, a farmer with infertile soils will prefer zero tillage to mulch. The discovery could boost soil fertility by utilizing minimal tillage, hence increasing livelihood and food security.

Furthermore, farmers may expect reduced output from infertile soils, resulting in a refusal to apply more costly strategies. This finding supports the findings of Musafiri *et al*. (2022). Furthermore, the coefficient for a farmer using modern farm technologies such as improved seeds is a significant promoter of the adoption of intercropping and mulching as conservation farming methods. However, modern farm technology is a promoter of farmers' uptake of cover crops and zero-tillage. Results from this research postulate

modern agricultural techniques to be an improving factor for the likelihood of farmers in Cameroon's South and East Forests using conservation farming strategies such as intercropping and mulching.

The number of animals owned has a favourable influence on intercropping, cover crops, and crop rotation adoption but has a negative influence on agroforestry adoption. The findings revealed that as animal ownership increased, so did the proclivity for intercropping, cover crops, and crop rotation. The larger requirement for animal manure for crop farms may explain the influence of livestock ownership on intercropping, cover cropping, and crop rotation. However, animal dung might potentially be used to boost soil fertility by being applied to agricultural land. Nonetheless, these outcomes line up with Ndeke, (2021), who indicate keeping livestock is a strong predictor of improved technology adoption.

Table 4. 14 Econometric Estimates of factors influencing CAP Adoption amid rural farm households in Cameroon

Parameters	**Agroforestry**		**intercropping**		**Cover cropping**		**Crop rotation**		**Mulching**		**Zero -tillage**	
	Coef	*Se*	*Coef*	*Se*	*Coef*	*Se*	*Coef*	*Se*	*Coef*	*Se*	*Coef*	*Se*
Gender	0.581***	0.158	0.239	0.157	-0.166	0.170	0.165	0.171	-0.148	0.185	0.210	0.167
Age	0.019**	0.007	-0.005	0.007	0.013*	0.007	-0.007	0.007	-0.007	0.009	0.015**	0.008
Land Size	0.047	0.035	-0.015	0.029	0.050*	0.030	0.008	0.034	0.028	0.031	-0.070	0.043
Farm Experience	-0.008	0.007	0.006	0.007	-0.008	0.007	-0.001	0.008	-0.005	0.008	0.003	0.007
Access to Extension	0.057	0.164	-0.166	0.165	0.423**	0.170	0.024	0.178	-0.446**	0.209	0.068	0.169
Agricultural Credit	0.217	0.212	-0.343	0.212	0.006	0.220	0.198	0.218	-0.006	0.245	-0.711**	0.226
Distance home-farm	0.003*	0.002	0.003*	0.001	0.001	0.002	0.000	0.002	0.003	0.002	0.003*	0.002
Number of farms	0.027	0.053	0.017	0.049	-0.038	0.060	-0.020	0.058	0.062	0.057	0.104*	0.057
Farmhouse size	-0.007	0.016	0.012	0.016	-0.008	0.017	-0.011	0.017	-0.005	0.018	-0.025	0.018
Marital status	0.014	0.060	-0.055	0.060	-0.079	0.066	0.025	0.065	0.044	0.072	-0.122*	0.066
Education	0.000	0.092	-0.022	0.091	0.089	0.094	-0.110	0.103	-0.055	0.119	0.155	0.095
Land ownership	-0.122	0.151	-0.181	0.152	0.349**	0.169	0.216	0.165	-0.004	0.177	-0.170	0.158
Soil fertility status	-0.003	0.108	-0.045	0.111	-0.089	0.122	-0.012	0.129	-0.439**	0.134	0.250**	0.116
Modern farm technique	0.075	0.160	0.310**	0.158	-0.327*	0.169	-0.173	0.174	0.803***	0.211	-0.857***	0.160
Government subsidy	0.127	0.304	0.145	0.295	-0.068	0.295	0.294	0.295	0.647**	0.337	0.052	0.317
Climate variability	0.265	0.360	0.706*	0.417	0.110	0.378	-0.573	0.496	0.216	0.434	-0.487	0.457
Livestock owned	-0.067***	0.018	0.098***	0.019	0.079***	0.021	0.061**	0.022	0.009	0.021	-0.026	0.019
Persistent soil erosion	0.168	0.160	-0.292*	0.158	0.269	0.166	0.175	0.171	0.055	0.188	0.142	0.163
_cons	-0.736	0.606	-1.174*	0.629	-2.256**	0.649	-0.691	0.713	-1.151	0.725	0.035**	0.660

N = 350 Log Likelihood = -1058.6109 Wald chi2 (114) = 252.23 Prob> Chi2= 0.000 *** 1%, ** 5%, * 10%
Source: Computed from Field Survey (2020)

4.4.2.2 Adoption Intensity

Smallholder farmers must enhance their adoption intensity to improve agricultural yields and revenue while also reducing the effects of climate change (Oyetunde-Usman *et al*., 2021). From our findings the model used is significant, as indicated by the LR Chi^2 (18) = 41.36 and Prob > chi^2 = 0.0014. This degree of significance shows that the ordered probit model is trustworthy. The gender of the household head indicated the severity of CAP adoption (Table 4.15).

Table 4. 15 Factors that influence the intensity of adopting Conservation Agricultural Practices

Variables	Coefficient	Std Error	P-Value
Gender	0.2550**	0.1219	0.037
Age	0.0061	0.0055	0.268
Land Size	0.0114	0.0228	0.617
Farm Experience	-0.0035	0.0054	0.518
Access to Extension	0.0126	0.1264	0.921
Agricultural Credit	-0.0369	0.1611	0.818
Distance from home to farm	0.0026**	0.0011	0.022
Number of fields cultivated	0.0554	0.0395	0.160
Household size	-0.0123	0.0121	0.311
Marital status	-0.0291	0.0469	0.536
Education	-0.0185	0.0709	0.794
Land ownership	-0.0007	0.1180	0.995
Perception of soil fertility	-0.0168	0.0859	0.845
Use of modern farm techniques	-0.1317	0.1224	0.282
Government subsidy	0.3784*	0.2257	0.094
Perception of climate variability	0.0231	0.2815	0.935
Livestock owned	0.0742***	0.0148	0.000
Persistent soil erosion	0.1439	0.1223	0.239
Number of observations =350	LR Chi^2 (18) = 41.36	Prob > chi^2 = 0.0014	
Log Likelihood = -612.735	Pseudo R^2 = 0.0326		

*** p<0.01, ** P<0.05, * p<0.1 Source: Computed from Field Survey (2020)

According to the findings, male-headed households improve their agricultural methods more than female house heads. This can be ascribed to the fact that men in this area have an edge over land and labour (Kasaw *et al*., 2019). However, these results are contrary to those of Oyetunde-Usman *et al*. (2021), which postulate that female-headed families boost

sustainable farming methods, attributing this to a shortage of complementary inputs. They are, nevertheless, identical to Musafiri *et al*. (2022). A short distance from home to farmland affects CA adoption intensity positively and significantly, which is consistent with other findings (Zakari *et al*., 2022). Given that valuable equipment and materials are typically housed in households for security reasons, the closer the land is to the house, the greater the likelihood of storing and, as a result, adopting CAP.

Our results reject the above claim which showed smallholder farmer adoption of more than one CAP increased with distance from the farm. This is attributed to the fact that households that reside far from the farm, nevertheless, are more likely to use CAP. This conclusion explains why farmers will want to optimize the amount of time they spend on the farm and so implement many farm technologies to ensure a satisfactory harvest if one way fails. Contrary to popular belief, access to farms that drive adoption may not be limited by distance and may rely on locally available information networks. The strong forecast of our results of government subsidies on multiple CAP adoption meant that smallholder farmers who got subsidies were more inclined to intensify agricultural methods. Receiving subsidies encourages the smallholder farmer to try a new farm practice, thus boosting their use of CAP.

Furthermore, livestock ownership has a considerable impact on CAP intensification, supporting table 4.15. This finding emphasizes the significance of animals in agricultural intensification, with the fact that animal droppings are employed as manure. However, these outcomes line up with the results of Ehiakpor *et al*. (2021), who ascribed cattle ownership to have a considerable impact on the intensity of sustainable farming methods uptake. This fervour is ascribed to the likelihood of selling animals to buy farm needs like agricultural chemicals, manures, and improved seeds.

4.5 Effects of Conservation Agriculture on smallholder farmers livelihood security

4.5.1 Characterization of livelihood

4.5.1.1 Household Nutrition Status

Figure 4.23 displays the food class consumed by farmers in the study area on a weekly basis. Farmers in their weekly consumption consumed more of starchy food specifically more of cassava and its derivatives in both regions (98.6%). This was followed by Protein (54.9%) in and vegetable (60.3%) in the east region, but generally protein was the second most consumed in both regions, followed by vegetable and very little quantities of Iron containing food like plantain and banana.

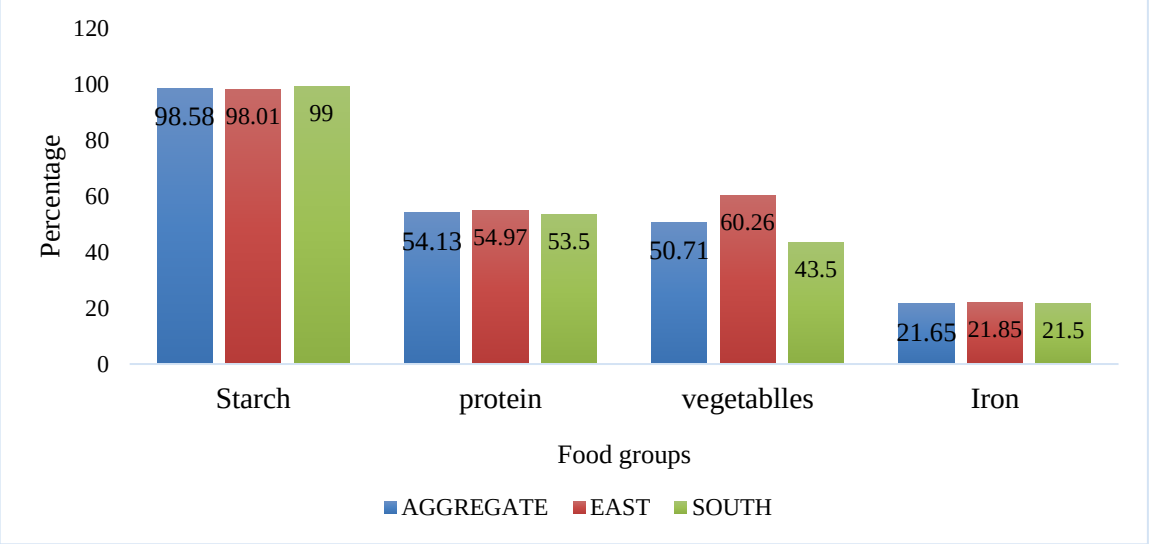


Figure 4. 23 Weekly food group household consumption (Source: Analysis from field survey, 2020)

Smallholder farmers diets in the study area composed mainly of starchy staples especially, cereals, roots, and tubers compared to other food groups. Animal flesh constitute the main source of protein in this area and consumption of fruits, legumes and vegetables source proteins is low when compared to other food groups and the individual nutrient requirements as shown on figure 4.23. The higher consumption of meat (bush meat) in

these two regions can be attributed to their proximity to forests. These results are in complete agreement with the results of (Herrador *et al*., 2015). Iron derivative foods were the least consumed in these two regions, this might lead to iron deficiency to the members of the household.

However, Iron deficiency is estimated to be the most prevalent nutritional deficiency, affecting four to five billion people. The estimated prevalence of iron deficiency among children under five years of age in 80 developing countries in 2004 was 54 %. In young children iron deficiency may impair growth, cognitive development, and immune function. In school-aged children, it can affect school performance, and in adults it may lower work capacity. Iron deficiency anaemia is responsible for tens of thousands of maternal deaths each year (UNSCN 2004). Generally, amidst the smallholder households, Diet was in majority not balanced 52.9%. Farmers averagely in a week will consume mostly unbalanced diet food types. On the other hand, 47.1% of the farmers consume balance diet (fig 4.24)

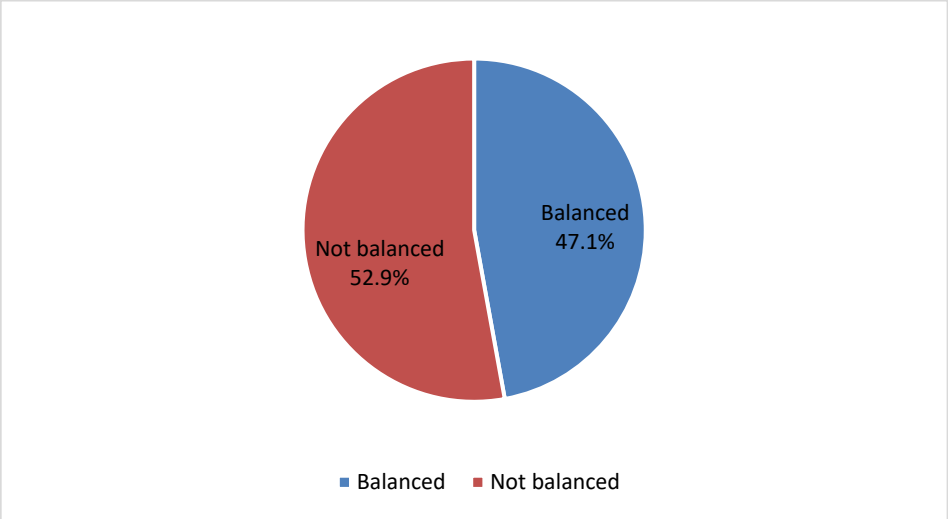


Figure 4. 24 Weekly diet type (Source: Analysis from field survey, 2020)

4.5.1.2 Household Health Status

Better health and nutrition, as related to labour productivity or better production organization (since deciders in good health generally have better intellectual capacities), can increase household income and economic growth. Poor health will result in a loss of days worked or in reduced worker capacity, which, when family and hired labour are not perfect substitutes or when there are liquidity constraints, is likely to reduce output. The elasticity of agricultural output or wages with respect to nutrition and health status is an indication of the strength of the productivity-nutrition and health relationship. Farmers of study area fall sick averagely two times a month in both regions of study and generally, both male and female households had on average 1 terminal disease patient in their households. The maximum number of terminal disease patients per household was two (Table 4.16)

Table 4. 16 Number of terminal disease patients in the household

Gender	N	Mean	Std. Dev	Minimum	Maximum
Male	210	1	0.5	1	2
Female	141	1	0.5	0	2
Total	351	1	0.5	0	2

(Source: Analysis from field survey, 2020)

With respect to healthcare, in the East region, household members mostly go to the hospital when seek 70.2%, followed using traditional herbs 58.94%, then roadside drug 29.5% (fig 4.25). The South region had a higher percentage consulting in the hospital (81%), this might be explained for their more accessibility to primary healthcare not far from the villages. This further explains the lower percentage (37.5%) of farmers in the south who used traditional herbs as compared to those of the East region and 29.5% for those who employed roadside medications. On a general perspective, majority of farmers in both

regions employed hospital care when they were sick, followed by traditional herbs and very few sought the aid of roadside medications. This is an indication that the farmers of this area were health secured for they had clinics available to them and medication when need arise. Farmers that use health centres when sick will obviously be treated quickly and will regain more strength to work curbing longer periods of sickness that will greatly reduce labour hours. These results were in concordance with those of Combary. (2016) who reported that farmers that used health centres services in the case of an unexpected disease during farming activities recorded a significantly higher farming productivity.

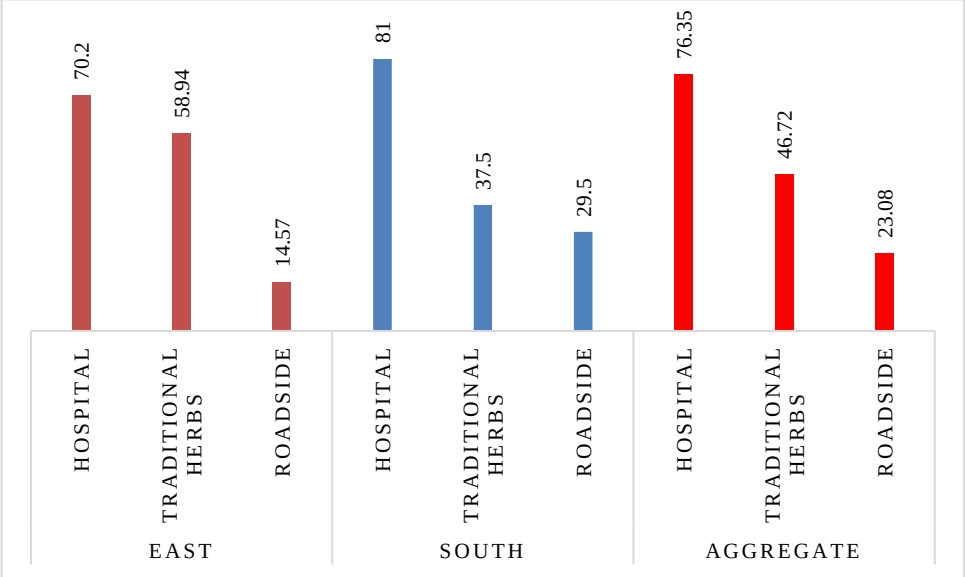


Figure 4. 25 Farmer use of health care facilities (Source: Analysis from field survey, 2020)

4.5.1.3 Household feeding times and Sanitation

Sanitation is the United Nations declared human right and without access to it, many communities are left vulnerable to impacts on health, dignity, negative economic and education effects. Lack of latrines mostly affects the poor, rural and marginalized communities as majority (71%) of those who do not use improved latrines live in rural areas where 90% of all open defecation takes place (table 4.17). In regions where the

population does not have access to sanitary facilities example latrines, people practice open defecation, exposing themselves and their communities to major health risks. Majority of households (77.4%) in the study area generally agreed to have latrines in their houses. This implies a reduction in rates of open defecation ensuring for improvement in household health status (fig 4.25).

Table 4. 17 Some selected livelihood characterization variables

Region	Variables	Min	Max	Mean	Std. dev
EAST	Average eating time	1	3	2.16	0.54
	Frequency of sickness	0	18	2.47	3.46
	Number of times toilet is cleaned	0	3	0.53	0.72
	Members living out of the village	0	14	2.77	3.06
	Number of schooling children	0	30	1.53	3.08
South	Average eating time	1	5	1.86	0.50
	Frequency of sickness	0	8	2.11	1.20
	Number of times toilet is cleaned	0	5	2.45	1.77
	Members living out of the village	0	25	2.75	4.01
	Number of schooling children	0	15	3.06	2.63
Aggregate	Average eating time	1	5	1.99	0.59
	Frequency of sickness	0	18	2.26	2.45
	Number of times toilet is cleaned	0	5	1.62	1.71
	Members living out of the village	0	25	2.76	3.66
	Number of schooling children	0	30	2.40	2.93

(Source: Analysis from field survey, 2020)

Households in the study area clean their latrines averagely two times (table 4.17) in a year but there is the tendency of indirect everyday cleaning. This is because most of these latrines are not the improved ones and so households with this type of latrines use them as bathrooms so as they bath, they clean automatically. These results corroborate with those of (Gashaw Dagnew *et al*., 2019).

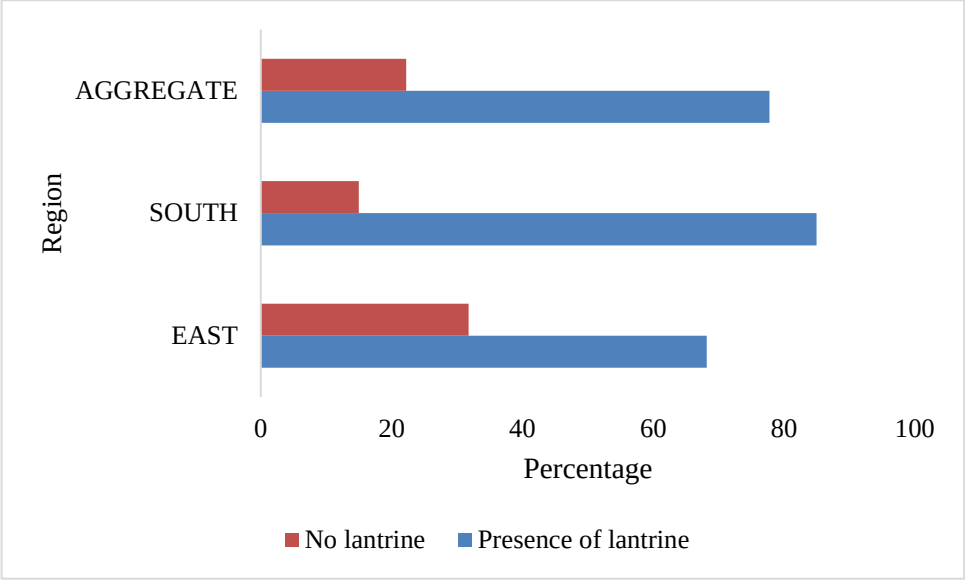


Figure 4. 26 Possession of latrine (Source: Analysis from field survey, 2020)

4.5.1.4 Household assets ownership

Figure 4.26 shows farmer ownership of household assets in the study area. A rapid diffusion of mobile phones/TV and radio can increase information flow, reduced telecommunication costs, and led to novel strategies for economic development. The ubiquity of assets throughout sub-Saharan Africa can offer new opportunities for rural households to realize a broader set of livelihood and development goals. Information and communication technologies (ICTs), including mobile phones, TVs and radios have been shown to help reduce poverty in sub-Saharan Africa by strengthening and expanding social networks, cutting down on travel costs, maximizing the outcomes of necessary journeys, managing human-wildlife conflict, conducting business and financial transactions, and increasing the efficiency of livelihood activities.

