Climate-Smart Agriculture: Building Resilience in the Upper Blue Nile Highlands of Ethiopia

By

Abyiot Teklu Meshesha

A Dissertation

Submitted to the Center for Rural Development Studies

Presented in Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Development Studies (Rural Development)

Addis Ababa University,
Addis Ababa, Ethiopia
April 2023

Climate-Smart Agriculture: Building Resilience in the Upper Blue Nile highlands of Ethiopia

By

Abyiot Teklu Meshesha

A Dissertation

Submitted to the Center for Rural Development Studies

Presented in Fulfillment of the Requirements for the Degree of

Doctor of Philosophy in Development Studies (Rural Development)

Addis Ababa University,
Addis Ababa, Ethiopia

April 2023

Declaration

I, the undersigned, declare that this is my original work, has never been presented in this or any other University, and that all the resources and materials used for the dissertation, have been fully acknowledged.

Name: _____

Signature: _____

Date: _____

Place: _____

Date of submission: _____

This dissertation has been submitted for examination with my approval as University supervisor.

Supervisor name: _____

Signature: _____

Date: _____

Dissertation Approval

Addis Ababa University

School of Graduate Studies

This is to certify that the dissertation prepared by Abyiot Teklu Meshesha entitled: "**Climate-Smart Agriculture: Building Resilience in the Upper Blue Nile Highlands of Ethiopia**" and submitted in fulfillment of the requirement for the Degree of Doctor of Philosophy (Rural Development) complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

Signed by the Examining Committee:

---------- ---------- ----------

Chairman, Examining Committee signature Date

---------- ---------- ----------

External Examiner signature Date

---------- ---------- ----------

Internal Examiner signature Date

---------- ---------- ----------

Advisor signature Date

---------- ----------

Chair of Department or Graduate Program Coordinator

Acknowledgment

I am deeply indebted to many people who, in one way or another, contributed to the accomplishment of this study. First and foremost, I am extremely grateful to my supervisors, Professor Belay Simane and Dr. Mintewab Bezabih, for their continuous guidance and encouragement, from which I immensely benefited throughout the study period. I feel privileged to have both of them as my supervisors, and it has been an excellent opportunity and experience to learn from their insightful minds. I would also like to express my sincere thanks to him for the facilitation of financial support for the successful completion of this study. This study would not have been possible without his all-around support and encouragement. I would like to express my sincere gratitude to Addis Ababa University for sponsoring my study. My deepest appreciation goes to PEER Project-Cycle 4 of the USG-University of California, Davis, for providing additional financial support towards the completion of my Ph.D. project. My gratitude also goes to the staff members at Addis Ababa University's Center for Rural Development, who have been helpful and supportive throughout my study period. I humbly acknowledge the cooperation of the sampled farmers, development agents, and regional, woreda, and kebele-level officials. The inspiration and motivation of my sweet son, Nolawi Abyiot, have been my major source of motivation. My heartfelt gratitude and love to my sweet wife, Genet Abebaw Dessie, for her encouragement and unwavering support in completing this dissertation I love you because you have also scared me a lot about this academic venture. My enthusiasm goes to my dearest mother, Garedech Hibiste, who gave her entire life to make sure that I and my siblings could climb the ladder of academic success. My heartfelt appreciation also goes to my dearest heroine, Sister Websera Teklu; my sisters, Sintayehu Teklu, Tafesech Teklu, and Bisteser Telku; and my brother, Sirabizu Teklu, and Amare Abate. My heartfelt appreciation also goes to my late, beloved uncle, Mr. Birhane. My sincere appreciation also goes to my dear friend and office mate Mr. Chalachew Arega and Mr. Bechaye Tesfaye. My heartfelt gratitude also goes to my dear friends Dereb Weldeyohanes, Lejalem Abebaw, and Tariku Dejene for the wonderful time we had together and the ideas we shared throughout this study. I am also thankful to all the CODS staff for their friendly support throughout this study. Thank you, holy saviors, merciful and passionate, for providing me with the blessings to complete this work.

Dedication

I dedicate this dissertation to my courageous and hardworking late mother, Ms. Garedech Hibsete Nigate. If it were my choice, I would have been called Abyiot Garedech.

Publication status

This dissertation is based four published papers.

Chapter 2: Teklu A., Simane B., Bezabih M. (2022). "Effects of perceptions on the adoption of climate-smart agriculture innovations: empirical evidence from the upper Blue Nile Highlands of Ethiopia", International Journal of Climate Change Strategies and Management, Vol. 14 No. 3, pp. 293-311. https://doi.org/10.1108/IJCCSM-04-2021-0035

Chapter 3 : Teklu A., Simane B., Bezabih M. (2022). Multiple adoptions of Climate-Smart Agriculture Innovation for agricultural sustainability: Empirical evidence from the Upper Blue Nile Highlands of Ethiopia. Climate and Risk management, Elsevier Journals. https://doi.org/10.1016/j.crm.2023.100477

Chapter 4: Teklu A., Simane B., Bezabih M. (2022). Effectiveness of Climate-smart Agriculture innovations in smallholder agriculture system in Ethiopia. Sustainability 2022, 14, 16143. https://doi.org/10.3390/su142316143

Chapter 5: Teklu, A.; Simane, B.; Bezabih, M. Effect of Climate Smart Agriculture Innovations on Climate Resilience among Smallholder Farmers: Empirical Evidence from the Choke Mountain Watershed of the Blue Nile Highlands of Ethiopia. Sustainability 2023, 15, 4331. https://doi.org/10.3390/su15054331

Table of Contents

Acknowledgment III
Publication status V
List of Tables IX
List of Figures X
Abbreviation and Acronyms XI
General Abstract XIII
Chapter One: General Introduction 1
1.1 Background and Justification 1
1.2. Concise literature review 4
1.3. Statement of the Problem 16
1.4 Research questions 19
1.5. Objectives 19
1.5.1. General objective 19
1.5.2. Specific objectives 19
1.6. Significance of the study 19
1.7. Scope of the Study 20
1.8. Limitations of the study 21
1.9. Structure of the dissertation 21
Chapter Two: Effects of perceptions on the adoption of CSA Innovations: Empirical evidence from the upper Blue Nile Highlands of Ethiopia 22
Abstract 22
2.1. Introduction 23
2.2. Research Methodology 26
2.2.1. The description of the study area 26
2.2.2. Data type and sources 27
2.2.3. Sampling design 27
2.2.4. Methods of data collection 28
2.2.5. Data analysis and Econometric model specification 29
2.3. Result and discussion 31
2.3.1. Adoption of CSA innovations 31
2.3.2 Perception of CSA innovations and its effects 32
2.3.3 Perception determinants of the adoption of CSA innovations 33

2.4. Discussions of findings 37
2.5. Conclusions and recommendations 38
2.5.1 Conclusion 38
2.5.2 Recommendation 39
Chapter Three: Multiple Adoptions of Climate-Smart Innovation for Agricultural Sustainability: Emprical evidence from the Upper Blue Nile Highlands of Ethiopia 41
Abstract 41
3.1. Introduction 42
3.2. Materials and Methods 45
3.2.1. Sampling design and data collection 45
3.2.2 Data analysis 46
3.3. Results and discussion 53
3.3.1. Rate of adoption of CSA innovations 53
3.3.2. Intensity of adoption of CSA innovations 54
3.3.3. Determinants of multiple adoptions of CSA innovations 55
3.3.4 Determinants of multiple adoptions of CSA innovations 56
3.4. Conclusion 62
Chapter Four: Effectiveness of Climate-Smart Agriculture Innovations in Smallholder Agriculture System in Ethiopia 64
Abstract 64
4.1. Introduction 64
4.2. Research Methodology 67
4.2.1 Measurements 67
4.2.1. Data analysis 71
4.3. Results and discussion 76
4.3.1. Livelihood Vulnerability and Adoption of CSA Innovations 76
4.3.2. Food Security and Adoption of CSA Innovations 80
4.3.3. GHG Emissions and Adoption of CSA Innovations 84
4.3.4. Impacts of Climate-Smart Agriculture Innovations: ESR Estimation Results 88
4.4. Conclusions 93
Chapter Five : Effect Of Climate-Smart Agriculture Innovations on Climate Resilience among Smallholder Farmers in Ethiopia 94
Abstract 94
5.1. Introduction 95

5.2. Research methodology 99
5.2.1. Measuring Climate Resilience 99
5.2.2. Data analysis 103
5.3. Results and discussion 104
5.3.1. Comparison of absorptive capacity of the adoption of CSA innovations 104
5.3.2. Comparison of adaptive capacity of the adoption of CSA innovations 108
5.3.3 Comparison of transformative capacity of the adoption of CSA innovations 111
5.3.4. Comparison of climate resilience capacity of the adoption of CSA innovations 113
5.3.5. Effect of CSA Innovations on climate resilience capacity 114
5.4. Conclusion 117
Chapter Six: General Discussion, Conclusions and Recommendations 120
6.1 Introduction 120
6.2. Perception towards Climate-smart Agriculture innovations 122
6.3. Multiple adoptions of Climate-Smart Agriculture innovations 124
6.4. Effect of Climate-smart Agriculture Innovation Adoption 125
6.4.1 Effect of Climate-smart Agriculture Innovation Adoption on Livelihood Vulnerability 126
6.4.2 Effect of climate-smart agriculture innovation adoption on food and nutrition security 130
6.4.3 Effect of Climate-smart Agriculture innovations on-farm greenhouse gas emissions 131
6.4.4 Effect of climate-smart agriculture innovation adoption on triple wins benefits 132
6.5. Effect of CSA innovations on the development of climate-resilient livelihoods 133
6.6. Conclusions and Recommendations 135
6.6.1 Conclusion 136
6.6.2. Recommendation 138
References 140

List of Tables

Table 1:Sample woredas/districts and kebeles 28
Table 2: Adoption of CSA innovations by agro-ecosystem 32
Table 3: Perception of CSA innovations and agroecosystem 33
Table 4: CSA innovations adoption matrix 34
Table 5: Perception determinants of the adoption of CSA innovations 36
Table 6: Description of dependent and explanatory variables 50
Table 7: Intensity of adoption of number of CSA innovations by agroecosystem 54
Table 8: Intensity of adoption of CSA innovations measured in area covered 55
Table 9: Pair-wise correlation of adoption of CSA innovation 56
Table 10: Marginal effect of adoption of CSA innovations 60
Table 11: Conditional expectations, treatment, and heterogeneity effects 75
Table 12: Relationship between food security and adoption of CSA innovation 81
Table 13: Comparison of food consumption score (FCS) 84
Table 14: Comparison of GHG emissions among CSA innovations 88
Table 15: Average expected LVI, FCS, and GHG emission with adoption of CSA innovations 92
Table 16: Climate resilience capacities indicators 102
Table 17: Comparison of absorptive capacity of the adoption of CSA innovations 106
Table 18 :Comparison of adaptive capacity of the adoption of CSA innovations 109
Table 19: Comparison of transformative capacity of the adoption of CSA innovations 112
Table 20 : Comparison of climate resilience capacity of the adoption of CSA innovations 114
Table 21: Adoption effect of CSA innovations on average expected climate resilience 116

List of Figures

Figure 1: Climate-resilient agriculture framework 14
Figure 2: Analytical framework for adoption and impact of CSA innovations 15
Figure 3: Map of the study area 27
Figure 4: Conceptual framework of multiple adoption of CSA innovation 44
Figure 5: Household food security status 80
Figure 6: Food security of adopters of CSA innovations. 82
Figure 7: Gross influxes of GHG and adoption of CSA innovations. 86
Figure 8: Comparison of GHG emission sources and CSA innovations. 87
Figure 9: Climate-resilient agriculture framework adopted from (Frankenberger et al., 2013) 99

Abbreviation and Acronyms

AAU	Addis Ababa University
ABGB	Above Ground Biomass
AES	Agroecosystem
AFOLU	Agriculture Forest and Other Land Use
ATT	Average Treatment effect on the Treated
ATU	Average Treatment effect on the Untreated
C	Carbon
CBO	Community Based Organization
CC	Climate change
CCAFS	Climate Change Agriculture and Food security
CH_4	Methane
CHIRPS	Climate Hazards Group Infra-Red Precipitation with Station data
CIAT	International Center for Tropical Agriculture
C-N	Carbon -Nitrogen
CO_2	Carbon dioxide
COP	Conference of Parties
CRGE	Climate Resilience Green Economy
CSA	Climate-smart Agriculture
CSAI	Climate-smart Agriculture Innovation
DAP	Di-ammonium Phosphate
DC	Districts of Columbia
ENSO	El Niño-Southern Oscillation
ESR	Endogenous Switching Regression
EX-ACT	Ex-Ante Carbon Tool
FAO	Food Agriculture Organization of the United Nations
FCS	Food Consumption Score
FDRE	Federal Democratic Republic of Ethiopia
FIML	Full Information Maximum Likelihood
FMNR	Farmer-Managed Natural Regeneration
FTC	Farmer Training Center
GDP	Gross Domestic Product
GHG	Green House Gas
GTP	Growth and Transformation Plan
HH	Household
HDDS	Household Dietary Diversity Score
IPCC	Inter-governmental Panel for Climate Change
LVI_IPCC	Livelihood Vulnerability index of Inter-governmental Panel For Climate Change
MDG	Millennium Development Goals
MOA	Ministry of Agriculture
MVP	Multivariate Probit

N_20	Nitrous oxide
NH_3	Ammonia
NMA	National Metrological Agency
NO_3	Nitrate
NPS	Nitrogen Prosperous Sulfate
OECD	Organization for Economic Co-operation and Development
OLS	Ordinary Least Square
PCA	Principal Component Analysis
PSNP	Productive Safety Net Programme
RIMA	Resilience Index Measurement and analysis
SAES	Social-Agro-Ecological Systems
SLA	Sustainable Livelihood Analysis
SLCSA	Sustainable Livelihood Climate-smart Agriculture
SLF	Sustainable Livelihood Framework
SLMP	Sustainable Livelihood Management Program
SP	Social Protection
SSN	Social Safety Net
STATA	Statistics and Data
SWC	Soil and Water Conservation
TLU	Tropical Livestock Unit
UK	United Kingdom
UNDP	United Nations Development Program
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development
USSR	United Soviet Socialist Republic
WASH	Water Sanitation and Hygiene
WFP	World Food Program
WG II	Working Group II

General Abstract

The scientific basis for conceptualizing how farm households achieve the three CSA pillars of "triple benefit" is not well developed. This dissertation examined the adoption and impacts of CSA innovations on simultaneously enhancing food security, climate adaptation, reducing GHG emissions, and building resilience capacities in 424 smallholder households from five agroecosystems in the upper Blue Nile Highlands Sub-basin of Ethiopia. A structured survey questionnaire was used to collect primary data, and a review of literature and documents was used to collect secondary data. The econometric models employed in this study are the multivariate probit model and endogenous switching regression (ESR). The dependent variables were eight CSA innovations, while the independent variables were crafted from the three pillars of CSA. Major CSA innovations adopted by farmers include improved variety, crop residue management, crop rotation, compost, row planting, soil and water conservation, intercropping, and agroforestry. Farmers' positive perceptions of the benefits of CSA innovations for increasing crop productivity, reducing agricultural vulnerability to climate change, and lowering farm GHG emissions have boosted adoption. The integrated technology adoption model explains the determinants of adopting multiple CSA innovations simultaneously. The economic constraint model demonstrated that farm size, number of plots, and access to financial services influence crop residue management, crop rotation, and agroforestry adoption. The diffusion innovation model, on the other hand, asserts that frequent extension visits, market access, access to information communication, social networks, and strong tenure security have no less of an impact on the adoption of CSA innovations such as improved variety, crop residue management, crop rotation, compost, SWC, and agroforestry. Formal education, more awareness about climate change and CSA, and the ability of CSA innovations to reduce the impact of climate change risks such as rising temperatures, increased hailstorms, and increasingly erratic rainfall have significantly increased the likelihood of adoption. CSA innovations such as improved variety, compost, row planting, and agroforestry have provided farmers with the benefit of enhancing food security and climate change adaptation while reducing GHG emissions from farm plots. Crop rotation provided farmers with enhanced food security and reduced livelihood vulnerability, while SWC met the goals of enhancing food security and reducing GHG emissions. Unfortunately, adopting crop residue management, one of the recommended CSA practices in Ethiopia, has not delivered on at least two of the CSA pillars. Different CSA innovations have

different effects on the climate resilience capacity of households. Except for SWC adopters, all CSA innovations significantly increased the climate resilience capacity of households. However, improved variety, crop residue management, and SWC have a more profound effect on the non-adopters than adopters would have had if non-adopters had adopted these CSA innovations. Strong absorptive, adaptive, and transformative capacity through strong disaster and early warning systems, climate-resilient infrastructure, a strong public agricultural extension system, a strong informal safety net, and social networks builds a climate-resilient agriculture system among adopters of CSA innovations among farmers. The adoption of CSA innovations has built a strong, climate-resilient livelihood among smallholder farmers. However, the adoption of crop rotation, row planting, and agroforestry has a profound effect on the adopters compared to non-adopters, while the adoption of improved variety, crop residue management, compost, and soil and water conservation (SWC) has a profound effect on the counter-factual adopters. Farmers' perceptions towards CSA innovations must be enhanced to increase the adoption of CSA innovations in the smallholder agriculture system. The CSA innovation scale-up strategies should focus on farmers' perceptions of CSA innovation benefits towards food security, climate change adaptation, and mitigation outcomes. Awareness of CSA needs the close collaboration of public extension as well as local institutions such as farmers' training centers. Livelihood asset-building programs and strong public extension systems via mobile phone, voice messaging, and radio enhance adoption. A policy to identify and scale up a portfolio of farm-level-specific CSA innovations is required. Farmers should be encouraged to adopt improved variety, crop rotation, compost, row planting, soil and water conservation, and agroforestry as the best portfolio of CSA innovation for highland smallholder agriculture systems. As a result, policies that improve governance, social cohesion, disaster communication, early warning systems, input supply of drought-resistant varieties, climate-smart extension services, and climate-resilient infrastructure are required.

***Keywords**: Climate change, CSA, food security, climate adaptation, climate mitigation, GHG emissions, climate resilience, absorptive capacity, adaptive capacity, transformative capacity*

Chapter One: General Introduction

1.1 Background and Justification

Climate change can affect sustainable development because of losses of ecosystem services, challenges to land and water management, effects on human health, particular risks of severe harm and loss in certain vulnerable areas, increasing prices of food commodities on the global market, consequences for migration flows at particular times and places, increasing risks of flooding, risks of food insecurity, systemic risks to infrastructures from extreme events, loss of biodiversity, and risks for rural livelihoods (Denton et al., 2015). Hence, the concept of sustainable development has been progressively mainstreamed into the climate change policy agenda.

In September 2015, the United Nations Sustainable Development Summit reinforced the importance of sustainable development by adopting the 2030 Agenda for Sustainable Development, comprising 17 new Sustainable Development Goals (SDGs). Even if most of these goals address the root causes of poverty (i.e., zero hunger, social inequality, access to education, health services, energy, and water), from 17 of SDG goals, the 2030 Agenda identified Goal 13 (climate action) that directly focuses on climate change-related risks and adaptive capacities (Azam & Okitasari, 2015). Thus, the integration of sustainable development and climate change has been the top negotiation point in the different conferences of parties (COP) including the recent COP27(Atwoli et al., 2022).

Climate change and agriculture are intertwined in three critical links. First, climate change reduces crop yield and productivity, exacerbating smallholder farmers' food insecurity (Niang, Oliver, et al., 2014). Second, agriculture should adapt to climate change to reduce climate-related livelihood vulnerability (Bouroncle et al., 2016). Third, agriculture contributes to GHG emissions, accounting for 13, 44, and 82 percent of CO_2, methane (CH_4), and nitrous oxide (N_2O) emissions, respectively, from 2007 to 2016. These emissions are projected to increase due to inorganic fertilizer application. Hence, major future increases in agricultural emissions are expected to take place in low-to-middle-income countries where the majority of farmers are smallholder farmers (IPCC, 2019).

Thus, a better understanding of how to integrate mitigation, adaptation, and sustainable development dimensions became an essential part of planning for and pursuing effective national

and international climate and development policies (Bizikova et al., 2007; Wilbanks & Sathaye, 2007). A new array of concepts emerged: climate-resilient pathways, low-carbon resilient development, and climate-compatible development aiming at identifying vulnerabilities to climate change impacts, assessing opportunities for reducing risks, and taking actions that are consistent with the goals of sustainable development (Denton, 2015).

Climate-Smart Agriculture (CSA) is one of these approaches that integrate sustainable development with climate change policies. CSA is an agricultural approach that reorients agricultural development in the face of anthropogenic climate change that synergizes mitigation and adaptation goals simultaneously. CSA was originally defined as "agriculture that sustainably increases productivity and income, resilience (adaptation), reduces/removes GHGs (mitigation), and enhances food security development goal"(FAO, 2018).

However, achieving the three goals of increasing productivity and income, enhancing sustainable adaptability, and contributing to the reduction or removal of greenhouse gases (GHGs) from the atmosphere to limit the global temperature below 2^0C above pre-industrial levels has been a daunting agricultural development policy challenge (IPCC, 2019).

Thus, CSA has gained significant traction among governments of developing countries, as well as bilateral and international donor agencies. In the latter case, the concept has fitted seamlessly into the overlapping space between aid for rural poverty, pro-poor climate (adaptation) assistance, and sustainable development more generally. CSA projects around the world have been facilitated by FAO and the World Bank and their partners. The importance of the approach on the global agricultural development agenda has been endorsed with the foundation of the Global Alliance on Climate-Smart Agriculture launched in September 2014 at the United Nations climate summit. The Alliance was set up as a 'voluntary, farmer-led, multi-stakeholder, action-oriented coalition committed to the incorporation of climate-smart approaches within food and agriculture systems(FAO, 2020).

Despite these developments, the CSA concept has come under critical scrutiny from major Non-Governmental Organizations (NGOs), charities, some farmer organizations, and governments. Criticism has focused on the potentially disproportionate emphasis given to mitigation in CSA, the focus on growth, and the long-term sustainability of the entire approach. There is also concern regarding the perceived misappropriation of the term by multinational agribusinesses

seeking to rebrand existing practices under a more benign label taking advantage of the fluidity of definitions and lack of criteria(Agriculture et al., 2015), where CSA can mean everything and nothing simultaneously (Caron, 2016). This is due to the concept being fairly new, and empirical evidence on joint mitigation and adaptation is emerging and limited. Stakeholder views, especially among non-governmental organizations, on CSA, remain divided (Chandra et al., 2016). Thus, the concept caused serious debates among farmers' unions and development organization World Bank and FAO in one group and La Via Campesina in the opposite (Campesina, 2015; Jacob, 2015). On top of these, thoughts in this field are volatile and not stabilized (Caron, 2016). However, rather than plunging into the abyss of conceptual and political debate, discussion on how to make the approach relevant and operational to smallholder farmers has paramount importance (Chandra, 2016).

CSA innovations refer to those innovations that improve food security, climate change adaptation, and mitigation (Kaczan et al., 2013). CSA involves new and old agricultural technologies, and these practices are already well-known and promoted under conservation agriculture, agroforestry, sustainable intensification, as well as sustainable land management (Branca et al., 2013; FAO, 2013a).

Most farmers' decisions to adopt CSA innovations depend on immediate economic benefits associated with these practices. These technologies and practices were meant for some specific goal of agricultural development, for instance, sustainable intensification for increasing productivity; agroforestry for enhancing farm income; sustainable land management for reducing land degradation and enhancing soil health; and conservation agriculture increasing carbon sequestration. However, in practice, many adaptation measures with economic benefits have also GHG mitigation co-benefits and vice versa (FAO, 2013a; Jirata et al., 2016).

CSA is not one particular plot-based practice or technology but a suite of practices that are integrated into an agricultural system, often across different scales (Thierfelder et al., 2017). To maximize the benefits and minimize the trade-offs, CSA takes into consideration the social, economic, and environmental context in which it will be applied (FAO, 2013a). Hence, it also consists of technological, policy, and institutional interventions, and that is spatiotemporal dependent (McCarthy et al., 2011; Zilberman et al., 2017).

1.2. Concise literature review

Ethiopia's CSA-related efforts have been focused on restoring degraded lands and supported by the government and its development partners through research and development, rural extension and advisory services, as well as direct implementation. Such CSA practices and technologies are largely implemented within the framework of the integrated watershed management approach through projects such as the Sustainable Land Management Programme (CIAT; BFS/USAID, 2017; FDRE, 2019). However, CSA is more than the restoration of degraded land because CSA is a reorienting of the agricultural development paradigm to lessen the burden of climate change on the agriculture sector (Lipper et al., 2014). Institutionally, the current Environment, Forest, and Climate Change Commission (EFCCC) deal with climate change issues while the Ministry of Agriculture (MoA) deals with projects and programs related to CSA(CSA) (FDRE, 2019).

Ethiopia has reacted to the growing burden of climate change on the economy by implementing and ratifying relevant international conventions and taking the necessary steps and measures to implement mitigation and adaptation responses to climate change (FDRE, 2011). For instance, Ethiopia has ratified the UNFCCC and its related appliance, the Kyoto Protocol, and presented its initial National Communications document to the UNFCCC in 2001. Ethiopia also presented the Climate Change National Adaptation Program of Action (NAPA) in 2007 to the UNFCCC and Nationally Appropriate Mitigation Actions in 2010. The agricultural sector adaptation plan of action has been prepared and has been implemented since 2011(Salehu et al., 2011). Ethiopia has also signed the Paris agreement that was adopted at COP21 in Paris by the 196 Parties to the UN Framework Convention on Climate Change to keep the global average temperature below two degrees Celsius (UNFCC, 2015).

Ethiopia initiated the Climate-Resilient Green Economy (CRGE) initiative in 2011 to reduce the impact of climate change on the economy, particularly on agriculture, and build a green economy to reach middle-income countries before 2030. CRGE is a resilient climate strategy, with four distinct pillars, to achieve development goals while mitigating 255 Mt CO_2e, compared to the business as usual economic scenario by 2030 (FDRE, 2015). CRGE aims to address both climate change adaptation and mitigation objectives and it is integrated into the Second Growth and Transformation Plan (GTP II). CRGE consists of more than 60 initiatives that include CSA

technologies that enhance the adaptive capacity of smallholder farmers such as soil and water conservation and agroforestry (FDRE, 2011). The CRGE envisioned that adaptation to climate change fully mainstreamed into development activities, reduce vulnerability, and contribute to an economic growth path that is resilient to climate change and extreme weather events. However, the most important part of climate-smart agriculture, assessing the impact of CSA on the triple win (food security, adaptation, and mitigation) benefit, has been lacking. Furthermore, in some areas, even what is considered CSA technology or innovations has not been well defined, and development practitioners and policymakers interpret the definition per their interests.

Despite the high potential for synergies between adaptation and mitigation activities, many barriers still prevent the widespread adoption and implementation of climate-smart agriculture in Ethiopia. A primary technical barrier is the lack of quantitative evidence on how different management practices, systems, and policy configurations affect mitigation and adaptive benefits, as well as agricultural yields, food security, biodiversity conservation, and ecosystem services (MoA, 2011). Second, more and more analyses are needed to demonstrate when and where pursuing adaptation and mitigation simultaneously is more beneficial and cost-effective than implementing them separately. Third, it is also important to develop, pilot, and implement landscape-level indicators (e.g., of agricultural production and resiliency, adaptive capacity, mitigation potential, ecosystem services, and human wellbeing) that can track the suite of synergies or tradeoffs that result from different agricultural development scenarios and be used to inform decision-making.

Theoretical framework

The theoretical framework for this study on the adoption and impact of CSA innovations on food security, climate change adaptation and mitigation as well as building climate resilience of smallholder farmers in Upper Blue Nile Highlands of Ethiopia draws on several theoretical perspectives. First, the study draws on the concept of adoption perception which is central to understanding the perceptual challenges faced by smallholder farmers in adopting CSA innovation. According to Adesina & Jojo(1995), ssmallholder farmers, as consumers, generally have subjective preferences for the characteristics of technologies, and their demand for the technology is significantly affected by their perceptions of the technology's attributes. Smallholder farmers in the Upper Blue Nile Highland of Ethiopia depend on their perception to

adopt agricultural technologies due to lack of communication and information gap, limited resources and lack of access to support services.

Second, the study draws on the concept of integrative adoption model for multiple adoptions of CSA innovations, which includes economic constraint, diffusion of innovation, and adopter perception models which explains how multiple benefits (food security, climate change adaptation and mitigation) can be achieved through adoption of multiple CSA innovations in the face of climate change (Hailemariam et al., 2019; Jat et al., 2018). Multiple CSA innovation adoption is defined as at least adopting two of the given CSA innovations.

Third , the study customized concept of the *triple win benefit* development objectives (Caron & Treyer, 2016), to reconcile the three objectives of sustainably increasing production and income, reducing vulnerability and enhance resilience, reduction or removal of GHGs emissions of smallholder farmers in the reality of climate change. In order to meet the *triple win benefit* development objectives in the smallholder highland agriculture system scale up of portfolio of CSA innovations is a prior agriculture development agenda. We hypothesized that the findings of this study would be in line with the core aspects of the notion of the "triple win benefit" and prove that adoption of CSA innovation in the study area indeed results in increased food security, reduced livelihood vulnerability, and low GHG emissions from farm plots, which in turn contributes to building a climate-resilient livelihood for smallholder farmers.

Finally, resilience is particularly relevant in the context of the impact of CSA innovation during climate change related disasters such as drought, flood, hailstorm, and erratic rainfall as smallholder farmers in the Upper Blue Nile Highland of Ethiopia need to build their resilience to climate related disasters. In order to build their resilience we proposed farmers to combine technology or innovations such as CSA innovations as well as their five asset pentagons of livelihood: human, natural, financial, physical, and social capitals in the form of personal or socio-demographic, economic, institutional, and environmental factors.

In the context of the study area, smallholder highland farmers have limited livelihood assets but exerted considerable effort in conserving their livelihood. This is in line with the result that farmers adopt multiple CSA innovations to meet the *triple win benefit's* development goals of enhancing food security, climate change adaptation and mitigation. Smallholder farmers' decision to adopt different CSA innovation emanates from their expectation and perception

towards the benefits these CSA innovations provide them in their livelihood. This study assumes that the farmer's behavior of making choices is rational. Therefore, the decision of a farmer to adopt multiple CSA innovations was motivated by the expected benefit derived from that combination of CSA innovation. A farmer decides to adopt a portfolio of CSA innovations that will deliver maximum utility which supports the theory of utility maximization is derived from the Von Neumann-Morgenstern utility function (Mwaura et al., 2021).

Overall, the theoretical framework for this study emphasizes the importance of understanding the adoption, vulnerabilities and resilience of smallholder farmers in the Upper Blue Nile Highland of Ethiopia in the context of climate change, and highlights the need for integrated and collaborative approaches to supporting their livelihoods. The framework will guide the research question, objectives, and methodology of the study, as well as the analysis and interpretation of the findings.

Empirical literature review

Empirical studies on the impact of CSA innovations on the livelihoods of smallholder farmers in the Upper Blue Nile Highland of Ethiopia have highlighted several key findings. These studies have used a range of research methods, including surveys, interviews, and case studies, to examine the effects of the CSA innovations on smallholder farmers.

One key finding is the impact of CSA innovations on the food security, particularly food availability, access and utilization. improved variety technology improves productivity and increases resilience to climate change, and hence it is an essential strategy in adaptation to future climate change (Demenge et al., 2015; Shiferaw et al., 2017; Akalu Teshome & Abate, 2013). Adoption of crop residue management increased crop yield during reduced precipitation, and climate change-induced drought, with adequate crop residue cover and weed control while reduced crop yield may be recorded with adequate residue cover during excessive precipitation (Bhupinderpal-Singh & Rengel, 2007). Crop rotation increases yield and profit and allows for sustained production (Shah et al., 2021). Long term application of compost increases crop yield and enhance productivity (Bedada et al., 2014). Row planting contributes not only to improvements in crop productivity, income, and household food security but also less inorganic fertilizer use and cost (Amare & Beyene, 2019b). Soil and water conservation that farmers implement in the study area are soil and stone bunds as well as planting animal forage along with

the physical soil and water conservation structure. These technologies can improve household food security and reduce vulnerability by increasing soil water availability, decreasing soil erosion, and ensuring nutrients and inputs are maintained in the plot (Akalu et al., 2016; De Graaff et al., 2013; Desalew M. & Aklilu A., 2017; Woldeamlak Bewekt, 2007). Agro-forestry enhances farmers' income from the sale of woody perennials and reduces food insecurity (Geremew Worku Kassie, 2016; Noulekoun et al., 2016; van Noordwijk et al., 2014).