Generally, farmers from the two regions owned more of phones than TV and radios (fig: 4.26). Phones are becoming a better and more assessable tool for communication which also helps in information dissemination thus extension services could use the phone numbers of farmers to send information in cases where they cannot make it to the villages.

Mobile telephony and the introduction of mobile-enabled information services provide ways to improve information dissemination to the knowledge intensive agriculture sector and helps to overcome information asymmetry existing among the group of farmers. It also helps, at least partially, to bridge the gap between the availability and delivery of agricultural inputs and agriculture infrastructure. Our findings were in line with those of (Quandt *et al*., 2020).

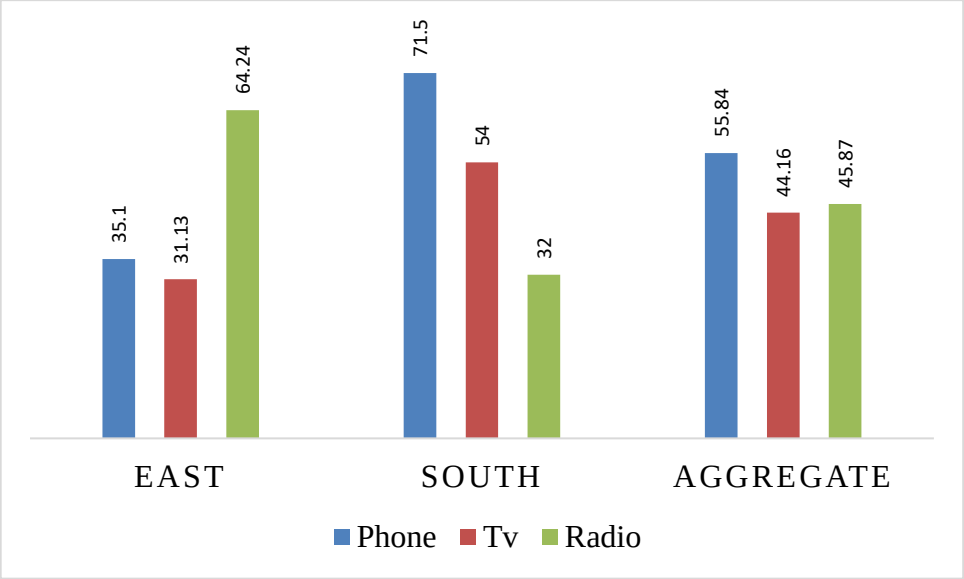


Figure 4. 27 Household assets ownership(Source: Analysis from field survey, 2020)

4.5.1.5 Portable Water sources and sanitation

Sources of portable water in the study area is shown on figure 4.27. Water supply and sanitation are often more challenging in rural areas, due to their environmental fragility and relatively poor economic conditions. Rural areas are home to most of those who lack access to unimproved sources of drinking water and safe sanitation: for example, in Sub-Saharan Africa, 10 % of the population consume untreated surface water, while 20 per cent of the rural population lack safe sanitation. In rural areas, public water provision and sanitation services, as well as water infrastructures such as water collection points, pit latrines and septic tanks, are often inadequately maintained and in poor shape.

Additionally, to this lack of services, natural water sources such as wells, pumps, and rivers are often contaminated and provide an unreliable supply. In the east the most common and available drinkable water source is the stream and borehole whilst in the south the most common is the spring and the borehole. In general, the most common and used drinkable water sources in this study area were the spring and borehole.

There was pipe born sources, but they were not functional and not maintained. These findings corroborated with those of Ako *et al*. (2010) who reported that the biggest problem in Cameroon is not the availability of water; it is the poor management and development of the resources, coupled with inadequate political will and commitment for the long term.

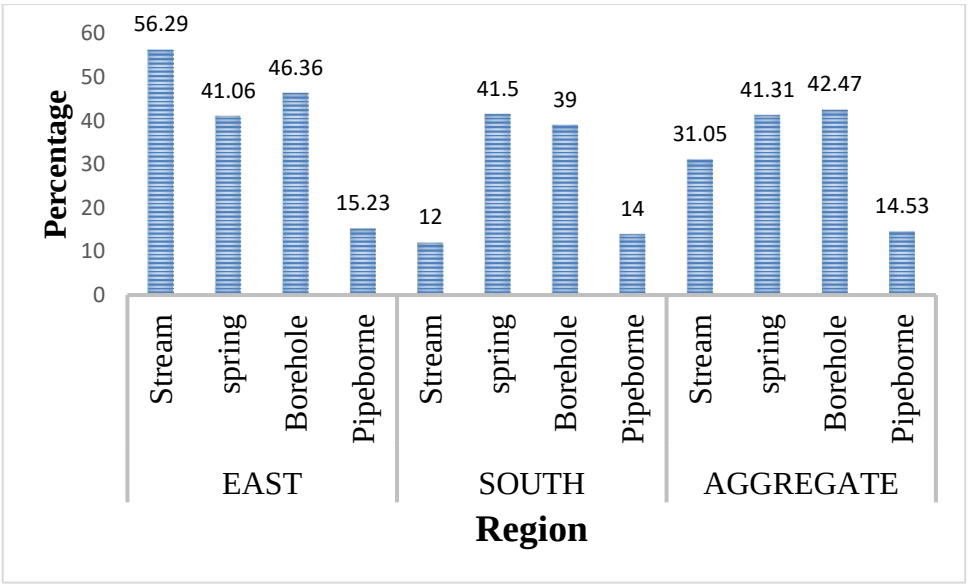


Figure 4. 28 Drinkable water sources (Source: Analysis from field survey, 2020)

4.5.2 Impact of Conservation Agriculture adoption on smallholder farmer livelihood security

4.5.2.1 Endogenous treatments effects with maximum likelihood

Farm income was the focus of the ESR's second set of outcome equations, which analysed the factors influencing the outcome considering CA adoption. The analysis showed that farmer and farm characteristics had a substantial impact on household well-being (Tables 4.18, 4.19 and 4.20). As seen on tables 4.18, age, number of cultivated lands, farm experience of the household head, and adoption of CA all significantly predicted farm income in the study area. Our results contradict those of Akter *et al*. (2021), who had education and marital status as factors that influenced farm income.

Table 4. 18 Endogenous treatments effects with maximum likelihood estimates in the East Region

	Outcome equation (logincome)		Selection equation (CA adoption)	
	Coef	Pvalue	Coef	Pvalue
Gender	-0.151	0.501	-0.301	0.392
Household size	-0.015	0.967	-0.270	0.68
Age	1.648	0.058*	-0.872	0.532
Landsize	-0.226	0.507	-0.101	0.854
Farm experience	-0.497	0.094*	0.521	0.289
Access to extension	-0.054	0.809	-0.692	0.07
Land ownership	-0.193	0.423	0.217	0.572
Number farmlands	0.163	0.06*	-0.408	0.027
Adoption	2.368	0.000***		
Education			0.192	0.586
Distance home-farm			0.406	0.319
Farm income			4.495	0
_cons	1.804	0.172	-23.454	0
Observations	150			
Wald Chi2(17)	92.85			
Prob>Chi2		0.000***		
lambda	-1.34446	0.000***		
sigma	1.2699758			
rho	-1.00000			

*Significant at 10%, **significant at 5%, ***significant at 1%. Source: Computed from Field Survey (2020)

Age of household head could be an eye opener for a farmer to know if there are issues with current production trends and will be prompted to seek solution by adoption CA which of course boast production and thus farm income. As might be expected, increasing financial success followed CA's widespread implementation. The more farmers embrace and implement CA practice on their farms, the greater the yields, and the more goods are sent to market.

Surprisingly, increased farm experience is associated with lower earnings. The older and more seasoned a farmer is, the less likely they are to embrace new farming techniques, leading to a decline in their farm's income. The financial success of farms was significantly and favourably impacted by the number of cultivated lands. The more the number of cultivated lands the more likely the farmer is to try out new farm methods which increases the level of CA adoption and thus increase yields which are associated with increase farm income. These results agree with those of Liang *et al*. (2021) and Makate *et al*. (2019).

Furthermore, our research demonstrated that gender played a positive and statistically significant role in farm income in the southern region (table. 4.19). When comparing households headed by men and women, those headed by women are 5% more likely to adopt CA technology. In line with the results of Khonje *et al*. (2018) and Teklewold *et al*. (2013). The farm income of south region farmers is significantly and favourably impacted by their ownership of land. Farmers who cultivate on their own plots have an advantage in adopting CA because it can boost their yield and, in turn, their income. Farm income is positively influenced by factors such as the gender, the farmer's experience, the owner's control over the land, and the use of CA.

Table 4. 19 Endogenous treatments effects with maximum likelihood estimates in the South Region

	Outcome equation (logincome)		Selection equation (CA adoption)	
	Coef	Pvalue	Coef	Pvalue
Gender	0.893	0.002***	-0.509	0.392
Household size	-0.019	0.969	-0.786	0.68
Age	-0.007	0.525	0.011	0.532
Landsize	0.229	0.532	0.117	0.854
Farm experience	-0.824	0.063*	1.443	0.289
Access to extension	0.025	0.928	-0.044	0.07*
Land ownership own	1.065	0.000***	-0.945	0.572
Number of fields cultivated	-0.080	0.36	-0.212	0.027**
Adoption	3.519	0.000***		
Education			-0.022	0.586
Distance home-farm			-0.931	0.319
Farm income			8.766	0.000***
_cons	2.656	0.000***	-45.758	0.000***
Observations	200			
Wald Chi2(17)	230.19			
Prob>Chi2		0.000***		
lambda	-1.922			
sigma	1.780			
rho	-1.000			

*Significant at 10%, **significant at 5%, ***significant at 1%. Source: Computed from Field Survey (2020)

These results align with those of Liang *et al*. 2021 who reported that, larger farmland owners are more likely to use adaptive and mitigative farm strategies. However, there is a strong and negative correlation between years of farming experience and farm income. Therefore, a farmer who adopts CA will experience an increase in farm income. This increase in farm income further encourages them to adopt more of CA in their cultivable lands.

Generally, gender is a positive and significant determinant of farm household income(table 4.20).Gender roles often dictate the division of labor within agricultural households(Tsige et al., 2020).

Table 4. 20 Endogenous treatments effects with maximum likelihood estimates in the Both Region

	Outcome equation (logincome)		Selection equation (CA adoption)	
	Coef	Pvalue	Coef	Pvalue
Gender	0.477	0.023**	-0.436	0.095*
Household size	0.012	0.972	-0.472	0.328
Age	0.098	0.905	0.065	0.95
Land size	-0.012	0.967	-0.247	0.539
Farm experience	-0.727	0.014**	0.531	0.167
Access to extension	-0.061	0.761	-0.369	0.158
Land ownership own	0.558	0.009***	-0.017	0.952
Number of fields cultivated	-0.017	0.808	-0.168	0.125
Adoption	3.447	0.000***		
Education			-0.101	0.681
Distance home-farm			-0.139	0.645
Farm income			4.721	0.000***
_cons	2.962	0.015**	-25.042	0.000***
Observations	350			
Wald Chi2(17)	294.79			
Prob>Chi2		0.000***		
lambda	1.914			
sigma	1.771			
rho	-1.000			

*Significant at 10%, **significant at 5%, ***significant at 1%. Source: Computed from Field Survey (2020)

Men and women may have different responsibilities and tasks related to farming activities. For example, men may be responsible for plowing, harvesting, and marketing produce, while women may engage in activities like planting, weeding, and processing. The division of labor can impact income generation, as different tasks may have varying levels of profitability or access to markets(Naz & Doneys, 2022). Farm experience appeared to be negatively affecting farm household income(table 4.20). Farm experience refers to the knowledge, skills, and expertise acquired by individuals through their years of involvement in farming activities(Chuma et al., 2022).

However, this form of human capital is typically considered valuable as it enables farmers to make informed decisions, implement effective farming practices, and adapt to various challenges (Iakovidis et al., 2022). This negative impact of farm experience on farm household income, therefore, suggests an interesting relationship between human capital and financial capital. However, this farm experience may be based on traditional or outdated farming methods that are no longer profitable or competitive in the current agricultural market. As technology, market demands, and farming techniques evolve, relying solely on past experiences without adapting to new practices can lead to reduced income(Sgroi, 2022).

Also, this farm experience may be focused on a particular type of crop or livestock production. If the farm household relies heavily on a single product or limited range of products, income can be vulnerable to price fluctuations, market saturation, or disease outbreaks(Zorn & Zimmert, 2022). Diversification into alternative crops, value-added products, or non-farm income sources can help mitigate these risks. However, farm experience alone may not be sufficient if farmers lack access to necessary resources such as land, capital, improved seeds, fertilizers, or modern farming equipment. Limited access to resources can hinder productivity and income generation, even for experienced farmers(Reimer et al., 2022).

Furthermore, landownership status had a positive and significant effect on farm household income. Owning land provides several benefits and opportunities for farmers that can contribute to their income generation. Owning land gives farmers greater control over their farming operations(Cong et al., 2020). They can make independent decisions regarding

crop selection, production techniques, and marketing strategies. This autonomy allows them to optimize their farming practices and maximize their income potential.

Additionally, adoption of conservation agriculture had a positive and strongly significant effect on farm income of smallholder farmers in the study area. Conservation agriculture practices help to improve soil health and fertility (Michler et al., 2019). By minimizing soil disturbance, such as reduced tillage or no-till practices, the soil structure is preserved, and beneficial soil organisms thrive. This leads to better nutrient availability and water-holding capacity, resulting in improved crop growth and productivity. Higher crop yields translate into increased farm income(Ng'ombe et al., 2017). Furthermore, adopting conservation agriculture can lead to cost savings for smallholder farmers. By minimizing soil disturbance, farmers can reduce the need for expensive machinery and fuel associated with conventional tillage. Additionally, conservation agriculture practices often require less labor for land preparation, allowing farmers to allocate their resources more efficiently. Lower production costs contribute to increased farm income(Dagunga et al., 2021).

4.5.2.2 Average treatment effects

Table 4. 21 Average treatments effects estimates in the study area

Index	Income		
	Estimate	Std.err	*p*value
ATE East region	1.495616	0.2527	0.000
ATE South region	3.116945	0.2285	0.000
ATE Aggregate	2.529378	0.1853	0.000

Source: Computed from Field Survey (2020)

According to Table 4.21, a farmer in the East who implements a CA strategy sees a 1.5-fold increase in farm income compared to a non-adopting farmer, while a farmer in the

South sees a 3-fold increase. On average, the study indicates that farmers who implement a CA strategy see 2.5 times increase in farm income compared to those who do not. However, giving an explanation to our results from ESR's Average Treatment Effect (ATE) analysis which demonstrate that non-adopters would have benefited from increased farm income had they adopted CSA technologies. According to these results, the adopters of CSA would have been worse off economically if they hadn't done so. Both Mujeyi *et al*., (2021) and Maseko, (2021) found results consistent with these.

4.6 Policy Interpretations of Empirical Findings

Overall, this study found that majority of respondents (95.4%) from both regions knows about climate change or have perceived climate change. This means that farmers in this area are fully aware of changes in climatic elements (Aidoo *et al*., 2021; Nyang'au *et al*., 2021; Ojo & Baiyegunhi, 2021). The nature of changes perceived by farmers of these regions are increased temperatures (61.3%), decrease in rainy days (60.7%), late rain periods (51.8%) and colder dry seasons (50%). This indicated that farming is affected to a large extent. These changes bring about wind/ thunderstorms (60.3%) which cause severe damages to crop by pulling crops out from the ground or knock them over. This could also dry out wet plants, move soil and cause erosion not leaving out the movement and dispersal of seeds. Perception is also higher among the female (96.2%) than the male farmers (94.8%).

These findings designate a link between climate perceptions and peasant household gender roles. This infer that men and women are more likely to perceive climate related changes that more directly affect their social activities undoubtedly due to their scuffles to fulfil their societal responsibilities. In this regard, women's traditional role of safeguarding food

availability in the household makes them profounder on the hindrances to realizing this goal. For instance, in these regions women are responsible for preserving (drying) of foodstuffs such as cassava and maize. Decrease in temperature can depict their quandary of having dry foodstuffs for longer periods of time under the sun; meanwhile the consequences of increased temperature, flood frequency, changes in seasons, late rains, drought severity and frequency present multiple restraints to achieving their role as homemakers. These findings are in conformity with previous studies in Ghana (Jamal *et al*., 2021; Assan *et al*., 2020), Uganda (Kisauzi *et al*., 2012).

The results present that farmers' age and farm experience are not significant predictor variables for the perception of climate variability contrary to our expectations. This fails to agree with the findings of Hitayezu *et al*. (2017), Kurukulasuriya *et al*. (2006), Gbetibouo *et al*. (2010) and Epule & Bryant, (2014). Who postulated that an ageing farmer becomes more familiarized with climatic events, he/she could lack complex cognitive and mental resources and rely on his personal experience to judge the riskiness of climate. Farmers' years of experience is a function of age and hence influences perception of variations in climatic elements. This could be attributed to the fact that many of the farmers in the study area are above 30 years of age with atleast10 years of farming experience. Throughout their farming years/ cropping cycles, they have witnessed crop damages, long periods of dry spells, windstorms which are some negative consequences of climate variability. Hence, should justify for the significance of the predictive power of farmers' age and farming experience on the perception of climate variability (Tripathi & Mishra, 2020). This is thus in agreement with the findings of Nyang'au *et al*., 2021.

Also access to extension services is weighty factor of climate perception. This can be ascribed to the fact that the farmers have access to extension services from agents in the Sub- Divisional Delegations of Agriculture and Rural Development; Fisheries, livestock, and Animal Industries; Forestry and Wildlife; Chamber of Agriculture. These agents disseminate information on climatic factors as well as new technologies to farmers to ensure best farm practices. The farming techniques include climate-smart agricultural strategies (intercropping, agroforestry, mulching, mixed cropping, zero tillage, bush fallowing, shifting cultivation, crop rotation, cover crops, artificial irrigation, soil water management, nutrient management, wood ash application, etc), and integrated pest management techniques which involves the use of biological, cultural, physical, mechanical, and in the worst-case chemical means to control crop pests. Workers from these agencies are better informed on changes occurred in climate over last few years and therefore when they associate with farmers, they play a critical role to help farmers to know of these changes and be able to determine if there are changes or not.

These findings are in conformity with those of Mairura *et al*. (2021), Nyang'au *et al*. (2021), and Foguesatto *et al*. (2020). These findings differ with those of Maddison 2006 who noted that perception of climate change appears to be a hinge on farmers' accumulated experience and provision of free extension service specifically related to climate change. On the other hand, Antwi-Agyei & Stringer, (2021), argues that farmers with access to extension services are likely to perceive changes in climate because the extension support provides information about climate and the current weather, which was the contrary to our findings.

On the Contrary, the results show that educational level is not a significant factor influencing perception. The mean level of education attainment was primary (51.4%) with respect to secondary (36.9), tertiary (2%) and never been to school (9.7%). This shows clearly that an overwhelming majority of the farmers attain primary education. This attributes to the fact that since most farmers had just primary education, they couldn't have had enough knowledge on climate change and hence poor perception. This varies with the results of Asrat & Simane, (2018) and Deresa *et al*. (2009) who reported educational level to be a significant predictor of farmer perception of climate change.

In addition, drought which is a factor of climate variability did not influence the perception of farmers on climate change. This could be because most of the farmers attributed the drought incidence to their cultural ties and some accused the companies in that area carrying out deforestation to be the ones that have exposed their land to drought. Some of these farmers even mentioned that they are very fine and never experienced drought till these timber companies started works of deforestation in this area.