Another key finding is the impact of CSA innovation on enhancing farmer's climate change adaptation and building resilience in the face of climate change. Agro-forestry enhances farmers' ability to adapt to climate change via multiple benefits it delivers such as increases income, reduces food insecurity, increases CO_2 sequestration, and reduce the vulnerability of agricultural systems and enhance the resilience of smallholders to current and future climate risks (Geremew Worku Kassie, 2016; Noulekoun, 2016; van Noordwijk, 2014).

Although immediate benefit from SWC has been scarce, in the long term, the SWC measures are profitable to farmers with low to medium opportunity costs of labor on gentle to moderate slopes. A central focus of soil and water conservation (SWC) practice is to reduce or eliminate soil erosion and degradation, the major environmental problem in the area (Birhanu, 2014; Simane, 2013). Mechanical conservation structures have shown the potential to improve average yields, reduce yield losses in drought years, and reduce soil erosion (Gebeyehu T. et al., 2013). SWC practices have moderate mitigation potential by reducing losses of sequestered carbon caused by erosion and may increase carbon sequestration through gains in biomass resulting from increased fertility. In terms of costs, applying mechanical measures is often labor-intensive, and may entail significant short-term opportunity costs (Akalu et al., 2013).

Row planting contributes to reduce inorganic fertilizer use and cost (Amare, 2019b). Improved variety technology improves resilience to climate change, and hence it is an essential strategy in adaptation to future climate change (Demenge, 2015; Shiferaw, 2017; Akalu Teshome, 2013).

The use of manure, compost, and green manure, as often used in organic systems, can reduce the need for synthetic fertilizer and hence reduce the cost of inorganic fertilizer use (Golabi et al., 2004; Qaswar et al., 2019). Crop rotation increases organic matter in the soil, improves soil structure, reduces soil degradation, and can result in higher yields and greater farm profitability in the long-term. Increased levels of soil organic matter enhance water and nutrient retention and

decrease synthetic fertilizer requirements(Arslan et al., 2015; Corbeels et al., 2015; Mupangwa et al., 2016). Crop residue management has several benefits regarding soil fertility. It is a CSA innovation because reduces on-farm cost, increases soil fertility and moisture retention, increases long-term yield, decreases yield variations, and increases income at the farm level under conditions of Erratic rainfall as well as a result of a gradual decrease of overall soil quality (Farnworth et al., 2016; Ngwira et al., 2014).

The final key finding is the impact of CSA innovation on reducing GHGs emissions directly or indirectly from the farm. Agro-forestry increases CO_2 sequestration and hence reducing the vulnerability of agricultural systems and enhancing the resilience of smallholders to current and future climate risks (Geremew Worku Kassie, 2016; Noulekoun, 2016; van Noordwijk, 2014). The use of manure, compost, and green manure, as often used in organic systems, can reduce the need for synthetic fertilizer and hence reduce NO2 emissions from the use of synthetic fertilizer (Golabi, 2004; Qaswar, 2019). Crop rotation increases organic matter in the soil, improves soil structure, and reduces soil degradation. Hence, increased levels of soil organic matter enhance water and nutrient retention and decrease synthetic fertilizer requirements (Arslan, 2015; Corbeels, 2015; Mupangwa, 2016). Incorporation of crop residue compared to their removal increases the organic matter content of the soil while burning of crop residue decreases the organic matter content as well as decreases the soil carbon content, increases the emission of CO_2 into the atmosphere and results in accumulation of phosphorus on the surface (Rimhanen & Kahiluoto, 2014).

Empirical studies on the impact of CSA innovations on the livelihoods of smallholder farmers in the Upper Blue Nile Highland of Ethiopia have highlighted the significance of adopting CSA innovations in combination not piece meal.

Previous studies on the impact of CSA innovations on the livelihoods of smallholder farmers in the Upper Blue Nile Highland of Ethiopia have used a range of econometric analysis methods to examine the effects of the innovation on agricultural production, income, food security, livelihood vulnerability, and resilience. These methods include regression analysis, multivariate probit model, propensity score matching (PSM), and endogenous switching regressions (ESR).

Several studies have used regression analysis to examine the impact of CSA practices on agricultural production and income. For example, (Hailemariam, 2019) used a regression

analysis to examine the effect of multiple adoption of CSA practices on the farm income and resilience.

Propensity score matching is a method for comparing outcomes between two groups that are not randomly assigned. Several studies have used propensity score matching to examine the impact of CSA practices on smallholder farmers compared to other groups. For example, Amare & Beyene (2019) used propensity score matching to compare the impacts of climate-smart agricultural practice (row planting) on the welfare of rural households in Ethiopia.

Endogenous switching regressions (ESR) method has been used to examine the impact of CSA innovations on food insecurity in Ethiopia. For example, a study by Sileshi et al.(2019) used a endogenous switching regressions analysis to examine the impact of soil and water conservation practices on household vulnerability to food insecurity in eastern Ethiopia, comparing the outcomes of households that adopt soil and water conservation practices against the counterfactual scenario of what if the non-adopters have been adopted soil and water conservation practices.

Econometric analysis methods have been widely used in previous studies on the impact of CSA innovation on the livelihoods of smallholder farmers in the Upper Blue Nile Highland of Ethiopia. These methods have enabled researchers to examine the effects of the CSA innovations on food security and wellbeing of smallholder farmers in the Upper Blue Nile Highland of Ethiopia.

A critical analysis of previous studies on the impact of CSA innovations on the livelihoods of smallholder farmers in the Upper Blue Nile Highland of Ethiopia highlights several key issues and gaps in the literature. While these studies have provided important insights into the challenges faced by smallholder farmers in adopting CSA innovations, there are several limitations to consider.

One key limitation of previous studies is their reliance on food security and welfare outcomes. Many studies have used survey data collected during the pandemic to examine the impact of CSA innovations on food security or insecurity of smallholder farmers. While this data provides valuable insights into the welfare of farmers, it may not capture the livelihood vulnerability of the smallholder farmers.

Another limitation is the limited focus on adaptation strategies. Smallholder farmers in the Upper Blue Nile Highland of Ethiopia are not a homogeneous group, and the impact of climate change on their livelihoods may vary by agroecosystems as well as the strategies they use to adapt to climate change. However, few studies have explicitly examined these differences or considered the livelihood vulnerability aspect.

There is limitation in analyzing the impact of CSA innovation on farm GHGs emissions. There is also a need for more rigorous evaluation of the effect of innovations in building resilience. While several studies have examined the impact of CSA practices, few have used rigorous evaluation methods to examine the resilience capacity of the household during climate change related disasters.

Finally, there is a need for more research on the livelihood vulnerability and building resilience in addition to the food security aspect of the impact. While the immediate effects of CSA innovation are important to understand, the innovations may have longer-term implications for reducing livelihood vulnerability, farm GHGs emissions, and building resilience. Future research should aim to address these gaps and provide a more comprehensive understanding of the impact of CSA innovations on smallholder farmers in the Upper Blue Nile Highland of Ethiopia.

While previous studies have provided valuable insights into the impact of COVID-19 on smallholder farmers in the Upper Blue Nile Highland of Ethiopia, there are several limitations and gaps that should be addressed in future research. This will enable a more nuanced understanding of the challenges faced by smallholder farmers during times of crisis and inform policy interventions aimed at supporting their livelihoods.

While previous studies have provided important insights into the impact of CSA practices on the livelihoods of smallholder farmers in the Upper Blue Nile Highland of Ethiopia, there are several gaps in the literature that need to be addressed in future research.

There is a need for more research on the impacts of the innovation in reducing livelihood vulnerability as well as GHG emissions on smallholder farmers. While many studies have focused on the immediate effects of CSA practices, the innovations may have longer-term implications for reducing livelihood vulnerability, farm GHGs emissions, and building resilience. Future research should aim to understand how the innovations have affected in reducing livelihood vulnerability as well as GHG emissions and build resilience.

Finally, addressing these research gaps will provide a more comprehensive understanding of the impact of CSA innovations on the livelihoods of smallholder farmers in the Upper Blue Nile Highland of Ethiopia and inform policy interventions aimed at supporting their resilience.

Theoretical and empirical evidences generally revealed that there is striking heterogeneity regarding selection of portfolio of CSA innovations by smallholder farmers. Enhancing adoption of CSA innovations is a critical aspect in addressing the *triple win benefit* of smallholder farmers in the study area as evidenced by the effect of the innovation in reducing livelihood vulnerability and building climate-resilient livelihood. However, effect of adoption of CSA innovations of the smallholder farmers is a function of endogenous (household endowment related) and exogenous (policies, institutions, and environmental) factors that influence the outcomes (enhanced food security, reduced livelihood vulnerability and farm GHGs emissions, and building climate-resilient livelihood) as clearly indicated by the conceptual framework of this study, which is customized from the notion of the *triple win benefit and sustainable livelihood framework* of development objectives.

Conceptual framework

The conceptual framework illustrated that the core components (CSA innovations, food security, livelihood vulnerability, and GHG emissions) and their interrelationships can be affected and determined by climate change (exposure to climate change risks) and five livelihood assets. The five livelihood assets and perceived benefits affect CSA adoption. These perceived benefits of CSA innovations such as perceived food security benefits, perceived adaptation benefits, and perceived mitigation benefits directly influence the adoption of CSA innovations. These adopted CSA innovations affect the CSA pillars (food security, climate change adaptation and mitigation) and climate resilience. CSA innovations not only directly impact food security, livelihood vulnerability, and agricultural GHGs emissions, but also indirectly impact on-farm GHG emissions. CSA innovations directly contribute to livelihood vulnerability as they enhance the availability of ecosystem goods and services important to the livelihood of smallholder agriculture systems as well as the domino effect of improving food security and reducing livelihood vulnerability will promote sustainable intensification rather than extensification, expanding to marginal areas such as hills and degraded lands, that substantially increase GHGs emissions. On the other hand, the impact of CSA adoption on livelihood vulnerability and food

security may dictate the type of CSA innovation to be adopted because in smallholder agriculture system household vulnerability is determined by food security. Thus, improving food security is a means for enhancing the availability of food, rural farm income, and other livelihood assets for farm households. Furthermore, these CSA pillars affect each other in the form of synergy and trade-offs.

The impact of CSA innovations on climate resilience differs among the various climate resilience capacities (absorptive, adaptive and transformative). Because CSA innovations, as well as CSA policies, strategies, and programs that leverage the five capitals, will increase smallholder farmers' climate resilience capacity in absorptive (the ability to withstand short-term shocks such as drought, erratic rainfall, and floods), adaptive (the ability to adapt to long-term climate effects such as increased temperature or reduced precipitation), and/or transformative (the ability to transform the environment) ways. As the first response measure when disaster struck, absorptive capacity is at the base of the pyramid, and it is a crucial step to go further to adaptive capacity. The second stage of response measures is to adapt to the disaster and develop adaptive capacity. The final stage of responding to shock and disaster is to change one's livelihood based on an assessment of adaptive capacity.

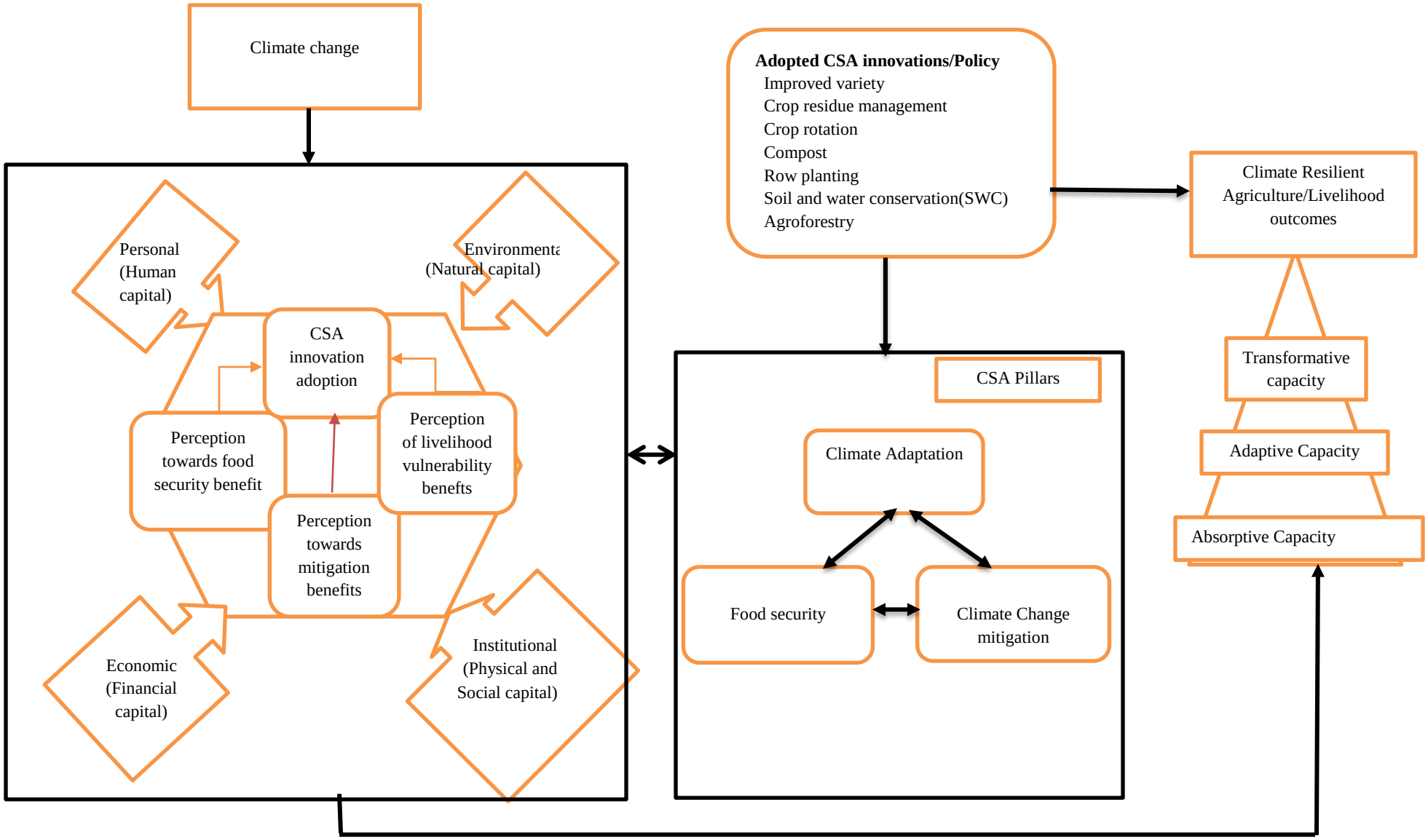

Figure 1: Climate-resilient agriculture framework

Source: Authors own construction

The analytical framework showed that farm households, plots, agroecosystem zones, and perceptions towards the benefits of CSA innovations affect the adoption of these innovations. These factors can be categorized into five livelihood assets of human, natural, financial, physical, and social capital. Adopted CSA innovations such as improved variety, crop residue management, crop rotation, compost, row planting, soil and water conservation (SWC), and agroforestry are hypothesized to deliver food security benefits measured in the food consumption score (FCS), reduce livelihood vulnerability measured in the livelihood vulnerability index, and reduce farm level GHG emissions and increase carbon sequestration measured in tons of GHG emissions per hectare per year. The CSA pillars are also expected to have synergy and trade-off effects. Furthermore, the cumulative effect of the CSA pillars improves the climate resilience capacity of smallholder farmers (Figure 2).

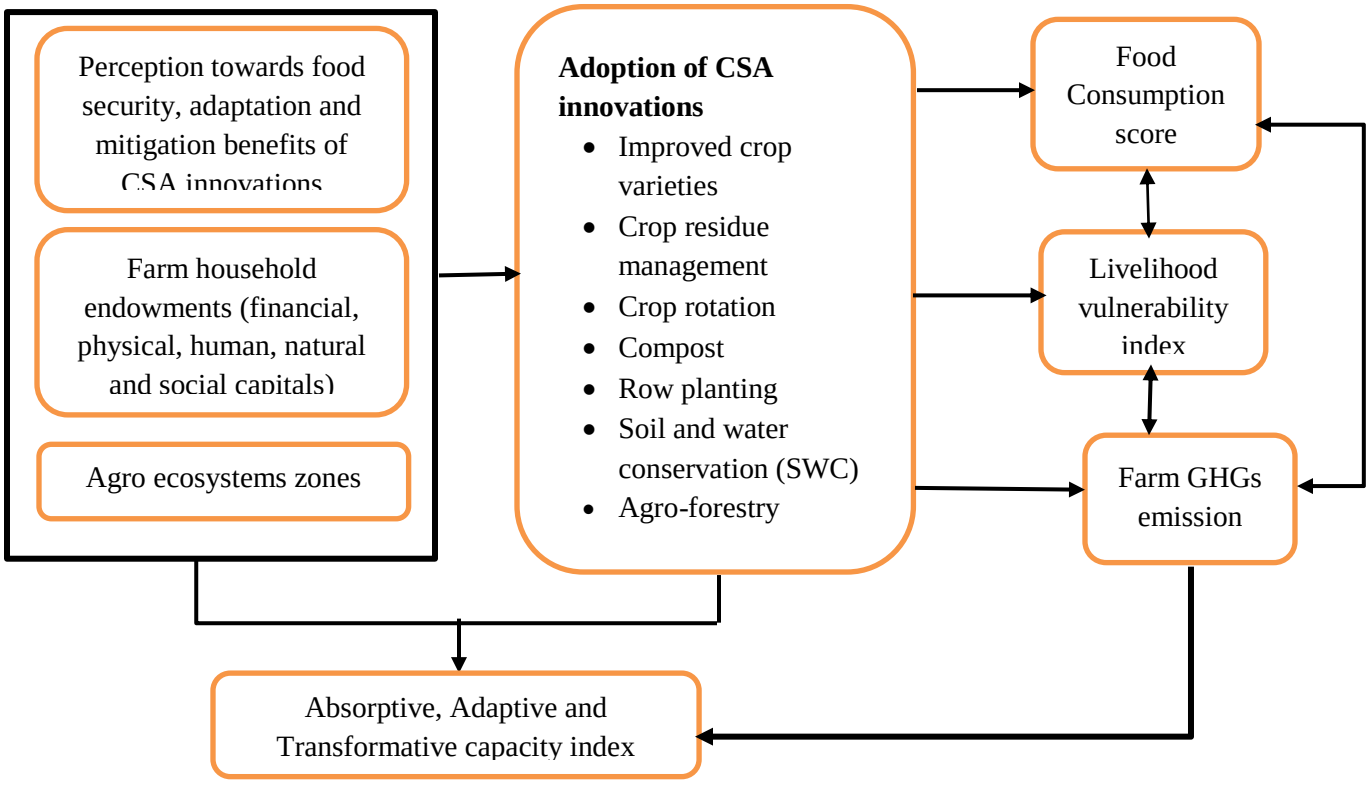

Figure 2: Analytical framework for adoption and impact of CSA innovations

1.3. Statement of the Problem

Ethiopia's smallholder agriculture suffers from a decline in land productivity, land degradation, shortage of land, water scarcity, and low adaptive capacity (Ermias et al., 2013; Gebremicael et al., 2013; Simane et al., 2016). When these problems are combined with climate change risks and low input and technology use, the smallholder agriculture system suffers from further productivity loss, increasing water scarcity, and a lack of adaptive capacity to respond to the risk of climate change (Simeneh & Fisseha, 2016; Yibekal et al., 2013). Whenever yield declines, smallholder households face malnutrition and food insecurity. Crops stored for the lean season also could be damaged due to crop-pastes caused by the changing climate. Moreover, road infrastructure will be washed away or closed, limiting access to the market and exacerbating food shortages (Berhane & Esayas, 2017; Melak & Birgit, 2014; Tofu et al., 2022).

Ethiopia's highlands are more vulnerable to climate change because of their wide variation in topography, climate, and agro ecosystems. Sloping areas are the most fragile lands in the highlands, as they are highly susceptible to erosion as well as agricultural expansion has been carried out towards these areas at the expense of natural resource degradation (particularly forests, water, and soils) (Ermias, 2013; Gebremicael, 2013; Niang et al., 2014b; Pender & Ehui, 2006; Samuel, 2006; Simane, 2016; Yalew et al., 2012). The shift of agricultural areas from more suitable land to marginal and environmentally fragile areas may exacerbate the problem of GHG emissions in three ways. First, degraded and overgrown farmland emits more GHG than cultivated land. Second, the cultivation of grazing land and wetland may release already stored carbon in the area and exacerbate GHG emissions (Delaney et al., 2002; Soussana et al., 2013). Finally, when smallholders deforest the natural forest area for cultivation, they increase the GHG emissions released into the atmosphere (EFCCC, 2020).

Several studies have found that smallholder agriculture can improve food security, adapt to climate change or resilience, and reduce GHG emissions by implementing a variety of CSA innovations such as sustainable land management (SLM), intercropping, crop rotation, soil and water conservation, modern input use, and agroforestry (Arslan, 2015; Deichert et al., 2017; Hailemariam, 2019; Hengsdijk & Verhagen, 2013; Jirata, 2016; Komarek et al., 2019; Makate, 2019; Paulos & Belay, 2017; Rimhanen et al., 2012; Teklewold et al., 2017; Tsige et al., 2020). However, despite different initiatives to enhance the uptake of CSA innovations adoption rate of CSA is quite low in rural areas of developing countries even with several national and

international initiatives to encourage the adoption (Asfaw et al., 2015; Kpadonou et al., 2017). The adoption of CSA innovations has become a challenging issue in the agricultural development policy agenda for sub-Saharan Africa, especially for eastern Africa (Leal Filho et al., 2015; Lipper et al., 2014). Hence, achieving the three goals of increasing food security, enhancing sustainable adaptability, and contributing to the reduction or removal of greenhouse gases (GHGs) from the atmosphere to limit the global temperature below 2^0C above pre-industrial levels has been a daunting agricultural development policy challenge in East Africa countries (IPCC, 2019; Trisos et al., 2022).

In Ethiopia, although there are no standard criteria to label an agriculture technology as CSA or not, MOA and GIZ have developed a CSA manual that identifies some of the technologies as CSA. According to the manual, crop residue management, crop rotation, compost, soil and water conservation, agroforestry, and improved varieties were identified as CSA (Deichert, 2017).

The justification of this dissertation emanates from the five theoretical gaps the CSA approach has in the smallholder agriculture system. First, as far as CSA innovations are concerned, there is relatively little empirical work on the study of farmers' perceptions of CSA innovations (Precious et al., 2018). The critical research gap in the existing literature is that most researchers focused on the profitability and economic constraints (access to capital, learning costs associated with innovation, or risk) adoption of agricultural technologies, disregarding the farmers' perception of the adoption of CSA innovations. However, perception of the perceived benefit of CSA innovations is the key to adoption by small-scale farmers (Meijer et al., 2015). Exploring perceptions of CSA innovations adoption is thus the first step in unravelling the CSA adoption puzzle, including determining whether there are potential gaps in available knowledge of CSA innovation among smallholder farming households (Fayso, 2018).

Second, despite the abundance of literature on the role of farmers' livelihood asset endowment in the decision to adopt new agricultural technologies little is known about the integrated contribution of environmental, economic, institutional, and socio demographic factors to agricultural technology adoption in the context of smallholder farmers. Hence, it is critical to identify the environmental, economic, institutional, and socio demographic factors that influence the rate of adoption of CSA innovations. With this backdrop, the study's main goal is to investigate the rate, intensity, and determinants of multiple adoptions of CSA innovations among smallholder farmers in Ethiopia's Upper Blue Nile Highlands.

Third, even though separate studies have looked at the impact of CSA practices on food security (Fentie & Beyene, 2019) and welfare (Tesfaye et al., 2021), there is a scarcity of research on the synergy and trade-off effect of CSA innovations on the food security, climate change adaptation, and mitigation benefit. Moreover, although there are few studies on the ex-post impact assessment of adoption of CSA innovations and its effect on household income and resilience (Teklewold et al., 2017; Teklewold, Gebrehiwot, et al., 2019) yet these studies not only have limited insight to the impact on food security, livelihood vulnerability, and mitigation at the micro level but also missed the synergy and trade-off effect of CSA technologies.

Fourth, although several pieces of literature on climate resilience are found globally, their approach to conceptualizing and measuring climate resilience differ (Constas & Barrett, 2013; Dixon & Stringer, 2015; Gaillard, 2010; Linkov et al., 2014). Recently, climate resilience as the absorptive, adaptive, and transformative capacity thinking has been gaining momentum (Asmamaw et al., 2019; Béné et al., 2015; Berhane, 2017). Some literature tried to assess building the climate resilience farming effect of push–pull technology (PPT) (Gugissa et al., 2022). Yet, there is a dearth of literature on the concept of absorptive, adaptive, and transformative capacity of climate resilience among smallholder farmers. Hence, there is a pressing need to understand which CSA innovations have successfully built smallholder climate resilience capacity and how these capacities were built among smallholder agriculture households (Silici et al., 2021).

Studies on CSA are new and limited in Ethiopia (Jirata, 2016; Negra et al., 2014; Rimhanen, 2012; Teklewold, 2017). In some of these literature, CSA has been studied as a single practice or anecdote (Teklewold, 2017) and in others as only carbon sequestration or climate mitigation (Rimhanen, 2012). Moreover, numerous literature exists on climate change adaptation strategies in Ethiopia while there is hardly any on the impact of CSA innovation (Asmare et al., 2019; Simane & Asrat, 2018; Temesgen & Rashid, 2009; Tesfaye & Seifu, 2016; Weldegebriel & Prowse, 2013; Woldeamlak et al., 2015; Yesuf & Ringler, 2008). Although, some literature examined the contribution of CSA innovations to food security in Africa (Lipper, 2014; Wekesa et al., 2018) still there is a lack of scientific evidence on the contributions of CSA innovations as a development intervention contributed to the reduction or removal of farm level GHG emissions and climate-resilient livelihood. Therefore, this dissertation examined the impact of adoption of different CSA innovations on food security, climate change adaptation, and mitigation, and

Building climate resilience capacities among smallholder farmers in the Upper Blue Nile Highlands of Ethiopia.

1.4 Research questions

This study attempts to answer the following research questions:

- What farm technology characteristics influence farmers' perception of CSA innovations?
- How do farmers adopt CSA innovations?
- How do CSA innovations affect food security?
- How do CSA innovations affect climate change adaptation?
- How do CSA innovations affect climate change mitigation?
- How do CSA innovations build the climate resilience of smallholder households?

1.5. Objectives

1.5.1. General objective

The main objective of this research is to examine the impact of CSA adoption on food security, climate change adaptation and mitigation, and the resilience-building capacities of smallholder agriculture farmers.

1.5.2. Specific objectives

The study intends to address the following specific objectives:

- Examine the effect of farmers' perceptions on the adoption of CSA innovations;
- Analyze the rate, intensity, and adoption determinants of CSA innovations;
- Examine the impact of CSA innovations on food security, livelihood vulnerability, and farm GHG emissions.
- Investigate how CSA innovations improve smallholder farmers' climate resilience.

1.6. Significance of the study

This study provides useful empirical information to policymakers, researchers, academicians, and various other stakeholders regarding the problems of perception of climate-smart agriculture, the impact of CSA on food security, adaptation, and mitigation, as well as its contribution to building climate resilience. It offers agro-ecosystem-specific policy recommendations targeted at smallholder farmers who live in climate change-prone areas of the highland regions. It offers a way out through selected CSA innovations and awareness about them. It helps policymakers come up with relevant policies that gear towards reducing climate change impacts through CSA

agriculture technologies, adoption and enhancing food security, improving climate change adaptation, building climate resilience capacity, and keeping the sustainability of the agriculture system.

The study relates CSA innovations to climate resilience and uses the SLF as a conceptual basis that provides the theoretical and methodological directions for designing the study and analyzing the findings. Resilience is a very broad concept, including many interrelated constituents and explanatory variables that are related to each other in complex ways. Thus, this study uses SLF because one of the principal outcomes of the livelihood approach is resilience. The study also makes a methodological contribution in terms of customizing and applying advanced econometric models in climate change adaptation and mitigation studies that link agricultural technologies (perception) and their impact on livelihood dimensions of food security and climate change adaptation as it entirely employs single equation regressions. Besides, the study pinpointed some gaps and limitations that future studies need to address. It can also serve as a case study for researchers and development actors to replicate similar or related studies by building on their limitations and producing recommendations of more robust and broader applicability.

1.7. Scope of the Study

This study makes a significant contribution to understanding the role of CSA practices in building climate resilience in smallholder agriculture. It has new indicators and methodological insights into the scientific realm of climate resilience measurement in smallholder agriculture.

This study has scope in geographical location, variables, depth of theoretical literature, and time interval. It is a one-time cross-sectional survey data collected from respondents from five woredas in East Gojam in Ethiopia. As a result, trend analysis of variables over time is not addressed for important variables, as well as dynamism is not addressed. In this study, variables such as Livelihood assets, climate change-related variables, food security-related variables, perception and knowledge of climate change, perception and knowledge of CSA, and seven CSA technologies in the smallholder farmer's community and climate resilience-related variables are included. It also measured the carbon sequestered at the farm level using the IPCC Tier 1 method without physical measurement.

The analysis is made at the household and farm level under the existing land tenure system. Collective decisions affecting CSA agriculture adoption and community land management

decisions at the landscape level are not addressed in this study, except for the community participation decision on land restoration. Despite these limitations, the study makes a substantial addition to the existing knowledge pool on CSA technologies, climate change and CSA perception, adoption of CSA technologies, and the overall impact of this on building climate resilience in rural livelihoods.

1.8. Limitations of the study

Food security is measured using the food consumption score (FCS), but the food utilization and food stability aspects of food security are addressed using modified HDDS. Although there are several GHG calculators, the study used EXACT due to its ease of use and data availability. IPCC Tier 1 method was used to analyse the carbon balance of farm households. Most of the analysis focuses on the household units due to the heterogeneity of the household characteristics in the specific agroecosystem pertinent to the specified analysis.

1.9. Structure of the dissertation

This study is organized into six chapters. Chapter one presents the general background, concise literature, problem statement, research questions and objective. Chapter two addresses the effect of perception on the adoption of CSA innovations. Chapter three deals with the multiple adoptions of CSA innovations and their determinants. Chapter four is the core of this dissertation and is devoted to the analysis of the impact of CSA innovations on household food security, livelihood vulnerability, and farm GHG emissions. Chapter five is devoted to the analysis of the impacts of CSA innovations on building climate resilience capacity. Finally, chapter six synthesizes the main findings of the core chapters of the study and their potential policy implications.

Chapter Two: Effects of perceptions on the adoption of CSA Innovations: Empirical evidence from the upper Blue Nile Highlands of Ethiopia

Abyiot Teklu, Belay Simane , Mintewab Bezabih,

Abyiot Teklu, abyiot.teklu@aau.edu.et, Addis Ababa University, College of Development Studies, Ethiopia

Belay Simane, simaneb@yahoo.com, Addis Ababa University, College of Development Studies, Ethiopia

Mintewab Bezabih, mintewabayele@gmail.com, Ethiopian Policy Studies Institute, Ethiopia.

Abstract

Purpose – Examine smallholder farmers' perceptions towards the adoption of climate-smart agriculture in smallholder farmers in the Upper Blue Nile Highlands of Ethiopia. Available research focused on profitability and economic constraints alone, disregarding the farmers' perception of the adoption of CSA innovations. There is relatively little empirical work on farmers' perceptions of innovations. Hence, a critical research gap that will strengthen CSA innovation research and practice includes understanding farmers' perceptions about CSA innovations and how these perceptions interact with their adoption.

Design/methodology/approach – A cross-sectional household survey was conducted among 424 smallholder farmers selected from five agroecosystems. A structured questionnaire was used to collect primary data, and a review of literature and documents was used to collect secondary data. The study used a multivariate probit model to examine perception factors affecting the likelihood of adopting multiple CSA innovations. The dependent variables were eight CSA innovations, while the independent variables were crafted from the three pillars of CSA.

Findings – Major CSA innovations adopted by farmers include improved variety, crop residue management, crop rotation, compost, row planting, soil and water conservation, intercropping, and agroforestry. Farmers' perception towards CSA innovations includes: CSA innovations sustainably increase productivity and income; enhance soil fertility; diversify livestock feed and energy sources; reduce soil erosion, weed infestation, and crop failure; enhance soil organic matter, reduce chemical fertilizer use, and rehabilitate the land. Farmers' positive perceptions of the benefits of CSA innovations for increasing crop productivity, reducing agricultural vulnerability to climate change, and lowering farm GHG emissions have boosted adoption.

Practical implications – Farmers' perceptions towards CSA innovations must be enhanced to increase the adoption of CSA innovations in the smallholder agriculture system. The CSA

innovation scale-up strategies should focus on farmers' perception of CSA innovation benefits towards food security, climate change adaption, and mitigation outcomes. Awareness of CSA needs the close collaboration of public extension as well as local institutions such as farmers' training centers.

Originality/value – The study adopts a multivariate probit model that models farmers' simultaneous CSA innovation choices. Hence, this study contributes to the literature in four significant areas. First, it argues for differential treatment of the perception of smallholder farmers about innovations is needed. Second, it recognizes the interdependence of the adoption of innovations. Third, some directly assess the farmers' perception while others use proxies to measure it. Finally, there are limited or no studies that address the perception of innovations within the lens of adopter perception theory.

Keywords: CSA, innovations, Blue Nile Highlands, crop residue management, crop rotation, compost, row planting, soil and water conservation, intercropping, agroforestry, adoption.

2.1. Introduction

Perception of climate change has been one of the important factors that enable or hinder the adoption of adaptation strategies among farmers in sub-Saharan Africa (Juana et al., 2013). As consumers, farmers evaluate the innovations they receive and practice based on the benefits that they provide to the farmers (Adesina & Jojo, 1995; Adesina & Moses, 1993; Workneh & Parikh, 1999). Some farmers may tend to adopt adaptation options to reduce the effect of climate change-induced risks such as droughts and floods, while others may prefer to adopt technologies that increase their productivity and income (Hailemariam et al., 2017a). The innovations may provide these benefits one by one, or multiple benefits may be obtained from a single innovation (Teklewold et al., 2018).

CSA (CSA), as an approach to agricultural development, reorients agricultural production systems to ensure food security in the face of climate change by building climate resilience and adapting to climate change and, if possible, reducing or removing greenhouse gas (GHG) emissions (Bazzana et al., 2021). CSA innovations are agricultural innovations that enable farmers to achieve at least two of the three pillars of CSA: food security, climate change adaptation, and mitigation.

Despite these potential benefits and national and international initiatives that promote the adoption of CSA innovations (Kpadonou et al., 2017; Solomon & Manuela, 2015), the adoption

of CSA innovations has been challenging for the sub-Saharan African agriculture development policy agenda (Lipper et al., 2014; Rao, 2011). Among others, a lack of economic and technological capacities, weak institutional settings, and a lack of awareness of CSA innovations can be largely attributed to the low adoption rate (Abegunde et al., 2019; Bazzana et al., 2021). Thus, several studies have shown that high climate change awareness increases the adoption of climate change adaptation strategies (Babatolu & Akinnubi, 2016; Saguye, 2017; Simane & Asrat, 2018; Tran Van et al., 2015).

Previous research focused on the perception of climate change as well as the impact and adaptation strategies of climate change on smallholder agriculture in Ethiopia (Desalegn & Filho, 2017; Esayas et al., 2019; Kahsay et al., 2019; Israel Rop & Adepoju Ib, 2017). Nyang'au et al. (2021) investigated farmers' perceptions of climate variability and change and the adaptation measures adopted to enhance their resilience toward climate change. Tran et al. (2019) examined the determinants of farmers' adoption of CSA technologies and the effects of their adoption on net rice income (NRI) in three provinces. However, these studies cannot address farmers' perceptions of CSA innovation benefits (Nyang'au et al., 2021; Tran et al., 2019). Only some studies have attempted to address the impact of farmers' perceptions and social interactions on CSA innovation adoption (Bazzana et al., 2021; Hailemariam et al., 2019). However, this literature focuses on the social context, i.e., social interaction, neighborhood effects, and social conformity of CSA innovation adoption rather than the adopters' perceptions of the CSA innovations, which is the research gap that this study aims to fill. Existing literature on the adoption of agricultural technologies is grounded on three principal theories: economic constraints, diffusion-innovation, and the adopter perception paradigm (Ngwira et al., 2014; Prager & Posthumus, 2010).

The first theory, the economic constraint theory, argues that individuals strive for profit or utility maximization, but observed patterns of adoption are determined by the asymmetrical distribution of resource endowments among farmers. Although the economic constraints model recognizes the importance of profitability and economic constraints (access to capital, learning costs associated with innovation, or risk), it fails to conceptualize the social dimensions of knowledge, information, communication, and rationality (Ngwira et al., 2014). The diffusion-innovation theory, the second theory, addresses the knowledge, information, and communication factors of an individual or societal difference. Thus, the "diffusion of innovations" theory describes how

agricultural technologies are adopted over time through communication, information, and knowledge. The "diffusion of innovations" theory has five characteristics that determine the rate of adoption of agricultural technologies: relative advantage, compatibility, complexity, trial-ability, and observability. In addition, the theory says that the decision to adopt an agricultural technology is a mental process consisting of five stages: knowledge, persuasion, decision, implementation, and confirmation. Rogers (2003) suggested that the innovativeness of an individual determines when the individual adopts technology and identified five successive adopter categories: innovators, early adopters, early majority, late majority, and laggards. Hence, the diffusion-innovation concern is that access to information is the key to the adoption of agricultural technologies (Rogers, 2003).

The other theory, the adopter perception theory, argues that adoption perception about the perceived benefit of agricultural technology is the key to adoption (Adesina & Jojo, 1995; Adesina & Moses, 1993; Workneh & Parikh, 1999). Smallholder farmers, as consumers, generally have subjective preferences for the characteristics of technologies, and their demand for the technology is significantly affected by their perceptions of the technology's attributes (Adesina & Jojo, 1995). As far as CSA innovations are concerned, there is relatively little empirical work on the study of farmers' perceptions of CSA innovations (Precious et al., 2018).

The critical research gap in the existing literature is that most researchers focused on the profitability and economic constraints (access to capital, learning costs associated with innovation, or risk) adoption of agricultural technologies, disregarding the farmers' perception of the adoption of CSA innovations. However, perception of the perceived benefit of CSA innovations is the key to adoption by small-scale farmers (Meijer et al., 2015). Exploring perceptions of CSA innovations adoption is thus the first step in unraveling the CSA adoption puzzle, including determining whether there are potential gaps in available knowledge of CSA innovation among smallholder farming households (Fayso, 2018).

Therefore, the study contributes to the literature in four significant areas. First, it acknowledges the contribution and differential treatment of the perception of smallholder farmers toward adopting CSA innovations. Second, it also highlights the interdependence between different CSA innovations and jointly analyses the decision to adopt the technologies. Third, it assesses directly the perception of CSA innovations rather than using proxies to measure it, unlike the previous studies. Therefore, the objective of this study is to analyze how farmers' perceptions of CSA

innovations affect their decision to adopt CSA innovations in the upper Blue Nile highland of Ethiopia.

2.2. Research Methodology

2.2.1. The description of the study area

The study was conducted in the Choke Mountain Watershed of the Blue Nile Highlands of Ethiopia. The lifeline of the watershed is the Choke Mountain, which is a biodiversity-rich hotspot area with unique flora and fauna and is referred to as the "water tower" of the upper Blue Nile Basin, where 60 rivers and 270 springs originate from; 29 of these rivers are responsible for a significant amount of water flowing into the upper Blue Nile (Simane et al., 2013).

Geographically, the Choke Mountain Watershed is located approximately between 90 38' 00" and 10055' 24" North latitude and 370 07' 00" to 380 17' 00" East longitude. It lies in the altitude range of 2100 to 4113 m.a.s.l. The watershed has a total land surface area of approximately 15,950 km2. The average annual rainfall in the watershed varies between 200 and 2200 millimeters (Simane et al., 2013). The average annual temperature ranges between 11.50°C and 27.50°C, and the slope gradient of the watershed varies from flat to steep slopes. There are eight dominant soil types found in the watershed, i.e., Alisols, Andosols, Cambisols, Leptosols, Luvisols, Nitosols, Phaeozems, and Vertisols (Simane et al., 2013). The climate of the watershed ranges from the hot, arid climate of the Abay (Blue Nile) Gorge to the cold, moist climate of the peak of Choke Mountain (Simane, 2013). The watershed is part of the north-western highlands that are known to be surplus-producing regions and the water tower of the Blue Nile (Benjamin et al., 2012). However, it is threatened by land and water resource degradation and an impending food shortage because of overexploited soils and overgrazing (Ermias et al., 2013).

The Choke Mountain watershed is divided into six distinct agroecosystem zones (Simane et al., 2013). The lowland and valley fragmented agroecosystem zone (AESZ1), the midland with black soil agroecosystem zone (AESZ2), the midland with brown soil agroecosystem zone (AESZ3), the midland sloping land agroecosystem zone (AESZ4), and the hilly and mountainous highlands agroecosystem zone (AESZ5), and the afro-alpine (AES6).

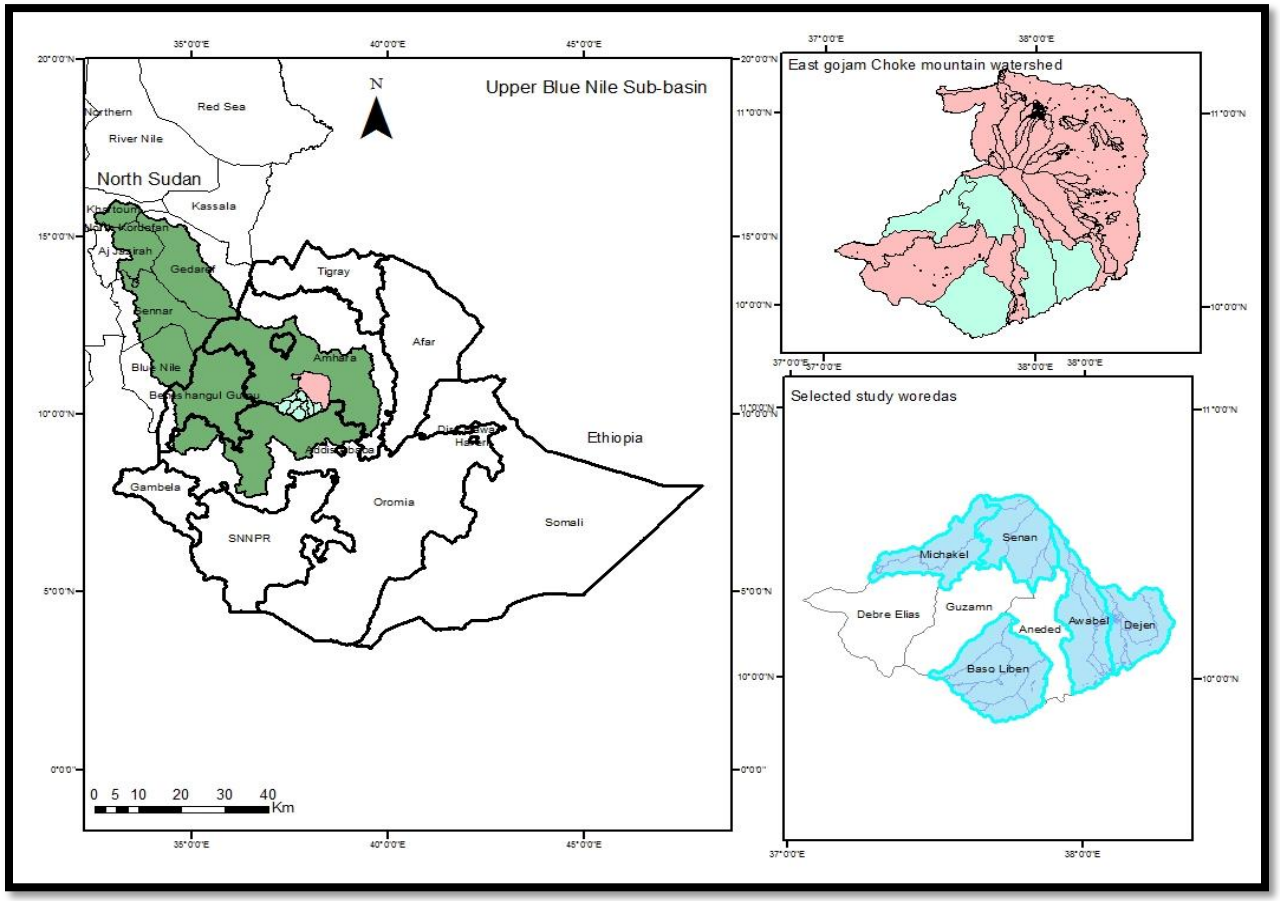

Figure 3: Map of the study area

2.2.2. Data type and sources

A quantitative cross-sectional survey in the East Gojjam zone's Dejen, Awobel, Basoliben, Machakel, and Sinan districts was conducted to collect the household data. The districts have been selected to represent the agroecosystems. Data was gathered at the household level on perceptions of CSA innovations. Secondary data was collected from each district agricultural office through a desk review.

2.2.3. Sampling design

The sample size determination was calculated based on finite population sample size calculation (Cochran, 1977). As there is no prior data on the current level of awareness of CSA innovations in the study area, the proportion of smallholder farmers who perceived CSA innovations as important innovations were assumed to be half of the population in the study area. Using the formula:

$$n_1 = \frac{Z^2_{1-\alpha/2}}{d^2} P(1-P)$$
$$= \frac{(1.96)^2(0.5)^2}{(0.05)^2}$$
$$= 385$$

Where n_1 is the sample size; $Z_{\alpha/2} = 1.96$ for a 95 percent confidence interval; P is the proportion of the population who said CSA innovations are important for climate change adaptation, P = 0.5; and d is the error margin, taking d = 0.05. The study also assumed a 10 percent non-response rate, which equates to 39 households. The sample size then becomes 424 smallholder households.

A multi-stage sampling technique was used to randomly select 424 households from the five districts. The selection of the districts was through purposive sampling taking into consideration the agroecosystem zone they represent. The sampling frame was a one-to-five mobilization register obtained from the kebele extension officers. Second, one kebele from each woreda was randomly selected. The selected kebeles are Gelegele from Dejen, Enebi from Awobel, Limichim from Basoliben, Debere kelemu from Machakel, and Yeted from Sinan. In the second stage, a systematic random sampling technique was employed to select households from each of the five kebeles using a sampling frame of a one-to-five community mobilization group register. Finally, 424 households were randomly drawn from the sample kebeles based on the probability proportional to size (PPS) sampling procedure (Table 1).

Table 1:Sample woredas/districts and kebeles

District/ Woreda	Kebele	Population of HHs	Sample size	Agroecosystem zone (AESZ)
Dejen	Gelgele	7,475	77	AESZ1: Lowland agroecosystem
Awabel	Enebi	5,416	55	AESZ2: Midland with black soil
Basoliben	Limichim	10,147	104	AESZ3: Midland with brown soil
Machakel	Debre Kelemu	6,207	63	AESZ4: Midland with sloping land
Sinan	Yeted	9,533	125	AESZ5: The hilly and mountainous highland
Total		**38,779**	**424**	

2.2.4. Methods of data collection

The household survey data was administered by well-trained and experienced enumerators using android tablets on a one-to-one interview basis. Through this instrument, information on the adoption of CSA innovations and farmers' perceptions of CSA innovation was collected from household heads. In collecting the data, each respondent was briefed about the purpose of the

survey, information confidentiality, and the average length of time that the interview would take, and the actual interview was conducted following the respondent's willingness to participate in the interview. Secondary data was collected through desk review and review of empirical literature and documents.

2.2.5. Data analysis and Econometric model specification

Data analysis was carried out using descriptive statistics and econometric models accompanied by SPSS and Stata statistical packages. Descriptive statistics such as mean, standard deviation, and percentages were used to analyze and present the perception of CSA innovations and their adoption. T-test, Chi-square test, and mean comparison tests were run to compare adopter and non-adopter groups to farmers' perception of CSA innovations.

The multivariate probit (MVP) model was used to analyze the perception factors affecting the decisions of farmers to adopt each of the CSA innovations. The dependent variable of the MVP model includes eight specific CSA innovations (improved variety, crop residue management, crop rotation, compost, intercropping, row planting, soil and water conservation, and agroforestry) that assume a value of 1 if farmers apply specific CSA innovations and 0 otherwise. The dependent variables were selected based on an extensive literature review on CSA innovations in sub-Saharan Africa in general and Ethiopia in particular. Although there is overlap in CSA pillar perceptions, the independent variables were crafted from the three pillars of CSA based on reviewed literature. Hence, the inclusion of independent variables in the model specification is also based on past empirical literature on the determinants of the adoption of agricultural technologies (Alomia-Hinojosa et al., 2018; Baudron et al., 2014; Hailemariam et al., 2019, 2017b; Kassie et al., 2015; Kidane et al., 2017; Kumar et al., 2015; Miheretu, 2014; Thierfelder et al., 2012; Valbuena et al., 2012). The independent variables selected for this study include perceptions: CSA increases productivity, soil fertility, income, soil organic matter, diversifies livestock feed sources, and diversifies alternative energy sources; CSA reduces the cost of production, the amount of synthetic fertilizer used, soil erosion, seeding rate, weed infestation, and crop failure; and CSA rehabilitates land.

The essence of using MVP stems from the fact that, inherently, smallholder farmers consider adopting multiple CSA innovations for different agricultural and livelihood outcomes. Some of these technologies render the synergetic effect (complimentary), while others trade-off effects

(substitutes). Hence, a failure to capture these complementarity and substitutable effects among CSA innovations will lead to bias and inefficient estimates (Greene, 2003).

The MVP econometric model is characterized by a set of binary dependent variables (Y_{ij}), such that:

$$\boldsymbol{Y_{ij}^{*} = \beta_i{}' X_{ij} + \varepsilon_{ij}}, \quad (1)$$

And

$$\boldsymbol{Y_{ij}} = \begin{cases} \mathbf{1},\ \boldsymbol{if\ Y_{ij}^{*} > 0} \\ \mathbf{0},\ \boldsymbol{otherwise} \end{cases} \quad (2)$$

Where i=1, … ,8 denotes the CSA innovations such as 1= Improved variety, 2= Crop rotation 3= Crop residue management, 4= Compost, 5= Row planting, 6= Intercropping, 7=Soil and Water Conservation (SWC), and 8=Agroforestry; and j=1, ..., n and n denotes the sample size.

The Equation (1) assumption is that a rational j^{th} farmer has a latent variable, Y^{*}_{ij} , which captures the unobserved preferences derived from the i^{th} CSA innovation. This latent variable is assumed to be a linear combination of observed perception of CSA innovations (X_{ij}) such as CSA increases productivity, soil fertility, income, soil organic matter, diversify livestock feed source, and diversify alternative energy source; CSA reduces the cost of production, the amount of synthetic fertilizer use, soil erosion, seeding rate, weed infestation, and crop failure as well as rehabilitates land, as well as unobserved characteristics captured by the stochastic error term ε_{ij}. The vector of parameters to be estimated is denoted by β_i. Given the latent nature of Y^{*}_{ij} , the estimations are based on observable binary discrete variables Y_{ij}, which indicate whether or not a farmer undertook the i^{th} CSA innovation. If the adoption of CSA innovation is independent of another CSA practice, then Equations (1) and (2) specify univariate probit models, where information on farmers' adoption of CSA innovation does not alter the prediction of the probability that they have adopted another CSA practice. Since we assumed the adoption of multiple CSA innovations, the error terms in Equation (1) jointly follow a multivariate normal (MVN) distribution, with 0 conditional mean and variance normalized to 1. Where ($\boldsymbol{\rho 1}$,$\boldsymbol{\rho 2}$,$\boldsymbol{\rho 3}$,$\boldsymbol{\rho 4}$,$\boldsymbol{\rho 5}$,$\boldsymbol{\rho 6}$, $\boldsymbol{\rho 7}$,$\boldsymbol{\rho 8}$) distributed MVN(0,Ω″) and the symmetric variance-covariance matrix ″ is given by

$$\Omega = \begin{bmatrix} \mathbf{1} & \boldsymbol{\rho_{12}} & \boldsymbol{\rho_{13}} & \cdots & \boldsymbol{\rho_{17}} \\ \vdots & & \ddots & & \vdots \\ \boldsymbol{\rho_{81}} & \boldsymbol{\rho_{82}} & \boldsymbol{\rho_{83}} & \cdots & \mathbf{1} \end{bmatrix}$$

Where ($\boldsymbol{\rho_{im}}$)denotes the pairwise correlation coefficient of the error terms corresponding to any two innovations adoption equations to be estimated in the model.

In the analysis, particular interest is the off-diagonal elements in the covariance matrix, $\boldsymbol{\rho_{im}}$ which represents the unobserved correlation between the stochastic component of the i^{th} and m^{th} innovations. This assumption means that Equation (2) gives an MVP model that jointly represents the adoption of a particular innovation. In this model, a positive correlation represents a synergy while a negative correlation represents the trade-off between the i^{th} and m^{th} innovations.

The study identified the important determinants of the adoption of climate-smart agriculture innovation measures using a multivariate probit model to provide policy information on which climate-smart agriculture pillars to target and how. Before modeling the number of innovations on farmers' perception, the study assessed the pairwise correlation coefficient of the farmers' perception of CSA innovations. The correlation result showed that some of the perceptions are correlated to each other so the issue of heteroskedasticity of the model was addressed using the robust standard error procedure. A robust standard error could effectively solve heteroskedasticity since it gives a relatively accurate p-value to ensure the significance of the regression model the study used (Wooldridge, 2013).

2.3. Result and discussion

2.3.1. Adoption of CSA innovations

Row planting (76 percent), compost (66 percent), SWC (51 percent), crop residue management (46 percent), crop rotation (37 percent), improved variety (31 percent), and agroforestry (21 percent) were the most preferred and adopted CSA innovations among smallholder farm households. However, the majority of farmers, or more than half, used row planting, compost, and soil and water conservation methods, while crop residue management, crop rotation, improved variety, and agroforestry were used by less than half of the households (Table 2).

Table 2: Adoption of CSA innovations by agro-ecosystem

CSA innovations	AESZ1 (%)	AESZ2 (%)	AESZ3 (%)	AESZ4 (%)	AESZ5 (%)	Average (%)
Row planting	32	31	97	98	94	**76**
Compost	45	29	89	84	66	**66**
SWC	78	27	34	65	50	**51**
Crop residue management	51	56	67	35	27	**46**
Crop rotation	42	44	41	37	26	**37**
Improved varieties	7	15	64	38	20	**31**
Agroforestry	1	5	42	17	22	**21**
Average	**36.6**	**29.6**	**62.0**	**53.4**	**43.6**	

Source: own computation

Significance level* p<0.1, ** p<0.05, *** p<0.01

a: a cell containing less than 5, the chi-squared value is not valid

2.3.2 Perception of CSA innovations and its effects

Table 3 presented the percentage of smallholder farmers that exhibited a particular perception of CSA innovations among agroecosystems. Using thirteen indicators of the benefits of CSA innovations, the farmer's perception towards the adoption of different CSA innovations was assessed. Among smallholder farmers, 91 percent, 86 percent, 80 percent, 64 percent, and 50 percent replied that CSA innovations increase productivity, increase soil fertility, increase income, increase soil organic matter, and reduce soil erosion, respectively. Furthermore, CSA innovations reduce the cost of chemical fertilizer when smallholder farmers use compost in their homestead farms, as well as the cost of production through less fertilizer, less weed infestation, and a lower seeding rate, according to 61 percent, 59 percent, and 55 percent of smallholder farmers, respectively. The chi-squared test revealed that perceptions of CSAI that CSA increases productivity, CSA increases soil fertility, CSA diversifies energy sources, CSA reduces soil erosion, CSA reduces production costs, CSA reduces the amount of chemical fertilizer used, CSA reduces seeding rate, and CSA rehabilitates land differ significantly across agroecosystems ($p<0.001$). Hence, the reason for adoption emanates from the characteristics of the innovations and the agroecosystems in which the farmers live.

Table 3: Perception of CSA innovations and agroecosystem

Perception of CSA innovations	AES1	AES2	AES3	AES4	AES5	Overall average	χ^2
Perception toward food security							
Increase productivity	70	52	99	62	101	91	19.9***
Increase income	58	51	84	51	96	80	6.82
Perception towards adaptation/ resilience							
Reduces seeding rate	18	12	76	48	78	55	81.9***
Reduces cost of production	26	32	73	46	71	59	29.3***
Increase soil fertility	60	49	103	56	94	86	26.7***
Reduces soil erosion	55	24	50	30	53	50	19.09***
Diversify energy source	26	9	38	14	35	29	9.3*
Diversify livestock feed source	37	27	41	25	54	44	2.75
Reduces crop failure	9	0	22	11	11	13	17.6***a
Reduces weed infestation	1	3	22	9	9	10	23.05*** a
Perception towards mitigation							
Increase soil organic carbon	42	33	69	46	80	64	5.25
Reduces the amount of chemical fertilizer	34	28	77	39	81	61	18.54***
Rehabilitates land	33	22	32	29	54	40	5.93***

***, **, * are significant at 1%, 5%, and 10%,, respectively

a : a cell containing less than 5 the chi-squared value is not valid

2.3.3 Perception determinants of the adoption of CSA innovations

Table 4 shows inherently smallholder farmers adopting multiple CSA innovations for different agricultural and livelihood outcomes. Some of these innovations provide synergetic effects (complimentary) or positive correlation, while others trade-off effects (substitutes) or negative effects. Hence, out of twenty-eight correlations of CSA innovations, fourteen of them are significant. This shows the appropriateness of the MVP model for the adoption of CSA innovations among smallholder farmers, which concurs with the studies of (Aryal et al., 2018; Teklewold et al., 2017, 2018, 2019).

Table 4: CSA innovations adoption matrix

	Improved variety	Crop rotation	Crop residue management	Compost	Row planting	Intercropping	SWC
Crop rotation	0.224***						
Crop residue management	0.156	-0.021					
Compost	0.127	-0.118	-0.371***				
Row planting	0.493***	0.059	-0.042	0.406***			
Intercropping	0.18	0.291**	-0.185	0.339***	0.375***		
SWC	-0.262***	-0.068	-0.373***	0.360***	0.066	0.019	
Agroforestry	0.191*	0.307***	0.014	0.092	0.390***	0.326***	0.053

Standard errors in parentheses ***, **, * are significant at 1%, 5%, and 10%, respectively

Likelihood ratio test of rho21 = rho31 = rho41 = rho51 = rho61 = rho71 = rho81 = rho32 = rho42 = rho52 = rho62 = rho72 = rho82 = rho43 = rho53 = rho63 = rho73 = rho83 = rho54 = rho64 = rho 74 = rho84 = rho65 = rho75 = rho85 = rho76 = rho86 = rho87 = 0;

$\chi2(28) = 129.886$; Prob > $\chi2 = 0.0000$

1=improved variety, 2=crop rotation, 3=crop residue management, 4=compost,5= row planting 6=intercropping, 7=soil and water conservation and 8=agroforestry

Table 5 showed that the overall relationship between the farmer's probability of adopting specific CSA innovation and explanatory variables is significant at the 1% level based on the values of Wald $\chi2(104)$ (Prob > $\chi2$=0.0000). Hence, according to the MVP result, farmers who perceive CSA innovations increase productivity are more likely to adopt improved variety, crop residue management, intercropping, and agroforestry. However, the perception that CSA innovations increase income did not affect any of the CSA innovations. Farmers who perceive that CSA innovations increase productivity are reluctant to adopt SWC because SWC decreases crop yield as it attracts pests and rodents, is difficult to tillage, requires much labour, and reduces farm size (Simeneh, 2015). However, a good perception of farmers towards the implications of CSA innovations on food security enhances the adoption of improved varieties, crop residue management, and agroforestry.

Framers who perceive that CSA innovation increases soil fertility are more likely to adopt crop residue management, crop rotation, and compost. Farmers who perceive that CSA innovation's increased diversification of fuel sources is expected to create more of an urge to adopt crop rotation, soil and water conservation, and agroforestry. Agroforestry and crop rotation have a synergistic effect which increases adoption. Farmers who perceive that CSA innovations reduce

soil erosion are more likely to adopt crop residue, crop rotation, intercropping, soil and water conservation, and agroforestry. Farmers who perceive that CSA innovations reduce weed infestation are more likely to adopt crop residue, crop rotation, compost, row planting, intercropping, and agroforestry. Farmers who perceive that CSA innovations reduce the cost of production cause more likely adoption of row planting. CSA innovations that reduce seeding rates are more likely to adopt improved varieties, compost, row planting, and agroforestry. Thus, a positive perception of farmers towards the implications of CSA innovations on climate change adaptation enhances the adoption of improved varieties, crop residue management, crop rotation, compost, row planting, soil and water conservation, intercropping, and agroforestry.

Likewise, the perception that CSA innovation increases soil organic matter and carbon may cause a more likely adoption of crop residue management and compost. Also, farmers' perception that CSA innovations reduce the amount of chemical fertilizer leads to a more probable adoption of improved varieties and compost, and a farmer's perception that CSA innovations rehabilitate land implies a higher expectation to adopt crop rotation. Thus, a positive perception of farmers towards the implications of CSA innovations on climate change mitigation enhances the adoption of crop residue management, crop rotation, and compost, while a negative perception of agroforestry increases soil organic carbon and helps farm-level climate mitigation.

Table 5: Perception determinants of the adoption of CSA innovations

Explanatory variables	Improved variety	Crop rotation	Crop residue management	Compost	Row planting	Intercropping	SWC	Agro-forestry
Perception implication towards food security								
Increase productivity	0.77(0.3)***	0.1(0.2)	1.5(0.3)***	-0.2(0.3)	0. 2(0.4)	1.5(0.5)***	-1.7(0.4)***	0.9(0.3)**
Increase income	0.18(0.20)	-0.01(0.2)	-0.3(0.25)	0.24(0.22)	-0.1(0.3)	0.4(0.4)	0.1(0.2)	-0.2(0.25)
Perception implication towards climate adaptation								
Increase soil fertility	0..2(0.26)	0.8(0.3)***	1.3(0.4)***	1.4(0.3)***	0.18(0.3)	0.7(0.5)	0.1(0.3)	0.4(0.4)
Diversify livestock feed source	-0.18(0. 17)	-0.3(0.17)*	0.01(0.2)	-0.37(0.2)*	-0.5(0.2)**	0.2(0.2)	-0.1(0.2)	-0.7(0.2)***
Diversify energy source	0.2(0.18)	0.3(0.18)*	0.05(0.2)	0.03(0.2)	0.3(0.24)	0.3(0.2)	0.5(0.18)***	1.5(0.2)***
Reduces soil erosion	-0.1(0.16)	0.6(0.17)***	0.45(0.18)**	-0.002(0.2)	-0.4(0.2)*	0.8(0.25)***	1.8(0.17)***	0.5(0.2)***
Reduces weed infestation	0.2(0.2)	0.8(0.24)***	0.5(0.27)*	0.9(0.3)**	1.3(0.4)***	1.2(0.3)***	-0.9(0.25)***	0.9(0.3)***
Reduces cost of production	0.18(0.17)	0.05(0.17)	0.13(0.2)	0.05(0.2)	0.4(0.2)*	-0.4(0.2)*	-0.05(0.2)	-0.2(0.2)
Reduces crop failure	-0.6(0.2)**	-0.4(0.2)*	0.7(0.2)	0.2(0.26)	0.5(0.3)	-0.1(0.3)	0.5(0.2)	0.3(0.2)
Reduces seeding rate	0.4(0.16)**	0.14(0.16)	-0.8(0.2)***	0.3(0.2)*	2.0(0.2)***	0.9(0.26)***	0.1(0.17)	0.8(0.2)***
Perception implication towards climate mitigation								
Increase soil organic carbon	-0.2(0.17)	-0.1(0.16)	1.96(0.2)***	0.7(0.19)***	0.12(0.2)	-0.1(0.2)	-0.02(0.2)	0.1(0.2)
Reduces synthetic fertilizer use	0.5(0.17)***	-0.24(0.17)	0.02(0.2)	1.17(0.2)***	0.3(0.3)	0.2(0.25)	-0.6(0.2)***	0.1(0.2)
Rehabilitates land	-0.15(0.16)	0.7(0.17)***	-0.4(0.2)**	-0.2(0.2)	-0.02(0.2)	-0.1(0.24)	0.25(0.18)	-0.1(0.2)
Constant	-1.9(0.36)***	-1.7(0.3)***	-3.6(0.5)***	-1.9(0.5)***	-0.4(0.4)	-4.8(0.8)***	0.7(0.4)	-3.1(0.5)***

Standard errors in parentheses ***, **, * are significant at 1%, 5%, and 10%,, respectively

2.4. Discussions of findings

Results in general revealed that farmers in the Upper Blue Nile Highlands are aware that the perception of CSA innovations adoption on food security, climate change adaptation, and mitigation. However, farmers' perceptions of the benefits of CSA innovations significantly differ among agroecosystems ($p<0.001$). First, farmers believe that the adoption of climate-smart innovations enhances food security through increased productivity and income (91 and 80 percent respectively) which is also supported by other studies in sub-Saharan Africa and Ethiopia. For instance, farmers who adopt maize potato intercropping, intercropped maize with grain legumes increased crop productivity (Baudron et al., 2014; Kidane et al., 2017; Miheretu, 2014; Thierfelder et al., 2012; Valbuena et al., 2012) and (Lal, 2006; Lorenz & Lal, 2014) argued that agroforestry increases yield via increased soil organic carbon. Other studies also support results and reported that crop residue retention and crop rotation and/or intercrop association among other benefits increase yield (Ngwira et al., 2013). Similarly, crop residue management and crop rotation of wheat and tef have also increased crop yield concurring with the perception of farmers (Araya et al., 2010). Although the majority of reviewed scientific studies showed an increase in crop yield due to SWC (Wolka et al., 2018), some literature shows a decrease in yield among adopters of SWC (Adimassu et al., 2017).