Adoption of at least a conservation agricultural practice increases a farmer's livelihood or ensures the farmers' livelihood is secured. This agreed with previous studies of Ali & Erenstein, (2017), As expected, farmers who adopted the conservation agricultural practices reported an increase in crop yields and the regression analysis confirmed this with its significance. Increase in crop output translates directly on farm income since they have more marketable surplus and thus more income. This is credited to the use of at least one or a combination of the conservation agricultural practices such as mulching, mixed cropping, intercropping, crop rotation, etc. This is in conformity with the study by Tshuma *et al*., 2012 who reported that CA strategies have huge potentials to improve food security

status of smallholder households as well as asset base and income levels, as such improving their livelihoods outcomes.

4.7 Discussion

Adaptation to climate change in smallholder agriculture is a very important tool for poverty reduction and maintenance of ecosystem health. This does not end here for it goes further to improve on agricultural productivity and income of smallholder farmers thus improving on their livelihoods. To adapt to climate change, farmers first perceive the fact that climate is changing after doing so they then adapt to these changes most often by changing or modifying their agricultural practices.

This thus, makes adaptation to climate change a two-step process where a farmer perceives climate change first then goes ahead to adapt. In the east and south regions of Cameroon, smallholder farmers well perceived this problem of changing climates, this was equally evident from field observations where you could see cracks on the ground, trees drying off and heatwave. From these a great number of these farmers attempted adaptations by adopting conservation agricultural practices to minimize the negative effects that compromised their farm productivity and livelihood security. However, different environmental, institutional, and socio-economic factors affect farmers' climate change perception and subsequent adaptation behaviour.

Our results revealed that farmers in this study area perceived climate change. This can be associated to late rains, shorter rainy seasons, temperature rises and the loss of crops due to rainfall and temperature changes in both regions. Furthermore, these environmental changes often cause reduced water availability and agricultural yield.

Regarding adaptation measures, better adaptation is revealed in the East as compared to the South region. This difference in the two regions is a call for further heightening of intervention in the two regions most especially in the south region to facilitate the prospect for enhanced climate change perception and adaption by taking up new agricultural practices most especially the conservation agricultural practices.

More so, we cannot over emphasize the relevance of different agronomic practices as adaptation measure is increasing over the years in the study area to lessen the challenges of climate factors on agriculture. Some of the agronomic practices such as adjusting planting dates is common in both regions in response to changes in the time of onset of rainy season, early cease of rain and temperature fluctuations. Agroforestry is another agronomic practice that has emerged in these regions attributed to farmers' risk aversion behaviour. Moreover, adopting agroforestry has a very pertinent role in climate change mitigation and thus promoting the crusade for REDD+. Farmers in the south are more likely to implement soil management practices as adaptation strategies than farmers of the East. This is because of the recurrent soil erosion and the terrain of most of their farms that makes these farms more susceptible (slopes) to climate change risks. Thus, farmers invest in soil conservation practices where they expect more risk from climate hazards. Farmers in the East region therefore invest more on crop and field conservation practices because they don't have issues with the terrain of their farms and do not experience a lot of soil erosion thus pay more attention to crop and field management.

Farmers who experience high/increase in crop yields did not see reasons of changing their farming methods. From field observations, these farmers feel comfortable with their traditional methods because most of the new technologies (integrated crop/livestock, stress tolerant crops, nutrient and water management, organic fertilizer application and wood ash application) introduced to them are so time consuming and demanding. However, farming

methods can be changed with more access to extension services. Whereby, farmers who received more training or technical know-how from the visits of these agents, were likely to adopt new farming methods (innovations).

To increase farmers knowledge and understanding on new agricultural techniques, extension services must therefore be strengthened in a timely and accurate manner. This can be done using the most appropriate communication and training methods and also documenting farmers appraisal of these new technologies. This is evident in both regions if access to extension service is increased there will be a subsequent increase in adoption of these farming practices as a form of adaptation to climate change in both regions.

The more the farmers experience windstorm, the more they adopted farming methods like intercropping and agroforestry. During windstorm, crops are destroyed prematurely leading to decrease in yields and thus household food insecurity. Intercropping brings diversity of species in the cropping systems and is considered to make the systems more resilient against windstorm. Furthermore, the trees in the agroforestry systems act as barriers, preventing crops from being pushed down by the windstorm thus providing farmers with financial security by making the system more suitable for subsistence farming. Farmers who added trees like mango, pear and plum as hedges, improved agricultural yields and income, ensuring more secure livelihood for the communities.

Most farmers who owned land did not adopt new farming methods. However, most of the farmers who cultivated on this land did report that these lands belong to the family and requires a consensus for any changes to be adopted. This therefore slows down the rate of adoption and most often kills aspiration of adopting new methods. The reason of low adoption of these practices in this area. Most of the farmers planted plantain, cassava, maize, groundnuts and cocoyam and they reported that the soils were moderately fertile, and their crops did well. Though they experienced decreases in general production, these farmers wondered why this was happening.

Most of the farmers attributed these decreases to changes in rainfall/temperature patterns where some complained that these times rains come very late and very little not giving room for crops to germinate well and thus decreases in crop yield. Though they do not see reasons of adopting new practices, this is because these farmers have very little access to

extension workers who will train them on these methods thus, they want to maintain their old methods not minding its consequences rather than losing all.

The most common practices used in this area were agroforestry, intercropping, bush fallow, zero/minimum tillage, cover crops and crop rotation. Crop rotations and bush fallow which constituted the field management practices were the highest contributors as conservation agricultural practices. This was so since they mostly rotated with legumes that are nitrogen fixing thus improving the fertility of the field.

The contributions from agroforestry and intercropping were very small because these two often act more in the mitigation arm of climate change while mulching was very small probably because it is practiced just by very few farmers in this area. Mulching is mostly practiced in areas with very low soil fertility like in the northwest region in Cameroon, thus since the study area have fertile soils, they seldom practice this method. Farmers in this area adopted more packages that contained at least a crop management practice. Their soils in this area are fertile thus they need just very little for soils management and, they had enough labour for field management. They, therefore, concentrated more on crop management against pests, climatic risk animal pest and in self-life preservation.

Also, the distance from farm to output/input markets of this area was to wide couple with poor road infrastructure thus increasing transportation cost in return reducing the money for households to invest in pesticide and fertilizer purchase and lesser money for the purchase of inputs. This makes farmers not to want to adopt practices that are money demanding and thus go for lesser packages. On the other hand, female farmers in this are adopted more of packages without field management components because this component demands for a lot of time and labour which only men can readily supply that or have the manpower to do that.

Farmers in this area had very little or no contact with extension agents especially the case of female farmers. This is because of the bad roads in these areas preventing extension workers from visiting and lack of follow-up on these extension advisers. Those farmers who were opportune to have contacts with extension workers were still not very different

when it comes to farming methods because most of these workers that have visited this area only trained them on specific crops and not farm methods.

Farmer organizations are also lacking in this area making it difficult for these farmers to gain access to agricultural credit and government subsidies. This is because farmer organizations are usually the best channels that organizations or government even microfinances use to assist farmers.

4.8 Chapter Summary

Smallholder farmers across the sites were found to have a high level of perception on climate change and variability. The study also indicated that smallholder farmers employed various adaptation strategies in order to deal with vagaries of weather with the most common strategies being agroforestry, cover crops, bush fallow, crop rotation, zero/minimum tillage and intercropping. Moreover, socio-economic factors greatly determined the adoption of these strategies. These coping and adaptation strategies were different between the east and south regions within the study area. However, the adoption of conservation agricultural strategies by these farmers had a significant effect on their farm revenue, especially those who adopted intercropping, cover crops and mulching. Coping and adaptation strategies also had a gender dimension.

Furthermore, men are more involved in household decision making than in farming activities. Also, gender is positively associated with farm revenue thus being a male farmer your revenue is increased by 15064frs probably because men in this area are more exposed to extension services and supply more labour. This will further help improve on their nutrition for our results indicates they feed more on starchy food making their diets to be unbalanced. The evidence presented here supports the hypothesis that, conservation agricultural practices significantly influence the smallholder farmer livelihood, and that socio-demographical and environmental factors are significant determinants of farmer perception and adaptation to climate change.

CHAPTER FIVE

5.0 SUMMARY, RECOMMENDATIONS AND CONCLUSIONS

5.1 Summary

About one billion people are hungry in the world with children under 5 being stunted. Food insecurity and low self-sufficiency is especially rampant in SSA where there are growing populations, shrinking farm sizes, poverty increase in climate risk and rapidly degrading soils. At least a doubling of agricultural yields is required over the coming decades especially in economies where populations depend on smallholder rain fed farming for their livelihoods. Although from the Malabo declaration countries especially Cameroon now allocates 10% of its budget to agriculture which offers an option for increasing agricultural production, it does not provide the whole solution. The population of Cameroon has grown rapidly in the past few years till date almost at same pace with agricultural production. This growth in population has not helped in poverty alleviation for there is increased poverty among the smallholder farmers.

Poverty levels of smallholder farmers in Cameroon has continued to increase leading to a decrease in living standards of these farmers, thus leading to livelihood insecurities among these farmers. Recently agricultural production in the smallholder farmer sector has experienced a decline. Thus, further exacerbating poverty levels and lowering living standards. With agriculture from the rural sector (smallholder) being the greatest engine for a countries economic growth a great challenge is posed to the country’s economy by these recent trends in population growth, agricultural production and poverty levels of farmers in this sector.

There is, therefore, the need to complement the afore mentioned with Conservation Agricultural (CA) technologies to achieve food and livelihood security. It was on this basis that this study was undertaken to better understand the complementarity of CA and REDD+ use in the South and East Regions of Cameroon as tools for improving farmer livelihood security. Thus, specifically sought to evaluate farmers' perception on climate change while identifying the various conservative agricultural practices used by these farmers as measures of adaptation to these changes while taking into consideration the gender aspect of this adaptation, to examine the effects of these adaptive measures they use on their livelihoods and also evaluating REDD+ potentials on these farmers. This quest thus led us to test some specific hypothesis like smallholder farmers do not perceive climate change, CAs have no significant effect on smallholder farmer livelihood and socio-demographic and environmental factors are not significant determinants of farmers choice of adaptive strategies.

Theorization in conservation agriculture intends to tie concepts to practice, pushing the frontiers academically and scientifically, explaining and extrapolating on present trends, challenges, and adaptation. Different researchers tend to explain different phenomenon within the field of conservation agriculture but have not wholly agreed on standard theories that cut across the main complexities and components. However, various theories have been imported and adapted into this field that we reviewed. The ever-expanding nature of CA imposes on research the necessity to constantly fine-tune theories in regard to the issues of mitigation, adaptation and food security.

Current research have spotlighted core issues, when linking rural farmers, gender response and technology adoption while mainstreaming matters of preference, intentions and marginalisation. Many theories were reviewed in this light. Amongst theories reviewed,

was the Utility theory which seeks to evaluate preferences by using choice modelling to estimate the utility associated with the change in CA strategy because of climate change. It further conforms to the economic notion that the value placed on a particular CA strategy reflects its attributes. This study was then grounded by Roger's theory of Utility where a farmer choses a particular conservation agricultural practice per their level of satisfaction derived from this practice.

Sampling to select sample size was done in a convenient multi-stage manner and the data for this study was collected using oral questionnaires with the semi structured questionnaire as instrument. both qualitative and quantitative analysis were employed in our study. Thorough descriptive analysis was done for every variable in the study. Descriptive statistics like frequencies, cross tabulations and independent samples test were generated to establish the characteristics.

Furthermore, to test the hypothesis of farmer perception the Heckman two stage model was adopted because in this context, a farmers' decision process to adopt a new CA practice involved two steps thus this model is best fitting since it corrects, or selection bias generated during the decision-making process. Thus, the farmer perceives that the climate is changing and responds to this change by adaptation measures. A multiple component analysis was used to identify the various CAs used by the farmers in the study area. Also testing the hypothesis of no significant effect of CA on farmer livelihood a multiple linear regression was employed. And finally, to test for the factors that determine the adoption of CA practices by farmers, a multinomial logit model was employed in this study where results from marginal effects were presented.

The results indicate that adoption rate of CAs was still low with crop management practices being the most dominant perhaps to meet food production for subsistence. The findings indicate that specific soil management and field management practices were less adopted. The study used primary data to establish socio-economic factors to Characterize REDD+ and CA adopters in both regions.

In the study, the established socio economic and demographic characteristics of farmers who used any of the improved technology in the South and East Regions of Cameroon were age, education level of the household head, land size, household size, access to agricultural credit, and access to extension services, and availability of any off-farm sources of income. Descriptive statistics show that over 96.9% and 95.5% of male and female famers respectively in the South and East region perceived climate change. As a result, 48.3% of farmers in the East used CA strategies compared to 35.5% in the South region. With the most adopted practices in both regions being Agroforestry, Bush fallow, Intercropping, zero/minimum tillage, cover crops and crop rotations, and main crops cultivated in these regions being cassava, cocoyam, maize, plantain, groundnut, and okra. In addition, the main source of farmer awareness of CA strategies was from their colleagues.

Farmers in these regions also had very low access to agricultural credit with more male farmers having access (42%) as compared to female (20%), extension services taking same trend as Agricultural credit, access to government subsidies with 92.02% of farmers having no access. These results suggest a need for improving on extension services and government subsidies to promote adoption of Conservation practices towards enhancing agricultural productivity and livelihood security. Challenges, lack of finance (51%) and

inadequate information on adaptive measures (40.5%) were major reasons for not using CA practices.

Factors associated with the perception of climate change and subsequent adoptions of CA technological packages were determined using the Heckman two stage model. Model results revealed that soil fertility, and soil erosion strongly influenced farmer perception on climate change while farm revenue, access to extension and land ownership were factors associated with the likelihood of adoption of both partial and full CA packages in South and East Regions.

Furthermore, gender of the household head has a positive effect on agroforestry adoption, with men more likely to adopt this practice. Old farmers tend to use agroforestry, cover crops, and zero tillage more, while young farmers prefer intercropping, crop rotation, and mulching. Farm size has a significant positive influence on cover cropping adoption, indicating that larger farms are more likely to adopt this practice. Contact with extension agents has a positive impact on cover crop uptake but a negative influence on mulching adoption.

Also, availability of loans for farming has a negative impact on zero tillage adoption. The distance between home and farm encourages the use of agroforestry, intercropping, and zero tillage. Land ownership facilitates the adoption of innovative farm methods, such as cover crops. Soil fertility has a positive impact on zero tillage adoption but a negative impact on mulching adoption. Adoption of modern farm technologies promotes the adoption of intercropping and mulching but also cover crops and zero tillage. The number of animals owned positively influences intercropping, cover crops, and crop rotation adoption but negatively influences agroforestry adoption.

However, the effects of CA strategy on farmer livelihood were determined using the multiple linear regression model. Model results revealed that Agroforestry, intercropping, bush fallow, cover crop systems, mulching and male headed households had a positive relationship with total farm revenue. Thus, suggesting that a farmer who adopted any of these methods in general will experience an increase in their farm income and male headed household experienced a more increase in farm income than female headed households.

5.2 Policy Recommendations

As per the findings of this study we recommend the following,

- Policymakers could consider implementing policies such as providing subsidies, tax incentives, or other forms of financial support to farmers who adopt these practices.
- While encouraging policy interventions that promote gender equality and encourage women's participation in farming activities are necessary.
- Policies should be developed to promote the use of windbreaks to mitigate the effects of windstorms on crops and soil erosion. The promotion of conservation agriculture practices could also be beneficial in areas where soil fertility is low, as these practices help to maintain soil moisture and nutrients.
- Policymakers should recognize that adoption of these practices is influenced by a variety of factors, including socio-economic status, education level, and access to information and institutional factors. Therefore, policies aimed at promoting the adoption of these practices should be designed in a way that takes these factors into account, to ensure that they are accessible and relevant to all farmers.

- The government should increase its investment, and prioritize the promotion and adoption of conservation agriculture practices by implementing a combination of education, financial and technical support, and regulatory frameworks that incentivize sustainable farming practices and supporting research and development to improve the effectiveness of these practices.
- Agroforestry and intercropping, although not exhibiting a high degree of conservation attributes, can also be promoted as complementary practices to the more established conservation practices. Efforts could be made to encourage farmers to adopt these practices through education and awareness campaigns, demonstration farms, and research on the economic and environmental benefits of these practices

5.3 Suggestions for future studies

One major area for further research should be to investigate the effectiveness of different financial incentives and subsidies on the adoption of sustainable agriculture practices by farmers. Conducting studies to understand the barriers that women face in accessing farming resources and identifying effective strategies to promote gender equality in agriculture. Furthermore, future research may be interested in evaluating the impact of windbreaks on crop yields and soil erosion and identifying optimal placement and design of windbreaks for different crops and landscapes. Overall, there is a need for interdisciplinary research that integrates insights from agronomy, social sciences, and economics to develop effective policy interventions that promote sustainable agriculture

practices while also addressing the needs and challenges faced by farmers in different contexts.

5.4 Conclusion

Generally, farmers of the South and East regions of Cameroon well perceive climate change but their adaptation was low, with crop management practices being the most dominant perhaps to meet food production for subsistence. The findings indicate that specific soil management and field management practices were less adopted. Furthermore, the best and profit maximizing strategies in this area were bush fallow, intercropping, cover crops, mulching and agroforestry. But those most performing and benefiting to the east were agroforestry and mulching though they practiced more of Bush-fallow and intercropping. While those peculiar to the South region were intercropping and cover crops, though they practiced more of agroforestry and bush-fallow. Also, farmers of the East region better adapted to these changes than those of the South.

Generally, the most common strategies used by farmers of this area are agroforestry, cover crops, bush fallow, crop rotation, zero/minimum tillage, and intercropping. Moreover, socio-economic factors greatly determine the adoption of these strategies which further indicated that likelihood of higher demand for CA strategies is positively influenced by gender of the household head, number of farmlands, perception of soil fertility, distance to input/output market, farm size, and number of annual contacts with extension service agents, and credit access. This observation provides a wider spectrum of interventions to improve the demand for CAs. The farmers in these regions feed mainly on starchy food and thus their diets present to be unbalanced and thus will be better off when farmers adapt the CA strategies for they also present to improve on farm revenue.

References

Abbass, K., Qasim, M. Z., Song, H., Murshed, M., Mahmood, H., & Younis, I. (2022). A review of the global climate change impacts, adaptation, and sustainable mitigation measures. *Environmental Science and Pollution Research*, *29*(28), 42539–42559.

Abegunde, V. O., Sibanda, M., & Obi, A. (2019). Determinants of the adoption of climate-smart agricultural practices by small-scale farming households in King Cetshwayo District Municipality, South Africa. *Sustainability*, *12*(1), 195.

Abid, M., Scheffran, J., Schneider, U. A., & Elahi, E. (2019). Farmer perceptions of climate change, observed trends and adaptation of agriculture in Pakistan. *Environmental Management*, *63*(1), 110–123.

Adegbeye, M. J., Kanth, P. R., Obaisi, A. I., Elghandour, M. M. M. Y., Oyebamiji, K. J., Salem, A. Z. M., Morakinyo-fasipe, O. T., & Cipriano-salazar, M. (2020). Sustainable agriculture options for production , greenhouse gasses and pollution alleviation , and nutrient recycling in emerging and transitional nations—An overview. *Journal of Cleaner Production*, *242*, 118319. https://doi.org/10.1016/j.jclepro.2019.118319

Adeyeye, S. A. O., Ashaolu, T. J., Bolaji, O. T., Abegunde, T. A., & Omoyajowo, A. O. (2023). Africa and the Nexus of poverty, malnutrition and diseases. *Critical Reviews in Food Science and Nutrition*, *63*(5), 641–656.

Aggarwal, P., Jarvis, A., Campbell, B., Zougmoré, R., Khatri-chhetri, A., Vermeulen, S., Loboguerrero, A. M., Sebastian, S., Kinyangi, J., Bonilla-Findji, O., Radeny, M.,

Recha, J., Martinez-Baron, D., Ramirez-Villegas, J., Huyer, S., Thornton, P., Wollenberg, E., Hansen, J., Alvarez-Toro, P., … Yen, B. (2018). The climate-smart village approach: Framework of an integrative strategy. *Ecology and Society*, *23*(1), 15. https://doi.org/ES-09844-230114

Agriculturae, S., & Olorunfemi, I. E. (2013). The Role Of Climate, Soil And Crop On Sustainable Agriculture In Nigerian Ecological Zones: A Brief Overview. *Sci. Agri*, *4*(1), 26–36.

Ahundjanov, B. B., & Akhundjanov, S. B. (2019). Gibrat's law for CO2 emissions. *Physica A*, *526*, 120944. https://doi.org/10.1016/j.physa.2019.04.180

A.i, A., A.s, C., & T.a, A. (2016). Analysis of Farmers' Vulnerability, Perception and Adaptation to Climate Change in Kwara State, Nigeria. *International Journal of Climate Research*, *1*(1), 1–16.

Aidoo, D. C., Boateng, S. D., Freeman, C. K., & Anaglo, J. N. (2021). The effect of smallholder maize farmers' perceptions of climate change on their adaptation strategies: The case of two agro-ecological zones in Ghana. *Heliyon*, *7*(11), e08307.