Second, farmers believe that the adoption of climate-smart innovations enhances climate change adaptation or resilience via increasing soil fertility (86 percent) concurs with the previous studies on crop residue management which reported that crop residue management, crop rotation, and compost through appropriate tillage system increases soil fertility (Bhupinderpal-Singh & Rengel, 2007; FAO, 2013; Giller et al., 2009). Likewise, a study in Malawi concurs with this result and reported that farmers have a positive perception of compost and that it improves soil productivity (Mustafa-Msukwa et al., 2011). However, this study showed a trade-off effect of adoption of crop residue management and compost due to the computation of demand for crop residue hindering the adoption of crop residue management as well as compost (FAO, 2013; Giller et al., 2009; Jaleta et al., 2013).

Similarly, farmers believe that CSA innovations reduce soil erosion (50 percent) which agrees with the result of (Akalu et al., 2013; Kagabo et al., 2013; Luangduangsitthideth et al., 2018) that reported soil erosion, soil fertility, and crop yield improves after adopting terraces along the mountainous area and another literature also reported agro-forestry based farming of 'khat', coffee,

and sugar cane has reduced soil erosion (Adane, 2009). Furthermore, the finding corroborates the findings that conservation agriculture i.e., crop rotation and crop residue management, not only improves soil health but also improves suppression of weed infestation (Ngwira et al., 2014; Palm et al., 2014). Another study (Mashingaidze, 2004) reported that farmland that is mulched and minimum tillage had less weed infestation than un-mulched and conventional tillage in maize–cowpea–sorghum rotation farming system. While maintaining permanent soil cover through crop residues, i.e., conservation agriculture impedes weed germination and hence reduces weed pressure (Muoni & Mhlanga, 2014). Also, the finding is supports (Fentie & Beyene, 2019) who reported that row planting not only reduces the seeding rate but also prevents water logging and increases productivity.

Finally, farmers believe that the adoption of climate-smart innovations reduces or removes GHGs from the farm and contributes to the local effort of climate mitigation through increased soil organic matter (64 percent). Several studies showed that the adoption of crop residue management increased soil carbon and it has been recommended as one mechanism of carbon sequestration (FAO, 2013; Humberto & Lal, 2010; Lal, 2006; Lorenz & Lal, 2014; Ngwira et al., 2012).

2.5. Conclusions and recommendations

2.5.1 Conclusion

Farmers' perceptions towards CSA innovations are one of the requirements to increase the adoption of CSA innovations in the smallholder agriculture system. Farmers' perception towards CSA innovations should include: CSA innovations sustainably increase productivity and income; CSA innovations enhance soil fertility; diversify livestock feed and energy source; reduces soil erosion, weed infestation, and crop failure; enhances soil organic matter, reduces chemical fertilizer use, and rehabilitates land.

A positive perception of farmers towards the implication of CSA innovations on food security enhances the adoption of improved variety, crop residue management, and agroforestry. Similarly, the positive perception of farmers towards the implication of CSA innovations on climate change adaptation enhances the adoption of improved variety, crop residue management, crop rotation, compost, row planting, soil and water conservation, intercropping, and agroforestry. Moreover, the positive perception of farmers towards the implication of CSA innovations on climate change mitigation enhances the adoption of crop residue management, crop rotation, and compost while lacking the perception that agroforestry increases soil organic carbon and helps farm-level climate

mitigation. Hence, the positive perception of farmers on the benefit of CSA innovations for enhancing crop productivity, reducing agricultural vulnerability to climate change, and reducing /removing of GHGs emissions from the farm has enhanced adoption.

Farmers in the midland with brown soil (AES3) and the hilly and mountainous agroecosystem zone (AES5) are more aware of CSA innovations' capacity to enhance food security and strengthen climate adaptation/resilience while farmers in the lowland/ Abay gorge agroecosystems zone (AES1) are most concerned and aware of CSA innovations capacity to contribute for climate adaptation/resilience. Finally, farmers in the hilly and mountainous agroecosystem zone (AES5) are aware of the climate mitigation capacity of CSA innovations.

Thus, following the perception of CSA innovations benefits farmers adopt CSA innovations that include improved variety, row planting, crop residue management, crop rotation, compost, soil and water conservation, intercropping, and agroforestry. There is a good farmer's perception of improved variety, crop residue management, crop rotation, compost, row planting, soil and water conservation, intercropping, and agroforestry to enhance climate change adaptation and increase food security while lacking awareness of agroforestry implication on supporting climate mitigation effort at farm level.

2.5.2 Recommendation

Strengthening efforts on enhancing farmers' adaptive capacity through awareness of CSA innovations should be put among the development milestones. However, as the farmers' perception varies across AES, extension services should focus on awareness of climate-smart innovations' capacity to enhance food security and strengthen climate adaptation in the midland with brown soil (AES3) and the hilly and mountainous agroecosystem zone (AES5). Whereas, extension services should focus on awareness of CSA innovations' capacity to contribute to climate adaptation/resilience in the low land/ Abay gorge agroecosystems zone (AES1). Extension services should focus on farmers' awareness of the capacity of CSA innovations to deliver climate adaptation (with mitigation co-benefits) in the hilly and mountainous agroecosystem zone (AES5). Designing policies that aim to enhance the information and communication gap of adoption of CSA innovations have a great potential to benefit from the innovations. Programs aimed to reduce the maladaptation of CSA innovations should focus on the bundle of innovations for a particular farmer not a piecemeal. Supporting farmers through training on CSA innovations such as agroforestry, compost making, and crop residue management is imperative for scaling CSA technologies. There

is also the need for governments and non-governmental organizations to invest in awareness creation of CSA innovations. Further research is also recommended regarding constructs of perception using exploratory factor analysis.

Chapter Three: Multiple Adoptions of Climate-Smart Innovation for Agricultural Sustainability: Emprical evidence from the Upper Blue Nile Highlands of Ethiopia

Abyiot Teklu [1], Belay Simane[2] , Mintewab Bezabih[3]

Abyiot Teklu, abyiot.teklu@aau.edu.et, Addis Ababa University, College of Development studies, Ethiopia

Belay Simane, belay.simane@aau.edu.et, Addis Ababa University, College of Development studies, Ethiopia

Mintewab Bezabih, mintewabayele@gmail.com, Ethiopian Policy Studies Institute, Ethiopia.

Abstract

Adoption of appropriate climate-smart innovations is the major step towards enhancing food security and building climate resilience capacity to sustainably maintain agricultural livelihoods. The purpose of this paper is to investigate the rate, intensity, and determinants of multiple adoptions of CSA innovations among smallholder farmers in Ethiopia's Upper Blue Nile Highlands. All CSA (CSA) innovations have a synergistic effect on the adoption of other innovations, except for Soil and Water Conservation (SWC). The economic constraint model demonstrated that farm size, number of plots, and access to financial services influence crop residue management, crop rotation, and agroforestry adoption. Hence, a larger number of plots, a larger total farm size, and access to rural savings and credit increase the probability of adoption. The diffusion of innovations model, on the other hand, asserted that frequent extension visits, market access, access to information communication, social networks, and strong tenure security have no less of an impact on the adoption of CSA innovations such as improved variety, crop residue management, crop rotation, compost, SWC, and agroforestry. Furthermore, farmers' perceived technology-specific characteristics of CSA innovations increase the likelihood of adoption. Hence, formal education, more awareness about climate change and CSA, and the ability of CSA innovations to reduce the impact of climate change risks such as rising temperatures, increased hailstorms, and increasingly erratic rainfall have significantly increased the likelihood of adoption. The integrated technology adoption model explains the determinants of adopting multiple CSA innovations simultaneously. Livelihood asset-building programs, and strong public extension systems via mobile phone, voice messaging, and radio enhances adoption. A policy to identify and scale up a portfolio of farm-level specific CSA innovations is required.

Keywords*: CSA; multiple adoptions; multivariate probit; economic constraint, diffusion of innovation, adopter perception; Ethiopia*

3.1. Introduction

Climate change and variability pose a significant threat to agricultural production and rural livelihoods, particularly for smallholder farmers (Murray et al., 2016). Hence, there is a growing interest in achieving food security while also responding to the effects of climate change through the implementation of a more climate-resilient and low-emissions CSA approach (Mango et al., 2018; Murray, 2016; Traore et al., 2021; Zerssa et al., 2021).

Existing smallholder farming practices are inefficient, use inefficient inputs, produce variable outputs, and lack resilience to risks and long-term climate change (Beddington et al., 2012; Murray, 2016; Zerssa, 2021). Consequently, appropriate agricultural technologies or practices are urgently required to alleviate constraints, increase productivity, enhance resilience and reduce or eliminate GHG emissions from smallholder farms to sustainably maintain agricultural livelihoods (Zerssa, 2021).

CSA(CSA) is an agricultural approach that reorients agricultural development in the face of anthropogenic climate change, simultaneously achieving mitigation and adaptation goals, effectively supporting development, and ensuring food security in a changing climate (Komarek, 2019; Lipper, 2014). CSA considers the social, economic, and environmental context to maximize benefits and minimize trade-offs. As a result, it also includes technological, policy, and institutional interventions that are dependent on the spatiotemporal context (Zilberman, 2017).

CSA innovations are a collection of technologies or practices that are integrated into an agricultural system at various scales (Makate, Makate, Mutenje, et al., 2019; Mutenje et al., 2019; Thierfelder, 2017). They include both new and old agricultural technologies that are already well-known and promoted as conservation agriculture, agroforestry, sustainable intensification, and sustainable land management (SLM) practices or technologies (Murray, 2016; Mutenje, 2019; Zerssa, 2021). Improved varieties, crop residue management, compost, row planting, physical soil and water conservation (SWC), and agroforestry are examples of climate-smart practices useful in smallholder agricultural production in the study area (Hailemariam, 2019; Simane et al., 2012).

Despite various initiatives to increase the adoption of these technologies through public agricultural extension programs, the adoption rate of CSA innovations is quite low in rural areas of developing countries in general, and Ethiopia in particular (Asfaw, 2015; Jerneck & Olsson, 2013; Kpadonou, 2017; Simane, 2012) because of limited or no access to basic agricultural technologies (Murray, 2016); improper identification, valuation, and prioritization of CSA innovations (Andrieu et al.,

2017); imperfect information, risk, uncertainty, institutional constraints, human capital, low input availability, and poor infrastructure (Bezabih et al., 2021; Tesfaye et al., 2021; Wordofa et al., 2021). Furthermore, social networks and learning as well as pro-environmental behavior (motivation and perception) also affect adoption decisions (Belay & Fekadu, 2021; Chaudhuri et al., 2021; Mekonnen et al., 2018; Zeweld, 2015; Zeweld et al., 2017, 2018, 2020).

Existing literature on the adoption of agricultural technologies is grounded on three principal theories; economic constraints, diffusion-innovation, and adopter perception paradigm (Ngwira, 2014; Prager & Posthumus, 2010). According to the economic constraint model, farmers strive for profit or utility maximization but asymmetrical distribution of resource endowments determine the rate and intensity of adoption (Samiee & Rezaei-Moghaddam, 2017). It recognizes the importance of profitability and economic constraints (access to capital, learning costs associated with innovation, or risk) in adoption decision (Fusco et al., 2020). However, it fails to conceptualize the social dimensions of knowledge, information, communication, and rationality.

The 'Diffusion of innovations' theory describes how agricultural technologies are adopted over time through communication, information, and knowledge (Montes de Oca Munguia et al., 2021). The 'diffusion of innovations' theory has five characteristics that determine the rate of adoption of the agricultural technologies: the relative advantage, compatibility, complexity, trial-ability and observability (Mlenga, 2015). In addition, the theory says that the decision to adopt an innovation is viewed as a cognitive process that follows stages of knowledge about the technology, persuasion, decision, implementation, and confirmation (Meijer et al., 2015; Ntshangase et al., 2018).

Hence, as part of persuasion and decision stages of knowledge about the technology of diffusion of innovations' theory, adoption perception about the perceived benefit of agricultural technology is the key to adoption (Adesina & Jojo, 1995; Adesina & Moses, 1993; Workneh & Parikh, 1999). Smallholder farmers, as consumers, generally have subjective preferences for characteristics of technologies and their demand for the technology is significantly affected by their perceptions of the technology's attributes (Adesina, 1995). A more recent literature (Abyiot, Belay, & Mintewab, 2022) demonstrated that farmers' perceptions of the technology's attributes, as well as the benefits of CSA innovations to food security, climate change adaptation, and mitigation, influenced the combinations of CSA innovations adopted.

In this study, economic constraint theory has been represented with the economic factor variables such as number of plots, total farm size, livestock holding, access to credit and saving as well as

remittance; diffusion innovation theory represented through the institutional factor variables such as extension service, mobile phone, distance to market, access to water point (hand pump well and public tap water), social networks, and tenure security which institutionally facilitates; adopter perception theory has been represented using socio-demographic and climate risk factor variables. Because, the diffusion-innovation through access to information about climate change is the key to adoption of CSA innovations (Hailemariam, 2019; Ouédraogo et al., 2019; Teklewold et al., 2013). Similarly, a socio demographic factor enhances adoption of CSA innovations while lower perception of climate risk perceptions decreases the likelihood of adoption of CSA innovations.

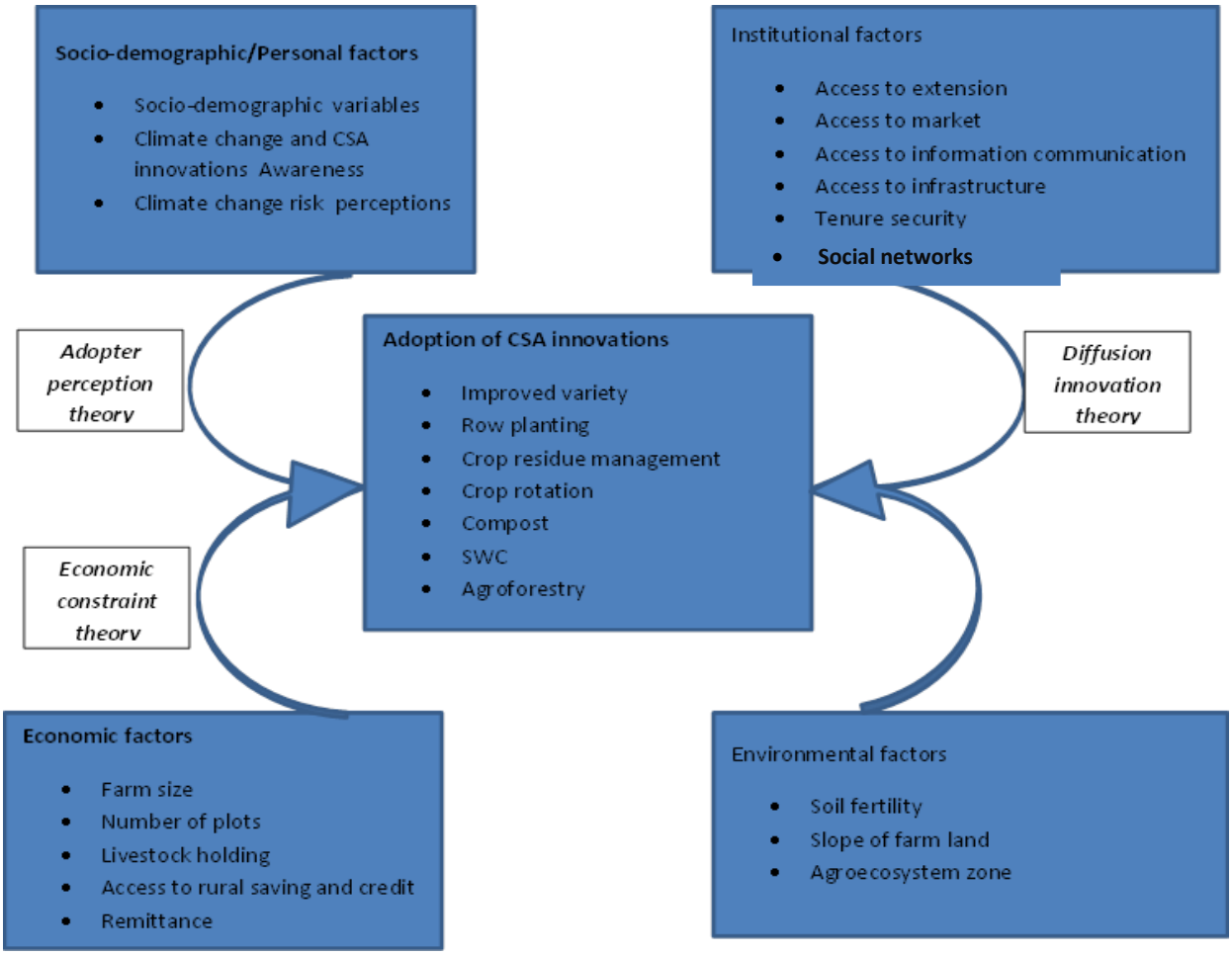

Figure 4: Conceptual framework of multiple adoption of CSA innovation

The review of the literature on agricultural technology adoption determinants revealed that determinants to adoption are diverse, but their interactions and compounded effects are scarce; and the majority of the determinants discovered relate broadly to biophysical, knowledge, and financial constraints on agricultural production and rural development, while rarely mentioned latent

perception factors to adoption (Abyiot, Belay, & Bezabih, 2022; Bezabih, 2021; Shackleton et al., 2015; Helen Teshome et al., 2021; Wordofa, 2021).

Furthermore, despite the abundance of literature on the role of farmers' livelihood asset endowment in the decision to adopt new agricultural technologies little is known about the integrated contribution of environmental, economic, institutional, and socio demographic factors to agricultural technology adoption in the context of smallholder farmers. Hence, it is critical to identify the environmental, economic, institutional, and socio demographic factors that influence the rate of adoption of CSA innovations. With this backdrop, the study's main goal is to investigate the rate, intensity, and determinants of multiple adoptions of CSA innovations among smallholder farmers in Ethiopia's Upper Blue Nile Highlands.

The study answer why farmers adopt CSA innovations and how smallholder farmers do adopts CSA innovations. Hence, the study's significance ranges from methodological to policy recommendation. First, the findings of this study will strengthen the methodological contribution to the literature in terms of integrating the three theories of agricultural technology adoption, diffusion innovation, economic constraint, and adopter perception, on the adoption of multiple CSA innovations. Second, the findings of this study will help to improve agriculture extension approach-based agroecosystem analysis. Finally, the findings of this study will add to the body of literature on smallholder farmers' efforts to adapt to and mitigate climate change in the Upper Blue Nile highland of Ethiopia.

3.2.Materials and Methods

3.2.1. Sampling design and data collection

The study sites and respondents were chosen using a multi-stage sampling technique followed by systematic random sampling. The first stage involved choosing five woredas[1] in the BNH based on the five Agro-ecosystems zones (AESZs), then kebeles[2] from each woreda. Finally, using a one-to-five community mobilization group register and a probability proportional to size (PPS) sampling procedure, a systematic random sampling technique was used to select 424 households from the five kebeles.

1 Woredas are districts of region

2 Kebeles are the lowest administrative structure where group of kebeles make up woreda

Quantitative data using a structured survey questionnaire that focused on household3 and farm characteristics was collected on a one-to-one interview basis by well-trained and experienced enumerators using android tablets. The structured questionnaire collected information on household heads socio-demographic characteristics (personal), economic characteristics, use of institutions and infrastructure, CSA innovations, livelihood assets, and climate risk perceptions.

Three methods were used to estimate the rate and intensity of adoption. To begin, households were classified as adopters or non-adopters of specific CSA innovations (improved varieties, crop residue management, crop rotation, compost, row planting, soil and water conservation (SWC), and agroforestry). Second, the number of CSA innovations adopted by a household, which represents the intensity of adoption, was counted. Finally, the amount of land allotted to each CSA innovation was measured to estimate the intensity of adoption and aggregated to give the household level area covered by CSA innovation. However, the intensity of adoption of improved variety was measured by the amount of improved variety used in kilograms.

3.2.2 Data analysis

The data was subjected to descriptive analysis in order to obtain frequencies and cross-tabulations that showed the data's relationships. The chi-square statistic was used to determine whether variations in agroecosystem zone between adopters and non-adopters of CSA innovation in the research area were statistically significant. The multivariate probit model (MVP) was used in the study to assess the factors influencing the likelihood of adopting multiple CSA innovations.

The dependent variables are adoption of improved variety, crop residue management, crop rotation, compost, row planting, soil and water conservation (SWC), and agroforestry Adoption assumes a value of 1 if farmers apply specific CSA innovation and 0 otherwise.

CSA innovations can have entry points such as the adoption of improved crop varieties, crop residue management, nutrient management, soil management, feed management, manure

3 Note: In this paper, we used the definition of a household usually employed by economist. A household is understood as a domestic unit with autonomous decision-making regarding production and consumption (Ellis 1988; Roberts 1991). The assumption underlying this definition is that a household has an unequivocal hierarchy of authority. In addition, the head of household have the power and exercising decision-making over the household's resources.

management, and agroforestry on the farm level (Jirata et al., 2016). Moreover, climate-smart technologies range from farm level to global policy and financial initiatives (FAO, 2013). CSA is not one particular plot-based practice or technology but a suite of practices that are integrated into an agricultural system, often across different scales (Thierfelder et al., 2017).

Sustainable intensification comprises of improved variety and row planting. Growing improved varieties of maize, wheat, and tef that supplied by the local peasant associations is common practice in the study area (Simane et al., 2016). Adoption of improved varieties improves productivity, increases resilience to climate change, and hence it is an essential strategy in adaptation to future climate change while increasing cost of production (Alemu, 2015; Amare & Beyene, 2019; Asfaw et al., 2010; Campbell et al., 2014; Kassie, Teklewold & Marenya, 2015; Negash, 2017; Pretty et al., 2017; Shiferaw et al., 2017; Teshome & Abate, 2013; Vandercasteelen, Dereje, et al., 2014).

Row planting of wheat, maize, and potato has been practiced in the study area for more than decades. Due to a recommendation from Agricultural Transformation Agency (ATA) and the government extension service, recently, the farmers have started to practice row planting of tef. Farmers broadcast the tef seed using a rate of 25-50 kg per hectare. This technology reduces seed rates and reduced competition between seedlings (Vandercasteelen, Regassa, et al., 2014). Thus, it contributes not only to improvements in crop productivity, income, and household food security but also less inorganic fertilizer use and cost (Amare & Beyene, 2019).

Conservation agriculture includes crop residue management, crop rotation, and compost (Kaczan et al., 2013; Thierfelder et al., 2016, 2017). Crop residue management reduces on-farm cost, increases soil fertility and moisture retention, increases long-term yield, decreases yield variations, and increases income at farm level under conditions of erratic rainfall as well as a result of a gradual decrease of overall soil quality (Farnworth et al., 2016; Ngwira et al., 2014).

Crop rotation involves growing different crops in a systematic and recurring sequence on the same land, including legume crops, cover crops, and green manures that eliminate the fallow period. It increases yield and profit and allows for sustained production as well as increases organic matter in the soil, improves soil structure, reduces soil degradation, and can result in higher yields and greater farm profitability in the long-term. Increased levels of soil organic matter enhance water and nutrient retention and decrease synthetic fertilizer requirements (Arslan et al., 2015; Corbeels et al., 2015; Mupangwa et al., 2016).

Compost is a mixture of decaying organic material made from farm manure, sewage sludge, agricultural residues, or food wastes (Shrestha et al., 2014). In the study area, compost is prepared continuously throughout the year by almost all community members on field crops as well as on backyard gardens (Simane et al., 2013). Use of manure, compost, and green manure, as often used in organic systems, can reduce the need for synthetic fertilizer and hence reduce the cost for inorganic fertilizer use (Golabi et al., 2004; Qaswar et al., 2019).

Sustainable land management includes soil and water conservation (SWC) and agro-forestry. Soil and water conservation that farmers implement in the study area are soil and stone bunds as well as planting animal forage along with the physical soil and water conservation structure. These technologies can improve household food security and reduce vulnerability by increasing soil water availability, decreasing soil erosion, and ensures nutrients and inputs are maintained in the plot (de Graaff, Aklilu, Ouessar, Asians-Velis, & Kessler, 2013; Desalew Meseret M. & Aklilu Amsalu T., 2017; Teshome, de Graaff, & Kassie, 2016). Although immediate benefit from SWC has been scarce, in the long term, the SWC measures are profitable to farmers with low to medium opportunity costs of labor on gentle to moderate slopes(Tenge et al., 2005). SWC practices are soil bund and stone bund(Adego et al., 2019).

Agro-forestry is a dynamic, ecologically based, natural resource management system that incorporates woody perennials such as trees, shrubs, palms, bamboos in the crops/livestock system. It can be practiced around the plot or homestead garden. This technology enhances farmers' ability to adapt to climate change via multiple benefits it delivers such as increases income from the sale of woody perennials, reduces food insecurity, increases CO2 sequestration and hence reduces the vulnerability of agricultural systems and enhance the resilience of smallholders to current and future climate risks (Kassie, 2016; Noulekoun et al., 2016). Agroforestry in the form of planting (and retaining) trees and shrubs in agricultural crop and livestock production systems is another CSA technology (Coulibaly et al., 2017). Trees can maintain or increase soil fertility and moisture retention by generating soil organic matter, and trees can function as live fences and sources of fuel, timber, or fiber as well as a source of food (Coulibaly et al., 2017).

The selection of the independent variables for empirical model specification was based on theoretical , conceptual frameworks, and past empirical adoption of agricultural technologies (Agidie et al., 2014; Hailemariam et al., 2017; Hailemariam, 2019; Jat, 2018; Menale Kassie et al., 2013; Knowler & Bradshaw, 2007; Shiferaw, 2017; Teklewold, 2013).They include socio-

demographic/personal factors such as age, sex, and education level of the household head. Personal factors often influence technology adoption decisions when there are market imperfection and institutional failure (Long et al., 2016; Melisse, 2018). Economic factors such as farm size and the number of plots may influence farmers' decisions to adopt agricultural technology. Institutional variables such as access to public extension services plays a crucial role in enhancing adoption (Chowdhury et al., 2014). Agricultural extension services on climate change and CSA practice-related topics such as conservation agriculture, soil and water conservation, climate change, and agronomic practices also influence the likelihood of the farmers' to adopt these technologies (Ntshangase, 2018). access to markets as well as information communication maters for adoption as farmers get information from multiple sources, including farmer to farmer communication, public extension service, and mobile phone and radio (Mittal & Mehar, 2012; Murage et al., 2012). Besides, tenure security, participation in watershed management, membership and participation social institutions(wenfel and mahber), social informal insurance in the form of receiving informal aid from friends and relatives during a difficult time, and. For environmental factor, we took soil fertility and plot slope of the farmland as a biophysical factor (Zerihun et al., 2014). The data analysis was conducted using descriptive statistics and econometric models in Stata 15 (Table 2).

Table 6: Description of dependent and explanatory variables

Dependent variables	Description of the variables	M[4]	SD
Improved variety	Dummy=1 if household adopt improved variety, 0 otherwise	0.31	0.46
Crop residue management	Dummy=1 if household adopt crop residue management, 0 otherwise	0.46	0.50
Compost	Dummy=1 if household adopt compost, 0 otherwise	0.66	0.47
Row planting	Dummy=1 if household adopt row planting, 0 otherwise	0.76	0.43
Crop rotation	Dummy=1 if household adopt crop rotation, 0 otherwise	0.37	0.48
SWC	Dummy=1 if household adopt soil and water conservation, 0 otherwise	0.51	0.50
Agroforestry	Dummy=1 if household adopt agroforestry , 0 otherwise	0.21	0.41
Explanatory variable			
Socio-demographic factors			
Sex	Dummy =1 if the sex of the household head is male, 0 otherwise	0.94	0.21
Age	Age of the household head in years	46.1	12.6
Education status	Not read and write=0, Read and write=1,Primary=2 , and Secondary=3	1.73	0.80
Farming experience	Farming experience of the household head in years	10.7	8.20
Climate Change awareness	Dummy=1 if the household head aware of climate change, 0 otherwise	0.18	0.40
CSA awareness	Dummy=1 if the household head aware of CSAI, 0 otherwise	0.20	0.40
Economic factors/			
Plots	Number of plots a household cultivate	4.30	1.70
Farm size	Farm size in hectares	1.54	0.80
Livestock holding	Number and types of livestock holding(TLU)	4.87	3.30
Access to credit	Dummy=1 if the household head received credit , 0 otherwise	0.51	0.50
Access to saving	Dummy=1 if the household head save in cash or in kind , 0 otherwise	0.18	0.40
Remittance	Dummy=1 if the household head received remittance , 0 otherwise	0.85	0.40
Institutional factors			
Extension service	How frequently get extension service? Always=5, Sometimes=4, Rarely=3 Once=2, and Never= 1	3.60	0.70
Distance to market	Log distance to the nearest market in walking minutes	3.88	0.80
Mobile phone	Dummy=1 if the household possess mobile phone , 0 otherwise	0.56	0.50
Public tap water point	Dummy=1 if the household access standpipe water , 0 otherwise	0.34	0.50

4 **M** is mean or average of variable, for categorical variables it shows percent i.e., improved variety(M=0.31) means 31% .

Hand pump water point	Dummy=1 if the household access Hand pump water point water , 0 otherwise	0.26	0.40
Solar home system	Dummy=1 if the household possess solar panel , 0 otherwise	0.39	0.50
Improved cook stove	Dummy=1 if the household possess improved cook stove, 0 otherwise	0.42	0.50
Community watershed management	Dummy=1 if the household participate in community watershed management, 0 otherwise	0.59	0.50
Wenfel[5]	Dummy=1 if the household head participate in wenfel, 0 otherwise	0.43	0.40
Mahber[6]	Dummy=1 if the household head member of mahber, 0 otherwise	0.86	2.30
Social informal safetynet	Number of friends to relay for informal aid and loan	4.30	0.40
Strong tenure security	Dummy=1 if the household head cultivate his/her own land , 0 otherwise	0.79	0.40
Environmental factors			
Poor soil fertility	Dummy=1 if the farm land has poor soil fertility self-rating, 0 otherwise	0.18	0.40
Slope of the farm land	Dummy=1 if the plot has medium to steep slope self-rating, 0 otherwise	0.03	0.20
Temperature increased	Dummy=1 if a farmer perceived a temperature increase, 0 otherwise	0.75	0.40
Rainfall decreased	Dummy=1 if rainfall decreased , 0 otherwise	0.75	0.50
Drought increased	Dummy=1 if a farmer perceived a drought increase , 0 otherwise	0.67	0.50
Flood increased	Dummy=1 if a farmer perceived a flood , 0 otherwise	0.68	0.50
Hailstorm increased	Dummy=1 if a farmer perceived a hailstorm increase , 0 otherwise	0.50	0.50
Erratic rainfall increased	Dummy=1 if a farmer perceived an erratic rainfall increase, 0 otherwise	0.77	0.40
Agro ecosystem zone			
AESZ1	Dummy=1 if the household is from the Lowland agroecosystem , 0 otherwise	0.18	0.40
AESZ2	Dummy=1 if the household is from the Midland with black soil, 0 otherwise	0.13	0.30
AESZ3	Dummy=1 if the household is from the Midland with brown soil, 0 otherwise	0.25	0.40
AESZ4	Dummy=1 if the household is from the Midland with sloping	0.15	0.40

5 Wenfel is reciprocal labour exchange group during ploughing, harvesting and threshing
6 Mahber is a religious social gathering of farmers commemorating the 12^{th},16^{th},19^{th},21^{th}, or 27^{th} of every month to fest and celebrate.

	land, 0 otherwise		
AESZ5	Dummy=1 if the household is from the mountainous highland, 0 otherwise	The hilly and	0.30 0.50

The MVP model's dependent variable has a value of 1 if farmers use a specific CSA innovation and a value of 0 otherwise. The MVP model models the influence of a set of different CSA innovation adoptions while allowing unobserved and unmeasured factors (error terms) to be freely correlated that capture the mutual impact between the adoption of different CSA innovations. When they decide to adopt based on the benefits of CSA innovations, one source of correlation may be the synergy (positive correlation) and trade-off (negative correlation) of these innovations. The essence of using MVP stems from the fact that smallholder farmers, by observation, consider adopting multiple CSA innovations for various agricultural and livelihood outcomes. Some of these technologies produce a synergistic (complimentary) effect, while others produce a trade-off effect (substitutes). As a result, failing to account for these unobserved factors and effects among CSA innovations will result in biased and inefficient estimates (Greene, 2003).

Model specification of multivariate probit (MVP) model

The MVP econometric model is characterized by a set of binary dependent variables (Y_{ij}), such that:

$$\boldsymbol{Y_{ij}^{*} = \beta_i' X_{ij} + \varepsilon_{ij}}, \quad (1)$$

And

$$\boldsymbol{Y_{ij} = \begin{cases} 1, \ if Y_{ij}^{*} > 0 \\ 0, \ otherwise \end{cases}} \quad (2)$$

Where i=1, … ,7 denotes the CSA innovations such as 1=improved variety 2=crop residue management, 3=crop rotation, 4= compost, 5= row planting, 6= SWC, and 7= agroforestry; and j=1, ..., n and n denotes the sample size.

The Eq. (1) assumption is that a rational j^{th} farmer has a latent variable, Y^{*}_{ij} , which captures the unobserved preferences derived from the i^{th}CSA innovation. This latent variable is assumed to be a linear combination of observed socio-demographic /personal, economic, institutional and environmental factors (X_{ij}), as well as unobserved characteristics captured by the stochastic error term ε_{ij}. The vector of parameters to be estimated is denoted by $\boldsymbol{\beta_i}$. Given the latent nature of Y^{*}_{ij},

the estimations are based on observable binary discrete variables Y_{ij}, which indicate adopt the i^{th} CSA innovation. Since, we assumed that adoption of multiple CSA innovations and innovation are independent of one another; the error terms in Eq. (1) jointly follow a multivariate normal (MVN) distribution, with 0 conditional mean and variance normalized to 1. Where ($\boldsymbol{\rho 1}$,$\boldsymbol{\rho 2}$,$\boldsymbol{\rho 3}$,$\boldsymbol{\rho 4}$,$\boldsymbol{\rho 5}$, $\boldsymbol{\rho 6}$, $\boldsymbol{\rho 7}$) distributed MVN(0,Ω″) and the symmetric variance-covariance matrix ″ is given by

$$\Omega = \begin{bmatrix} \boldsymbol{1} & \boldsymbol{\rho_{12}\rho_{13}} \cdots & \boldsymbol{\rho_{17}} \\ \vdots & \ddots & \vdots \\ \boldsymbol{\rho_{71}} & \boldsymbol{\rho_{72}\rho_{73}} \cdots & \boldsymbol{1} \end{bmatrix}$$

where ($\boldsymbol{\rho_{im}}$) denotes the pairwise correlation coefficient of the error terms corresponding to any two CSA innovations' adoption equations to be estimated in the model.

In the analysis, the off-diagonal elements in the covariance matrix $\boldsymbol{\rho_{im}}$ are important as they represent the unobserved correlation between the stochastic component of the i^{th} and m^{th}CSA innovations. This assumption means that Eq. (2) gives an MVP model that jointly represents the adoption of a particular CSA innovation. In this model, a positive correlation represents a synergy while a negative correlation represents trade-off between the i^{th} and m^{th}CSA innovations (Kurgat et al., 2020; Zakaria et al., 2020).

To determine the effect of independent variables on the adoption the final analysis contains marginal effect analysis result based on Eq(3) (Greene, 2003). Therefore, the marginal effect of observed personal, economic, institutional, and environmental factors (Xij) were calculated because marginal effects measure the impact that a small unit change in one independent variable has on the adoption of specific CSA innovations while all other variables are held constant.

$$\text{Marginal Effect of } X_{ij} = \Pr(Y_i = 1|X, X_{ij} = 1) - \Pr(Y_i=1|X, X_{ij} = 0) \quad (3)$$

3.3.Results and discussion

3.3.1. Rate of adoption of CSA innovations

Different CSA innovations have different levels of adoption. The major CSA innovations adopted were row planting, compost, SWC, crop residue management, crop rotation, improved crop variety, and agro-forestry with adoption rates of 76, 66, 51, 46, 37, 31, and 21 percent of the farm households, respectively (Table 2). Similar findings have been reported on the rate of SWC adoption (49.6 percent) in Ethiopia (Akalu, 2013) and Nigeria (Ojo et al., 2021)(67 percent). Similarly, the rate of adoption of soil and water conservation is lower than in Kenya (Kalele et al., 2021). Amare and Abebe (2019) reported row planting rate of adoption (40 percent), significantly

lower than our finding (76 percent). This is because our study considered wheat, maize, and potato row planting while the previous study considered only tef row planting. The adoption rate of improved variety in this study (31 percent) is lower than in Mali (Ouédraogo, 2019)(57 percent) due to awareness about CSA. Similarly, adoption rate of agroforestry (21 percent) is much lower than traditional agroforestry system that consists of different trees species (86.7 percent) of Homestead, Boundary Mixed with crops, Grazing land, and Hedge row planting (Gizaw, 2018). This is because Gizaw(2018) considered several Acacia species of agroforestry systems such as Gerbi/Acacia albidia/ Acacia abyssinica, Tedecha (Acacia tortilis), and wacho while our study considered only few fruit trees and boundary tree plantings of *Eucalyptus globulus.*

3.3.2. Intensity of adoption of CSA innovations

Table 8 shows the intensity of CSA innovation adoption was also calculated based on the number of CSA innovations adopted simultaneously by a farmer as well as the area covered by specific CSA innovations. The minimum and maximum numbers of CSA innovations adopted were zero and seven, respectively, with an average of three CSA innovations adopted simultaneously. The midland with brown soil agroecosystem zone (AESZ3) adopted the highest average number of CSA innovations (4.33) while the midland with black soil agroecosystem zone (AESZ2) adopted the lowest average number of CSA innovations (2.07). This is because AESZ3 has more fertile land and a medium slope while AESZ2 has a flat plain area that is prone to flood disasters every year.

Table 7: Intensity of adoption of number of CSA innovations by agroecosystem

Agroecosystem	Observation	Mean	Std. Dev.	Min	Max
AESZ1	76	2.55	1.5	0	6
AESZ2	55	2.07	1.3	0	5
AESZ3	105	4.33	1.42	1	7
AESZ4	63	3.75	1.47	1	7
AESZ5	124	3.08	1.42	0	6
Average	423	3.27	1.62	1	7

Source: Survey 2018

Furthermore, the study used the area covered by the CSA innovation as a proxy for the intensity of adoption. Row planting has the highest adoption intensity (0.64 ha), followed by crop residue management (0.44 ha), and agroforestry has the lowest adoption intensity (0.002 ha), followed by

crop rotation (0.20ha). Agroforestry is practiced in the form of a small home garden with a few fruit trees and boundary tree plantings of *Eucalyptus globulus* (Table 4).

Table 8: Intensity of adoption of CSA innovations measured in area covered

CSA innovations	Mean	Std. Dev.	Min	Max
Row planting (in ha)	0.64	0.66	0	3.5
Crop residue management (in ha)	0.44	0.64	0	3.5
SWC (in ha)	0.27	0.43	0	3
Compost (in ha)	0.21	0.32	0	5
Crop rotation (in ha)	0.20	0.41	0	2.5
Agro forestry (in ha)	0.002	0.02	0	0.25

Source: Survey 2018

3.3.3. Determinants of multiple adoptions of CSA innovations

The results of the multivariate analysis revealed that farmers adopted multiple CSA innovations simultaneously, which is consistent with several studies that claim farmers preferred multiple adoption of CSA practices over piecemeal adoption (Aryal et al., 2018; Hailemariam, 2019; Teklewold, Gebrehiwot, et al., 2019). Table 5 shows the pair wise correlation of CSA innovations adoption in the multivariate probit model. The correlation's overall goodness of fit is highly significant. Thirteen of the twenty-one pairs of pairwise correlations of CSA innovations are statistically significant (Wald $\chi 2$ (21) = 119; $p< 0.01$). The pairwise correlation reveals that compost adoption has a significant synergistic effect on improved variety adoption ($p< 0.01$), crop residue management ($p< 0.01$), row planting ($p< 0.01$), and agroforestry ($p< 0.1$). Row planting has a significant synergistic effect on adoption of agroforestry ($p< 0.01$), improved variety ($p< 0.01$), and crop rotation ($p< 0.05$), but has a trade-off effect on SWC adoption ($p< 0.01$). SWC has a significant synergistic effect on crop rotation adoption ($p< 0.05$), but has a negative trade-off effect on crop residue management ($p< 0.01$). Adoption of agroforestry has a significant synergistic effect on cop rotation ($p< 0.01$) and improved variety ($p< 0.1$) that is consistent with previous research (Mwungu et al., 2020). The adoption of improved varieties has a significant synergistic effect on crop rotation adoption ($p< 0.05$). Except for SWC adoption, which has a trade-off effect on row planting and crop residue management, all CSA innovations have a synergistic effect on the adoption of other CSA innovations that supports the findings of (Kpadonou, 2017) who reported

that several practices are interdependent, with some complementary and others substitutable. Another study by (Hailemariam, 2019) concluded, similar to our finding, that smallholder agricultural production can be characterized by complementarities between CSA practices.

Table 9: Pair-wise correlation of adoption of CSA innovation

CSA innovations	Compost	Row Planting	SWC	Agro-forestry	Improved variety	Crop residue management
Row Planting	0.42 (0.11) ***	1				
SWC	-0.08(0.10)	-0.18(0.10)***	1			
Agro-forestry	0.21(0.12)*	0.62(0.15)***	-0.005(0.11)	1		
Improved variety	0.42(0.11)***	0.72(0.14)***	-0.14(0.11)	0.19(0.13)*	1	
Crop residue management	0.36(0.10)***	0.06(0.10)	-0.29(0.10)***	0.15(0.11)	0.12(0.1)	1
Crop rotation	0.09(0.11)	0.27(0.11)**	0.23(0.10)**	0.37(0.11)***	0.22(0.1)**	0.04(0.10)
$\chi 2$ (21) =	160.7					
Prob> $\chi 2$ =	0.0000					
Sample size =	423					

Standard errors in parentheses ***, **, * are significant at 1%, 5%, and 10%, respectively

Likelihood ratio test of rho21 = rho31 = rho41 = rho51 = rho61 = rho71 = rho32 = rho42 = rho52 = rho62 = rho72 = rho43 = rho53 = rho63 = rho73 = rho54 = rho64 = rho 74 = rho65 = rho75 = rho76 = 0

3.3.4 Determinants of multiple adoptions of CSA innovations

Socio-demographic factors

Table 6 depicts the marginal effect of CSA innovation adoption. The marginal effect shows that male-headed households have a 32.2 percent higher probability of adopting crop residue management and a 13.1 percent higher probability of adopting agroforestry, respectively. However, some findings argue that the effect of gender on adoption is inconclusive, even if women do the majority of the work (Aryal et al., 2020; Tsige, 2020). More educated farmers are 9.2 percent more likely to use crop residue management and 2.9 percent more likely to use SWC, indicating that CSA innovation adoption is knowledge intensive (Kpadonou, 2017; Wordofa et al., 2020). Farmers who are aware of climate change are 10.1% more likely to use SWC. Farmers who are aware of CSA innovation are 33.0, 10.5, 9.7, and 6.7 percent more likely to adopt crop residue management, compost, SWC, and agroforestry, respectively, due to the labor-, knowledge-, and capital-intensive nature of these innovations. Farmers who perceive a climate change risk of rising temperatures are

13.7 percent more likely to use crop residue management and 5.7 percent more likely to use crop rotation, respectively. Farmers who perceive an increase in hailstorm risk as a result of climate change are more likely to use crop residue management, SWC, and improved variety, respectively. Farmers who perceive an increase in erratic rainfall as a climate change risk have a 4.8 and 4.7 percent higher probability of adopting improved varieties and compost, respectively, indicating that climate risks influence the probability and level of CSA adoption (Aryal, 2018).

According to adopter perception theory, farmers' perceptions about the characteristics of innovation facilitate adoption. According to the estimates, changes in the perceived technology-specific characteristics of CSA innovations increase the likelihood of adoption. Hence, formal education, more awareness about climate change and CSA, and the ability of CSA innovations to reduce the impact of climate change risks such as rising temperatures, increased hailstorms, and increased erratic rainfall have significantly increased the likelihood of adoption of CSA innovations. Hence, based on farmers' perception of CSA innovations, farmers adopt CSA innovations to reduce the effect of increasing temperatures, hailstorms, and erratic rainfall on their livelihood (Abyiot, 2022).

Economic factors

Farmers with a large number of plots are 3.2 percent less likely than farmers with a small number of plots to use crop residue management. Farmers with a large total farm size are 4.0 and 3.7 percent more likely to adopt crop rotation and agroforestry, respectively. Similar findings of Makate et al. (2019) showed that farmers with a small total farm size (Makate, Makate, Mango, et al., 2019b) adopt less number of technologies. Farmers who save in cash or kind are 5.6 and 5.3 percent more likely than farmers who do not save in cash or kind to use crop residue management and crop rotation, respectively. Farmers who receive remittances are 5.3 percent more likely than farmers who do not receive remittances to use row planting.

According to the economic constraint model, farm size, number of plots, and financial access all influence crop residue management, crop rotation, and agroforestry adoption. Hence, a larger number of plots, a larger total farm size, and access to rural savings and credit increase the probability of adoption of CSA innovations.

Institutional factors

Farmers who receive frequent extension visits have 2.6, 3.1, and 2.15 percent more probability to adopt improved variety, crop rotation, and SWC than farmers who less frequently get extension

service while 7.8 percent lower probability of adopting crop residue management Our result supports findings of Makate et al. (2019) who reported that access to extension services are more effective than credit in encouraging farmers to adopt CSA technologies (Makate, 2019b). Farmers who have greater market access are 2.3 percent more likely to use compost than farmers who have less market access. Farmers with greater access to information (mobile phones) are 4.2 and 5 percent more likely to adopt improved variety and crop rotation, respectively. Mwungu et al.(2020) also found that access to agricultural information facilitates the adoption of CSA technologies which supports our finding.

Farmers with better access public tap water point are 11.3 and 5.0 percent more likely to use improved variety and crop residue management, respectively. Similarly, farmers with greater access to hand pump water point are 4.7, 14.5, and 6.1 percent more likely to use improved variety, crop residue management, and crop rotation, respectively. Farmers who gain access to Solar Home System are 4.4 percent more likely to adopt SWC. Farmers who gain access to improved cook stove are 4.2, 10.6, 4.2, and 4.3 percent more likely to adopt improved variety, crop residue management, compost, and SWC, respectively.

Farmers who participate in community watershed management are 8.9 percent more likely to adopt crop residue management. Farmers who take part in "wenfel" have a 4.9 and 4.3 percent higher likelihood of using crop rotation and compost, respectively. Farmers who belong to the social religious group "mahber" have a 6.7 and 6.1 percent higher likelihood of adopting SWC and improved variety, respectively, because membership in social/agricultural groups and local institutions improves the scaling of climate-smart innovations (Makate, 2019b; Zakari et al., 2019).Farmers with strong social informal safetynet are one percent more likely to adopt crop rotation. Farmers with strong tenure security are 10.9 and 5.2 percent more likely to adopt crop residue management and agroforestry, respectively than farmers with weak tenure security, such as farmers who rent or share the land they cultivate, because strong tenure security ensures confidence in the investment (Ng'ang'a et al., 2019).

The diffusion innovations model assumes that agricultural technologies are adopted over time through communication, information, and knowledge. As a result, frequent extension visits, market access, information communication access, social networks, and strong tenure security encourage the adoption of CSA innovations such as improved variety, crop residue management, crop rotation, compost, SWC, and agroforestry.

Environmental factors

Farmers with poor fertility farmland are 4.3 percent more likely to use compost. The lowland and Abay gorge agroecosystem zones (AESZ1) adopted improved variety, compost, and row planting, SWC, and agroforestry more than the hilly and mountainous highland agroecosystem zones (AESZ5). Similarly, the agroecosystem zone of the midland with black soil adopted improved varieties, compost, row planting, and agroforestry. The midland with a brown soil agroecosystem zone (AESZ3), on the other hand, implemented improved variety, crop residue management, compost, and agroforestry. Finally, the agroecosystem zone of the midland with sloping land (AESZ4) adopted improved variety and agroforestry.

Table 10: Marginal effect of adoption of CSA innovations

Variables	Improved variety dy/dx	Crop residue management dy/dx	Crop rotation dy/dx	Compost dy/dx	Row planting dy/dx	SWC dy/dx	Agroforestry dy/dx
Socio-demographic factors							
Gender	0.083(0.92)	0.322(0.11)***	0.11(1.58)	0.085(0.28)	0.066(1.27)	0.092(1.32)	0.131(2.54)**
Age	0.002(0.05)	-0.001(0.002)	0.002(0.83)	0.002(1.02)	0.001(0.27)	0.002(0.87)	0.002(2.05)**
Education status	0.026(1.19)	0.092(0.027)***	0.03(0.09)	0.027(0.18)	0.021(0.29)	0.029(2.22)**	0.024(1.91)*
Farming experience	0.002(0.76)	-0.005(0.003)*	0.003(0.17)	0.003(1.26)	0.002(0.49)	0.003(0.87)	0.002(0.8)
Climate Change awareness	0.074(1.9)*	-0.1(0.1)	0.096(0.16)	0.108(0.09)	0.078(0.12)	0.101(2.85)***	0.073(1.84)*
CSA awareness	0.072(1.95)*	0.33(0.091)***	0.09(0.28)	0.105(2.29)**	0.08(1.15)	0.097(2.36)**	0.067(2.19)**
Economic factors							
Plots	0.014(1.32)	-0.032(0.016)**	0.016(0.32)	0.015(0.09)	0.011(1)	0.016(0.98)	0.013(1.00)
Farm size	0.035(1.47)	0.068(0.043)	0.04(2.1)**	0.04(1.56)	0.026(0.56)	0.041(0.86)	0.037(2.42)**
Livestock holding	0.008(0.63)	-0.001(0.009)	0.009(1.24)	0.009(1.86)*	0.006(0.93)	0.009(1.5)	0.007(1.58)
Access to credit	0.041(0.44)	-0.052(0.045)	0.048(0.42)	0.042(0.48)	0.033(0.12)	0.044(1.48)	0.039(0.09)
Access to saving	0.057(0.18)	0.052(0.055)	0.056(3.86)***	0.053(2.34)**	0.041(1.57)	0.058(1.07)	0.05(1.2)
Remittance	0.053(0.8)	0.048(0.06)	0.064(0.49)	0.057(1.27)	0.053(2.28)**	0.057(0.47)	0.043(1.58)
Institutional factors							
Extension service	0.026(2.15)**	-0.078(0.03)**	0.031(2.99)***	0.03(0.89)	0.025(0.32)	0.029(2.15)**	0.024(1.43)
Distance to market	0.025(0.2)	0.012(0.028)	0.029(0.09)	0.023(2.3)**	0.023(0.44)	0.027(0.54)	0.023(1.43)
Mobile phone	0.042(1.65)*	0.01(0.046)	0.05(1.82)*	0.042(0.47)	0.034(0.04)	0.047(0.56)	0.041(0.18)
Public tap water point	0.05(2.02)**	0.113(0.053)**	0.057(0.6)	0.051(0.16)	0.042(1.15)	0.054(0.23)	0.046(0.28)
Hand pump water point	0.047(2.52)**	0.145(0.059)**	0.061(3.15)***	0.054(1.00)	0.052(1.06)	0.055(1.58)	0.045(1.12)
Solar home system	0.039(0.99)	-0.051(0.044)	0.046(0.74)	0.042(1.01)	0.033(0.5)	0.044(1.71)*	0.036(0.56)

Improved cook stove	0.042(2.69)***	0.106(0.046)**	0.05(0.68)	0.042(3.53)***	0.034(0.3)	0.043(4.35)***	0.039(1.54)
Community watershed management	0.044(0.41)	0.089(0.05)*	0.051(1.78)*	0.049(1.16)	0.038(1.2)	0.049(0.47)	0.041(0.5)
Wenfel7	0.042(0.26)	-0.082(0.048)*	0.049(2.46)**	0.043(2.76)***	0.039(0.9)	0.046(1.78)*	0.039(0.81)
Mahber8	0.061(2.39)**	0.031(0.062)	0.068(1.1)	0.056(1.26)	0.038(0.42)	0.067(3.8)***	0.065(0.56)
Social informal safetynet	0.008(1.14)	0.013(0.009)	0.01(1.99)**	0.009(0.27)	0.007(1.4)	0.009(1.44)	0.008(0.76)
Strong tenure security	0.05(1.67)*	0.109(0.053)**	0.056(1.09)	0.047(0.54)	0.039(0.11)	0.053(0.42)	0.052(2.3)**
Environmental factors							
Poor soil fertility	0.05(1.84)*	-0.019(0.056)	0.057(1.07)	0.048(1.14)	0.043(2)**	0.058(0.2)	0.047(1.94)*
Slope of the farm land	0.045(0.85)	-0.047(0.049)	0.053(0.97)	0.049(1.77)*	0.04(0.31)	0.051(1.84)*	0.041(0.3)
Temperature increased	0.043(1.13)	0.137(0.052)***	0.057(2.16)**	0.049(0.21)	0.041(0.14)	0.05(1.65)	0.045(1.66)*
Rainfall decreased	0.043(0.94)	0.011(0.048)	0.051(0.35)	0.044(0.51)	0.036(1.26)	0.048(1.75)*	0.041(0.2)
Drought increased	0.045(1.2)	-0.018(0.048)	0.053(1.46)	0.047(0.12)	0.036(1.89)*	0.047(0.5)	0.04(0.32)
Flood increased	0.042(1.95)*	0.036(0.046)	0.048(0.13)	0.043(0.89)	0.033(1.05)	0.045(0.2)	0.04(0.92)
Hailstorm increased	0.041(2.69)***	0.101(0.046)**	0.049(0.28)	0.043(0.08)	0.035(0.35)	0.044(2.03)**	0.039(1.27)
Erratic rainfall increased	0.048(2.07)**	-0.036(0.049)	0.053(0.55)	0.047(2.04)**	0.038(0.31)	0.048(1.83)*	0.041(0.39)
AESZ1	0.096(3.2)***	0.075(0.08)	0.087(0.95)	0.071(2.18)**	0.049(7.84)***	0.081(4.34)***	0.136(3.67)***
AESZ2	0.091(2.91)***	0.108(0.083)	0.091(1.44)	0.075(4.11)***	0.052(6.95)***	0.086(0.16)	0.089(2.6)***
AESZ3	0.069(1.94)*	0.383(0.076)***	0.086(0.02)	0.078(2.46)**	0.074(1.01)	0.079(0.47)	0.063(2.37)**
AESZ4	0.063(2.18)**	-0.018(0.075)	0.08(0.53)	0.072(0.45)	0.097(1.12)	0.074(1.65)	0.059(1.67)*

Source: own computation

Standard errors in parentheses ***, **, * are significant at 1%, 5%, and 10%, respectively

7 Wenfel is reciprocal labour exchange group during ploughing, harvesting and threshing

8 Mahber is a religious social gathering of farmers commemorating the 12^{th}, 16^{th}, 19^{th}, 21^{th}, or 27^{th} of every month to fest and celebrate.

3.4.Conclusion

CSA innovations are chosen in a three-step process that includes farmers' perceptions of climate change, the decision to adapt, and the selection of innovations for multiple adoptions. The primary goal of this paper was to investigate the rate, intensity, and determinants of various climate-smart innovations among smallholder farmers in the Upper Blue Nile Highland of Ethiopia. The major CSA innovations adopted were row planting, compost, SWC, crop residue management, crop rotation, improved crop variety, and agro-forestry with adoption rates of 76, 66, 51, 46, 37, 31, and 21 percent, respectively. Three clusters of intensity of adoption of CSA innovations were observed the mid-land agroecosystem zones (AESZ3 and AESZ4), which have the highest intensity of adoption, the lowland Abay gorge and its surrounding midland agroecosystem zones (AESZ1 and AESZ2) with the lowest intensity of adoption, and the hilly and mountainous highland agroecosystem zone (AESZ5) with modest level of intensity of adoption. In terms of CSA innovations, row planting has the highest intensity of adoption (0.64ha), followed by crop residue management (0.44ha) while agroforestry has the lowest intensity of adoption (0.002 ha).

CSA (CSA) innovations have a synergistic effect on the adoption of other innovations, with the exception of Soil and Water Conservation (SWC). The economic constraint model demonstrated that farm size, number of plots, and access to financial services influence crop residue management, crop rotation, and agroforestry adoption. Hence, a larger number of plots, a larger total farm size, and access to rural savings and credit increase the probability of adoption. The diffusion innovation model, on the other hand, asserted that frequent extension visits, market access, access to information communication, social networks, and strong tenure security have no less of an impact on the adoption of CSA innovations such as improved variety, crop residue management, crop rotation, compost, SWC, and agroforestry. Furthermore, farmers' perceived technology-specific characteristics of CSA innovations increase the likelihood of adoption. Hence, formal education, more awareness about climate change and CSA, and the ability of CSA innovations to reduce the impact of climate change risks such as rising temperatures, increased hailstorms, and increased erratic rainfall have significantly increased the likelihood of adoption. The integrated technology adoption model explains the determinants of adopting multiple CSA innovations simultaneously. Therefore scaling up CSA innovations in the study area requires:

rural primary education that enables farmer to raise their awareness about climate change and climate-smart agriculture; improving public extension services, mobile phone accessibility such as agro and climate voice and text message, and improving basic services such as clean water access are important incentives for CSA innovation adoption. Policies must also aim to promote farm-level specific portfolio identification of CSA innovations based on farmers' specific climate change risk perceptions through effective farmer participation.

Chapter Four: Effectiveness of Climate-Smart Agriculture Innovations in Smallholder Agriculture System in Ethiopia

Abyiot Teklu [1], Belay Simane[2] , Mintewab Bezabih[3]

Abyiot Teklu, abyiot.teklu@aau.edu.et, Addis Ababa University, College of Development studies, Ethiopia

Belay Simane, belay.simane@aau.edu.et, Addis Ababa University, College of Development studies, Ethiopia

Mintewab Bezabih, mintewabayele@gmail.com, Ethiopian Policy Studies Institute, Ethiopia.

Abstract

The scientific basis for conceptualizing how farm households achieve the three cli-mate-smart agriculture (CSA) pillars, "triple benefit", is not well developed. This paper examined the impacts of CSA innovations on simultaneously enhancing food security, climate adaptation, and reducing GHG emissions. A cross-sectional household survey was collected among a multi-stage sample of 424 smallholder farmers selected from five agroecosystems of the Upper Blue Nile Highlands in Ethiopia and analysed using an endogenous switching regression (ESR) mod-el. CSA innovations: improved variety, compost, row planting, and agroforestry have provided farmers with the benefit of enhancing food security and climate change adaptation, reducing GHG emissions from farm plots. Crop rotation provided farmers with enhanced food security and reduced livelihood vulnerability, while SWC met the goal of enhancing food security and reducing GHG emissions. Unfortunately, adopting crop residue management, one of the recommended CSA practices in Ethiopia, has not delivered at least two of the CSA pillars, adaptation or mitigation benefits Farmers should be encouraged to adopt improved variety, crop rotation, compost, row planting, soil and water conservation, and agroforestry as the best portfolio of CSA innovation for highland smallholder agriculture systems.

Keywords: climate-smart agriculture; livelihood vulnerability; food security; GHG emissions; synergy; trade off, Ethiopia

4.1. Introduction

Current agricultural development policies, strategies, and technologies are not in sync with the global effort to mitigate current and future climate change trends, nor do they provide a window of opportunity for smallholder farmers to build climate resilience (UNFCC, 2015). Climate change and agriculture are intertwined in three critical links. First, climate change affects crop yield and productivity which causes the food insecurity of smallholder farmers to exacerbate (Niang et al., 2014). Second, for sustainable future agricultural development, agriculture should

adapt to climate change to reduce climate related livelihood vulnerability (Bouroncle et al., 2016). Third, agriculture is a source of greenhouse gas (GHG) emissions that accounted 13, 44, 82 percent of carbon dioxide (CO_2), methane (CH4), and nitrous oxide (N2O) emissions (IPCC, 2019). Therefore, future and current development policies should address the complex challenges of sustainable farming, food security, and the current and anticipated climate change (Arora, 2019; FAO, 2013a).

Land degradation, land scarcity, low input use, water scarcity, and a lack of adaptive capacity all contribute to a decline in land productivity in Ethiopian smallholder agriculture (Ermias, 2013; Gebremicael, 2013; Simane, 2016). When these issues are combined with the risk of climate change, the smallholder agriculture system suffers from additional productivity loss, increased water scarcity, and a lack of adaptive capacity to respond to the risk of climate change (Simeneh, 2016; Yibekal, 2013). Whenever yield declines, smallholder households face malnutrition and food insecurity. Crops stored for the lean season also could be damaged due to crop-pests caused by the changing climate. Moreover, road infrastructure will be washed away or closed, limiting access to the market and exacerbating food shortages (Melak, 2014; Woldeamlak, 2012).

The shift of agricultural areas from more suitable land to marginal and environmentally fragile areas may exacerbate the problem of GHG emissions in three ways. First, degraded and abundant farmland emits more greenhouse gases than cultivated land. Second, the cultivation of grazing land and wet land may release already stored carbon in the area and exacerbate GHG emissions (Porter et al., 2013). Finally, when smallholders deforest the natural forest area for cultivation, they increase the GHG emissions released into the atmosphere.

CSA (CSA) and livelihood diversification can improve the resilience and sustainability of African food systems in the face of climate change (Kerr et al., 2022). CSA integrates sustainable productivity, resilience (adaptation), emissions reductions, food security, and development objectives (FAO, 2013a; Martin et al., 2011; Zerssa, 2021). CSA innovations involve new and old agricultural technologies, and these practices are already well-known and promoted under the conservation agriculture (Harrison et al., 2019; Mutenje, 2019; Thierfelder, 2017), agroforestry (Abbas et al., 2017; Amadu et al., 2020; Charles et al., 2013; Lasco et al., 2014; Mbow et al., 2014; Reppin et al., 2020), sustainable intensification (Campbell et al., 2014;

Clay & Zimmerer, 2020; Menale Kassie et al., 2015), as well as sustainable land management (Beyene et al., 2017; Kombat et al., 2021; Paulos, 2017; Zerssa, 2021). Hence, CSA is not a particular plot-based practice or technology but a suite of practices that are integrated into an agricultural system, often across different scales (Thierfelder, 2017).

Ethiopia has adopted CSA to meet the adaptation and mitigation objectives of the Climate-resilient green economy (CRGE) strategy in the highland agriculture system (FDRE, 2019). Soil erosion or land degradation restoration practices through soil and water conservation measures, agroforestry, and area closures were the major initiatives (Eshete et al., 2020; FDRE, 2019). Such CSA practices and technologies are largely implemented within the framework of the integrated watershed management approach through projects such as the Sustainable Land Management Programme (FDRE, 2019).