Ajzen, I. (1991). The theory of planned behavior. *Organizational Behavior and Human Decision Processes*, *50*(2), 179–211.

Akinyemi, B. E., & Mushunje, A. (2019). Land ownership and usage for agriculture: Empirical evidence from South African Living Conditions Survey Land ownership and usage for agriculture: Empirical evidence from South African Living Conditions Survey. *Cogent Social Sciences*, *5*(1). https://doi.org/10.1080/23311886.2019.1663691

Ako, A. A., Eyong, G. E. T., & Nkeng, G. E. (2010). Water resources management and integrated water resources management (IWRM) in Cameroon. *Water Resources Management*, *24*(5), 871–888.

Akter, S., Gathala, M. K., Timsina, J., Islam, S., Rahman, M., Hassan, M. K., & Ghosh, A. K. (2021). Adoption of conservation agriculture-based tillage practices in the rice-maize systems in Bangladesh. *World Development Perspectives*, *21*, 100297.

Ali, A., & Erenstein, O. (2017). Assessing farmer use of climate change adaptation practices and impacts on food security and poverty in Pakistan. *Climate Risk Management*, *16*, 183–194. https://doi.org/10.1016/j.crm.2016.12.001

Ali, S., Rizwan, M., Hussain, A., ur Rehman, M. Z., Ali, B., Yousaf, B., Wijaya, L., Alyemeni, M. N., & Ahmad, P. (2019). Silicon nanoparticles enhanced the growth

and reduced the cadmium accumulation in grains of wheat (Triticum aestivum L.). *Plant Physiology and Biochemistry*, *140*, 1–8.

Altieri, M. A., & Nicholls, C. I. (2017). The adaptation and mitigation potential of traditional agriculture in a changing climate. *Climatic Change*, *140*(1), 33–45. https://doi.org/10.1007/s10584-013-0909-y

Amare, A., & Simane, B. (2017). Determinants of smallholder farmers ' decision to adopt adaptation options to climate change and variability in the Muger Sub basin of the Upper Blue Nile basin of Ethiopia. *Agriculture & Food Security*, 1–20. https://doi.org/10.1186/s40066-017-0144-2

Amoo, L. M., & Fagbenle, R. L. (2020). Chapter 15—Climate change in developing nations of the world. In *Applications of Heat, Mass and Fluid Boundary Layers*. Elsevier Ltd. https://doi.org/10.1016/B978-0-12-817949-9.00023-2

Anandajayasekeram, P., & Gebremedhin, B. (2009). *Integrating innovation systems perspective and value chain analysis in agricultural research for development: Implications and challenges* (Vol. 16). ILRI (aka ILCA and ILRAD).

Anang, B. T., & Asante, B. O. (2020). Farm household access to agricultural services in northern Ghana. *Heliyon*, *6*(11), e05517.

Ananth, P. N., Barik, N. K., & Babu, S. C. (2019). Can institutional convergence force agricultural development in pluralistic extension systems: A case of Krishi Vigyan Kendra (the farm science center) in India. In *Agricultural Extension Reforms in South Asia*. Elsevier Inc. https://doi.org/10.1016/B978-0-12-818752-4.00007-2

Angelsen, A. (2009). *Realising REDD+: National strategy and policy options*. Cifor.

Aniah, P., Kaunza-nu-dem, M. K., & Ayembilla, J. A. (2019). Smallholder farmers ' livelihood adaptation to climate variability and ecological changes in the savanna agro ecological zone of Ghana. *Heliyon*, *March*, e01492. https://doi.org/10.1016/j.heliyon.2019.e01492

Antwi-Agyei, P., & Stringer, L. C. (2021). Improving the effectiveness of agricultural extension services in supporting farmers to adapt to climate change: Insights from northeastern Ghana. *Climate Risk Management*, *32*, 100304.

Arora, N. K. (2019). Impact of climate change on agriculture production and its sustainable solutions. *Environmental Sustainability*, *2*(2), 95–96.

Arya, S., Chavan, D., Aiman, S., Kumar, S., & Research-national, I. (2019). *Reducing Greenhouse Gas Emission From Waste Land fi ll*. https://doi.org/10.1016/B978-0-12-803581-8.11022-7

Aryal, J. P., Sapkota, T. B., Khurana, R., Khatri-Chhetri, A., Rahut, D. B., & Jat, M. L. (2019). Climate change and agriculture in South Asia: Adaptation options in smallholder production systems. In *Environment, Development and Sustainability* (Issue 0123456789). Springer Netherlands. https://doi.org/10.1007/s10668-019-00414-4

Aryal, J. P., Sapkota, T. B., Khurana, R., Khatri-Chhetri, A., Rahut, D. B., & Jat, M. L. (2020). Climate change and agriculture in South Asia: Adaptation options in smallholder production systems. *Environment, Development and Sustainability*, *22*(6), 5045–5075.

Ashraf, M., Arshad, A., Patel, P. M., Khan, A., Qamar, H., Siti-Sundari, R., Ghani, M. U., Amin, A., & Babar, J. R. (2021). Quantifying climate-induced drought risk to livelihood and mitigation actions in Balochistan. *Natural Hazards*, *109*(3), 2127–2151.

Asrat, P., & Simane, B. (2018). Farmers' perception of climate change and adaptation strategies in the Dabus watershed, North-West Ethiopia. *Ecological Processes*, *7*(1). https://doi.org/10.1186/s13717-018-0118-8

Assefa, A., & Laerhoven, F. V. (2018). The interplay between planned and autonomous adaptation in response to climate change: Insights from rural Ethiopia. *World Development*, *107*, 87–97. https://doi.org/10.1016/j.worlddev.2018.03.001

Autio, A., Johansson, T., Motaroki, L., Minoia, P., & Pellikka, P. (2021). Constraints for adopting climate-smart agricultural practices among smallholder farmers in Southeast Kenya. *Agricultural Systems*, *194*, 103284.

Awono, A., Somorin, O. A., Eba'a Atyi, R., & Levang, P. (2014). Tenure and participation in local REDD+ projects: Insights from southern Cameroon. *Environmental Science and Policy*, *35*, 76–86. https://doi.org/10.1016/j.envsci.2013.01.017

Awotide, B. A., Karimov, A. A., & Diagne, A. (2016). Agricultural technology adoption, commercialization and smallholder rice farmers' welfare in rural Nigeria. *Agricultural and Food Economics*, *4*(1). https://doi.org/10.1186/s40100-016-0047-8

Ayal, D. Y., & Leal Filho, W. (2017). Farmers' perceptions of climate variability and its adverse impacts on crop and livestock production in Ethiopia. *Journal of Arid Environments*, *140*, 20–28.

Ayanlade, A., Radeny, M., & Akin-Onigbinde, A. I. (2018). Climate variability/change and attitude to adaptation technologies: A pilot study among selected rural farmers'

communities in Nigeria. *GeoJournal*, *83*(2), 319–331. https://doi.org/10.1007/s10708-017-9771-1

Bagagnan, A. R., Ouedraogo, I., Fonta, W. M., Sowe, M., & Wallis, A. (2019). Can protection motivation theory explain farmers' adaptation to climate change decision making in The Gambia? *Climate*, *7*(1), 1–14. https://doi.org/10.3390/cli7010013

Bager, S. L., Dinesh, D., Olesen, A. S., Andersen, S. P., Eriksen, S. L., & Friis, A. (2017). *Scaling-Up Climate Action in Agriculture*.

Baker, P., Russ, K., Kang, M., Santos, T. M., Neves, P. A., Smith, J., Kingston, G., Mialon, M., Lawrence, M., & Wood, B. (2021). Globalization, first-foods systems transformations and corporate power: A synthesis of literature and data on the market and political practices of the transnational baby food industry. *Globalization and Health*, *17*(1), 58.

Ballesteros, A., Nakhooda, S., Werksman, J., & Hurlburt, K. (2010). Power, responsibility, and accountability: Rethinking the legitimacy of institutions for climate finance. *Climate L.*, *1*, 261.

Bandauko, E., Kutor, S. K., & Arku, R. N. (2022). Trapped or not trapped? An empirical investigation into the lived experiences of the urban poor in Harare's selected informal settlements. *African Geographical Review*, 1–20.

Banerjee, O., Bagstad, K. J., Cicowiez, M., Dudek, S., Horridge, M., Alavalapati, J. R. R., Masozera, M., Rukundo, E., & Rutebuka, E. (2020). Science of the Total Environment Economic , land use , and ecosystem services impacts of Rwanda ' s Green Growth Strategy: An application of the IEEM + ESM platform. *Science of the Total Environment*, *729*, 138779. https://doi.org/10.1016/j.scitotenv.2020.138779

Bárcena, T. G., Kiær, L. P., Vesterdal, L., Stefánsdóttir, H. M., Gundersen, P., & Sigurdsson, B. D. (2014). Soil carbon stock change following afforestation in Northern Europe: A meta-analysis. *Global Change Biology*, *20*(8), 2393–2405. https://doi.org/10.1111/gcb.12576

Barnett, M. L. (2006). *The keystone advantage: What the new dynamics of business ecosystems mean for strategy, innovation, and sustainability*. Academy of Management Briarcliff Manor, NY 10510.

Belay, A., Aman, M. M., & Haji, P. J. (2020). *DETERMINANTS OF FARMERS'CHOICES OF ADAPTATION STRATEGIES TO CLIMATE CHANGE:*

THE CASE OF GUANGUA DISTRICT OF AWI ZONE, AMHARA NATIONAL REGIONAL STATE, NORTHWESTERN ETHIOPIA [PhD Thesis]. haramaya university.

Belay, A., Recha, J. W., Woldeamanuel, T., & Morton, J. F. (2017). Smallholder farmers' adaptation to climate change and determinants of their adaptation decisions in the Central Rift Valley of Ethiopia. *Agriculture and Food Security*, *6*(1). https://doi.org/10.1186/s40066-017-0100-1

Bele, M. Y., Somorin, O., Sonwa, D. J., Nkem, J. N., & Locatelli, B. (2011). Forests and climate change adaptation policies in Cameroon. *Mitigation and Adaptation Strategies for Global Change*, *16*(3), 369–385. https://doi.org/10.1007/s11027-010-9264-8

Ben Hassen, T., & El Bilali, H. (2022). Impacts of the Russia-Ukraine war on global food security: Towards more sustainable and resilient food systems? *Foods*, *11*(15), 2301.

Bernier, Q., Meinzen-Dick, R., Kristjanson, P., Haglund, E., Kovarik, C., Bryan, E., Ringler, C., & Silvestri, S. (2015). Gender and institutional aspects of climate-smart agricultural practices: Evidence from Kenya. *CCAFS Working Paper*, *79*.

Beyene, A. D., Mekonnen, A., Randall, B., & Deribe, R. (2019). Household level determinants of agroforestry practices adoption in rural Ethiopia. *Forests, Trees and Livelihoods*, *28*(3), 194–213.

Bhattacharya, A. (2019). Global Climate Change and Its Impact on Agriculture. In *Changing Climate and Resource Use Efficiency in Plants*. https://doi.org/10.1016/b978-0-12-816209-5.00001-5

Bhattarai, B. (2022). Agrobiodiversity Management for Gender-Equitable Adaptation to Climate Change: Investigating the Gendered Roots of Vulnerability in the Nepal Himalayas. In *Agriculture, Natural Resources and Food Security* (pp. 439–451). Springer.

Bhattarai, H. P. (2021). Responses of Indigenous People to the Climate Changes: A Case Study of the Surels of Dolakha District of Nepal. *Patan Pragya*, *9*(02), Article 02. https://doi.org/10.3126/pragya.v9i02.42028

Biddle, J. (2012). Retrospectives: The introduction of the Cobb-Douglas regression. *Journal of Economic Perspectives*, *26*(2), 223–236.

Birkenmaier, J., Huang, J., & Kim, Y. (2016). Food insecurity and financial access during an economic recession: Evidence from the 2008 SIPP. *Journal of Poverty*, *20*(2), 194–213.

Bizikova, L., Larkin, P., Mitchell, S., & Waldick, R. (2019). Land Use Policy An indicator set to track resilience to climate change in agriculture: A policy- maker ' s perspective. *Land Use Policy*, *82*(November 2018), 444–456. https://doi.org/10.1016/j.landusepol.2018.11.057

Bocchiola, D., Brunetti, L., Soncini, A., Polinelli, F., & Gianinetto, M. (2019). Impact of climate change on agricultural productivity and food security in the Himalayas: A case study in Nepal. *Agricultural Systems*, *171*(January), 113–125. https://doi.org/10.1016/j.agsy.2019.01.008

Bodnar, A. L., Cortes-Burgos, L. A., Cook, K. K., Dinh, D. M., Groppi, V. E., Hajos, M., Higdon, N. R., Hoffmann, W. E., Hurst, R. S., Myers, J. K., Rogers, B. N., Wall, T. M., Wolfe, M. L., & Wong, E. (2005). Discovery and Structure−Activity Relationship of Quinuclidine Benzamides as Agonists of α7 Nicotinic Acetylcholine Receptors. *Journal of Medicinal Chemistry*, *48*(4), 905–908. https://doi.org/10.1021/jm049363q

Boko, M., Niang, I., Nyong, A., Vogel, C., Githeko, A., Medany, M., Osman-Elasha, B., Tabo, R., Yanda, P., Dubois, G., wa Githendu, M., Hilmi, K., Misselhorn, A., Ziervogel, G., Semmazzi, F., Senouci, M., Niang, I., Nyong, A., Vogel, C., … Hanson, C. (2007). Africa. Climate change. *Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, 433–467.

Bonabana-wabbi, J., & Taylor, D. B. (2002). *Assessing Factors Affecting Adoption of Agricultural Technologies: The Case of Integrated Pest Management (IPM) in Kumi District , Eastern*.

Boutillier, S., & Uzunidis, D. (2014). The theory of the entrepreneur: From heroic to socialised entrepreneurship. *Journal of Innovation Economics Management*, *14*(2), 9–40.

Breschi, S., & Malerba, F. (1997). Sectoral innovation systems: Technological regimes, Schumpeterian dynamics, and spatial boundaries. *Systems of Innovation: Technologies, Institutions and Organizations*, *1*, 130–156.

Brockhaus, M., Di Gregorio, M., Djoudi, H., Moeliono, M., Pham, T. T., & Wong, G. Y. (2021). The forest frontier in the Global South: Climate change policies and the promise of development and equity. *Ambio*, *50*, 2238–2255.

Broeck, G. V. D., & Kilic, T. (2019). Dynamics of off-farm employment in Sub-Saharan Africa: A gender perspective. *World Development*, *119*, 81–99. https://doi.org/10.1016/j.worlddev.2019.03.008

Bryceson, D. F. (2019). Gender and generational patterns of African deagrarianization: Evolving labour and land allocation in smallholder peasant household farming , 1980 – 2015. *World Development*, *113*, 60–72. https://doi.org/10.1016/j.worlddev.2018.08.021

Buckley, R. (2010). Climate Change. *Adventure Tourism Management*, *1850*(c), 123–135. https://doi.org/10.1016/B978-1-85617-834-1.10008-0

Cadman, T., Maraseni, T., Ma, H. O., & Lopez-Casero, F. (2017). Five years of REDD+ governance: The use of market mechanisms as a response to anthropogenic climate change. *Forest Policy and Economics*, *79*, 8–16. https://doi.org/10.1016/j.forpol.2016.03.008

Camargo, F. A. O., Silva, L. S., Merten, G. H., Carlos, F. S., Baveye, P. C., & Triplett, E. W. (2017). Brazilian Agriculture in Perspective: Great Expectations vs Reality. In *Advances in Agronomy* (Vol. 141). Elsevier Inc. https://doi.org/10.1016/bs.agron.2016.10.003

Cammarano, D., Ceccarelli, S., Grando, S., Romagosa, I., Benbelkacem, A., Akar, T., Al-yassin, A., Pecchioni, N., Francia, E., & Ronga, D. (2019). The impact of climate change on barley yield in the Mediterranean basin. *European Journal of Agronomy*, *106*(March), 1–11. https://doi.org/10.1016/j.eja.2019.03.002

Campbell, B. M., Thornton, P., Zougmoré, R., van Asten, P., & Lipper, L. (2014a). Sustainable intensification: What is its role in climate smart agriculture? *Current Opinion in Environmental Sustainability*, *8*, 39–43. https://doi.org/10.1016/j.cosust.2014.07.002

Campbell, B. M., Thornton, P., Zougmoré, R., van Asten, P., & Lipper, L. (2014b). Sustainable intensification: What is its role in climate smart agriculture? *Current Opinion in Environmental Sustainability*, *8*, 39–43. https://doi.org/10.1016/j.cosust.2014.07.002

Cardinael, R., Umulisa, V., Toudert, A., Olivier, A., Bockel, L., & Bernoux, M. (2018). Revisiting IPCC Tier 1 coefficients for soil organic and biomass carbon storage in agroforestry systems. *Environmental Research Letters*, *13*(12), 124020.

Carrijo, D. R., Lundy, M. E., & Linquist, B. A. (2017). Rice yields and water use under alternate wetting and drying irrigation: A meta-analysis. *Field Crops Research*, *203*, 173–180.

Chandio, A. A., & Yuansheng, J. (2018). Determinants of Adoption of Improved Rice Varieties in Northern Sindh, Pakistan. *Rice Science*, *25*(2), 103–110. https://doi.org/10.1016/j.rsci.2017.10.003

Chandra, A. (2017). *Climate-Smart Agriculture in Practice: Insights from smallholder farmers, Timor-Leste and the Philippines, Southeast Asia*. 344. https://doi.org/10.5465/APBPP.2002.7517527

Chandra, A., Mcnamara, K. E., Dargusch, P., Maria, A., & Dalabajan, D. (2017). Gendered vulnerabilities of smallholder farmers to climate change in con fl ict-prone areas: A case study from Mindanao , Philippines. *Journal of Rural Studies*, *50*, 45–59. https://doi.org/10.1016/j.jrurstud.2016.12.011

Chatterjee, S., Chandra, B., Viswavidyalaya, K., Goswami, R., Mission, R., Educational, V., Bandopadhyay, P., Chandra, B., & Viswavidyalaya, K. (2015). *Methodology of Identification and Characterization of Farming Systems in Irrigated Agriculture: Study in West Bengal State of India Methodology of Identification and Characterization of Farming Systems in Irrigated Agriculture: Case Study in West Bengal*. *September*.

Chepkoech, W., Mungai, N. W., Stöber, S., & Lotze-campen, H. (2019). Understanding Adaptive Capacity of Smallholder African Indigenous Vegetable Farmers to Climate Change in Kenya. *Climate Risk Management*, 100204. https://doi.org/10.1016/j.crm.2019.100204

Chiputwa, B., Wainaina, P., Nakelse, T., Makui, P., Zougmoré, R. B., Ndiaye, O., & Minang, P. A. (2020). Transforming climate science into usable services: The effectiveness of co-production in promoting uptake of climate information by smallholder farmers in Senegal. *Climate Services*, *20*, 100203. https://doi.org/10.1016/j.cliser.2020.100203

Choden, K., Keenan, R. J., & Nitschke, C. R. (2020). An approach for assessing adaptive capacity to climate change in resource dependent communities in the Nikachu

watershed , Bhutan. *Ecological Indicators*, *114*(1140), 106293. https://doi.org/10.1016/j.ecolind.2020.106293

Chowdhooree, I. (2019). International Journal of Disaster Risk Reduction Indigenous knowledge for enhancing community resilience: An experience from the south-western coastal region of Bangladesh. *International Journal of Disaster Risk Reduction*, *40*(April 2018), 101259. https://doi.org/10.1016/j.ijdrr.2019.101259

Chuma, G. B., Mondo, J. M., Ndeko, A. B., Bagula, E. M., Lucungu, P. B., Bora, F. S., Karume, K., Mushagalusa, G. N., Schmitz, S., & Bielders, C. L. (2022). Farmers' knowledge and Practices of Soil Conservation Techniques in Smallholder Farming Systems of Northern Kabare, East of DR Congo. *Environmental Challenges*, *7*, 100516.

Clark, D. A. (2002). *Visions of development: A study of human values*. Edward Elgar Publishing.

Clark, H., Coll-seck, A. M., Banerjee, A., Peterson, S., Dalglish, S. L., Ameratunga, S., Balabanova, D., Sachdev, H. S., Saleh, R., Shawar, Y. R., Shiffman, J., Simon, J., Sly, P. D., Stenberg, K., & Tomlinson, M. (2020). *The Lancet Commissions A future for the world ' s children? A WHO – UNICEF – Lancet Commission*. *6736*(19). https://doi.org/10.1016/S0140-6736(19)32540-1

Clay, N., & Zimmerer, K. S. (2020). Land Use Policy Who is resilient in Africa ' s Green Revolution? Sustainable intensi fi cation and Climate Smart Agriculture in Rwanda. *Land Use Policy*, *97*(March 2019), 104558. https://doi.org/10.1016/j.landusepol.2020.104558

Cleeve, E. A., Debrah, Y., & Yiheyis, Z. (2015). Human Capital and FDI Inflow: An Assessment of the African Case. *WORLD DEVELOPMENT*, *74*, 1–14. https://doi.org/10.1016/j.worlddev.2015.04.003

Conforti, P., Ahmed, S., & Markova, G. (2018). *Impact of disasters and crises on agriculture and food security, 2017*.

Cong, J., Gao, C., Han, D., Li, Y., & Wang, G. (2020). Science of the Total Environment Stability of the permafrost peatlands carbon pool under climate change and wild fi res during the last 150 years in the northern Great Khingan. *Science of the Total Environment*, *712*, 136476. https://doi.org/10.1016/j.scitotenv.2019.136476

Conway, G. (2014). On being a smallholder. *New Directions for Smallholder Agriculture*, 15–35. https://doi.org/10.1093/acprof:oso/9780199689347.003.0002

Cordovil, C. M. S., Bittman, S., Brito, L. M., Goss, M. J., Hunt, D., Serra, J., Gourley, C., Aarons, S., Skiba, U., Amon, B., Vale, M. J., & Cruz, S. (2020). Chapter 22. Climate-resilient and smart agricultural management tools to cope with climate change-induced soil quality decline. In *Climate Change and Soil Interactions*. LTD. https://doi.org/10.1016/B978-0-12-818032-7.00022-9

Cui, X. (2020). Climate Change and Adaptation in Agriculture: Evidence from US Cropping Patterns. *Journal of Environmental Economics and Management*, 102306. https://doi.org/10.1016/j.jeem.2020.102306

Dagunga, G., Abubakari, K., & Agebase Awuni, J. (2021). Conservation agricultural practices: Determinants and effects on soil health for sustainable production in northern Ghana. *Review of Agricultural and Applied Economics (RAAE)*, *24*(1340-2021–767), 3–12.

Daniso, B. (2022). Factors affecting farmers' decision to participate in various agricultural related information sources in Ethiopia. *Cogent Food & Agriculture*, *8*(1), 2133347.

De Sy, V., Herold, M., Achard, F., Beuchle, R., Clevers, J., Lindquist, E., & Verchot, L. (2015). Land use patterns and related carbon losses following deforestation in South America. *Environmental Research Letters*, *10*(12), 124004.

Deininger, K., & Castagnini, R. (2006). Incidence and impact of land conflict in Uganda. *Journal of Economic Behavior and Organization*, *60*(3), 321–345. https://doi.org/10.1016/j.jebo.2004.04.008

Delprato, M., & Akyeampong, K. (2017). The Effect of Early Marriage Timing on Women ' s and Children ' s Health in Sub-Saharan Africa and Southwest Asia. *Annals of Global Health*. https://doi.org/10.1016/j.aogh.2017.10.005

Dendir, Z., & Simane, B. (2019). Livelihood vulnerability to climate variability and change in different agroecological zones of Gurage Administrative Zone, Ethiopia. *Progress in Disaster Science*, *3*, 100035. https://doi.org/10.1016/j.pdisas.2019.100035

Dercon, S., & Gollin, D. (2014). *CSAE Working Paper WPS / 2014 T 22 Agriculture in African Development: A Review of Theories and Strategies *. 44*(0), 1–42.

Deressa, T. T., Hassan, R. M., & Ringler, C. (2011). Perception of and adaptation to climate change by farmers in the Nile basin of Ethiopia. *Journal of Agricultural Science*, *149*(1), 23–31. https://doi.org/10.1017/S0021859610000687

Dhahri, S., & Omri, A. (2020). Foreign capital towards SDGs 1 & 2– Ending Poverty and hunger: The role of agricultural production. *Structural Change and Economic Dynamics*. https://doi.org/10.1016/j.strueco.2020.02.004

Dinar, A., Tieu, A., & Huynh, H. (2019). Water scarcity impacts on global food production. *Global Food Security*, *23*(May), 212–226. https://doi.org/10.1016/j.gfs.2019.07.007

Diouf, N. S., Ouedraogo, I., Zougmoré, R. B., Ouedraogo, M., Partey, S. T., & Gumucio, T. (2019). Factors influencing gendered access to climate information services for farming in Senegal. *Gender, Technology and Development*, *23*(2), 93–110. https://doi.org/10.1080/09718524.2019.1649790

Diwakar, V., Lovell, E., Opitz-stapleton, S., Shepherd, A., & Twigg, J. (2019). *Child poverty , disasters and climate change*. *March*.

Donaldson, T., & Walsh, J. P. (2015). *Research in Organizational Behavior Toward a theory of business*. *35*, 181–207.

Doss, C. R., & Morris, M. L. (2001). *How does gender affect the adoption of agricultural innovations? The case of improved maize technology in Ghana*. *25*.

Drucker, P. (2014). *Innovation and entrepreneurship*. Routledge.

Duker, A., Cambaza, C., Saveca, P., Ponguane, S., Mawoyo, T. A., Hulshof, M., Nkomo, L., Hussey, S., Pol, B. V. D., Vuik, R., Stigter, T., & Zaag, P. V. D. (2020). Using nature-based water storage for smallholder irrigated agriculture in African drylands: Lessons from frugal innovation pilots in Mozambique and Zimbabwe. *Environmental Science and Policy*, *107*(September 2019), 1–6. https://doi.org/10.1016/j.envsci.2020.02.010

Dzanku, F. M. (2019). Food security in rural sub-Saharan Africa: Exploring the nexus between gender , geography and off-farm employment. *World Development*, *113*, 26–43. https://doi.org/10.1016/j.worlddev.2018.08.017

Ehiakpor, D. S., Danso-Abbeam, G., & Mubashiru, Y. (2021). Adoption of interrelated sustainable agricultural practices among smallholder farmers in Ghana. *Land Use Policy*, *101*, 105142.

Ekwere, G. E. (2016). The effect of agricultural cooperatives on cassava production in Awka North LGA of Anambra State, Nigeria. *Academia Journal of Agricultural Research*, *4*(10), 616–624.

Elias, P., Leonard, S., Cando, L., Fedele, G., Gaveau, D. L. a, Locatelli, B., Martius, C., Murdiyarso, D., Sunderlin, W. D., & Verchot, L. V. (2014). *Synergies across a*

REDD+ landscape: Non-carbon benefits, joint mitigation and adaptation, and an analysis of submissions to the SBSTA. *71*, 8p.

Engel, S., & Muller, A. (2016). *Payments for environmental services to promote " climate-smart agriculture "? Potential and challenges*. *47*. https://doi.org/10.1111/agec.12307

Engelhardt, K. A. M., & Ritchie, M. E. (2001). *Effects of macrophyte species richness on wetland ecosystem functioning and services*. *411*(June), 687–689.

Enrici, A. M., & Hubacek, K. (2018). Challenges for REDD+ in Indonesia. *Ecology and Society*, *23*(2).

Epule, T. E. (2021). Recent patterns of exposure, sensitivity, and adaptive capacity of selected crops in Cameroon. *Agriculture*, *11*(6), 550.

Epule, T. E., & Bryant, C. R. (2014). Maize production responsiveness to land use change and climate trends in Cameroon. *Sustainability*, *7*(1), 384–397.

Epule, T. E., Dhiba, D., Etongo, D., Peng, C., & Lepage, L. (2021). Identifying maize yield and precipitation gaps in Uganda. *SN Applied Sciences*, *3*(5), 537. https://doi.org/10.1007/s42452-021-04532-5

Eriksson, M., Giovannini, S., & Ghosh, R. K. (2020). Is there a need for greater integration and shift in policy to tackle food waste? Insights from a review of European Union legislations. *SN Applied Sciences*, *2*, 1–13.

Erokhin, V., & Gao, T. (2020). Impacts of COVID-19 on trade and economic aspects of food security: Evidence from 45 developing countries. *International Journal of Environmental Research and Public Health*, *17*(16), 5775.

Esayas, B., Simane, B., Teferi, E., Ongoma, V., & Tefera, N. (2019). Climate Variability and Farmers' Perception in Southern Ethiopia. *Advances in Meteorology, 2019*, e7341465. https://doi.org/10.1155/2019/7341465

Fadina, A. M. R., & Barjolle, D. (2018). Farmers' adaptation strategies to climate change and their implications in the Zou Department of South Benin. *Environments*, *5*(1), 15.

Falchetta, G., Gernaat, D. E. H. J., Hunt, J., & Sterl, S. (2019). Hydropower dependency and climate change in sub-Saharan Africa: A nexus framework and evidence-based review. *Journal of Cleaner Production*, *231*, 1399–1417. https://doi.org/10.1016/j.jclepro.2019.05.263

Fanzo, J., Davis, C., McLaren, R., & Choufani, J. (2018). The effect of climate change across food systems: Implications for nutrition outcomes. *Global Food Security*, *18*(June), 12–19. https://doi.org/10.1016/j.gfs.2018.06.001

FAO. (2015). *Assessing climate change vulnerability in fisheries and aquaculture: Available methodologies and their relevance for the sector, by Cecile Brugère and Cassandra De Young. FAO Fisheries and Aquaculture Technical Paper No. 597. Rome, Italy.*

FAO. (2017). The future of food and agriculture: Trends and challenges. In *The future of food and agriculture: Trends and challenges*. https://doi.org/ISBN 978-92-5-109551-5

Fidèle, S., Dedehouanou, A., Araar, A., Ousseini, A., Laouali, A., & Jabir, M. (2018). *Spillovers from off-farm self-employment opportunities in rural Niger*. https://doi.org/10.1016/j.worlddev.2017.12.005

Foguesatto, C. R., Artuzo, F. D., Talamini, E., & Machado, J. A. D. (2020). Understanding the divergences between farmer's perception and meteorological records regarding climate change: A review. *Environment, Development and Sustainability*, *22*(1), 1–16.

Frank, S., Havlík, P., Soussana, J.-F., Wollenberg, E. K., & Obersteiner, M. (2017). The potential of soil organic carbon sequestration for climate change mitigation and food security. *CCAFS Info Note*.

Friedmann, M., Kilcline, K., Keating, B., Nangia, V., West, P. C., Howden, M., Cairns, J., Baethgen, W., Claessens, L., Herrero, M., Giller, K. E., Baedeker, T., Thornton, P. K., Ramirez-Villegas, J., Kumar, S., Bunn, C., & Whitbread, A. (2018). A framework for priority-setting in climate smart agriculture research. *Agricultural Systems*, *167*(August), 161–175. https://doi.org/10.1016/j.agsy.2018.09.009

Gadédjisso-Tossou, A. (2015). Understanding Farmers' Perceptions of and Adaptations to Climate Change and Variability: The Case of the Maritime, Plateau and Savannah Regions of Togo. *Agricultural Sciences*, *06*(12), Article 12. https://doi.org/10.4236/as.2015.612140

Garske, B., Heyl, K., Ekardt, F., Weber, L. M., & Gradzka, W. (2020). Challenges of food waste governance: An assessment of European legislation on food waste and recommendations for improvement by economic instruments. *Land*, *9*(7), 231.

Gashaw Dagnew, G., Abebaw, A. F., Lemma Wake, S., & Derso, A. G. (2019). Assessment of Latrine use and Associated Factors among Rural Community

Members in Chiro Zuria Woreda Particularly in Kilinso and Nejebas Kebele. *J Microb Biochem Technol*, *11*(2), 410. https://doi.org/10.4172/1948-5948.1000410

Gbetibouo, G. A., Hassan, R. M., & Ringler, C. (2010). Modelling farmers' adaptation strategies for climate change and variability: The case of the limpopo basin, South Africa. *Agrekon*, *49*(2), 217–234. https://doi.org/10.1080/03031853.2010.491294

Gebre, G. G., Isoda, H., Amekawa, Y., & Nomura, H. (2019). Gender differences in the adoption of agricultural technology: The case of improved maize varieties in southern Ethiopia. *Women's Studies International Forum*, *76*, 102264.

Gebre, G. G., Isoda, H., Rahut, D. B., Amekawa, Y., & Nomura, H. (2021). Gender differences in agricultural productivity: Evidence from maize farm households in southern Ethiopia. *GeoJournal*, *86*(2), 843–864. https://doi.org/10.1007/s10708-019-10098-y

Gebreegziabher, Z., Stage, J., Mekonnen, A., & Alemu, A. (2016). Climate change and the Ethiopian economy: A CGE analysis. *Environment and Development Economics*, *21*(2), 205–225.

Gebremariam, G., & Tesfaye, W. (2018). The heterogeneous effect of shocks on agricultural innovations adoption: Microeconometric evidence from rural Ethiopia. *Food Policy*, *74*(C), 154–161.

Ghanian, M., M. Ghoochani, O., Dehghanpour, M., Taqipour, M., Taheri, F., & Cotton, M. (2020). Understanding farmers' climate adaptation intention in Iran: A protection-motivation extended model. *Land Use Policy*, *94*(May 2019), 104553. https://doi.org/10.1016/j.landusepol.2020.104553

Ghoochani, O. M., Ghanian, M., Baradaran, M., & Azadi, H. (2017). Multi stakeholders' attitudes toward Bt rice in Southwest, Iran: Application of TPB and multi attribute models. *Integrative Psychological and Behavioral Science*, *51*(1), 141–163.

Gorettie, N. N., Justine, N. J., & Allan, B. (2019). *Impacts of Climate Change on Small Holder Households in Mt. Elgon Region of Uganda: Does Gender Matter?* 673–690. https://doi.org/10.1007/978-3-030-12974-3_30

Gowdy, J., & Baveye, P. (2019). And Sustainable Agriculture. In *Agroecosystem Diversity*. Elsevier Inc. https://doi.org/10.1016/B978-0-12-811050-8.00027-3

Grafakos, S., Trigg, K., Landauer, M., Chelleri, L., & Dhakal, S. (2019). Analytical framework to evaluate the level of integration of climate adaptation and mitigation in cities. *Climatic Change*, *154*(1), 87–106.

Grainger, M. (2010). World summit on food security (UN FAO, Rome, 16–18 November 2009). *Development in Practice*, *20*(6), 740–742.

Grantham, T. E., Matthews, J. H., & Bledsoe, B. P. (2019). Shifting currents: Managing freshwater systems for ecological resilience in a changing climate. *Water Security*, *8*(October), 100049. https://doi.org/10.1016/j.wasec.2019.100049

Guido, Z., Knudson, C., Finan, T., Madajewicz, M., & Rhiney, K. (2020a). Shocks and cherries: The production of vulnerability among smallholder coffee farmers in Jamaica. *World Development*, *132*, 104979. https://doi.org/10.1016/j.worlddev.2020.104979

Guido, Z., Knudson, C., Finan, T., Madajewicz, M., & Rhiney, K. (2020b). Shocks and cherries: The production of vulnerability among smallholder coffee farmers in Jamaica. *World Development*, *132*, 104979. https://doi.org/10.1016/j.worlddev.2020.104979

Gutzler, D. S. (2014). Climate and Climate Change: Climate Variability: Seasonal and Interannual Variability. *Encyclopedia of Atmospheric Sciences: Second Edition*, *2*, 61–68. https://doi.org/10.1016/B978-0-12-382225-3.00029-3

Gyasi, R. M., Peprah, P., & Odame, D. (2020). Journal of A ff ective Disorders Association of food insecurity with psychological disorders: Results of a population-based study among older people in Ghana. *Journal of Affective Disorders*, *270*(October 2019), 75–82. https://doi.org/10.1016/j.jad.2020.03.088

Hall, R. (2011). Land grabbing in Africa and the new politics of food. *Future Agricultures, Policy Brief*. http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Land+Grabbing+in+Africa+and+the+New+Politics+of+Food#0

Halliday, M. A. K., Matthiessen, C. M. I. M., Santosa, R., Priyanto, A. D., Nuraeni, A., Ellyawati, H. C., Rohmawati, I., Alvionita, R., Iedema, R., Feez, S., White, P. R. R. R., Painter, C., Sobhie, M., Reza Atai, M., Amin Mozaheb, M., Oleh, Komunikasi, J. I., Jurnal, L., Doi, L., … Ahmadvand, M. (2016). No Title. *Nusa*, *5*(1), 1689–1699. https://doi.org/10.1017/CBO9781107415324.004

Hamid, S., & Mir, M. Y. (2021). Global Agri-food sector: Challenges and opportunities in COVID-19 pandemic. *Frontiers in Sociology*, *6*, 647337.

Hamilton, H., Henry, R., Rounsevell, M., Moran, D., Cossar, F., Allen, K., Boden, L., & Alexander, P. (2020). Exploring global food system shocks, scenarios and outcomes. *Futures*, *123*, 102601.

Hammed, T. B., Wandiga, S. O., Mulugetta, Y., & Sridhar, M. K. C. (2018). Improving knowledge and practices of mitigating green house gas emission through waste recycling in a community, Ibadan, Nigeria. *Waste Management*, *81*, 22–32. https://doi.org/10.1016/j.wasman.2018.09.044

Harkness, C., Semenov, M. A., Areal, F., Senapati, N., Trnka, M., Balek, J., & Bishop, J. (2020). Agricultural and Forest Meteorology Adverse weather conditions for UK wheat production under climate change. *Agricultural and Forest Meteorology*, *282–283*(August 2019), 107862. https://doi.org/10.1016/j.agrformet.2019.107862

Harvey, C. A., Saborio-Rodríguez, M., Martinez-Rodríguez, M. R., Viguera, B., Chain-Guadarrama, A., Vignola, R., & Alpizar, F. (2018). Climate change impacts and adaptation among smallholder farmers in Central America. *Agriculture & Food Security*, *7*(1), 1–20.

Harvey, J., Garrido, C. J., Savov, I., Agostini, S., Padrón-Navarta, J. A., Marchesi, C., López Sánchez-Vizcaíno, V., & Gómez-Pugnaire, M. T. (2014). 11B-rich fluids in subduction zones: The role of antigorite dehydration in subducting slabs and boron isotope heterogeneity in the mantle. *Chemical Geology*, *376*, 20–30. https://doi.org/10.1016/j.chemgeo.2014.03.015

Heckman, J. J. (n.d.). *The Common Structure of Statistical Models of Truncation, Sample Selection and Limited Dependent Variables and a Simple Estimator for Such Models*.

Herrador, Z., Perez-Formigo, J., Sordo, L., Gadisa, E., Moreno, J., Benito, A., Aseffa, A., & Custodio, E. (2015). Low dietary diversity and intake of animal source foods among school aged children in Libo Kemkem and Fogera Districts, Ethiopia. *PloS One*, *10*(7), e0133435.

Herrera, D. A., Ault, T. R., Fasullo, J. T., Coats, S. J., Carrillo, C. M., Cook, B. I., & Williams, A. P. (2018). Exacerbation of the 2013–2016 pan-Caribbean drought by anthropogenic warming. *Geophysical Research Letters*, *45*(19), 10–619.

Herrero, M., Ringler, C., Steeg, J. V. D., Koo, J., & Notenbaert, A. (2010). Climate variability and climate change and their impacts on Kenya's agricultural sector. *ILRI, Nairobi. Kenya*, 1–56. https://doi.org/10.5539/jsd.v6n2p9

Hertel, T. W., & Lobell, D. B. (2014). Agricultural adaptation to climate change in rich and poor countries: Current modeling practice and potential for empirical contributions. *Energy Economics*, *46*, 562–575. https://doi.org/10.1016/j.eneco.2014.04.014

Hertel, T. W., & Rosch, S. D. (2010). Featured Article Climate Change , Agriculture , and Poverty. *Applied Economic Perspectives and Policy*, *32*(3), 355–385. https://doi.org/10.1093/aepp/ppq016

Hilson, G. (2016). The Extractive Industries and Society Farming , small-scale mining and rural livelihoods in Sub-Saharan Africa: A critical overview. *The Extractive Industries and Society*, *3*(2), 547–563. https://doi.org/10.1016/j.exis.2016.02.003

Hitayezu, P., Wale, E., & Ortmann, G. (2017). Assessing farmers' perceptions about climate change: A double-hurdle approach. *Climate Risk Management*, *17*, 123–138. https://doi.org/10.1016/j.crm.2017.07.001

Holka, M., Kowalska, J., & Jakubowska, M. (2022). Reducing Carbon Footprint of Agriculture—Can Organic Farming Help to Mitigate Climate Change? *Agriculture*, *12*(9), 1383.