Choke mountain is part of the Blue Nile highlands which are known to be surplus-producing regions and the water tower of the Blue Nile. Agriculture is the main economic activity and source of livelihood. The farming system is characterized by a wheat-maize-tef-dominated mixed crop-livestock production system. The Ethiopian ard (or maresha), an ancient plow, is used for tillage that leads to high rates of on-field erosion, particularly on steep slopes (Simane et al., 2016). Overgrazing and deforestation have also contributed to erosion and soil fertility decline. Livestock feed shortages (open grazing) and fuel wood demands continue to exert significant pressure on the resource base. Hence, the watershed is threatened by land and water resource degradation and an impending food shortage (Ermias et al., 2013). Consequently, low agricultural productivity, severe land degradation, and climate change and variability have become the characteristics of this area (Simane & Benjamin F., 2014). Hence, smallholders shift their cultivation towards hilly and marginal lands, natural forests, grazing land, and protected wet lands (Rickard, 2015).

Even though separate studies have looked at the impact of CSA practices on food security (Fentie & Beyene, 2019) and welfare (Tesfaye et al., 2021), there is a scarcity of research on the synergy and trade-off effect of CSA innovations on the food security, climate change adaptation, and mitigation benefit. Moreover, although there are few studies on the ex-post impact assessment of adoption of CSA innovations and its effect on household income and resilience (Teklewold et al., 2017; Teklewold, Gebrehiwot, et al., 2019) yet these studies not only have

limited insight to the impact on food security, livelihood vulnerability, and mitigation at the micro level but also missed the synergy and trade-off effect of CSA technologies. Therefore, this study examined the synergy and trade-off of CSA innovations in delivering the food security, climate change adaptation, and mitigation among smallholder farmers in the Blue Nile Highlands of Ethiopia.

4.2. Research Methodology

4.2.1 Measurements

In measuring the CSA triple benefit, food security, livelihood vulnerability, and carbon balance outcomes, the study used three standard food security, livelihood vulnerability, and carbon balance, calculators. For food security measurement, chosen from among many food security measurements, the study used the food consumption score (FCS), which shows the quantity and quality of food consumed by a household in the last seven days (World Food Programme, 2008). FCS encompasses food security's food availability, access, and utilization aspects (Maxwell et al., 2013; Wekesa, 2018). It is a composite score based on the dietary diversity, food frequency, and relative nutritional importance of the various food groups consumed. FCS is calculated as follows:

$$FCS = a_{staple}X_{staple} + a_{pulse}X_{Pulse} + a_{veg}X_{veg} + a_{fruit}X_{fruit} + a_{animal}X_{animal} + a_{sugar}X_{sugar} + a_{dairy}X_{dairy} + a_{oil}X_{oil} \quad (1)$$

where FCS is the food consumption score; Xi is the frequencies of food items i consumed in the past 7 days; ai is the weight of each food group; and i is staple, pulse, vegetable, fruit, animal, sugar, dairy, and oil.

The thresholds for identifying households with poor and borderline food consumption were determined using dietary pattern assumptions, with a score of less than 21 showing a less than 1470 calorie intake (Kcal/capita/day) (Huang et al., 2015), or less than 1680 calorie intake (Kcal/capita/day) (Aweke et al., 2021), and scores above 35 showing an acceptable threshold level of above 2100 calorie intake (Kcal/capita/day) (Huang, 2015; World Food Programme, 2008). Households with scores between 21 and 35 were considered to have borderline food consumption (Lovon & Mathiassen, 2014), a calorie intake of between 1470 and 2100 calories (Kcal/capita/day) (Huang, 2015) or a calorie intake between 1680 and 2100 calories

(Kcal/capita/day) (Aweke, 2021). When compared to the calorie intake method, poor and borderline groups were considered to be food insecure (Huang, 2015).

Food availability was taken care of by the FCS (WFP, 2009). As high food consumption increases the possibility that a household achieves nutrient adequacy, food utilization is included through the household's frequency of the utilization of the available food or accessed food (Marivoet et al., 2019; Maxwell, 2013; Wekesa, 2018). A modified Household Dietary Diversity Score (HDDS) was calculated for each household using data on the consumption of different food items over the previous 7 days (FAO, 2010b). The food items were categorized into 8 different food groups, with each food group counting toward the household score if a food item from the group was consumed by anyone in the household in the previous seven days. The modified HDDS, then, was a continuous score from 0 to 8. The food groups used to calculate the modified HDDS were: cereals, roots and tubers, pulses, vegetables, fruits, meat, eggs, fish, milk and milk products, oils and fats, sugar, and condiments.

A risk and hazard model was used in the study to assess smallholder farmers' household vulnerability to climate change (Füssel & Klein, 2006; Fussel, 2007; Füssel, 2012). Thus, the current study used an indicator (composite index) approach to assess smallholder farmers' vulnerability to climate change based on the livelihood vulnerability index (LVI) developed by (Hahn et al., 2009) and adopted for agroecosystem analysis by (Simane, 2016). However, unlike (Simane, 2016)and (Hahn, 2009), this study used household-level primary data and took into account several variables to capture the level of exposure to climate hazards as well as the adaptive capacity and sensitivity to climate change. Hence, the indices used in this study integrated the LVI and the IPCC-LVI (Dendir & Simane, 2019; Hahn, 2009; Madhuri et al., 2014; Maru et al., 2021; Simane, 2016).

The present study focused only on major factors (major components and sub-components). Additionally, the study adopted an end-point vulnerability assessment framework that integrates vulnerability concepts that combine information on potential climate impacts and the socio-economic capacity to cope and adapt. It weighed the importance of various indicators and computed the LVI using the balanced weighting approach. The current vulnerability analysis involved the calculation of a balanced, weighted average LVI (composite index) in which each major component contributes equally to the overall index. Accordingly, first, the raw data were

transformed into appropriate measurement units, such as percentages, ratios, and indices, and then the indicators measured on different scales were standardized (Equations (2) and (3)).

$$S_{xi} = \frac{S_{xa} - S_{xmin}}{S_{xmax} - S_{xmin}} \quad (2)$$

while

where S_{xi} is the standardized value for the indicator x, S_{xa} is the observed (average) major component indicator for CSA innovation a, and S_{xmin} and S_{xmax} are the minimum and maximum values, respectively, for the indicator across the seven CSA innovations. Then, the major component indicators are averaged (Equation (4)).

$$S_{xi} = 1 - \frac{S_{xa} - S_{xmin}}{S_{xmax} - S_{xmin}} \quad (3)$$

$$M_{aj} = \frac{\sum_{i=1}^{n} S_{xi}}{n} \quad (4)$$

where Maj represents the j major components for CSA innovation a; index S_{xi} represents the indicators for the major component M indexed by j; N runs from 1 to 9, which makes up each major component; and n is the number of indicators in the major component M. Equation (5) combines the weighted averages of all the major components M to generate the LVI score. The number of indicators which are compressed to determine the weights of each major component is W_j. Values for each of the eight major components for a CSA innovation a were calculated and averaged (Equation (5)) to obtain LVI:

$$LVI_a = \frac{\sum_{j=1}^{N} W_j M_{aj}}{\sum_{j=1}^{N} W_j} \quad (5)$$

where LVIa is the LVI for CSA innovation a, the value of which ranges from 0 (least vulnerable) to 1 (most vulnerable); M_{aj} is the major component of CSA innovation a; and W_j is the weight of the major component. The weights of each major component, W_j, are determined by the number of sub-components that make up each component, and all components contribute equally to the overall LVI. However, IPCC-LVI was calculated using the IPCC vulnerability definition. Major components were categorized into the three IPCC contributing factors of exposure (natural hazard and climate change), sensitivity (ecosystem and agriculture), and adaptive capacity

(wealth, innovation, infrastructure, and social network). Then, the IPCC contributing factors for CSA innovations were calculated based on the following formula (Equation (6)):

$$IPCC_CF_a = \frac{\sum_{k=1}^{N} W_j M_{ak}}{\sum_{k=1}^{N} W_k} \quad (6)$$

where $IPCC_CF_a$ denotes the IPCC contributing factor for CSA innovation a; M_{ak} denotes the major component index by k; and N denotes the number of contributing LVI major components. The IPCC-LVI was calculated after the exposure, sensitivity, and adaptive capacity of CSA innovations. Hence:

$$LVI - IPCC = (E - AC) * S \quad (7)$$

where IPCC-LVI is the LVI value calculated following the IPCC vulnerability definition, which ranges from −1 (least vulnerable) to 1 (most vulnerable); E denotes exposure; AC denotes adaptive capacity; and S denotes sensitivity.

Following the guidelines of GHG calculator selection (Colomb et al., 2013), the study selected the EX-ACT (EX-Ante Carbon Balance Tool) for the availability of data and simplicity of calculation (Srinivasarao et al., 2016). The EX-ACT is an open-source GHG calculator consisting of a set of 18 modules linked to Microsoft Excel sheets, into which researchers insert information on the country- or region-specific data on soil types and climatic conditions together with basic data on land use, land use change, and land management practices foreseen under intervention activities as compared to a "business-as-usual" scenario (Srinivasarao, 2016). Using EX-ACT, the GHG influxes from CSA innovations were calculated using Equations (8)–(10). This net emissions value per unit of farmland was considered as the carbon balance, i.e., net carbon emissions per hectare (ton CO2 e/ha/yr). Based on (IPCC, 2006), GHG emissions, carbon stock, and carbon balance at the farm level were calculated as follows:

$$\text{GHG emissions} = \text{activity data} * \text{GHG emission factor} \quad (8)$$

$$\text{Carbon stock} = \text{Above and below} - \text{ground biomass} * \text{carbon stock exchange factor} \quad (9)$$

$$\text{Carbon balance} = \sum \text{GHG emissions} - \sum \text{carbon stocks} \quad (10)$$

where activity data is GHG influxes, which include afforestation; annual agriculture; perennial agriculture; livestock; and input and investment. Hence, the GHG influxes were measured using

land use/land cover change proxy measures such as the planting of trees such as Eucalyptus globulus, the annual crop land system that includes the cropping system, improved agronomic practices, improved nutrient management, no-till and residue retention, water management, manure application, yield per hectare, the number of livestock, the types of livestock, and the quantity of livestock products, liming, fertilizer (UREA and UPS), and energy consumption, i.e., wood fuel. These variables were used in the analysis and describe the GHG emissions from each CSA innovation intervention area that was measured using farm size (in ha), crop yield (qt/ha), the absolute number and types of livestock and livestock products (milk and meat in tons), lime use (in tons), and fire wood (in tons/year).

4.2.1. Data analysis

The data was subjected to descriptive analysis in order to obtain frequencies and cross-tabulations that showed the data's relationships. Mean, standard deviation, and percentage were utilized depending on the nature of the variable and the need for presentation. T-test and chi-square test were used to determine whether variations in the CSA innovation adoption on food security or livelihood vulnerability or GHG emissions in the research area were statistically significant. The study used the Endogenous Switching Regression (ESR) to examine the impact and determinants of CSA innovations on livelihood vulnerability, food security, and GHG emission. The dependent variables for the ESR are adoption of CSA innovations such as improved variety, crop residue management, crop rotation, compost, row planting, soil and water conservation, and agroforestry (Abate et al., 2015a; Akalu, 2016; Hailemariam, 2017, 2019; Kindie et al., 2017; Mihretie et al., 2022; Shiferaw et al., 2014a). The independent variables were selected based on extensive literature review on CSA innovations in sub-Saharan Africa and Ethiopia that are primarily based on past empirical literature on the determinants of food security or adaptation strategies or GHG emissions.

The adoption and impact of CSA innovations on food security, livelihood vulnerability, and GHG emissions were modeled in the setting of a two-stage framework using an endogenous switching regression model (Di Falco, Veronesi, Yesuf, et al., 2011). In the first stage, we used a selection model for CSA innovation adoption where a smallholder farmer chooses to implement CSA innovations if their gain with regard to food security, livelihood vulnerability, and GHG emissions outweighs the loss incurred due to its adoption.

Let G^* be the latent variable that captures the expected food security gains from its adoption with respect to not adopting. The latent variable is specified as

$G^*_i = Z_i\alpha + u_i$ with $G_i = 1$ if $G^*_i > 0$ otherwise $G_i = 0$ (1)

That is, farmer i will adopt CSA innovation ($G_i = 1$) in response to different socio-demographic, economic, institutional, and environmental factors, if $G^*_i > 0$ otherwise 0. The vector Z represents variables that maximize the farmer's food security, livelihood vulnerability, and GHG emission gains by adopting CSA innovations.

In the second stage, the model estimation simultaneously controlled the effect of factors on adoption decisions and their outcomes by estimating a simultaneous equations model of the adoption of CSA innovation and its impact on the outcome variable with ESR using the full information maximum likelihood (FIML) estimation method. Instrumental variables were used as selection instruments, not only those automatically generated by the non-linearity of the selection model of adoption but also other variables that directly affect the adoption of CSA innovations, though not their impact on the outcome variables.

In our case, the study used selection instruments in the outcome variable function of the variables related to wealth, education, access to extension, and awareness of CSA. The study established the admissibility of these instruments through a simple falsification test; if a variable is a valid selection instrument, it affects adoption decisions but not the outcome (food consumption score, livelihood vulnerability index, and farm GHG emission).

To account for selection biases, an ESR model were used for the outcome variables (food consumption score, livelihood vulnerability index, farm GHG emission, and climate resilience capacity index), in which farmers face two regimes: Regime 1, to adopt and Regime 2, not to adopt, defined as follows:

$$U_{1i} = X_i\beta_1 + \epsilon_{1i} \quad (11)$$

$$U_{2i} = X_i\beta_2 + \epsilon_{2i} \quad (12)$$

$$G_i^* = \partial(U_{1i} - U_{2i}) + Z_i\alpha + u_i \quad (13)$$

Here, G_i^* is a latent variable that determines the utility obtained whether the household i adopts a CSA innovation or not; U_{ji} is the outcome variable value of a household i who adopts CSA innovation and j = Regime 1 and Regime 2; and Z_i is a vector of characteristics that influences

the decision to adopt the innovation but not the outcome variable value. X_i is a vector of household characteristics that are thought to influence the decision to adopt the innovation, β1, β2, and γ are vectors of parameters, and u_i, ϵ_{1i}, and ϵ_{2i} are the error terms.

The regression model coefficient of adoption, which measures the impact of adopting the innovation, should be random. However, in the case of the adoption of CSA innovations, farmers freely choose the particular CSA innovation they want to adopt with their consent. Hence, there is the problem of self-selection, which leads to selection bias. The decision to adopt a given innovation is likely to be affected by unobservable characteristics that may be correlated with the outcome variables (food consumption score, livelihood vulnerability index, farm GHG emissions, and climate resilience capacity index). Finally, the error terms in Equations (12)–(14) are assumed to have a trivariate normal distribution (υ, ε1, ε2) ~ N(0, Σ):

$$\sum = \begin{matrix} \sigma_{\upsilon}^2 & \sigma_{\upsilon 1} & \sigma_{\upsilon 2} \\ \sigma_{1\upsilon} & \sigma_1^2 & . \\ \sigma_{2\upsilon} & . & \sigma_2^2 \end{matrix}$$

where σ_{υ}^2 is the variance in the adoption of Equation (13), which is equal to 1, since the coefficients are estimable only up to a scale factor; σ_1^2 and σ_2^2 are the variances of the error terms in the outcome variable of Equations (11) and (12); and $\sigma_{1\upsilon}$ and $\sigma_{2\upsilon}$ represent the covariance of υi and ε1i and ε2i. Since Equations (11) and (12) are not observed simultaneously, the covariance between ε1i and ε2i is not defined (reported as dots in the covariance matrix). An important implication of the error structure is that, because the error term of the selection in Equation (13) u_i is correlated with the error terms of the outcome variable of Equations (11) and (12) (ε1i and ε2i), the expected values of ε1i and ε2i, conditional on the sample selection, are nonzero.

$$E = (\varepsilon_{1i}|G_i = 1) = \sigma_{1\upsilon}\frac{\phi(Z_i\alpha)}{\Phi(Z_i\alpha)} = \sigma_{1\upsilon}\lambda_{1i} \quad (14)$$

$$E = (\varepsilon_{2i}|G_i = 0) = \sigma_{1\upsilon}\frac{\phi(Z_i\alpha)}{1 - \Phi(Z_i\alpha)} = \sigma_{2\upsilon}\lambda_{2i} \quad (15)$$

where ϕ (.) is the standard normal probability density function, Φ(.) the standard normal cumulative density function, λ1i = $\frac{\phi(Z_i\alpha)}{\Phi(Z_i\alpha)}$, and λ2i = – $\frac{\phi(Z_i\alpha)}{1-\Phi(Z_i\alpha)}$. If the estimated covariances $\sigma_{1\upsilon}$ and $\sigma_{2\upsilon}$ are statistically significant, then the decision to adopt and the outcome variable are

correlated, that is, evidence of endogenous switching is found and rejects the null hypothesis of the absence of sample selectivity bias. An efficient method to estimate endogenous switching regression models is full information maximum likelihood estimation (Lokshin & Sajaia, 2010). The logarithmic likelihood function(Lokshin & Sajaia, 2004) given the previous assumptions regarding the distribution of the error terms is:

$$\ln \text{Li} = \sum_{i=1}^{N} \boldsymbol{A_i}\left[ln\, \boldsymbol{ln}\, \boldsymbol{\phi}\left(\frac{\boldsymbol{\epsilon_{1i}}}{\boldsymbol{\sigma_1}}\right) - \boldsymbol{ln}\, \boldsymbol{ln}\, \sigma_1 + \boldsymbol{ln}\, \boldsymbol{ln}\, \Phi(\boldsymbol{\theta_{1i}})\right] + (1 - \text{Ai})[ln\, \boldsymbol{ln}\, \boldsymbol{\phi}\left(\frac{\boldsymbol{\epsilon_{2i}}}{\boldsymbol{\sigma_2}}\right) - \boldsymbol{ln}\, \boldsymbol{ln}\, \sigma_2 + \boldsymbol{ln}\, \boldsymbol{ln}\left(\mathbf{1} - \boldsymbol{\Phi}(\boldsymbol{\theta_{2i}})\right)] \quad (16)$$

where θji = $\frac{\boldsymbol{z_i\alpha} + \frac{\boldsymbol{\varepsilon_{ij}}}{\boldsymbol{\sigma_j}}\boldsymbol{\rho_j}}{\sqrt{(\mathbf{1}-\boldsymbol{\rho_j^2})}}$, and j = 1, 2, with ρj denoting the correlation coefficient between the error term u_i of the CSA innovation adoption in Equation (13) and the error term εji of Equation (16), respectively. The ESR model can be used to compare the expected outcome variable of the farm households that adopt particular innovation (a) to the farm households that do not adopt (b) and to investigate the expected outcome variable result in the counterfactual hypothetical cases (c), in which the adopted farm households do not adopt and (d) the non-adoption farm household adopts (Table 2).

$\boldsymbol{E}(\boldsymbol{U_{1i}}|\text{Gi=1}) = X_{1i}\beta_1 + \boldsymbol{\sigma_{1v}}\,\lambda 1\text{i}$;

$\boldsymbol{E}(\boldsymbol{U_{2i}}|\text{Gi=0}) = X_{2i}\beta_2 + \boldsymbol{\sigma_{2v}}\,\lambda 2\text{i}$;

$\boldsymbol{E}(\boldsymbol{U_{2i}}|\text{Gi=1}) = X_{1i}\beta_2 + \boldsymbol{\sigma_{2v}}\,\lambda 1\text{i}$;

$\boldsymbol{E}(\boldsymbol{U_{1i}}|\text{Gi=0}) = X_{2i}\beta_1 + \boldsymbol{\sigma_{1v}}\,\lambda 2\text{i}$.

Cases (a) and (b) along the diagonal of Table 2 represent the actual expectations observed in the sample. Cases (c) and (d) represent the counterfactual expected outcome variable. In addition, the effect of the treatment "to adopt" on the treated (ATT), as the difference between (a) and (c), was calculated as:

$$\text{ATT} = \text{E}(\text{U}_{1\text{i}}|\text{G}_\text{i} = 1) - \text{E}(\text{U}_{2\text{i}}|\text{G}_\text{i} = 1) = \text{X}_{1\text{i}}(\beta_1 - \beta_2) + (\boldsymbol{\sigma_{1v}} - \boldsymbol{\sigma_{2v}})\lambda_{1\text{i}}$$

which represents the effect of the adoption of CSA innovations on the outcome variable result of the farm households that actually adopt a particular CSA technology (Heckman & Navarro-

Lozano, 2004). Similarly, the effect of the treatment on the untreated (TU) for the farm households that actually do not adopt was calculated as the difference between (d) and (b):

$$TU = E(U_{1i}|G_i = 0) - E(U_{2i}|G_i = 0) = X_{2i}(\beta 1 - \beta_2) + (\sigma_{1v} - \sigma_{2v})\lambda_2 i$$

The expected outcomes described in Equations (a)–(d) can also be used to calculate the effects of heterogeneity. The effect of base heterogeneity (Carter & Milon, 2005) for the group of farm households that decides to adopt as the difference between (a) and (d) can be calculated as:

$$H1 = E(U_{1i}|G_i = 1) - E(U_{1i}|G_i = 0) = (X_{1i} - X_{2i})\beta_{1i} + \sigma_{1v}\,(\lambda_{1i} - \lambda_{2i})$$

Similarly, for the group of farm households that decides not to adopt, the effect of base heterogeneity is the difference between (c) and (b):

$$H2 = E(U_{2i}|G_i = 1) - E(U_{2i}|G_i = 0) = (X_{1i} - X_{2i})\beta_{2i} + \sigma_{2v}\,(\lambda_{1i} - \lambda_{2i})$$

Finally, the transitional heterogeneity (TH) was investigated, that is, whether the effect of adopting the innovation is larger or smaller for farm households that actually adopt the innovation or for farm households that actually do not adopt; however, in the counterfactual case, if they do adopt, that is the difference between Equations (9) and (10) (i.e., TT and TU).

Table 11: Conditional expectations, treatment, and heterogeneity effects

	Adoption Decision		Treatment Effect
	To Adopt	Not to Adopt	
Adopters	$Y11 = \boldsymbol{E}(\boldsymbol{U_{1i}}\|Gi=1)$	$Y21 = \boldsymbol{E}(\boldsymbol{U_{2i}}\|Gi=1)$	ATT = Y11 − Y21
Non-adopters	$Y10 = \boldsymbol{E}(\boldsymbol{U_{1i}}\|Gi=0)$	$Y20 = \boldsymbol{E}(\boldsymbol{U_{2i}}\|Gi=0)$	ATU = Y10 − Y20
Heterogeneity effects	H1 = Y11 − Y10	H2 = Y21 − Y20	TH = ATT − ATU

Note: Y11 and Y20 represent observed expected CSA innovation adoption outcome variable; Y10 and Y21 represent counterfactual expected outcome variable Gi = 1 if farm households adopt CSA innovation; Gi = 0 if farm households do not adopt; Y1i: the outcome variable if farm households adopt; Y2i: outcome variable if farm households do not adopt; TT: the effect of adopting the innovation on the farm households that adopt the innovation; TU: the effect of adoption of the innovation on the untreated; H1: the effect of base heterogeneity for farm

households that adopt the innovation; H2: the effect of base heterogeneity for farm households that do not adopt the innovation; TH = (H1 – H2, i.e., transitional heterogeneity.

4.3. Results and discussion

4.3.1. Livelihood Vulnerability and Adoption of CSA Innovations

The livelihood vulnerability index (LVI) provides information on the components of livelihood vulnerability. These components include natural disaster and climate change exposure, ecosystem and agriculture sensitivity, wealth, technology, infrastructure use, knowledge, and social networks. On the other hand, the IPCC-LVI identifies which of the exposure, adaptive capacity, and sensitivity factors has a significant impact on agricultural vulnerability to climate change.

The mean comparison of adopters and non-adopters of CSA innovations using the major components of exposure, sensitivity, and adaptive capacity is presented in Appendix A Table A1. Accordingly, adopters of improved varieties have a significantly lower natural disaster and climate change index and a higher ecosystem index but a lower agriculture index than non-adopters. Hence, adopters of improved varieties have a lower climate change exposure index than non-adopters due to their adoption of high-yielding and drought-resistant varieties (Shiferaw et al., 2014b; Thierfelder et al., 2016). In terms of adaptive capacity, adopters of improved varieties have significantly higher wealth and technology indices while having a lower knowledge skill index than non-adopters. Hence, adopters of improved varieties have a higher adaptive capacity index than non-adopters because the adoption of improved maize varieties increases the adoption of mineral fertilizers coupled with increased extension services (Abate, 2015a; Kindie, 2017). Thus, adopters of improved varieties have a lower climate change exposure index as well as a higher adaptive capacity index than non-adopters. Consequently, their IPCC-LVI is closer to zero (0.09), which is significantly lower than that of non-adopters (0.12) ($p < 0.01$), which shows that adopters are significantly less vulnerable to climate change than non-adopters. Hence, the adoption of improved varieties significantly enhances adaptation to climate change, which concurs with studies (Shiferaw, 2014b; Teklewold, 2017, 2019), which reported that improved varieties enhance climate resilience and food security through the adoption of high-yield, improved wheat varieties and drought-resistant maize varieties among smallholder farmers.

Adopters of crop residue management have a higher climate change exposure index than non-adopters. In terms of the sensitivity of their livelihood, adopters of crop residue management have a lower ecosystem and agriculture index than non-adopters, which results in them having a lower sensitivity index (0.36) than non-adopters (0.38) ($p < 0.01$). In terms of adaptive capacity, adopters have a significantly lower wealth index and a lower social network index than non-adopters ($p < 0.05$). Yet, adopters of crop residue management have a higher adaptive capacity index (0.35) than non-adopters (0.33), but there is no difference in the IPCC-LVI among adopters and non-adopters.

Crop residue management on farm plots might be considered essential in promoting the physical, chemical, and biological aspects of soil health in smallholder agriculture systems due to the dearth of substitute organic amendments. However, smallholder farmers must make trade-offs when managing crop residues because of several alternative uses such as livestock feed and fuel sources (Jaleta et al., 2015; Turmel et al., 2015), which is the case in the study area. One reason for the trade-off effect of crop residue management is the lack of crop residue for farm management (Tittonell et al., 2015). Furthermore, recent research has indicated that the quality of tef crop residue is the least desired benefit by farmers (Mihretie, 2022). Thus, conclusions about the effect of crop residue management in reducing livelihood vulnerability to climate change in particular and enhancing adaptation to climate change in general are inconclusive.

Adopters of crop rotation have a higher natural disaster and climate change exposure index than non-adopters. This shows that areas with a variable climate or environmental stress-response characteristics adopt crop rotation, which supports the finding of (Menale Kassie, 2013), who reported that it allows farmers to grow products that can be harvested at different times and in different climates, helping weed management and reducing pests and diseases infestations (Menale Kassie, 2013). In terms of adaptive capacity, the wealth index and knowledge index of adopters are significantly lower than non-adopters. However, the adaptive capacity index of adopters (0.35) is significantly higher than that of non-adopters (0.33), so technology, infrastructure, and social networks offset the deficits in the wealth and knowledge indices of adopters. However, the adaptive capacity index does not offset the natural disaster and climate change index. Hence, there is a significantly higher IPCC-LVI for adopters (0.12) than for non-adopters (0.10). Crop rotation makes farmers' livelihoods more vulnerable to climate change

because farmers in spatiotemporally climate-change-exposed agroecosystems prefer crop rotation, and their adaptive capacities in terms of technology adoption, wealth, knowledge, infrastructure, and social networks do not offset exposure to climate change.

Among several problems with land degradation, low organic matter content is the major one (Golabi, 2004). Compost adopters have a higher ecosystem sensitivity index, which shows that compost is an important organic fertilizer because of its nutrient content and diverse effects on soil fertility and crop productivity, while non-adopters have a lower agricultural sensitivity index. This suggests that the adoption of compost improves soil structure, resulting in greater resistance to erosion, improved water infiltration, and increased water holding capacity, which results in improved crop yield (Zerssa, 2021). Hence, adopters of compost have a significantly higher sensitivity index (0.38) than non-adopters (0.36) ($p < 0.01$) because of the higher ecosystem sensitivity of the agroecosystems. In terms of adaptive capacity, adopters of compost have significantly lower wealth and infrastructure indexes than non-adopters. However, the adaptive capacity index of adopters of compost (0.34) is significantly higher than non-adopters (0.32) ($p < 0.01$). Hence, there is a significantly lower IPCC-LVI for adopters (0.11) than for non-adopters (0.12) ($p < 0.01$). Thus, the adoption of compost significantly reduces livelihood vulnerability to climate change.

Farmers adopt row planting not only to reduce seed rates but also to allow more spacing between seedlings, to permit easy weeding, and to reduce competition between seedlings (Yirgalem Eshete et al., 2021), which increases productivity and reduces vulnerability to climate change. The study shows that adopters of row planting have a lower natural disaster and climate change exposure index than non-adopters. This suggests that adopters of row planting live in less climate-change-exposed agroecosystems than non-adopters. Adopters also have a higher ecosystem sensitivity index but a lower agricultural sensitivity index than non-adopters. This suggests that the higher ecosystem sensitivity of adopters of row planting is offset by good crop yield. However, due to the higher ecosystem sensitivity of the agroecosystem, adopters of row planting have a significantly higher sensitivity index (0.38) to climate change than non-adopters (0.34) ($p < 0.01$). In terms of adaptive capacity, though adopters of row planting have significantly lower wealth and knowledge than non-adopters, the overall adaptive capacity index of adopters of row planting is higher (0.34) than that of non-adopters (0.32) ($p < 0.01$). The

IPCC-LVI result, on the other hand, reveals that the agricultural livelihood vulnerability to climate change of adopters of row planting (0.106) is significantly lower than that of non-adopters (0.123) ($p < 0.01$). Hence, the adoption of row planting has the significant impact of reducing agricultural livelihood vulnerability to climate change and enhances adaptation to climate change in smallholder agriculture systems. This result concurs with studies such as (Fentie & Beyene, 2019) which reported that row planting enhances food security and adaptation to climate change.

Soil and water conservation (SWC) techniques include soil bunds, stone bunds, bench terraces, vegetative barriers, and tied ridges (Wolka et al., 2018). SWC adopters have significantly higher natural disaster and climate change exposure indexes than non-adopters. This shows that adopters of SWC are farmers who live in the lowland Abay gorge (AESZ1), the midland sloping land (AESZ4), and the hilly and mountainous highland (AESZ5) agroecosystem zones. Hence, the climate change exposure index of adopters (0.67) of SWC is significantly higher than that of non-adopters (0.59) ($p < 0.01$). Although they have a marginally significantly higher ecosystem index (0.32) than non-adopters (0.31) ($p<0.1$), there is no significant sensitivity index difference between adopters and non-adopters of SWC. In terms of adaptive capacity, the innovation index of adopters of SWC is lower than that of non-adopters. Hence, the IPCC-LVI result shows that adopters of SWC have higher agricultural livelihood vulnerability to the climate change index (0.123) than non-adopters (0.097) ($p < 0.05$). Thus, adopters of SWC are more vulnerable to climate change than non-adopters. This result concurs with the finding that the effect of SWC on improving crop yield is dependent on rainfall characteristics and types of crop, slope, and soil. Moreover, the effect of SWC on crop yield is negatively correlated with rainfall for SWC techniques, including level Fanya juu, graded soil bunds, stone bunds, and trash lines, which are the main characteristics of the Choke mountain watershed (Kato et al., 2011; Wolka, 2018).

Agroforestry is a climate-smart agriculture system that diversifies the environmental and socioeconomic benefits of smallholder farmers sustainably, and agroforestry adopters are thought to be more resilient to the increased intensity of extreme weather events caused by climate change (Charles, 2013). In this study, agroforestry adopters have a higher (0.67) climate change exposure index than non-adopters (0.62) ($p < 0.05$). In terms of the sensitivity index, they have a higher ecosystem index (0.35) and a lower agricultural sensitivity index (0.30) than non-

adopters. However, they have a significantly higher sensitivity index (0.384) than non-adopters (0.365) ($p < 0.05$). In terms of adaptive capacity, they have higher technology adoption (0.83) and lower wealth (0.61) and knowledge (0.75) indexes than non-adopters. However, adopters of agroforestry have a significantly higher adaptive capacity (0.35) index than non-adopters (0.33) ($p < 0.01$). Unfortunately, the IPCC-LVI result shows that there is no significant difference between the livelihood vulnerability index of adopters and non-adopters of agroforestry (Appendix A Table A1). This is due to the marginal adoption of agroforestry as farmland border trees and homestead gardens, as well as wood lots, rather than as an agricultural system that supports their livelihood.