Huang, D., & Drescher, M. (2015). Urban crops and livestock: The experiences, challenges, and opportunities of planning for urban agriculture in two Canadian provinces. *Land Use Policy*, *43*, 1–14. https://doi.org/10.1016/j.landusepol.2014.10.011

Hughes, S. (2020). Principles , drivers , and policy tools for just climate change adaptation in legacy cities. *Environmental Science and Policy*, *111*(May), 35–41. https://doi.org/10.1016/j.envsci.2020.05.007

Hulme, M., Doherty, R., Ngara, T., New, M., & Lister, D. (2001). African climate change: 1900-2100. *Climate Research*, *17*(2 SPECIAL 8), 145–168. https://doi.org/10.3354/cr017145

Hussain, S., Huang, J., Huang, J., Ahmad, S., Nanda, S., Anwar, S., Shakoor, A., Zhu, C., Zhu, L., & Cao, X. (2020). Rice production under climate change: Adaptations and mitigating strategies. *Environment, Climate, Plant and Vegetation Growth*, 659–686.

Hyland, M., & Russ, J. (2019). Water as destiny – The long-term impacts of drought in sub-Saharan Africa. *World Development*, *115*, 30–45. https://doi.org/10.1016/j.worlddev.2018.11.002

Iakovidis, D., Gadanakis, Y., & Park, J. (2022). Farm-level sustainability assessment in Mediterranean environments: Enhancing decision-making to improve business sustainability. *Environmental and Sustainability Indicators*, *15*, 100187.

Islam, M. R. (2019). *The Science of Global Warming 10.1*. *2012*.

Islam, M. S., & Kieu, E. (2020). Tackling regional climate change impacts and food security issues: A critical analysis across ASEAN, PIF, and SAARC. *Sustainability*, *12*(3), 883.

Janvry, A. D., Sadoulet, E., & Suri, T. (2017). Field Experiments in Developing Country Agriculture. In *Handbook of Economic Field Experiments* (Vol. 2). Elsevier Ltd. https://doi.org/10.1016/bs.hefe.2016.08.002

Johannessen, J.-A., Olsen, B., & Lumpkin, G. T. (2001). Innovation as newness: What is new, how new, and new to whom? *European Journal of Innovation Management*.

Jones-Garcia, E., & Krishna, V. V. (2021). Farmer adoption of sustainable intensification technologies in the maize systems of the Global South. A review. *Agronomy for Sustainable Development*, *41*(1), 1–20.

Jost, C., Kyazze, F., Naab, J., Neelormi, S., Kinyangi, J., Zougmore, R., Aggarwal, P., Bhatta, G., Chaudhury, M., Tapio-Bistrom, M. L., Nelson, S., & Kristjanson, P. (2016). Understanding gender dimensions of agriculture and climate change in smallholder farming communities. *Climate and Development*, *8*(2), 133–144. https://doi.org/10.1080/17565529.2015.1050978

Jumrani, J., & Rai, V. N. (2020). Chapter 1—The unacceptable status quo: Malnutrition challenges of the developed and developing world. In *Wheat and Barley Grain Biofortification*. Elsevier Inc. https://doi.org/10.1016/B978-0-12-818444-8/00001-8

Kabir, J., Cramb, R., Alauddin, M., Gaydon, D. S., & Roth, C. H. (2020). Land Use Policy Farmers ' perceptions and management of risk in rice / shrimp farming systems in South-West Coastal Bangladesh. *Land Use Policy*, *95*(September 2019), 104577. https://doi.org/10.1016/j.landusepol.2020.104577

Kabubo-Mariara R M//Falco, S di, J. (2016). The impact of climate change on food calorie production and nutritional poverty: Evidence from Kenya. *Environment for Development Discussion Paper - Resources for the Future (RFF)*, *December*, 35 pp.

Karimipour, H., Tam, V. W. Y., Burnie, H., Le, K. N., Karimipour, H., Tam, V. W. Y., Burnie, H., & Le, K. N. (2019). Quantifying the effects of general waste reduction on greenhouse-gas emissions at public facilities. *Journal of the Air & Waste Management Association*, *0*(0), 1–11. https://doi.org/10.1080/10962247.2019.1642967

Karlsson, L., & Thompson, J. (n.d.). *"Triple wins" or "triple faults"? 197*.

Kassie, M., Stage, J., Diiro, G., Muriithi, B., Ledermann, S. T., Pittchar, J., Midega, C., & Zeyaur, K. (2018). *Land Use Policy Push – pull farming system in Kenya: Implications for economic and social welfare*. *77*(September 2017), 186–198. https://doi.org/10.1016/j.landusepol.2018.05.041

Kebede, A. Z., Dhillon, B. S., Schipprack, W., Araus, J. L., Bänziger, M., Semagn, K., Alvarado, G., & Melchinger, A. E. (2011). Effect of source germplasm and season on the in vivo haploid induction rate in tropical maize. *Euphytica*, *180*(2), 219–226. https://doi.org/10.1007/s10681-011-0376-3

Kharroubi, S., Naja, F., Diab-El-Harake, M., & Jomaa, L. (2021). Food insecurity pre-and post the COVID-19 pandemic and economic crisis in Lebanon: Prevalence and projections. *Nutrients*, *13*(9), 2976.

Khonje, M. G., Manda, J., Mkandawire, P., Tufa, A. H., & Alene, A. D. (2018). Adoption and welfare impacts of multiple agricultural technologies: Evidence from eastern Zambia. *Agricultural Economics*, *49*(5), 599–609.

Kober, T., Köberle, A. C., van der Zwaan, B., Beach, R. H., Vasquez-Arroyo, E., Cai, Y., Lucena, A. F. P., Rochedo, P. R. R., Daenzer, K., Gernaat, D., Hejazi, M., van Vuuren, D. P., & Turner, S. (2018). Interactions between climate change mitigation and adaptation: The case of hydropower in Brazil. *Energy*, *164*, 1161–1177. https://doi.org/10.1016/j.energy.2018.09.005

Kotir, J. H. (2011). Climate change and variability in Sub-Saharan Africa: A review of current and future trends and impacts on agriculture and food security. *Environment, Development and Sustainability*, *13*(3), 587–605. https://doi.org/10.1007/s10668-010-9278-0

Kramer, M. R., & Porter, M. (2011). *Creating shared value* (Vol. 17). FSG Boston, MA, USA.

Kumar, A., & Sharma, A. (2018). Socio-Sentic framework for sustainable agricultural governance. *Sustainable Computing: Informatics and Systems*. https://doi.org/10.1016/j.suscom.2018.08.006

Kuntashula, E., Chibwe, T., & Chabala, L. M. (2017). Enabling Agricultural Transformation Through Climate Change Policy Engagement. *Smart Technologies for Sustainable Smallholder Agriculture: Upscaling in Developing Countries*, 233–256. https://doi.org/10.1016/B978-0-12-810521-4.00012-8

Kurgat, B. K., Lamanna, C., Kimaro, A., Namoi, N., Manda, L., & Rosenstock, T. S. (2020). Adoption of climate-smart agriculture technologies in Tanzania. *Frontiers in Sustainable Food Systems*, *4*, 55.

Kurukulasuriya, P., Mendelsohn, R., Hassan, R., Benhin, J., Deressa, T., Diop, M., Eid, H. M., Fosu, K. Y., Gbetibouo, G., Jain, S., Mahamadou, A., Mano, R., Kabubo-mariara, J., El-marsafawy, S., Molua, E., Ouda, S., Ouedraogo, M., Se, I., Maddison, D., … Dinar, A. (2006). *Will African Agriculture Survive Climate Change ? 20*(3), 367–388. https://doi.org/10.1093/wber/lhl004

Laborde, D., Martin, W., & Vos, R. (2020). Poverty and food insecurity could grow dramatically as COVID-19 spreads. *International Food Policy Research Institute (IFPRI), Washington, DC*.

Le Quéré, C., Jackson, R. B., Jones, M. W., Smith, A. J. P., Abernethy, S., Andrew, R. M., De-Gol, A. J., Willis, D. R., Shan, Y., Canadell, J. G., Friedlingstein, P., Creutzig, F., & Peters, G. P. (2020). Temporary reduction in daily global CO2 emissions during the COVID-19 forced confinement. *Nature Climate Change*, *10*(7), 647–653. https://doi.org/10.1038/s41558-020-0797-x

Lee, M., & Gambiza, J. (2022). The adoption of conservation agriculture by smallholder farmers in southern Africa: A scoping review of barriers and enablers. *Journal of Rural Studies*, *92*, 214–225.

Lehmann, I., Martin, A., & Fisher, J. A. (2018). Why Should Ecosystem Services Be Governed to Support Poverty Alleviation? Philosophical Perspectives on Positions in the Empirical Literature. *Ecological Economics*, *149*(March), 265–273. https://doi.org/10.1016/j.ecolecon.2018.03.003

Leisner, C. P. (2020). Climate change impacts on food security-focus on perennial cropping systems and nutritional value. *Plant Science*, *293*, 110412.

Lenaerts, B., Collard, B. C. Y., & Demont, M. (2019). Plant Science Review: Improving global food security through accelerated plant breeding. *Plant Science*, *287*(April), 110207. https://doi.org/10.1016/j.plantsci.2019.110207

Lewin, K. (1943). Forces behind food habits and methods of change. *Bulletin of the National Research Council*, *108*(1043), 35–65.

Liang, Z., Zhang, L., Li, W., Zhang, J., & Frewer, L. J. (2021). Adoption of combinations of adaptive and mitigatory climate-smart agricultural practices and its impacts on rice yield and income: Empirical evidence from Hubei, China. *Climate Risk Management*, *32*, 100314. https://doi.org/10.1016/j.crm.2021.100314

Liu, T., Bruins, R. J. F., & Heberling, M. T. (2018). Factors influencing farmers' adoption of best management practices: A review and synthesis. *Sustainability (Switzerland)*, *10*(2), 1–26. https://doi.org/10.3390/su10020432

Long, T. B., Blok, V., & Coninx, I. (2019). The diffusion of climate-smart agricultural innovations: Systems level factors that inhibit sustainable entrepreneurial action. *Journal of Cleaner Production*, *232*, 993–1004. https://doi.org/10.1016/j.jclepro.2019.05.212

Lybbert, B. T., & Sumner, D. (2010). *Agricultural Technologies for Climate Change Mitigation and Adaptation in Developing Countries: Policy Options for Innovation and Agricultural Technologies for Climate Change Mitigation and Adaptation in Developing Countries: Policy Options for Innovati*. *6*.

Mabon, L., & Shih, W. (2018). What might ' just green enough ' urban development mean in the context of climate change adaptation? The case of urban greenspace planning in Taipei Metropolis , Taiwan. *World Development*, *107*, 224–238. https://doi.org/10.1016/j.worlddev.2018.02.035

Madsen, S., Bezner Kerr, R., Shumba, L., & Dakishoni, L. (2021). Agroecological practices of legume residue management and crop diversification for improved smallholder food security, dietary diversity and sustainable land use in Malawi. *Agroecology and Sustainable Food Systems*, *45*(2), 197–224.

Maina, K. W., Ritho, C. N., Lukuyu, B. A., & Rao, E. J. O. (2020). Socio-economic determinants and impact of adopting climate-smart Brachiaria grass among dairy farmers in Eastern and Western regions of Kenya. *Heliyon*, *6*(6), e04335. https://doi.org/10.1016/j.heliyon.2020.e04335

Mairura, F. S., Musafiri, C. M., Kiboi, M. N., Macharia, J. M., Ng'etich, O. K., Shisanya, C. A., Okeyo, J. M., Mugendi, D. N., Okwuosa, E. A., & Ngetich, F. K. (2021). Determinants of farmers' perceptions of climate variability, mitigation, and adaptation strategies in the central highlands of Kenya. *Weather and Climate Extremes*, *34*, 100374.

Makame, M. O., & Shackleton, S. (2020). Perceptions of climate variability and change in relation to observed data among two east coast communities in Zanzibar, East Africa. *Climate and Development*, *12*(9), 801–813.

Makate, C., Makate, M., Mango, N., & Siziba, S. (2019). Increasing resilience of smallholder farmers to climate change through multiple adoption of proven climate-smart agriculture innovations. Lessons from Southern Africa. *Journal of*

Environmental Management, *231*(September 2018), 858–868. https://doi.org/10.1016/j.jenvman.2018.10.069

Mann, B. M. E. (2009). *DO GLOBAL WARMING AND CLIMATE CHANGE REPRESENT A SERIOUS THREAT TO OUR WELFARE AND ENVIRONMENT ?* 193–230. https://doi.org/10.1017/S0265052509090220

Mantey, V., Mburu, J., & Chumo, C. (2020). Determinants of adoption and disadoption of cage tilapia farming in southern Ghana. *Aquaculture*, *525*(February), 735325. https://doi.org/10.1016/j.aquaculture.2020.735325

Marconi, L., & Armengot, L. (2020). Agriculture , Ecosystems and Environment Complex agroforestry systems against biotic homogenization: The case of plants in the herbaceous stratum of cocoa production systems. *Agriculture, Ecosystems and Environment*, *287*(August 2019), 106664. https://doi.org/10.1016/j.agee.2019.106664

Martey, E., & Kuwornu, J. K. M. (2021). Perceptions of Climate Variability and Soil Fertility Management Choices Among Smallholder Farmers in Northern Ghana. *Ecological Economics*, *180*(September 2020), 106870. https://doi.org/10.1016/j.ecolecon.2020.106870

Martial, A., Akata, E. A., Njomo, D., & Agrawal, B. (2017). Assessment of Building Integrated Photovoltaic (BIPV) for sustainable energy performance in tropical regions of Cameroon. *Renewable and Sustainable Energy Reviews*, *80*(September 2016), 1138–1152. https://doi.org/10.1016/j.rser.2017.05.155

Mary, S., Saravia-matus, S., & Gomez, S. (2018). Does nutrition-sensitive aid reduce the prevalence of undernourishment? ☆. *Food Policy*, *74*(March 2017), 100–116. https://doi.org/10.1016/j.foodpol.2017.11.008

Maseko, S. (2021). *The impact of climate-smart technology adoption on farmers welfare in Northern Zambia* [PhD Thesis]. University of Pretoria.

Mason-D'Croz, D., Sulser, T. B., Wiebe, K., Rosegrant, M. W., Lowder, S. K., Nin-Pratt, A., Willenbockel, D., Robinson, S., Zhu, T., Cenacchi, N., Dunston, S., & Robertson, R. D. (2019). Agricultural investments and hunger in Africa modeling potential contributions to SDG2 – Zero Hunger. *World Development*, *116*, 38–53. https://doi.org/10.1016/j.worlddev.2018.12.006

Masson-Delmotte, V., Zhai, P., Pörtner, H.-O., Roberts, D., Skea, J., Shukla, P. R., Pirani, A., Moufouma-Okia, W., Péan, C., & Pidcock, R. (2018). Global warming of 1.5 C. *An IPCC Special Report on the Impacts of Global Warming Of*, *1*(5).

Mbatu, R. S. (2016). REDD + research: Reviewing the literature, limitations and ways forward. *Forest Policy and Economics*, *73*, 140–152. https://doi.org/10.1016/j.forpol.2016.09.010

Mbow, C., Smith, P., Skole, D., Duguma, L., & Bustamante, M. (2014). Achieving mitigation and adaptation to climate change through sustainable agroforestry practices in africa. *Current Opinion in Environmental Sustainability*, *6*(1), 8–14. https://doi.org/10.1016/j.cosust.2013.09.002

McCarthy, N., Lipper, L., & Branca, G. (2011). Climate-Smart Agriculture: Smallholder Adoption and Implications for Climate Change Adaptation and Mitigation. *Mitigating Climate Change in Agriculture Series 4*, *October*, 1–37. https://doi.org/FAO Mitigatiion of Climate Change in Agriculture Series 4

Meadows, M. E. (2006). *Global Change and Southern Africa*. *44*(June), 135–145. https://doi.org/10.1111/j.1745-5871.2006.00375.x

MEKONNEN, Z., WOLDEAMANUEL, T., & KASSA, H. (2019). Socio-ecological vulnerability to climate change/variability in central rift valley, Ethiopia. *Advances in Climate Change Research*, *10*(1), 9–20. https://doi.org/10.1016/j.accre.2019.03.002

Meskerem, A., & Degefa, T. (2015). Household food security status and its determinants in Girar Jarso Woreda, north Shewa zone of Oromia region, Ethiopia. *Journal of Sustainable Development in Africa*, *17*(7), 118–137.

Meyfroidt, P. (2017). Trade-o ff s between environment and livelihoods: Bridging the global land use and food security discussions. *Global Food Security*, *xxxx*, 0–1. https://doi.org/10.1016/j.gfs.2017.08.001

Mhonyera, G., Masunda, S., & Meyer, D. F. (2023). Measuring the pass-through effect of global food price volatility and South Africa's CPI on the headline inflation of Zimbabwe. *Cogent Food & Agriculture*, *9*(1), 2212458.

Michler, J. D., Baylis, K., Arends-kuenning, M., & Mazvimavi, K. (2019). Conservation agriculture and climate resilience ☆. *Journal of Environmental Economics and Management*, *93*, 148–169. https://doi.org/10.1016/j.jeem.2018.11.008

Minasny, B., Arrouays, D., McBratney, A. B., Angers, D. A., Chambers, A., Chaplot, V., Chen, Z.-S., Cheng, K., Das, B. S., & Field, D. J. (2018). Rejoinder to Comments on Minasny et al., 2017 Soil carbon 4 per mille Geoderma 292, 59–86. *Geoderma*, *309*, 124–129.

Mogaka, B. O., Bett, H. K., & Karanja Ng'ang'a, S. (2021). Socioeconomic factors influencing the choice of climate-smart soil practices among farmers in western Kenya. *Journal of Agriculture and Food Research*, *5*, 100168.

Molua, E. L. (2007). The economic impact of climate change on agriculture in Cameroon. *World Bank Policy Research Working Paper*, *4364*.

Molua, E. L. (2022). Private farmland autonomous adaptation to climate variability and change in Cameroon. *Rural Society*, *31*(2), 115–135.

Mortoja, Md. G., & Yigitcanlar, T. (2022). Understanding political bias in climate change belief: A public perception study from South East Queensland. *Land Use Policy*, *122*, 106350. https://doi.org/10.1016/j.landusepol.2022.106350

Movilla-Pateiro, L., Mahou-Lago, X. M., Doval, M. I., & Simal-Gandara, J. (2021). Toward a sustainable metric and indicators for the goal of sustainability in agricultural and food production. *Critical Reviews in Food Science and Nutrition*, *61*(7), 1108–1129.

Muchangi, C. T. (2016). *Influence of farmer's characteristics, agricultural extension and technology specific factors on adoption of organic farming technologies in Embu west sub county, Embu, Kenya*. 95.

Mugumaarhahama, Y., Mondo, J. M., Cokola, M. C., Ndjadi, S. S., Mutwedu, V. B., Kazamwali, L. M., Cirezi, N. C., Chuma, G. B., Ndeko, A. B., Ayagirwe, R. B. B., Civava, R., Karume, K., & Mushagalusa, G. N. (2021). Socio-economic drivers of improved sweet potato varieties adoption among smallholder farmers in South-Kivu Province, DR Congo. *Scientific African*, *12*. https://doi.org/10.1016/j.sciaf.2021.e00818

Mugure, A., Oino, P. G., & and Benard Mwori Sorre. (2013). Land Ownership and its Impact on Adoption of Agroforestry Practices among Rural Households in Kenya: A Case of Busia County. *International Journal of Innovation and Applied Studies*, *4*(3), 552–559.

Mujeyi, A., Mudhara, M., & Mutenje, M. (2021). The impact of climate smart agriculture on household welfare in smallholder integrated crop–livestock farming systems: Evidence from Zimbabwe. *Agriculture & Food Security*, *10*(1), 1–15.

Muldoon-smith, K., & Greenhalgh, P. (2019). Energy Research & Social Science Suspect foundations: Developing an understanding of climate-related stranded assets in the global real estate sector. *Energy Research & Social Science*, *54*(September 2018), 60–67. https://doi.org/10.1016/j.erss.2019.03.013

Mulwa, C. K., & Visser, M. (2020). Farm diversification as an adaptation strategy to climatic shocks and implications for food security in northern Namibia. *World Development*, *129*, 104906. https://doi.org/10.1016/j.worlddev.2020.104906

Muriithi, L. N., Onyari, C. N., Mogaka, H. R., Gichimu, B. M., Gatumo, G. N., & Kwena, K. (2021). Adoption determinants of adapted climate smart agriculture technologies among smallholder farmers in Machakos, Makueni, and Kitui Counties of Kenya. *Journal of Agricultural Extension*, *25*(2), 75–85.

Musafiri, C. M., Kiboi, M., Macharia, J., Ng'etich, O. K., Kosgei, D. K., Mulianga, B., Okoti, M., & Ngetich, F. K. (2022). Adoption of climate-smart agricultural practices among smallholder farmers in Western Kenya: Do socioeconomic, institutional, and biophysical factors matter? *Heliyon*, *8*(1), e08677.