4.3.2. Food Security and Adoption of CSA Innovations

From the total sample households, less than one-third (33 percent) of the households were food secure (had an acceptable food consumption score), whereas more than two-thirds of the households were food insecure, with 46 and 21 percent of the households having a borderline and poor food consumption score, respectively (Figure 5).

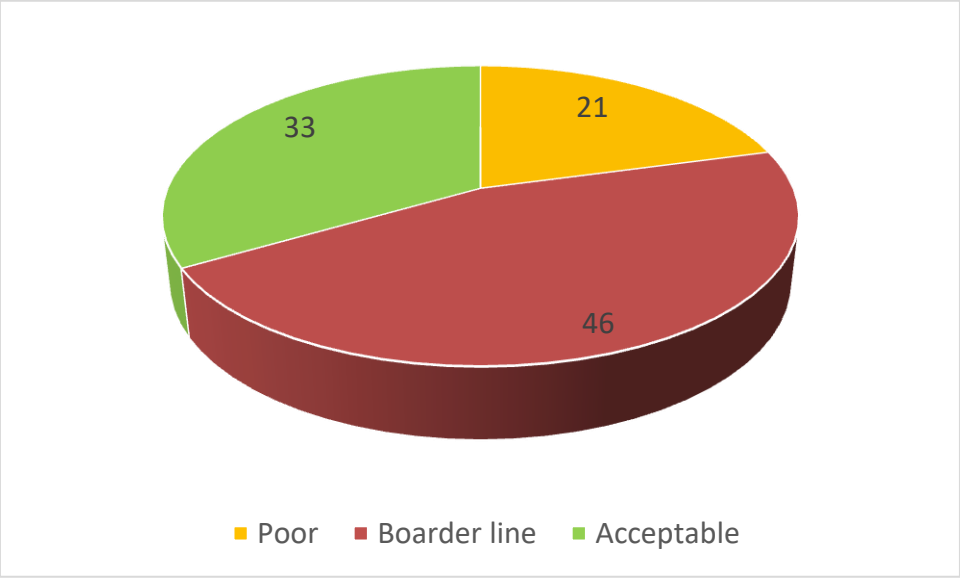

Figure 5: Household food security status

Smallholder farmers adopt CSA innovations for their different CSA benefits, either for food security or climate adaptation or both. Table 12 shows that crop residue management (positive) and SWC (negative) adoption have a significant relationship with the food security status of the household ($p < 0.01$). Adopters of SWC have more poor food consumption households than non-

adopters, indicating that more SWC adopter households are food insecure than non-adopter households, i.e., they lack daily staple and vegetable consumption, as well as consumption of oil and pulses four times a week, whereas adopters of crop residue management have more acceptable food consumption households than non-adopters, indicating that they represent food-secure households with daily staple and vegetable consumption, as well as consumption of oil and pulses at least four times a week.

Table 12: Relationship between food security and adoption of CSA innovation

CSA Innovation	Adoption Category	Food Security Status			Chi^2
		Poor	Borderline	Acceptable	
Improved variety	Adopter	17.8	43.4	38.8	2.6
	Non-adopter	22.1	46.9	31.0	
Crop residue management	Adopter	9.7	44.1	46.2	39.4 ***
	Non-adopter	30.3	47.4	22.4	
Crop rotation	Adopter	22.6	47.1	30.3	1.1
	Non-adopter	19.8	45.2	35.1	
Compost	Adopter	21.9	44.4	33.7	0.83
	Non-adopter	18.8	48.6	32.6	
Row planting	Adopter	18.9	46.3	34.8	3.14
	Non-adopter	26.7	44.6	28.7	
Soil and water conservation (SWC)	Adopter	30.8	42.5	26.6	27.9 ***
	Non-adopter	10.5	49.3	40.2	
Agroforestry	Adopters	17.2	49.4	33.3	0.97
	Non-adopters	21.7	44.9	33.3	

Significance level: *** $p < 0.01$.

In terms of HDDS, adopters of SWC have the lowest (3.83), while adopters of agroforestry have the highest HDDS (4.43). Adopters of crop rotation, compost, crop residue management, and row planting have a medium HDDS value, which shows that the dietary diversity of adopters of these CSA innovations still needs improvement. For the diversity and quality of food consumed

in the last seven days, the seven-day-recall household dietary diversity score (HDDS) was compared among the adopters and non-adopters of specific CSA innovations. Hence, adopters of improved varieties (4.25) have a higher HDDS than non-adopters (3.78); adopters of crop residue management (4.11) have a higher HDDS than non-adopters (3.76); adopters of compost (4.07) have a higher HDDS than non-adopters (3.60); adopters of row planting (4.06) have a higher HDDS than non-adopters (3.45), and adopters of agroforestry (4.43) have a higher HDDS than non-adopters (3.80). Thus, adopters of improved varieties, crop residue management, compost, row planting, and agroforestry consume better-diversified diets of food than non-adopters (Figure 6). Therefore, the adoption of these CSA innovations improves the food utilization component of the food security of smallholder households. However, the effect of the adoption of CSA innovation differs for different food security components. For instance, improved variety, crop residue management, compost, and row planting have significant positive effects on food availability and access to food security, while agroforestry has a significant positive effect on food utilization of the food security component. Moreover, SWC negatively affects the food availability and access component of food security.

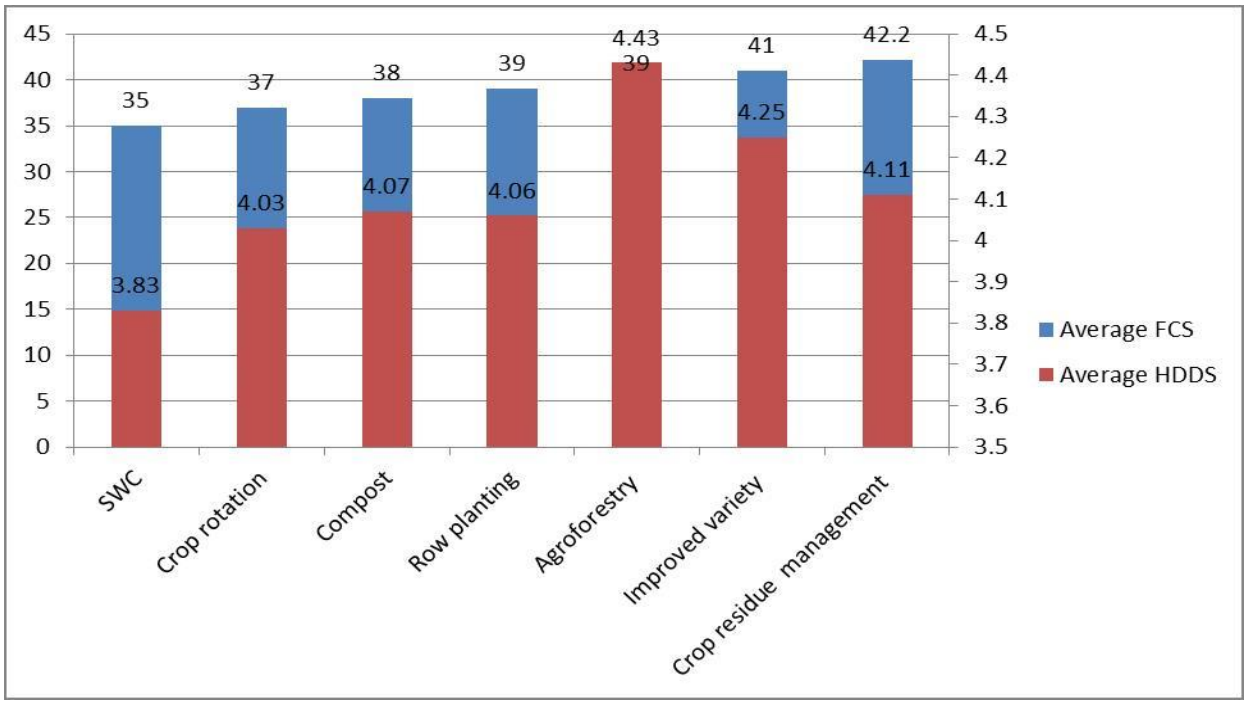

Figure 6: Food security of adopters of CSA innovations.

To reveal the effect of CSA adoption on the FCS, a simple mean comparison, along with an independent *t*-test, was conducted between the adopters and non-adopters of each CSA

innovation. Table 13 shows that both adopters of improved varieties (40.6) and non-adopters (37.1) have an acceptable food security status, with adopters having a significantly higher FCS value than non-adopters with a positive effect of food security ($p < 0.01$), which concurs with studies (Shiferaw, 2014a; Teklewold, Mekonnen, et al., 2019), which reported that improved varieties significantly enhance household food security through the adoption of high-yield, improved wheat varieties. Similarly, both adopters of row planting (38.9) and non-adopters (36.2) have an acceptable food security status with a positive effect on food security ($p < 0.05$), which concurs with the finding of (Amare & Beyene, 2019a), who reported that row planting enhances the food security of adopters. Adopters of crop residue management have acceptable food security (42.2) and a significantly higher FCS value than non-adopters, who have borderline food security (34.7) ($p < 0.01$). Likewise, adopters of SWC have borderline food security (35.0) and a significantly lower FCS value than non-adopters who have acceptable food security (41.0), with a negative effect on food security ($p < 0.01$). This result concurs with the finding that the effect of SWC on improving crop yield was dependent on rainfall characteristics, type of crop, slope, and soil. Moreover, the effect of SWC on crop yield was negatively correlated with rainfall for SWC techniques, including level Fanya juu, graded soil bunds, stone bunds, and trash lines, which are the main characteristics of the Choke mountain watershed (Kato, 2011; Wolka, 2018). In general, improved varieties, row planting, and crop residue management enhance food availability as well as the food access component of food security for smallholder households, whereas, SWC reduces the food availability as well as the food access component of food security for smallholder households.

Table 13: Comparison of food consumption score (FCS)

CSA Innovations	Food Consumption Score (FCS)			Household Dietary Diversity Score (HDDS)		
	Adopter	Non-Adopter	*t* Value	Adopter	Non-Adopter	*t* Value
Improved varieties	40.6(1.0)	37.1(0.6)	3.0 ***	4.25	3.78	0.47 ***
Crop residue management	42.2(0.7)	34.7(0.7)	7.3 ***	4.11	3.76	0.35 ***
Crop rotation	37.4(0.9)	38.6(0.7)	1.0	4.03	3.87	0.17
Compost	38.4(0.7)	37.8(0.9)	0.6	4.07	3.60	0.49 ***
Row planting	38.9(0.6)	36.2(1.1)	2.1 **	4.06	3.45	0.58 ***
SWC	35.4(0.8)	41.0(0.7)	−5.3 ***	3.83	4.01	0.18
Agroforestry	38.9(1.1)	38.0(0.6)	0.7	4.43	3.80	0.63 ***

Standard errors in parentheses: * $p < 0.05$, *** $p < 0.01$.

4.3.3. GHG Emissions and Adoption of CSA Innovations

The descriptive statistics were calculated for the GHG sink as well as the GHG source among CSA innovations. In the analysis, the five GHG influxes were calculated separately and summarized. These GHG influxes were afforestation; annual agriculture; perennial agriculture; livestock; input and investment. Hence, the GHG influxes were measured using land use/land cover change proxy measures such as the planting of trees such as *Eucalyptus globulus*, the annual crop land system, which includes the cropping system, improved agronomic practices, improved nutrient management, no-till and residue retention, water management, manure application, yield per hectare, the number of livestock, the types of livestock, and the quantity of livestock products, liming, and fertilizer (UREA and UPS), and energy consumption, i.e., consumption of wood fuel. These variables were used in the analysis and describe the GHG emissions from each CSA innovation intervention area that was measured using farm size (in

ha), crop yield (qt/ha), the absolute number and types of livestock, number of livestock products (milk and meat in tons), amount of lime use (in tons), and amount of fire wood used (in tons/year) (Appendix C Table A2).

In terms of afforestation (wood lot), adopters of compost afforest the largest area (29 ha) with Eucalyptus wood lot, while adopters of agroforestry afforest the smallest area (12 ha). This is because farmers allocate their land for home gardens, and there is no extra area for wood lots available. The productivity of each crop shows that adopters of row planting have the highest yield for tef (47.8 qt/ha), maize (44.5 qt/ha), wheat (47.7 qt/ha), potato (18.8 qt/ha), faba bean (9.1 qt/ha), and barley (9.3 qt/ha), while adopters of agroforestry have the lowest productivity for tef (13.6 qt/ha), maize (14.6 qt/ha), wheat (16.5 qt/ha), potato (6.1 qt/ha), faba bean (2.6 qt/ha), and barley (2.9 qt/ha). Livestock holding shows adopters of row planting have the highest number of livestock and types among CSA innovation adopters. In terms of farm output (milk and meat), adopters of row planting (59 tons) have the highest output, while adopters of agroforestry have the lowest farm output. This is due to the marginal adoption of agroforestry as farmland border trees and homestead gardens, as well as wood lots, rather than as an agricultural system that supports their livelihood.

Input and investment include the use of chemical fertilizer. Adopters of row planting have the highest input use among CSA innovations. Energy consumption shows adopters of row panting have the highest tonnage of firewood used in a year. Annual agriculture and afforestation or wood lots are the two important sinks of GHG emissions, while livestock and input and investment are the two consistent sources of GHG emissions in the smallholder farming system. The C sequestration and GHG emission potential of each CSA innovation, however, differ, along with the GHG influxes. In terms of CSA innovations, compost (−10.36 MtCO2e) and row planting (−8.87 MtCO2e) have the highest, while crop residue management (−2.147 MtCO2e) has the least potential to sequester carbon dioxide equivalent GHG emissions (Figure 7).

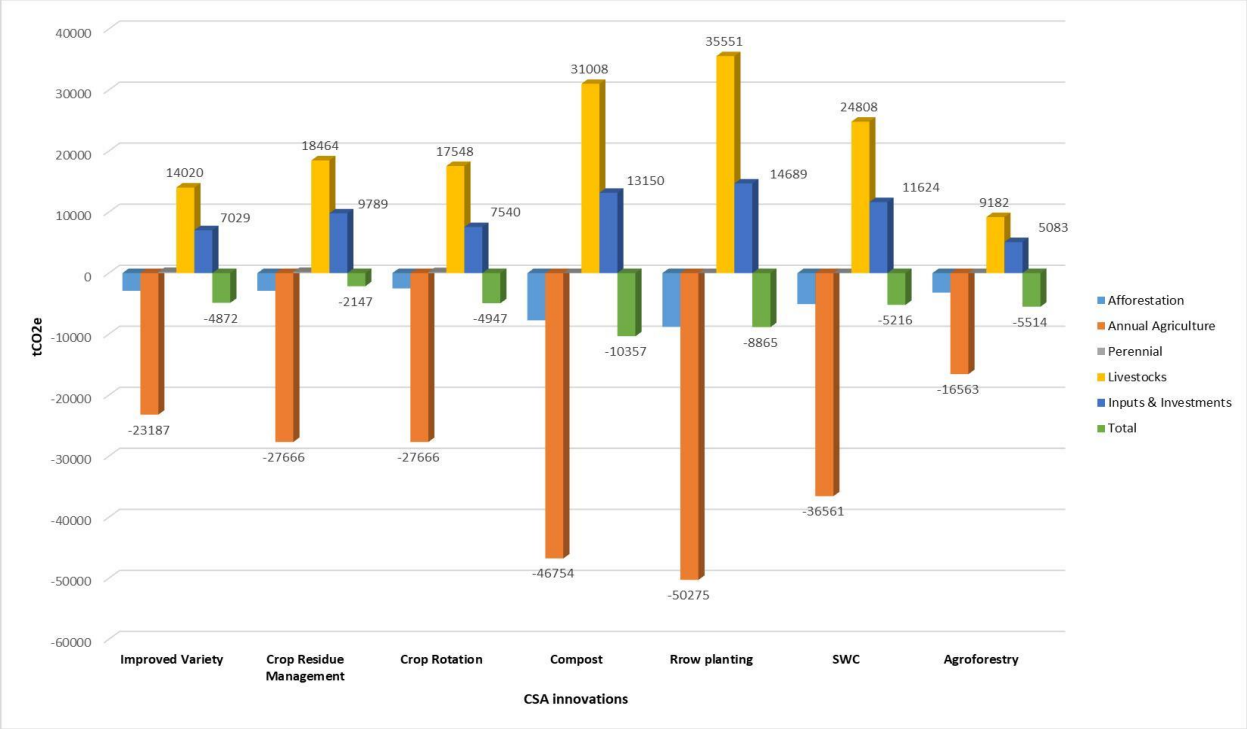

Figure 7: Gross influxes of GHG and adoption of CSA innovations.

Whole-farm GHG balances were disaggregated into farm compartments (Figure 8). In terms of biomass, all CSA innovations are sinks, and they have similar GHG sink potential. Soil has the highest GHG sink potential, with the highest sink potential recorded for compost and row planting adopters. The other source of GHG is enteric fermentation (livestock), which mainly emits CH4; in this regard, row planting and SWC adopters are the major emitters of GHG from enteric fermentation because they have a high density of livestock and have the largest enteric fermentation emissions with mean values of 2.4 tCO_2 eq ha^{-1} yr^{-1}, while adopters of crop residue management have the lowest enteric fermentation emission (1.8 t CO_2 eq ha^{-1} yr^{-1}). Carbon (CO_2) and nitrous oxide (N_2O) emissions from inorganic fertilizer (UREA and NPS) application accounts show that adopters of improved variety, row planting, SWC, and agroforestry are the biggest sources of GHG emission in terms of input use.

C sequestration in soils and biomass growth, when combined, offsets 5 to 52 percent of farm emissions. Woody biomass (above- and belowground) accounts for 5.1 percent of C removals among farm components affecting C sequestration. Farmers who use row planting and compost have the highest tree density and the highest C fluxes in above- and belowground biomass, with

0.89 t CO_2 eq ha^{-1} yr^{-1}. The remaining 64–94% of total farm GHG removals (5.7 t CO_2 eq ha^{-1} yr^{-1}) are accounted for by soil C sequestration. Compost users who apply the most manure to their soils experience soil C sequestration rates greater than 2.7 t CO_2 eq ha^{-1} yr^{-1}. Among cropping systems, wheat–maize registers the highest rates of C sequestration (25% of soil removals), followed by tef–wheat (22%) and potato–barley (20%).

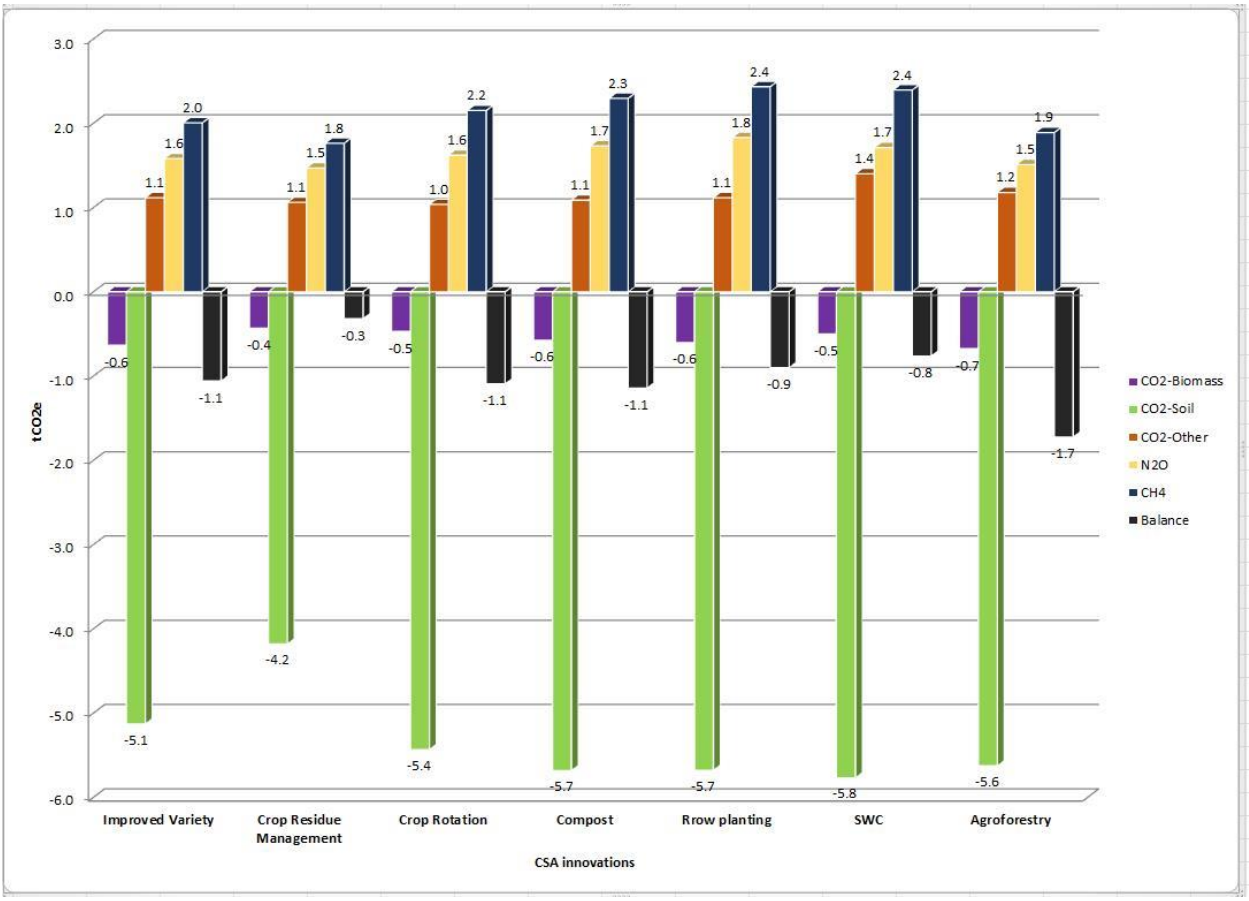

Figure 8: Comparison of GHG emission sources and CSA innovations.

Total emissions per year and intensity per output were calculated for farm-level GHG emissions. These two measurements show a difference in the levels of GHG emissions of CSA innovations for adopters. Hence, adopters of compost and SWC have lower farm GHG emissions per year than non-adopters. Similarly, crop residue management and compost adopters have a lower intensity of GHG emissions (net GHG emissions per yield) than non-adopters. Compost adopters have both lower gross emissions and net GHG emissions per yield than non-adopters. As a result, crop residue management, compost, and SWC are carbon sinks, and these CSA innovations can increase farm-level carbon sequestration capacity (Table 14).

Table 14: Comparison of GHG emissions among CSA innovations

CSA Innovations	GHG Emission (per ha per year)			Net GHG Emission (per ha per year per yield)		
	Adopter	**Non-Adopter**	***t* Value**	**Adopter**	**Non-Adopter**	***t* Value**
Improved varieties	3.35(0.3)	3.56(0.2)	−0.5	2.2(0.2)	2.4(0.3)	−0.8
Crop residue management	3.21(0.3)	3.75(0.2)	−1.44	1.9(0.2)	2.7(0.4)	−1.7 *
Crop rotation	3.12(0.3)	3.7(0.2)	−1.5	2.0(0.3)	2.5(0.3)	−1.0
Compost	3.0(0.2)	4.41(0.3)	−3.5 ***	1.8(0.2)	3.2(0.5)	−2.9 ***
Row planting	3.4(0.2)	3.81(0.4)	0.9	2.2(0.3)	2.7(0.5)	−0.9
SWC	3.1(0.3)	3.88(0.2)	−2.0 **	2.0(0.3)	2.6(0.4)	−1.5
Agroforestry	3.4(0.5)	3.5(0.2)	0.3	2.4(0.3)	2.3(0.3)	0.2

Standard errors in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

4.3.4. Impacts of Climate-Smart Agriculture Innovations: ESR Estimation Results

Research on impact evaluation usually faces two main challenges: establishment of a viable counterfactual, attribution effect, and addressing long, unpredictable lag times (World Food Programme, 2008). The sample mean comparison shows the impact of CSA innovation on the three CSA pillars. However, this naive comparison drives misleading conclusions because the approach does not consider that the difference in the outcome may be caused by observable as well as unobservable characteristics. Hence, the ESR model was used to prove that, indeed, the adopters and non-adopters of specific CSA innovation have different outcome values, taking into consideration the unobservable characteristics that may correlate.

The focus of this section is on the impact of CSA innovations on the outcome variables of livelihood vulnerability, food security, and farm GHG emissions. Hence, Column A of Table 15 presents the true average adoption effects of CSA innovation on livelihood vulnerability, food security, and GHG emission under actual adoption conditions. Column B shows the counterfactual values of livelihood vulnerability, food security, and GHG emission. Column C presents the effect of CSA innovation on livelihood vulnerability, food security, and GHG emissions, computed as the difference between Columns A and B.

Table 15 shows that the adoption of improved varieties has lower livelihood vulnerability and GHG emission, with a higher food security status than actual as well as counterfactual non-adopters. Hence, the adoption of improved varieties significantly reduces agricultural livelihood vulnerability to climate change, enhances food security, and reduces GHG emissions. This finding concurs with (Abate, 2015a; Khatri-Chhetri et al., 2016; Makate, 2019b; Ng'ombe et al., 2017), who reported that improved varieties not only enhance productivity but also increase income and may effectively reduce food insecurity and poverty in the medium-to-long term (Mango et al., 2017). Moreover, the finding concurs with (Mutenje, 2019), which reported that adoption of improved variety, inter alia, reduces livelihood vulnerability and manages risk more effectively for smallholder farmers so that they can adapt to climate change and extreme weather events such as drought shock.

Adoption of crop residue management has higher livelihood vulnerability and higher GHG emissions, i.e., maladaptation, with higher food security than actual and counterfactual non-adopters. Adoption of crop residue management improves food security, concurrent with literature in Mozambique, which showed that crop residue management with associated practices has significantly improved food security in Zimbabwe and Malawi (Mango, 2017) but increased the agricultural livelihood vulnerability to climate change as well as, against all odds, increased the GHG emission from smallholder farms. This finding is in line with (Bazzana et al., 2021), who further reported that the adoption of crop residue management among other innovations not only enhances food security but also is an effective strategy for improving rural populations' well-being. However, the maladaptation of crop residue management comes from the competition of crop residue for livestock feed and fuel sources rather than soil fertility management.

Adoption of crop rotation has lower agricultural vulnerability to climate change, lower food security, i.e., maladaptation, and lower GHG emission than actual as well as counterfactual non-adopters. Hence, the adoption of crop rotation reduces the agricultural livelihood vulnerability to climate change and farm GHG emissions while reducing the food security of smallholder agriculture households, which is maladaptation. Previous findings (Ng'ombe, 2017) support this result, reporting that the adoption of crop rotation increases crop revenue per hectare. Moreover, the 31-year data on crop rotation data (Gaudin et al., 2015) supported this finding and reported

that crop rotation, along with minimum tillage, increases yield in hot and dry years, which is a highly likely scenario under future changes. Furthermore, this finding is also consistent with (Brouder & Gomez-Macpherson, 2014), which reported that crop rotation not only reduces the risk of pests and disease, which is the main cause of crop failure and reduced yield in Africa due to projected climate change (Niang, 2014a), but also suppresses weed infestation (Mashingaidze & Twomlow, 2017). In addition, crop rotation and consumption of pulses are strongly directly correlated (Nyanga, 2012). Furthermore, this finding supports the finding of (Ngwira et al., 2012), which reported that crop rotations increase soil organic carbon in smallholder agriculture.

Adoption of compost has lower agricultural vulnerability to climate change and GHG emissions but higher food security than actual as well as counterfactual non-adopters. Hence, the adoption of compost reduces the agricultural livelihood vulnerability to climate change and farm GHG emissions while enhancing the food security of smallholder agriculture households. This finding concurs with several pieces of literature which reported that manure, organic fertilizer, or compost enhances food security and reduces GHG emissions (Al-Sari et al., 2018; Akalu Teshome et al., 2014; Warnars & Hivos, 2014).

Adoption of row planting has lower agricultural vulnerability to climate change and GHG emissions but a higher FCS than non-adoption. Hence, the adoption of row planting enhances food security while reducing the agricultural livelihood vulnerability to climate change and GHG emissions from smallholder farms. Literature that examined the impact of row planting on labor productivity showed that row planting significantly increases the total labor requirement and allocation, resulting in a substantial drop in labor productivity (Vandercasteelen et al., 2018). Row planting increases not only tef yield but also tef income, as well as per capita food consumption (Ayal et al., 2018; Fentie, 2019; Negash, 2017; Tamirat, 2020).

Adoption of soil and water conservation measures such as soil/stone bunds has lower livelihood vulnerability but higher food security and GHG emission, i.e., maladaptation, than non-adoption. The adoption of SWC enhances food security and reduces agricultural livelihood vulnerability to climate change but increased smallholder farm GHG emissions. This finding backs up previous research that evaluated the impact of SWC practices in Ethiopia and found that SWC practices are effective in reducing surface run-off and nutrient loss, as well as controlling soil erosion (Akalu, 2013; Desalew & Aklilu, 2017; Simeneh, 2016). However, studies have shown that the

impacts of SWC practices on crop yield and the economic viability of SWC practices are inconsistent, and results are site specific (Adimassu et al., 2017). Additionally, soil and stone bunds reduce crop yield for the first few years (Adimassu et al., 2014; Menale Kassie et al., 2011) while increasing crop yield (Vancampenhout et al., 2006). Soil and water conservation improves crop productivity and crop yields on terraced fields for tef, barley, and maize (Adgo et al., 2013). Although the literature on the impact of SWC on food security is limited, a study in Eastern Ethiopia discovered that adopting soil and water conservation not only positively impacts per capita food consumption expenditure and net crop value, but also significantly reduces the likelihood of farmers being food insecure (Sileshi et al., 2019).

Adoption of agroforestry has a lower LVI and GHG emission but a higher FCS than actual as well as counterfactual non-adopters. Hence, the adoption of agroforestry reduces agricultural livelihood vulnerability to climate change and enhances food security while reducing smallholder farm GHG emissions.

Hence, a smallholder agriculture system can enhance food security, adapt to climate change, or build resilience and reduce GHG emissions by implementing a variety of CSA innovations such as sustainable land management (SLM), intercropping, crop rotation, soil and water conservation, modern input use, and agroforestry on farm plots (Asmare, 2019; Deichert, 2017; Hailemariam, 2019; Jirata, 2016; Makate, 2019; Paulos, 2017; Teklewold, 2019; Tsige, 2020)

Table 15: Average expected LVI, FCS, and GHG emission with adoption of CSA innovations

CSA Innovations	Livelihood Vulnerability Index (LVI)			Food Consumption Score (FCS)			Farm GHG Emission		
	Actual LVI if Farm Households Do Adopt (A)	Counterfactual LVI if Farm Households Do Not Adopt (B)	Adoption Effects on LVI (C)	Actual FCS if Farm Households Do Adopt (A)	Counterfactual FCS if Farm Households Do Not Adopt (B)	Adoption Effects on FCS (C)	Actual GHG if Farm Households Do Adopt (A)	Counterfactual GHG if Farm Households Do Not Adopt (B)	Adoption Effects on GHG (C)
Improved variety	0.65(0.003)	0.69(0.002)	ATT = −0.04 (0.004) ***	40.2(0.51)	28.2(0.5)	ATT = 12.0 (0.7) ***	3.65(0.15)	5.6(0.21)	ATT = −193 (0.25) ***
Crop residue management	0.67(0.002)	0.63(0.002)	ATT = 0.034 (0.004) ***	42.16(0.35)	15.31(0.44)	ATT = 26.85 (0.57) ***	3.2(0.19)	−1.8(0.19)	ATT = 4.95 (0.27) ***
Crop rotation	0.68(0.003)	0.72(0.003)	ATT = −0.043 (0.004) ***	37.3(0.42)	38.75(0.38)	ATT = −1.41 (0.56) **	3.28(0.15)	4.7(0.21)	ATT = −1.4 (0.26) ***
Compost	0.67(0.002)	0.71(0.002)	ATT = −0.05 (0.003) ***	38.4(0.3)	23.7(0.42)	ATT = 14.75 (0.50) ***	3.11(0.14)	5.8(0.15)	ATT = −2.68 (0.21) ***
Row planting	0.67(0.002)	0.72(0.20)	ATT = −0.06 (0.003) ***	38.9(0.24)	37.1(0.31)	ATT = 1.77 (0.39) ***	3.51(0.11)	4.57(0.15)	ATT = −1.05 (0.19) ***
SWC	0.68(0.002)	0.72(0.002)	ATT = −0.05 (0.003) ***	35.5(0.4)	33.75(0.26)	ATT = 1.69 (0.52) ***	3.05(0.22)	−2.14(0.13)	ATT = 5.2 (0.18) ***
Agroforestry	0.67(0.005)	0.73(0.003)	ATT = −0.06 (0.005) ***	38.75(0.67)	23.6(0.49)	ATT = 15.11 (0.83) ***	3.6(0.17)	7.5(0.13)	ATT = −3.93 (0.36) ***

Standard errors in parentheses** $p < 0.05$ and *** $p < 0.01$.