Musafiri, C. M., Macharia, J. M., Ng, O. K., Kiboi, M. N., Okeyo, J., Shisanya, C. A., Okwuosa, E. A., Mugendi, D. N., & Ngetich, F. K. (2020). Farming systems ' typologies analysis to inform agricultural greenhouse gas emissions potential from smallholder rain-fed farms in Kenya. *Scientific African*, *8*, e00458. https://doi.org/10.1016/j.sciaf.2020.e00458

Musavengane, R., & Kloppers, R. (2020). Social capital: An investment towards community resilience in the collaborative natural resources management of community-based tourism schemes. *Tourism Management Perspectives*, *34*(March 2019), 100654. https://doi.org/10.1016/j.tmp.2020.100654

Mvodo, E. S. M., & Liang, D. (2012). Cassava sector development in Cameroon: Production and marketing factors affecting price. *Agricultural Sciences*, *03*(05), 651–657. https://doi.org/10.4236/as.2012.35078

Mylonas, I., Stavrakoudis, D., Katsantonis, D., & Korpetis, E. (2020). Better farming practices to combat climate change. In *Climate Change and Food Security with Emphasis on Wheat*. Elsevier Inc. https://doi.org/10.1016/B978-0-12-819527-7.00001-7

Mytelka, L. K. (2000). Local systems of innovation in a globalized world economy. *Industry and Innovation*, *7*(1), 15–32.

Naz, F., & Doneys, P. (2022). Gender-based differences in access to and use of loans from rural credit programs for flood adaptation in the farming-dependent char communities of Bangladesh. *Women's Studies International Forum*, *95*, 102651.

Ndeke, A. M. (2021). *Gender Influence on Soil Fertility and Water Management Technologies Uptake among Smallholder Farmers in Tharaka Nithi County* [PhD Thesis]. University of Embu.

Ndiritu, S. W., Kassie, M., & Shiferaw, B. (2014a). Are there systematic gender differences in the adoption of sustainable agricultural intensification practices? Evidence from Kenya. *Food Policy*, *49*, 117–127.

Ndiritu, S. W., Kassie, M., & Shiferaw, B. (2014b). Are there systematic gender differences in the adoption of sustainable agricultural intensification practices? Evidence from Kenya. *Food Policy*, *49*, 117–127. https://doi.org/10.1016/j.foodpol.2014.06.010

Negera, M., Alemu, T., Hagos, F., & Haileslassie, A. (2022). Determinants of adoption of climate smart agricultural practices among farmers in Bale-Eco region, Ethiopia. *Heliyon*, *8*(7), e09824. https://doi.org/10.1016/j.heliyon.2022.e09824

Nelson, G. C., Rosegrant, M. W., Palazzo, A., Gray, I., Ingersoll, C., Robertson, R., Tokgoz, S., & Zhu, T. (2010). *Food security and climate change*.

Nelson, S., & Huyer, S. (2016). A Gender-responsive Approach to Climate-Smart Agriculture Evidence and guidance for practitioners. *Practice Brief: Climate Smart Agriculture*, 9.

Nerlove, M. (1956). Estimates of the elasticities of supply of selected agricultural commodities. *American Journal of Agricultural Economics*, *38*(2), 496–509.

Ngin, C., Chhom, C., & Neef, A. (2020). Climate change impacts and disaster resilience among micro businesses in the tourism and hospitality sector: The case of Kratie , Cambodia. *Environmental Research*, *186*(November 2019), 109557. https://doi.org/10.1016/j.envres.2020.109557

Ng'ombe, J. N., Kalinda, T. H., & Tembo, G. (2017). Does adoption of conservation farming practices result in increased crop revenue? Evidence from Zambia. *Agrekon*, *56*(2), 205–221. https://doi.org/10.1080/03031853.2017.1312467

Nhemachena, C. (2008). *Determinants of African farmers' strategies for adapting to climate change: Multinomial choice analysis RASHID HASSAN*. *2*(1), 83–104.

Njoh, A. J., Etta, S., Ngyah-etchutambe, I. B., Enomah, L. E. D., Tabrey, H. T., & Essia, U. (2019). Opportunities and challenges to rural renewable energy projects in Africa: Lessons from the Esaghem Village , Cameroon solar electri fi cation project. *Renewable Energy*, *131*, 1013–1021. https://doi.org/10.1016/j.renene.2018.07.092

Nw-egypt, M., Vetter, T., & Rieger, A. (2019). Water harvesting as a key for understanding adapted ancient livelihoods in an arid environment – Approaches to dryland archaeology in the Eastern. *Journal of Arid Environments, June 2018*, 1–22. https://doi.org/10.1016/j.jaridenv.2019.02.009

Nyang'au, J. O., Mohamed, J. H., Mango, N., Makate, C., & Wangeci, A. N. (2021). Smallholder farmers' perception of climate change and adoption of climate smart agriculture practices in Masaba South Sub-county, Kisii, Kenya. *Heliyon*, *7*(4), e06789.

Nyantakyi-Frimpong, H., Matou, P., & Isaac, M. E. (2019). Smallholder farmers’ social networks and resource-conserving agriculture in Ghana: A multicase comparison using exponential random graph models. *Ecology and Society*, *24*(1). https://doi.org/10.5751/es-10623-240105

Oduro-ofori, E., Aboagye Anokye, P., & Acquaye, N. E. A. (2014). Effects of Education on the Agricultural Productivity of Farmers in Offinso Municipality. *International Journal of Development Research*, *4*(9), 1951–1960.

Ojo, T. O., & Baiyegunhi, L. J. S. (2021). Climate change perception and its impact on net farm income of smallholder rice farmers in South-West, Nigeria. *Journal of Cleaner Production*, *310*, 127373. https://doi.org/10.1016/j.jclepro.2021.127373

Okeowo et al. : (2015). *5*(1), 12–16.

Olayide, S. (n.d.). *O and Heady, EO, 1982. Introduction to Agricultural Production Economics*. Ibadan University Press, Ibadan.

Ortiz-Bobea, A., Ault, T. R., Carrillo, C. M., Chambers, R. G., & Lobell, D. B. (2021). Anthropogenic climate change has slowed global agricultural productivity growth. *Nature Climate Change*, *11*(4), 306–312.

Otekunrin, O. A., Otekunrin, O. A., Momoh, S., & Ayinde, I. A. (2019). How far has Africa gone in achieving the zero hunger target? Evidence from Nigeria. *Global Food Security*, *22*(August), 1–12. https://doi.org/10.1016/j.gfs.2019.08.001

Owoeye, S. M., Oseni, B. M., & Gayawan, E. (2020). Heliyon Estimating lifetime malnourished period and its statistics based on the concept of Markov chain with reward. *Heliyon*, *6*(April 2019), e04073. https://doi.org/10.1016/j.heliyon.2020.e04073

Oyetunde-Usman, Z., Olagunju, K. O., & Ogunpaimo, O. R. (2021). Determinants of adoption of multiple sustainable agricultural practices among smallholder farmers

in Nigeria. *International Soil and Water Conservation Research*, *9*(2), 241–248. https://doi.org/10.1016/j.iswcr.2020.10.007

Pandey, B., & Choudhary, K. K. (2019). Air Pollution: Role in Climate Change and Its Impact on Crop Plants. In *Climate Change and Agricultural Ecosystems*. Elsevier Inc. https://doi.org/10.1016/B978-0-12-816483-9.00009-8

Parven, A., Pal, I., Witayangkurn, A., Pramanik, M., Nagai, M., Miyazaki, H., & Wuthisakkaroon, C. (2022). Impacts of disaster and land-use change on food security and adaptation: Evidence from the delta community in Bangladesh. *International Journal of Disaster Risk Reduction*, *78*, 103119.

Pausata, F. S. R., Gaetani, M., Messori, G., Berg, A., Souza, D. M. D., Sage, R. F., & Peter, B. (2020). Review The Greening of the Sahara: Past Changes and Future Implications. *One Earth*, *2*(3), 235–250. https://doi.org/10.1016/j.oneear.2020.03.002

Pauw, E. D., & Ramasamy, S. (2019). Rapid detection of stressed agricultural environments in Africa under climatic change 2000 – 2050 using agricultural resource indices and a hotspot mapping approach. *Weather and Climate Extremes*, *April*, 100211. https://doi.org/10.1016/j.wace.2019.100211

Pesaran, M. H. (2015). *Time series and panel data econometrics*. Oxford University Press.

PINIEwSkI, Mi., MEzGHANI, Abdel., Szczesniak, M., & Kundzewicz, Z. W. (2017). *Regional projections of temperature and precipitation changes: Robustness and uncertainty aspects*.

Ponce, C. (2020). Intra-seasonal climate variability and crop diversification strategies in the Peruvian Andes: A word of caution on the sustainability of adaptation to climate change. *World Development*, *127*, 104740. https://doi.org/10.1016/j.worlddev.2019.104740

Potapowicz, J., Szumi, D., & Polkowska, Ż. (2019). *Science of the Total Environment The in fl uence of global climate change on the environmental fate of anthropogenic pollution released from the permafrost Part I. Case study of Antarctica*. *651*, 1534–1548. https://doi.org/10.1016/j.scitotenv.2018.09.168

Prober, S. M., Doerr, V. A. J., Broadhurst, L. M., Williams, K. J., & Dickson, F. (2019). Shifting the conservation paradigm: A synthesis of options for renovating nature under climate change. *Ecological Monographs*, *89*(1), e01333. https://doi.org/10.1002/ecm.1333

Pumariño, L., Sileshi, G. W., Gripenberg, S., Kaartinen, R., Barrios, E., Muchane, M. N., Midega, C., & Jonsson, M. (2015). Effects of agroforestry on pest, disease and weed control: A meta-analysis. *Basic and Applied Ecology*, *16*(7), 573–582.

Quandt, A., Salerno, J. D., Neff, J. C., Baird, T. D., Herrick, J. E., Terrence McCabe, J., Xu, E., & Hartter, J. (2020). Mobile phone use is associated with higher smallholder agricultural productivity in Tanzania, East Africa. *PLoS ONE*, *15*(8 August), 1–16. https://doi.org/10.1371/journal.pone.0237337

Ray, D. K., West, P. C., Clark, M., Gerber, J. S., Prishchepov, A. V., & Chatterjee, S. (2019). Climate change has likely already affected global food production. *PloS One*, *14*(5), e0217148.

Raza, A., Razzaq, A., Mehmood, S. S., Zou, X., Zhang, X., Lv, Y., & Xu, J. (2019). Impact of climate change on crops adaptation and strategies to tackle its outcome: A review. *Plants*, *8*(2), 34.

Reimer, A., Doll, J. E., Boring, T. J., & Zimnicki, T. (2022). Scaling up conservation agriculture: An exploration of challenges and opportunities through a stakeholder engagement process. *Journal of Environmental Quality*.

Richards, K. R. (2019). Policy and research implications of recent carbon-sequestering analysis. In *Economic Issues in Global Climate Change* (pp. 288–308). CRC Press.

Riedy, C. (2016). *Climate Change*. https://doi.org/10.1002/9781405165518.wbeos0737

Ringler, C., Zhu, T., Cai, X., Koo, J., & Wang, D. (2010). Climate Change Impacts on Food Security in Sub-Saharan Africa Insights from Comprehensive Climate Change Scenarios. *Food Policy*, *466*(January), 28. https://doi.org/10.1038/nature09146

Rogers, B. C., Brown, R. R., De Haan, F. J., & Deletic, A. (2015). Analysis of institutional work on innovation trajectories in water infrastructure systems of Melbourne, Australia. *Environmental Innovation and Societal Transitions*, *15*, 42–64.

Rojas-downing, M. M., Nejadhashemi, A. P., Harrigan, T., & Woznicki, S. A. (2017). Climate Risk Management Climate change and livestock: Impacts , adaptation , and mitigation. *Climate Risk Management*, *16*, 145–163. https://doi.org/10.1016/j.crm.2017.02.001

Rosenzweig, C., Mbow, C., Barioni, L. G., Benton, T. G., Herrero, M., Krishnapillai, M., Liwenga, E. T., Pradhan, P., Rivera-Ferre, M. G., & Sapkota, T. (2020). Climate change responses benefit from a global food system approach. *Nature Food*, *1*(2), 94–97.

Rötter, R. P., Hoffmann, M. P., Koch, M., & Müller, C. (2018). Progress in modelling agricultural impacts of and adaptations to climate change. *Current Opinion in Plant Biology*, *45*, 255–261. https://doi.org/10.1016/j.pbi.2018.05.009

Rouzitalab, Z., Maklavany, D. M., Jafarinejad, S., & Rashidi, A. (2019). Lignocellulose-based Adsorbents: A Spotlight Review of the Effective Parameters on Carbon Dioxide Capture Process. In *Chemosphere*. Elsevier B.V. https://doi.org/10.1016/j.chemosphere.2019.125756

Rowhani, P., Lobell, D. B., Linderman, M., & Ramankutty, N. (2011). Agricultural and Forest Meteorology Climate variability and crop production in Tanzania. *Agricultural and Forest Meteorology*, *151*(4), 449–460. https://doi.org/10.1016/j.agrformet.2010.12.002

Sah Akwen, N. (2017). "Not Migrating After All": Young Farmers and Climate Change Adaptation in Cameroon. Young Farmers and Climate Change Adaptation in Cameroon. In *Beyond Agricultural Impacts: Multiple Perspectives on Climate Change and Agriculture in Africa*. Elsevier Inc. https://doi.org/10.1016/B978-0-12-812624-0.00010-7

Salvini, G. (2016). *REDD + and Climate Smart Agriculture in landscapes From national design to local implementation*. 151.

Sandel, M. J. (2013). Market reasoning as moral reasoning: Why economists should re-engage with political philosophy. *Journal of Economic Perspectives*, *27*(4), 121–140.

Sanz, M. J., & Cite, D. N. (2018). *IPCC: Chapter 1: Framing and Context Table of Contents*. 1–60.

Seddon, N., Chausson, A., Berry, P., Girardin, C. A., Smith, A., & Turner, B. (2020). Understanding the value and limits of nature-based solutions to climate change and other global challenges. *Philosophical Transactions of the Royal Society B*, *375*(1794), 20190120.

Selahkwe, C., Nformi, M. I., Lengah, T. N., Nchanji, E. B., & Fotang, C. (2021). Factors That Determine the Adoption of Improved Irish Potato Technologies by Farmers in the Western Region of Cameroon. *Agricultural Sciences*, *12*(12), 1404–1413.

Sgroi, F. (2022). Evaluating of the sustainability of complex rural ecosystems during the transition from agricultural villages to tourist destinations and modern agri-food systems. *Journal of Agriculture and Food Research*, *9*, 100330.

Shafiq, M., & Mahmood, S. (2022). Spatial Assessment of Forest Cover Change in Azad Kashmir, Pakistan. *Advanced GIS*, *2*(2).

Shakhawat, M., Arshad, M., Qian, L., Zhao, M., Mehmood, Y., & Kächele, H. (2019). Economic impact of climate change on crop farming in Bangladesh: An application of Ricardian method. *Ecological Economics*, *164*(March), 106354. https://doi.org/10.1016/j.ecolecon.2019.106354

Sherman, M., Berrang-ford, L., Lwasa, S., Ford, J., Namanya, D. B., Llanos-cuentas, A., & Maillet, M. (2016). *Drawing the line between adaptation and development: A systematic literature review of planned adaptation in developing countries*. https://doi.org/10.1002/wcc.416

Singh, S. (2020). Farmers' perception of climate change and adaptation decisions: A micro-level evidence from Bundelkhand Region, India. *Ecological Indicators*, *116*, 106475.

Skreli, E., Imami, D., Jámbor, A., Zvyagintsev, D., & Çera, G. (2015). The impact of government subsidies on the olive and vineyard sectors of Albanian agriculture. *Studies in Agricultural Economics*, *117*(3), 119–125. https://doi.org/10.7896/j.1525

Sollen-Norrlin, M., Ghaley, B. B., & Rintoul, N. L. J. (2020). Agroforestry benefits and challenges for adoption in Europe and beyond. *Sustainability (Switzerland)*, *12*(17), 1–20. https://doi.org/10.3390/su12177001

Solomon, S. (2007). IPCC (2007): Climate change the physical science basis. *Agu Fall Meeting Abstracts*, *2007*, U43D-01.

Somboonsuke, B., Phitthayaphinant, P., Sdoodee, S., & Kongmanee, C. (2018). Farmers' perceptions of impacts of climate variability on agriculture and adaptation strategies in Songkhla Lake basin. *Kasetsart Journal of Social Sciences*, *39*(2), 277–283. https://doi.org/10.1016/j.kjss.2018.05.006

Somorin, O. A., Brown, C. P. H., Visseren-Hamakers, I. J., Sonwa, D. J., Arts, B., & Nkem, J. (2012). The congo basin forests in a changing climate: Policy discourses on adaptation and mitigation (REDD+). *Global Environmental Change*, *22*(1), 288–298. https://doi.org/10.1016/j.gloenvcha.2011.08.001

Sonwa, D. (2017). Forest and Climate Change Response in Africa. *Frontiers of African Studies*, *May*, 71–82.

Sonwa, D. J., Somorin, O. A., Jum, C., Bele, M. Y., & Nkem, J. N. (2012). Vulnerability, forest-related sectors and climate change adaptation: The case of Cameroon. *Forest Policy and Economics, 23*, 1–9. https://doi.org/10.1016/j.forpol.2012.06.009

Soussana, J.-F., Lutfalla, S., Smith, P., Lal, R., Chenu, C., & Ciais, P. (2017). Answer to the viewpoint "sequestering soil organic carbon: A nitrogen dilemma." *Environmental Science & Technology, 51*(20), 11502–11502.

Sridhar, A., Balakrishnan, A., Jacob, M. M., Sillanpää, M., & Dayanandan, N. (2023). Global impact of COVID-19 on agriculture: Role of sustainable agriculture and digital farming. *Environmental Science and Pollution Research, 30*(15), 42509–42525.

Stout, L. (2012). *The shareholder value myth: How putting shareholders first harms investors, corporations, and the public*. Berrett-Koehler Publishers.

Swinnen, J., & Vos, R. (2021). COVID-19 and impacts on global food systems and household welfare: Introduction to a special issue. *Agricultural Economics*, *52*(3), 365–374.

Syano, N. M., Nyangito, M. M., Wasonga, O. V., & Kironchi, G. (2022). Agroforestry practices and factors influencing their adoption by communities in the drylands of Eastern Kenya. *Agroforestry Systems*, *96*(8), 1225–1235.

Talanow, K., Topp, E. N., Loos, J., & Martín-López, B. (2021). Farmers' perceptions of climate change and adaptation strategies in South Africa's Western Cape. *Journal of Rural Studies, 81*, 203–219.

Tang, K., & Hailu, A. (2020). Smallholder farms' adaptation to the impacts of climate change: Evidence from China's Loess Plateau. *Land Use Policy*, *91*(April), 104353. https://doi.org/10.1016/j.landusepol.2019.104353

Tanumihardjo, S. A., Mcculley, L., Roh, R., Lopez-ridaura, S., Palacios-rojas, N., & Gunaratna, N. S. (2019). Maize agro-food systems to ensure food and nutrition security in reference to the Sustainable Development Goals. *Global Food Security*, *April*, 100327. https://doi.org/10.1016/j.gfs.2019.100327

Tegegne, Y. T., Ramcilovic-Suominen, S., FOBISSIE, K., Visseren-Hamakers, I. J., Lindner, M., & Kanninen, M. (2017). Synergies among social safeguards in FLEGT and REDD + in Cameroon. *Forest Policy and Economics*, *75*, 1–11. https://doi.org/10.1016/j.forpol.2016.11.005

Teklewold, H., Kassie, M., & Shiferaw, B. (2013). Adoption of multiple sustainable agricultural practices in rural Ethiopia. *Journal of Agricultural Economics*, *64*(3), 597–623. https://doi.org/10.1111/1477-9552.12011

Teklu, A., Simane, B., & Bezabih, M. (2022). Effectiveness of Climate-Smart Agriculture Innovations in Smallholder Agriculture System in Ethiopia. *Sustainability*, *14*(23), 16143.

the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security. (2017). *HLPE. 2017. Nutrition and food systems*. *September*.

Thornton, P. K., Ericksen, P. J., Herrero, M., & Challinor, A. J. (2014). Climate variability and vulnerability to climate change: A review. *Global Change Biology*, *20*(11), 3313–3328. https://doi.org/10.1111/gcb.12581

Thornton, P. K., Steeg, J. V. D., Notenbaert, A., & Herrero, M. (2009). The impacts of climate change on livestock and livestock systems in developing countries: A review of what we know and what we need to know. *Agricultural Systems*, *101*(3), 113–127. https://doi.org/10.1016/j.agsy.2009.05.002

Toborn, J., & Harvesting, R. W. (2011). Adoption of agricultural innovations, converging narratives, and the role of Swedish agricultural research for development. *Unpublished Discussion Paper*.

Touma, D., Stevenson, S., Lehner, F., & Coats, S. (2021). Human-driven greenhouse gas and aerosol emissions cause distinct regional impacts on extreme fire weather. *Nature Communications*, *12*(1), 1–8.

Tripathi, A., & Mishra, A. K. (2020). Climate Risk Management Knowledge and passive adaptation to climate change: An example from Indian farmers. *Climate Risk Management*, *2016*, 1–13. https://doi.org/10.1016/j.crm.2016.11.002

Tsige, M., Synnevåg, G., & Aune, J. B. (2020). Gendered constraints for adopting climate-smart agriculture amongst smallholder Ethiopian women farmers. *Scientific African*, *7*, e00250. https://doi.org/10.1016/j.sciaf.2019.e00250

Tulus, V., Hany, M., Cabeza, L. F., Vallès, M., & Jiménez, L. (2019). Economic and environmental potential for solar assisted central heating plants in the EU residential sector: Contribution to the 2030 climate and energy EU agenda. *Applied Energy*, *236*(September 2018), 318–339. https://doi.org/10.1016/j.apenergy.2018.11.094

Uk, P. S. (2007). *Coordinating Lead Authors:*

van den Heuvel, F. P., de Langen, P. W., van Donselaar, K. H., & Fransoo, J. C. (2011). Identification of Employment Concentration and Specialization Areas: Theory and Application. *Beta Working Paper*, *354*(August), 26p. https://doi.org/10.1002/agr

Vanlauwe, B., Hungria, M., Kanampiu, F., & Giller, K. E. (2019). Agriculture , Ecosystems and Environment The role of legumes in the sustainable intensi fi cation of African smallholder agriculture: Lessons learnt and challenges for the future. *Agriculture, Ecosystems and Environment*, *284*(March), 106583. https://doi.org/10.1016/j.agee.2019.106583

Verburg, P. H., Alexander, P., Evans, T., Magliocca, N. R., Malek, Z., Rounsevell, M. D., & van Vliet, J. (2019). Beyond land cover change: Towards a new generation of land use models. *Current Opinion in Environmental Sustainability*, *38*, 77–85.

Waaswa, A., Oywaya Nkurumwa, A., Mwangi Kibe, A., & Ngeno Kipkemoi, J. (2022). Climate-Smart agriculture and potato production in Kenya: Review of the determinants of practice. *Climate and Development*, *14*(1), 75–90.

Wekesa, B. M., Ayuya, O. I., & Lagat, J. K. (2018a). Effect of climate-smart agricultural practices on household food security in smallholder production systems: Micro-level evidence from Kenya. *Agriculture and Food Security*, *7*(1), 1–14. https://doi.org/10.1186/s40066-018-0230-0

Wekesa, B. M., Ayuya, O. I., & Lagat, J. K. (2018b). Effect of climate-smart agricultural practices on household food security in smallholder production systems: Micro-level evidence from Kenya. *Agriculture and Food Security*, *7*(1), 1–14. https://doi.org/10.1186/s40066-018-0230-0

Weldegebriel, N. W., & Gustavsson, H. (2017). Climate Change Adaptation and Mitigation Strategies Vis-À-Vis the Agriculture and Water Sectors in Ethiopia—Case Review/Study of the EPCC Project. *Environment Pollution and Climate Change*, *01*(03), 1–8. https://doi.org/10.4172/2573-458x.1000125

Westermann, O., Förch, W., Thornton, P., Körner, J., Cramer, L., & Campbell, B. (2018). Scaling up agricultural interventions: Case studies of climate-smart agriculture. *Agricultural Systems*, *165*(June), 283–293. https://doi.org/10.1016/j.agsy.2018.07.007

Westholm, L., & Arora-Jonsson, S. (2015). Defining Solutions, Finding Problems: Deforestation, Gender, and REDD+ in Burkina Faso. *Conservation and Society*, *13*(2), 189. https://doi.org/10.4103/0972-4923.164203

Wiebe, K., Robinson, S., & Cattaneo, A. (2019a). Climate Change , Agriculture and Food Security: Impacts and the Potential for Adaptation and Mitigation. In *Sustainable Food and Agriculture* (Issue 2016). Elsevier Inc. https://doi.org/10.1016/B978-0-12-812134-4.00004-2

Wiebe, K., Robinson, S., & Cattaneo, A. (2019b). Climate Change, Agriculture and Food Security. In *Sustainable Food and Agriculture* (Issue 2016). Elsevier Inc. https://doi.org/10.1016/b978-0-12-812134-4.00004-2

Wiréhn, L. (2018). Nordic agriculture under climate change: A systematic review of challenges, opportunities and adaptation strategies for crop production. *Land Use Policy*, *77*(April), 63–74. https://doi.org/10.1016/j.landusepol.2018.04.059

Wood, S. A., Jina, A. S., Jain, M., Kristjanson, P., & DeFries, R. S. (2014). Smallholder farmer cropping decisions related to climate variability across multiple regions. *Global Environmental Change*, *25*(1), 163–172. https://doi.org/10.1016/j.gloenvcha.2013.12.011

Workineh, A., Tayech, L., & Ehite, H. K. (2020). Agricultural technology adoption and its impact on smallholder farmers welfare in Ethiopia. *African Journal of Agricultural Research*, *15*(3), 431–445. https://doi.org/10.5897/ajar2019.14302

Xiao, D., Liu, D. L., Wang, B., Feng, P., Bai, H., & Tang, J. (2020). Climate change impact on yields and water use of wheat and maize in the North China Plain under future climate change scenarios. *Agricultural Water Management*, *238*(January), 106238. https://doi.org/10.1016/j.agwat.2020.106238

Xiukang, W. (2018). *The Effects of Mulch and Nitrogen Fertilizer on the Soil Environment of Crop Plants The Effects of Mulch and Nitrogen Fertilizer on the Soil Environment of Crop Plants*. *41330858*. https://doi.org/10.1016/bs.agron.2018.08.003

Xu, X., Hu, H., Tan, Y., Yang, G., Zhu, P., & Jiang, B. (2019). Quantifying the impacts of climate variability and human interventions on crop production and food security in the Yangtze River Basin, China, 1990–2015. *Science of the Total Environment*, *665*, 379–389. https://doi.org/10.1016/j.scitotenv.2019.02.118

Yamoah, F. A., & Kaba, J. S. (2022). Integrating climate-smart agri-innovative technology adoption and agribusiness management skills to improve the livelihoods of smallholder female cocoa farmers in Ghana. *Climate and Development*, 1–7.

Yang, T., Siddique, K. H. M., & Liu, K. (2020). Cropping systems in agriculture and their impact on soil health-A review. *Global Ecology and Conservation*, e01118. https://doi.org/10.1016/j.gecco.2020.e01118

Yatich, F., Karanja, A., & Obulinji, H. (2022). Effects of Climate Smart Agriculture Practices on Household Livelihoods in Soy Sub-county Kenya. *Journal of Geography, Environment and Earth Science International*, *26*(10), 49–55.

Yazdanpanah, M., Wheeler, S. A., Zuo, A., & Zobeidi, T. (2022). Understanding the influence of Iranian farmers' climate change beliefs on their adaptation strategies and mitigation intentions. *Climate and Development*, 1–13.

Yigezu, Y. A., Mugera, A., El-Shater, T., Aw-Hassan, A., Piggin, C., Haddad, A., Khalil, Y., & Loss, S. (2018). Enhancing adoption of agricultural technologies requiring high initial investment among smallholders. *Technological Forecasting and Social Change*, *134*(April), 199–206. https://doi.org/10.1016/j.techfore.2018.06.006

Yirga, B., Megento, T. L., & Habetemariam, K. Y. (2023). Urban forest management in Addis Ababa, Ethiopia. A policy policy Arrangement Approach. *Urban Forestry & Urban Greening*, *79*, 127809.

Yohannes, H., Soromessa, T., & Argaw, M. (2015). Carbon stock analysis along slope and slope aspect gradient in Gedo Forest: Implications for climate change mitigation. *Journal of Earth Science and Climate Change*, *6*(9), 305.

Yu, D., Liu, Y., Shi, P., & Wu, J. (2019). Projecting impacts of climate change on global terrestrial ecoregions. *Ecological Indicators*, *103*(19), 114–123. https://doi.org/10.1016/j.ecolind.2019.04.006

Zakari, S., Ibro, G., Moussa, B., & Abdoulaye, T. (2022). Adaptation Strategies to Climate Change and Impacts on Household Income and Food Security: Evidence from Sahelian Region of Niger. *Sustainability*, *14*(5), Article 5. https://doi.org/10.3390/su14052847

Zegeye, M. K., Bekitie, K. T., & Hailu, D. N. (2022). Spatio-temporal variability and trends of hydroclimatic variables at Zarima Sub-Basin North Western Ethiopia. *Environmental Systems Research*, *11*(1), 27. https://doi.org/10.1186/s40068-022-00273-5

Zeng, D., Alwang, J., Norton, G., Jaleta, M., Shiferaw, B., & Yirga, C. (2018). Land ownership and technology adoption revisited: Improved maize varieties in Ethiopia. *Land Use Policy*, *72*(October 2017), 270–279. https://doi.org/10.1016/j.landusepol.2017.12.047

Zhang, F., Engel, B. A., Zhang, C., Guo, S., Guo, P., & Wang, S. (2019). Agricultural production planning approach based on interval fuzzy credibility-constrained bi-level programming and Nerlove supply response theory. *Journal of Cleaner Production*, *233*, 1158–1169. https://doi.org/10.1016/j.jclepro.2019.06.096

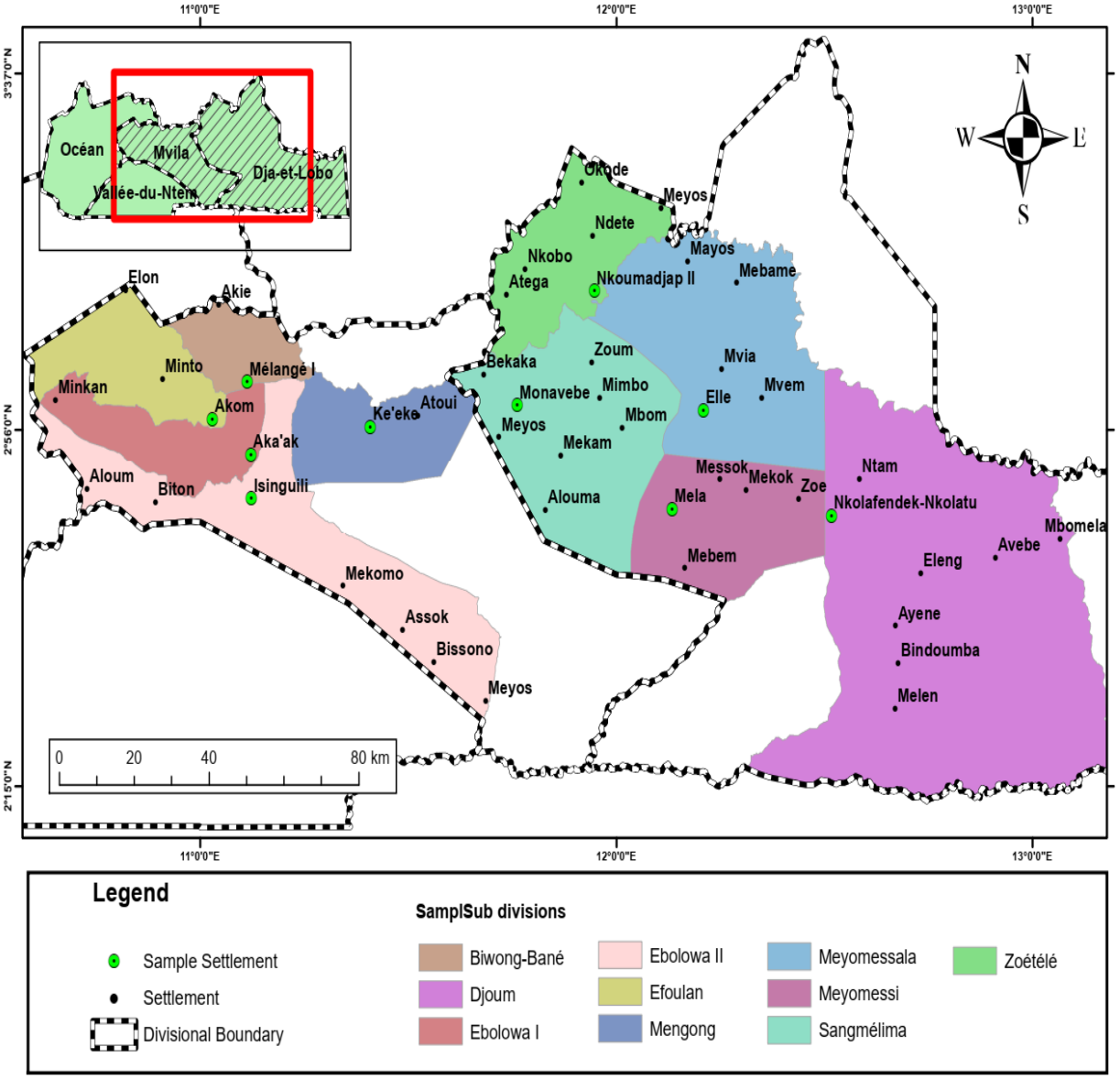
Zhou, J., Lang, X., Du, B., Zhang, H., Liu, H., Zhang, Y., & Shang, L. (2016). Litterfall and nutrient return in moist evergreen broad-leaved primary forest and mixed subtropical secondary deciduous broad-leaved forest in China. *European Journal of Forest Research*, *135*(1), 77–86. https://doi.org/10.1007/s10342-015-0918-7

Zorn, A., & Zimmert, F. (2022). Structural change in the dairy sector: Exit from farming and farm type change. *Agricultural and Food Economics*, *10*(1), 1–31.

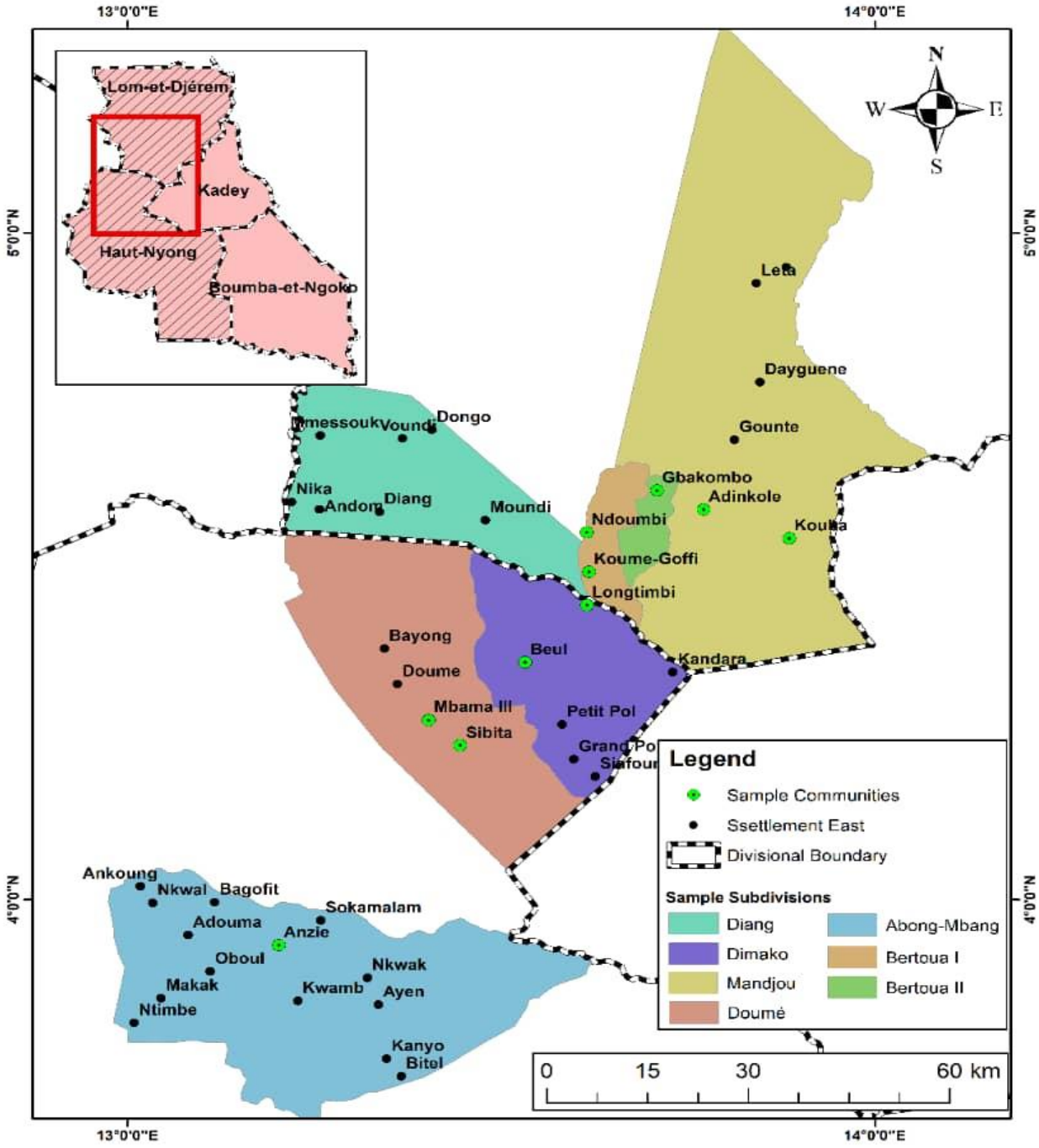
Zulu-Mbata, O., Chapoto, A., & Hichaambwa, M. (2016). *Determinants of conservation agriculture adoption among Zambian smallholder farmers*.

ANNEXIS

Annex 1: Map of Study Area(South Region)


11°0'0"E
12°0'0"E
13°0'0"E
3°37'0"N
2°56'0"N
2°15'0"N
N
W
E
S
Océan
Mvila
Dja-et-Lobo
Vallée-du-Ntem
Okode
Meyos
Ndete
Nkobo
Atega
Nkoumadjap II
Mayos
Mebame
Elon
Akie
Minto
Mélangé I
Minkan
Akom
Aka'ak
Ke'eke
Atoui
Bekaka
Zoum
Mvia
Monavebe
Mimbo
Mvem
Elle
Mbom
Meyos
Mekam
Aloum
Biton
Isinguili
Alouma
Messok
Mekok
Zoe
Mela
Ntam
Nkolafendek-Nkolatu
Mbomela
Avebe
Eleng
Mebem
Mekomo
Assok
Bissono
Meyos
Ayene
Bindoumba
Melen
0
20
40
80 km
Legend
Sample Settlement
Settlement
Divisional Boundary
SamplSub divisions
Biwong-Bané
Djoum
Ebolowa I
Ebolowa II
Efoulan
Mengong
Meyomessala
Meyomessi
Sangmélima
Zoétélé

Annex 2: Map of Study Area (East Region)



Annex 3 Description of Variables

Table 4.19 :

Variables	Calibration	Expected sign
Outcome Variables		
Agroforestry	Adoption of Agroforestry (Dummy, yes=1, No =0)	+
Intercropping	Adoption of Intercropping (Dummy, yes=1, No =0)	+
Cover Crop	Adoption of the Cover crop (Dummy, yes=1, No =0)	+
Crop Rotation	Adoption of Crop rotation (Dummy, yes=1, No =0)	+
Mulching	Adoption of Mulching (Dummy, yes=1, No =0)	+
Zero/minimum Tillage	Adoption of zero/minimum tillage (Dummy, yes=1, No =0)	+
Control Variables		
Gender	Gender of farmhouse head (Dummy, female=1, male=0)	+/-
Age	Age of farmhouse head (years)	+/-
Land Size	Farmland size (hectares)	+/-
Farm Experience	Household head farming experience (Years)	+
Extension advises	Access to extension service (Dummy, yes=1, No= 0)	+
Agriculture Credit	Access to agricultural credit (Dummy, yes=1, No= 0)	+
Distance from Home to Farm	Distance from farm households to farmland (in kilometres)	-
Farms Cultivated	Number of farms cultivated (in numbers)	+/-
Household Size	Number of family members(count)	+/-
Marital Status	1 = single; 2 = common-law; 3 = married monogamous; 4 = married polygamous; 5 = widowed; 6 = Divorced/Separated	+/-
Education	Years of education of household head(count)	+
Land Ownership	Land ownership status (1= family, 2= owned land, 3= leased land	+
Perception of Soil Fertility	Perception of fertility status of soil (1=very fertile, 2=moderately fertile, 3= not fertile	+/-
Use of sustainable Farm Techniques	Modern farm technology (dummy, 1=yes, No =0)	+
Received Government Subsidies	Farmers who received government subvention (dummy, yes=1, No=0)	+
Perception of Climate Variability	If farmers perceive variability in climate (Dummy, yes=1, No=0)	+/-

(Source: Designed by authors, 2022)