4.4. Conclusions

Climate-smart agriculture (CSA) innovations are essential for enhancing household food security, reducing vulnerability, and reducing farm-level GHG emissions. However, the empirical foundation for understanding how farm households achieve these three major goals of the current climate and development agenda, or the "triple benefit", is far from being established. In this paper, the effects of CSA innovations on the triple benefit were examined. An endogenous switching regression model was used to explore a survey of 424 farm households and 1818 farm plots in the Blue Nile highlands of Ethiopia. Results showed that the adoption of improved variety, compost, row planting, and agroforestry simultaneously delivers the three CSA benefits of enhanced household food security, reduced vulnerability, and reduced farm-level GHG emissions. Similarly, the adoption of crop rotation reduces livelihood vulnerability and farm GHG emissions simultaneously. Soil and water conservation measures, or adoption of stone/soil bunds on farm plots, meet the goal of climate change adaptation as well as food security, as they enhance food security and reduce livelihood vulnerability simultaneously, whereas, the adoption of crop residue management meets only the food security goals of CSA. Some of the CSA innovations, improved variety, compost, row planting, and agroforestry, provide farmers with the benefit of enhanced food security and climate change adaptation and reduced GHG emission from farm plots, while other CSA innovations, crop rotation, and SWC, also deliver the two CSA pillars as they provide farmers with either enhanced food security and/or reduced livelihood vulnerability and/or reduced GHG emissions. Unfortunately, adopting crop residue management, one of the recommended CSA practices in Ethiopia, does not deliver at least two of the CSA pillars, which means it is not a CSA innovation. Farmers should be encouraged to adopt improved variety, crop rotation, compost, row planting, soil and water conservation, and agroforestry as the best portfolio of CSA innovation for highland smallholder agriculture systems as these innovations reduce the trade-off and increase synergy among CSA pillars and maintain agricultural sustainability in the face of climate change. Policies that encourage simultaneous adoption of the CSA portfolio should be devised as incentives. Competition surrounding crop residue utilization for soil fertility management and as a livestock feed source should be resolved by encouraging farmers to plant more forage trees on SWC structures, reducing the burden of crop residue as a livestock feed source.

Chapter Five : Effect Of Climate-Smart Agriculture Innovations on Climate Resilience among Smallholder Farmers in Ethiopia

Abyiot Teklu [1], Belay Simane[2] , Mintewab Bezabih[3]

Abyiot Teklu, abyiot.teklu@aau.edu.et, Addis Ababa University, College of Development studies, Ethiopia

Belay Simane, belay.simane@aau.edu.et, Addis Ababa University, College of Development studies, Ethiopia

Mintewab Bezabih, mintewabayele@gmail.com, Ethiopian Policy Studies Institute, Ethiopia.

Abstract

Smallholder farmers' capacities need to be strengthened to enable them to better withstand the upcoming impacts of climate change that not only include the responsive capacity but also consider innovation, learning, and anticipation to be prepared for the projected impacts of a changing climate on the agriculture system. The objective of this paper is to examine the impact of climate-smart agriculture (CSA) innovations on building climate resilience capacity in smallholder agriculture systems. A cross-sectional household survey was conducted among a multi-stage sample of 424 smallholder farmers selected from five agro-ecosystems of the Upper Blue Nile Highlands in Ethiopia. The study used an endogenous switching regression (ESR) model to examine the impact of CSA innovations on building climate resilience capacity among smallholder farmers. Different CSA innovations have different effect on climate resilience capacity of households. Except SWC adopters, all CSA innovations significantly increased the climate resilience capacity of households. However, improved variety, crop residue management, and SWC have profound effect on the non-adopters than adopters had if non-adopters would have adopted these CSA innovations. Strong absorptive, adaptive, and transformative capacity through strong disaster and early warning systems, climate-resilient infrastructure, a strong public agricultural extension system, a strong informal safety net, and social networks build a climate-resilient agriculture system of adopters of CSA innovations farmers. The adoption of CSA innovations has built strong climate-resilient livelihoods among smallholder farmers. However, adoption of crop rotation, row planting, and agroforestry has a profound effect on the the adopters than non-adopters while improved variety, crop residue management, compost, and soil and water conservation (SWC) adoption has a profound effect on the counter-factual adopters. Thus, scaling up CSA innovations expands the benefit of CSA innovation on building the climate resilience capacities of households. Thus, strong risk management, disaster mitigation, early warning systems, adaptive strategies, information and training, informal safety net, social network, and

infrastructure use may build climate resilience capacity of smallholder farmers by facilitating adoption of CSA innovation. Therefore, policies that strengthen good governance, social cohesion, disaster communication, early warning systems, input supply of drought resistance varieties, climate-smart extension service, and climate-resilient infrastructure are necessary.

Key word: climate-smart agriculture, climate resilience, absorptive capacity, adaptive capacity, transformative capacity, innovations, Ethiopia

5.1. Introduction

Climate change significantly impact smallholder farmers' livelihoods because of heavy or erratic rainfall, temperature rise, sudden hailstorms, repeated droughts, and floods to worsen in the future (IPCC, 2019). Even though Africa has contributed the least to greenhouse gas emissions, key development sectors have suffered widespread loss and damage due to anthropogenic climate change (Ayugi et al., 2022). Climate projections show that the drought changes over East Africa follow a "dry get drier and wet gets wetter" trend (Haile et al., 2020). Hence, climate change is straining Africa's agriculture, forestry, fisheries, and aquaculture (Trisos, 2022).

Smallholder farmers are the primary target of the adverse effects of climate change, as they lose food, water, and livelihood security (Harvey et al., 2018). Smallholder farmers' capacities need to be strengthened to withstand the climate change-related stresses, shocks, and impacts, not only including the responsive capacity to already known threats but also should consider innovation, learning, and anticipation for the projected impacts of a changing climate on the agriculture system (Béné & Doyen, 2018; Linkov, 2014).

Climate resilience is the ability of agricultural systems to absorb and recover from climatic shocks and stresses while positively adapting and transforming their structures and means of living in the face of long-term change and uncertainty (Béné, 2020; Béné et al., 2014, 2016; Béné, 2018). It is a combination of an agricultural system's absorptive, adaptive, and transformative capacities, which can be delimited based on the responses to the level of climatic shocks and stresses (Béné, 2014). Hence, in this study, we defined climate resilience as a smallholder agricultural system's capacity to persist, incrementally change or transform in the face of persistent climate change stress and

shocks (Béné, 2014). Hence, climate resilience building involves intervention that promotes absorptive, adaptive, and transformative capacities.

Absorptive capacity is similar to coping capacity, which refers to the ability of a social-ecological system, such as a smallholder agriculture system, to manage and recover from adverse climate change conditions using available skills and resources. Food security of the household will be primarily affected by the climate risk shocks and stresses such as drought so the absorptive capacity of the household towards food insecurity should be strengthened (Bizikova et al., 2017). Thus, absorptive capacity of the household should include all available resources in the socio-ecological system (Peng et al., 2018). However, adaptive capacity won't be an option once the household has used all of its absorptive capacity (Béné et al., 2012). Adaptive capacity includes the various adjustments and strategies that households undergo in order to maintain the sustainability of their livelihood (Béné, 2012) . It is the ability to design and implement effective adaptation strategies or react to evolving hazards and stresses to reduce the likelihood of their occurrence and the magnitude of harmful outcomes resulting from climate-related hazards (Berger et al., 2014). However, as the intensity of stress and shock increases beyond the adaptive capacity, households will need to resort to applying transformative capacity in order to survive. Transformative capacity deals with the ability of a social system to adapt to, anticipate, and absorb climate extremes and disasters by adopting transforming policies that change the institutional rules of the game(Béné, 2014).

Climate-resilient agriculture safeguards food security by enhancing smallholder farmers' productivity and transforms the current system to withstand the current and future climate change effects on smallholder farmers' livelihoods (Gugissa, 2022). Climate-resilient households are thus more active in anticipating, resisting, coping with, and recovering from the shock impacts of climate change and maintaining or improving their living standards(Christopher & Mark, 2014). Hence, building a climate-resilient agriculture system is a priority that policymakers should not overlook when facing the challenge of future and current climate change risks (Christopher, 2014; Djalante et al., 2013).

Several climate-smart agriculture (CSA) innovations can deliver climate resilience outcome (Dougill et al., 2021; Gori Maia et al., 2022). For instance adoption of drought resistance, early maturing, and high-yield improved varieties (Shikuku et al., 2019), crop residue management, crop

rotation, compost, agroforestry, as well as soil and water conservation structures may lessen the effect of drought through water management (Alfani et al., 2021; Garg et al., 2020; Kumar et al., 2020; Webb et al., 2017).

In Ethiopia, the impact of climate change is manifested mainly through drought and food insecurity. Since the 1970s, meteorological droughts and agriculture have resulted in chronic food insecurity(FDRE, 2019). Historical and more recent climate-related events such as the 2008/2009 and 2011 food security crises in the Horn of Africa as well as the 2015/2016 El Nino effect have highlighted the impact of droughts and floods on food production, access to markets, and income from agricultural activities(Bahta & Myeki, 2022; Kosmowski, 2018; Mare et al., 2018).

Ethiopian agriculture is characterized by rain-fed, subsistence farming, practised on too small a land size to be viable, with a low yield and exposed to climate change risk due to its reliance on timely and sufficient rainfall (Kassaye et al., 2022; Komarek, 2019). Overreliance on rain-fed smallholder agriculture, widespread poverty, and land degradation increase Ethiopia's vulnerability to climate change and variability(Assefa & Laerhoven, 2018). Hence, Ethiopia is one of the most vulnerable country to climate change and with the least capacity to respond (Hailemariam, 2019; Komarek, 2019; Teklewold, 2019).

The Choke mountain watershed is located in Ethiopia's Blue Nile Highlands and comprises six distinct agroecosystem zones(Simane, 2013). Agriculture is the main economic activity and source of livelihood. A wheat-maize-tef-dominated mixed crop-livestock production system characterizes the farming system. The Ethiopian ard (or maresha), an ancient plough, is used for tillage, leading to high rates of on-field erosion, particularly on steep slopes (Simane, 2016). Overgrazing and deforestation have also contributed to erosion, soil fertility decline, livestock feed shortages (open grazing), and fuel wood demands continue to exert significant pressure on the resource base (Abyiot, 2022). Land degradation-induced climate change risks pose significant challenges for Ethiopia's Blue Nile Highlands (Paulos, 2017). Consequently, low agricultural productivity, severe land degradation, and climate change and variability threatened the livelihood of the smallholder agriculture household (Simane, 2016).

Although several pieces of literature on climate resilience are found globally, their approach to conceptualizing and measuring climate resilience differ (Constas, 2013; Dixon, 2015; Gaillard, 2010; Linkov, 2014). Tambo (2016) used the climate resilience index to evaluate the climate

resilience of Ghanaian districts. Most empirical studies on resilience to climate change defined resilience as the other side of vulnerability (Hailemariam, 2017; Temesgen et al., 2011), sustainability to community based institutions (Simane, 2013), adaptive capacity (Kebede, 2020), and societal-transformative capacity (Lemlem et al., 2016; Lemlem & Darnhofer, 2015). Most of these literatures support "…the ability of a system to bounce back or return to equilibrium following disturbance…" Holling (1973). However, we need to transform our definition of resilience in the face of climate change to embraces the ability of a system not simply to bounce back but also to adapt and transform (Béné, 2012).

Recently, climate resilience as the absorptive, adaptive, and transformative capacity thinking has been gaining momentum (Asmamaw, 2019; Béné, 2015; Berhane, 2017). Some literature tried to assess building the climate resilience farming effect of push–pull technology (PPT) (Gugissa, 2022). Yet, there is a dearth of literature on the concept of absorptive, adaptive, and transformative capacity of climate resilience among smallholder farmers.

Hence, there is a pressing need to understand which CSA innovations have successfully built smallholder climate resilience capacity and how these capacities were built among smallholder agriculture households (Silici, 2021). Therefore, this study aims to investigate the effect of CSA innovations in building the climate resilience (absorptive, adaptive, and transformative) capacity of smallholder farmers in the Upper Blue Nile Highlands of Ethiopia.

This study adopted an integrated social-ecological understanding of resilience for the analytical framework of climate-resilient agriculture (Adger, 2005; Béné, 2020, 2016, 2018). Hence, according to the climate-resilient agriculture framework, adopting CSA innovations affects risk management, informal safety net, disaster mitigation and early warning system (DMEWS), adaptation strategies, wealth and income, food security, information and training, social networking, and infrastructure. These are sub-components of the major component of climate resilience capacity, such as the smallholder agriculture system's absorptive, adaptive, and transformative capacity. The absorptive, adaptive, and transformative capacities influence the climate resilience capacity of the smallholder agriculture household. Absorptive capacity also influences adaptive capacity as well as transformative capacity.

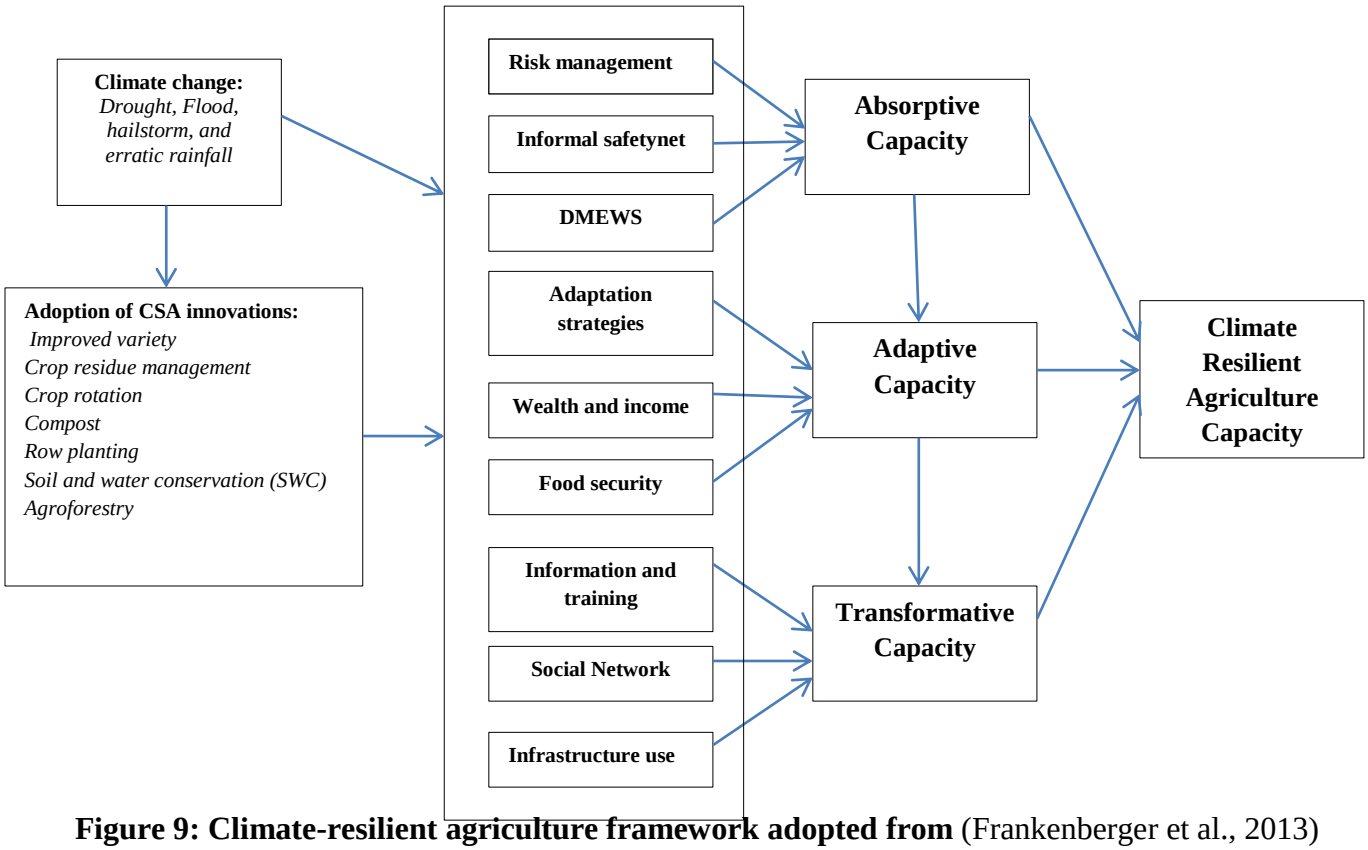

Figure 9: Climate-resilient agriculture framework adopted from (Frankenberger et al., 2013)

5.2. Research methodology

5.2.1. Measuring Climate Resilience

Resilience, a latent variable, is a dynamic multidimensional concept. In this study, the resilience tool proposed by FAO is adapted to measure farm households' resilience to climate change-induced shocks (FAO, 2013b). Adopting from FAO's analytical framework, climate resilience explains why one household more resilient to climate change while another household is not. This analytical framework explains the interaction between shocks and their effects on households, with resilience accounting for the difference in outcomes between two similar households exposed to the same shock.

The resilience framework tool consists of three major components and ten sub-components. The three major components include absorptive capacity (ABP), adaptive capacity (ADP), and transformative capacity (TRAN). Further, these three major components were sub-divided into the nine sub-components that include risk management (RM), social safetynet (SSN), disaster mitigation and early warning system (DMEWS), adaptation strategies (ADPS), wealth (W), food

security (FS), information and training (IT), social-network (SN), and use of infrastructure (INFRA). Each of the nine sub- components has a specific set of variables collected from households that can convey climate resilience capacities of smallholder farmers. Hence, climate resilience index was constructed based on these indicators as climate resilience is a function of these nine indicators that can be combined to give absorptive, adaptive and transformative capacities of smallholder farmers.

CRi_j = f (RM_j, SSN_j, $DMEWS_j$, $ADPS_j$, W_j, FS_j, IT_j, , SNj, $INFRA_i$) ……..…….... (1)

Where CRI_j is climate resilience capacity index of household j, and RM_j, SSN_j, $DMEWS_j$, $ADPS_j$, W_j, FS_j, IT_j, SN_j, $INFRA_i$ are risk management (RM), social safety net (SSN), disaster mitigation and early warning system (DMEWS), adaptation strategies(ADPS), wealth (W), food security (FS), information and training (IT), social-network (SN), and use of infrastructure (INFRA) sub-component value of household j. for j =1…, n. Also, ABP_j=f(RM_j, SSN_j, $DMEWS_j$), ADP_j=f($ADPS_j$, W_j, FS_j) , and TRN_j=f(ES_j, SN_j, $INFRA_i$). To estimate CRi_i, it is necessary to estimate separately RM_j, SSN_j, $DMEWS_j$, $ADPS_j$, W_j, FS_j, IT_j, SN_j, and $INFRA_i$ which are they latent variables9.

In this study, a two-stage procedure was used to estimate households' CRi. During the first stage, nine resilience blocks were estimated using principal component analysis (PCA) based on 42 indicators. In this study, PCA was used both for data reduction and identification of the dominant factors that explain household's resilience to climate change risks.

In order to obtain principal components, the study used Kaiser Criterion of extracting factors with eigenvalues greater than one. Thus, the heaviest loading of principal component expressed in terms of the variables as an index for each household that captured largest amount of information.

The resilience blocks include risk management (RM), social safetynet (SSN), disaster mitigation and early warning system (DMEWS), adaptation strategies(ADPS), wealth (W), food security (FS), extension services (ES), social-network (SN), and presence and use of infrastructure (INFRA). Based on the factor loading of each indicator, the resilience index of each individual household was computed using the PCA following the equation 2 as follows:

$$C_i = \sum_{k=1} f_{ki}\left(\frac{(x_{ki}-\bar{x})}{\delta_k}\right) \quad \text{.....(2)}$$

9 Variables that are not measured or cannot be directly observed in a given survey rather constructed from the set of indicators

Where f_{ki} is the component loading generated by PCA for the k^{th} variable of the i^{th} sub-component; $x_{ki}$is the observed value for the kth variable of the i^{th} sub-component ; $\bar{x}$ and δ_k are the mean and standard deviation respectively of the k^{th} variable of the i^{th} sub-component on overall the households, the value k varies according to the number of variables in the sub component.

In the second stage, the climate resilience capacity index is derived from a weighted average of the interacting components estimated in the first stage using the standardized value of the variables that created the factor loadings in the first stage. The CRi was then obtained from a weighted average of the ten sub-components using equation (3).

$$CRi = \frac{\sum_{i=1}^{11} w_i C_i}{\sum_{i=1}^{11} w_i} \quad \ldots\ldots\ldots\

Table 16: Climate resilience capacities indicators

Major Components	Sub components	Indicators	Literature
Absorptive capacity	**Risk management**	Decrease quantity of meal	(Tsegaye et al., 2018)
		Decrease diversity of meal	(Tsegaye, 2018)
		Borrow grain	(Melese et al., 2021)
		Seek NGO help	(Melese, 2021)
		Borrow cash	(Melese, 2021)
		Sales of livestock	(Melese, 2021)
		Labor work	(Melese, 2021)
	Informal safetynet	Social insurance	(Endris et al., 2020)
		Informal support	(Endris, 2020)
		Friend support	(Endris, 2020)
	Disaster mitigation and early warning system (DMEWS)	Social communication	(T. Bradley et al., 2016)
		Mobile phone	(T. Bradley, 2016)
		Soil fertility Parcel 1	(van Ginkel & Biradar, 2021)
		Soil fertility Parcel 2	(van Ginkel, 2021)
		Slope of Parcel 1	(Aditya et al., 2020; Uchimura et al., 2015)
		Slope of Parcel 2	(Aditya, 2020; Uchimura, 2015)
Adaptive capacity	**Adaptation strategies**	Late sowing of crop	(Ali et al., 2021; Ke Liu et al., 2022)
		Use of drought resistant variety	(Tofa et al., 2021)
		Use of crop residual for farm	(Adego et al., 2019)
		Use of water harvesting technologies	(Ndlovu et al., 2020)
	Wealth and Income	Durable Asset	(Alemu et al., 2017)
		Farm size	(Alemu, 2017)
		Livestock holding	(Alemu, 2017)
		Number of plots	(Alemu, 2017)
		Farm income	(Alemu, 2017)
	Food security	Household Dietary Diversity Score (HDDS)	(Shekuru et al., 2022)
		Food consumption score (FCS)	(Getaneh et al., 2022)
		Crop Diversity	(Adjimoti & Kwadzo, 2018)
	Information and training	Access to extension service	Wonde et al.(2022)
Transformative		Extension Service on IO	(Ketemaw et al., 2022)

capacity		Extension Service on CC	(Ketemaw, 2022)
		Extension service on productivity	(Ketemaw, 2022)
		FTC training	(Ketemaw, 2022)
	Social Network	Participation in watershed management	(Bekele et al., 2018)
		Membership in mahber	(Awoke, 2021)
		Participation in Debo/Wenfel	(Fitawek & Legesse, 2018)
	Infrastructure use	Access to health post	(Aynalem & Melesse, 2021)
		Access to market	(Usman & Callo-Concha, 2021)
		Access to FTC	(Yekini et al., 2019)
		Access to all weather road	(Wudad et al., 2021)
		Access to water and sanitation	(Ayele et al., 2020)
		Access to school	(Congdon Fors et al., 2019)

5.2.2. Data analysis

The data was subjected to descriptive analysis in order to obtain frequencies and cross-tabulations that showed the data's relationships. Mean, standard deviation, and percentage were utilized depending on the nature of the variable and the need for presentation. T-test and chi-square test were used to determine whether variations in the CSA innovation adoption on climate resilience were statistically significant. The study used the ESR model to estimate the effect of CSA innovations on climate resilience. The dependent variables for the ESR are adoption of CSA innovations such as improved variety, crop residue management, crop rotation, compost, row planting, SWC, and agroforestry (Abate et al., 2015b; Akalu, 2016; Hailemariam, 2017; Kindie, 2017; Mihretie, 2022; Shiferaw, 2014a; Teklewold, 2019). The independent variables were selected based on extensive literature review on socio demographic, economic, institutional, and environmental factors of climate resilience.

Endogenous switching regression (ESR

Endogenous switching regression (ESR) estimation model assumes that farmers that adopted the CSA innovations may have systematically different characteristics from the farmers that did not adopt, and they may have decided to adopt based on expected outcome they obtained from adopting it. Unobservable characteristics of farmers and their farm may affect both the adoption decision and its outcome resulting in inconsistent estimates. For example, if only the wealthy, informed, skilled or motivated farmers choose to adopt and the analysis fail to control for these

factors, then upward bias will be incurred. Thus, the study account for the endogeneity of adoption decision i.e., controlling the effect of factors on the adoption decision and its outcome simultaneously , by estimating a simultaneous equations model of adoption of CSA innovation and its impact with ESR by full information maximum likelihood (FIML) estimation method.

For the model to be identified, it is important to use instrumental variables as selection instruments, not only those automatically generated by the non-linearity of the selection model of adoption but also other variables that directly affect adoption of CSA innovations but not its impact. The study established the admissibility of these instruments by performing a simple falsification test: if a variable is a valid selection instrument, it will affect adoption decision but it will not affect the climate resilience capacity (Di Falco, Veronesi, & Yesuf, 2011).

5.3. Results and discussion

5.3.1. Comparison of absorptive capacity of the adoption of CSA innovations

Table 17 shows that adopters of improved variety (p =.002) and crop residue management (p =.004) households significantly enhanced the disaster and early warning systems of their livelihoods through better mobile phone and social communication than non-adopter households, which concurs with the finding by Adzawla et al. (2020), who reported that information on the occurrence of a climate shock such as floods increases the climate resilience capacity of farmers in Ghana. Adopters of SWC households, on the other hand, have significantly worse disaster mitigation and early warning systems than non-adopters to deal with climate change-related floods because they live in mountainous areas where mobile and social communication are difficult (p =.015). Furthermore, farmers who practice crop residue management have a significantly better informal safety net in the form of community support from friends and neighbors in the event of a disaster (p<.001). Crop rotation adopters (p =.012), on the other hand, have a shaky informal safety net of community support. Thus, improved variety and crop residue management adopters have a high capacity to absorb the effects of climate change-related disasters such as drought and flooding, whereas crop rotation adopters have a low capacity to withstand climate change-related disasters. Several papers have supported the findings of this study (Hanson-Easey et al., 2018; Heinkel et al., 2022). Paul et al., (2021) reported that mobile phone technologies can be used to improve inclusivity and local knowledge production for disaster risk mitigation systems in resilience building. Heinkel et al. (2022) also support mobile phone usage during disaster

preparedness and increase resilience by improving mobile phone messaging to be used for communication during disasters as well as by establishing a redundant communication structure. Hanson-Easey et al. (2018) reported that social communication mediates the dissemination and interpretation of natural hazard risk messages in the community. Finally, (Räsänen et al., 2020) findings concur with the current study and report that community resilience through the interaction-based community of informal social networks is more visible in disaster response and recovery.

Poor risk management strategies that focus on food consumption styles, borrowing grains and cash, distress livestock sales, and labor have not helped household absorptive capacity, whereas disaster risk mitigation and early warning systems, as well as informal safety nets, enhance household absorptive capacity, thereby building the climate resilience capacity of CSA innovators.

Table 17: Comparison of absorptive capacity of the adoption of CSA innovations

Indicators	Category	Improved variety	Crop residue management	Crop rotation	Compost	Row planting	SWC	Agro forestry
Decrease Quantity of Meal	Adopter	0.027	-0.012	-0.02	-0.01	-0.02	0.01	-0.05
	Non-adopter	-0.012	0.011	0.012	0.01	0.07	-0.01	0.01
Decrease Diversity of Meal	Adopter	0.06	-0.01	-0.03	0.00	-0.01	0.01	-0.08
	Non-adopter	-0.03	0.01	0.02	0.01	0.04	-0.01	0.02
Borrow grain	Adopter	0.02	-0.07	0.04	0.00	0.03	0.02	-0.03
	Non-adopter	-0.01	0.06	-0.03	0.01	-0.10	-0.02	0.01
Seek NGO help	Adopter	-0.017	-0.042	0.001	-0.011	0.005	0.002	-0.055
	Non-adopter	0.007	0.036	-0.001	0.021	-0.016	-0.003	0.014
Borrow Cash	Adopter	0.06	0.05	-0.04	0.02	0.01	-0.01	-0.07
	Non-adopter	-0.03	-0.04	0.02	-0.04	-0.01	0.01	0.02
Sales of livestock	Adopter	0.07	0.02	-0.02	0.01	-0.03	0.00	-0.05
	Non-adopter	-0.03	-0.02	0.01	-0.02	0.10	0.00	0.01
Labour work	Adopter	-0.01	0.08	-0.12	-0.01	-0.04	0.00	-0.01
	Non-adopter	0.00	-0.07	0.07	0.01	0.11	0.00	0.00
Risk management	**Adopter**	**0.032**	**0.001**	**-0.025**	**0.001**	**-0.008**	**0.005**	**-0.049**
	Non-adopter	**-0.014**	**-0.001**	**0.014**	**-0.001**	**0.026**	**-0.005**	**0.013**
	Difference	**0.045(0.036)**	**0.002(0.033)**	**-0.039(0.034)**	**0.001(0.035)**	**-0.034(0.039)**	**0.01(0.03)**	**-0.061(0.041)**
Friend support	Adopter	-0.012	0.048	-0.065	0.009	-0.02	-0.004	-0.05
	Non-adopter	0.005	-0.041	0.037	-0.017	0.064	0.004	0.013
Informal Social insurance	Adopter	0.027	0.035	-0.034	0.024	0.007	0.036	0.042
	Non-adopter	-0.003	-0.018	0.03	-0.026	0.004	-0.025	-0.003
Informal aid	Adopter	0.073	0.101	-0.036	0.018	0.004	-0.014	0.06
	Non-adopter	-0.032	-0.086	0.021	-0.036	-0.013	0.014	-0.016
Informal safetynet	**Adopter**	**0.03**	**0.06**	**-0.044**	**0.017**	**-0.003**	**0.007**	**0.017**
	Non-adopter	**-0.01**	**-0.048**	**0.029**	**-0.026**	**0.018**	**-0.003**	**-0.002**
	Difference	**0.04(0.031)**	**0.109***(0.028)**	**-0.074**(0.03)**	**0.043(0.03)**	**-0.022(0.034)**	**0.01(0.03)**	**0.019(0.036)**
Social communication	Adopter	0.02	0.049	0.003	0.007	0.001	0.017	0.025
	Non-adopter	-0.009	-0.042	-0.002	-0.014	-0.002	-0.018	-0.007
Mobile Phone communication	Adopter	0.035	0.017	0.022	0.001	0.000	0.005	0.013
	Non-adopter	-0.017	-0.016	-0.014	-0.005	-0.004	-0.007	-0.005
Soil fertility Parcel 1	Adopter	0.022	0.007	-0.001	0.022	0.003	-0.032	-0.026
	Non-adopter	-0.01	-0.007	0.001	-0.043	-0.007	0.032	0.007
Soil Fertility Parcel 2	Adopter	0.011	0.001	0.023	0.012	-0.006	-0.035	-0.05
	Non-adopter	-0.005	-0.001	-0.014	-0.023	0.02	0.036	0.013
Slope of Parcel 1	Adopter	0.132	0.088	0.049	0.033	0.002	-0.087	0.106
	Non-adopter	-0.058	-0.076	-0.028	-0.063	-0.005	0.089	-0.028
Slope of Parcel 2	Adopter	0.098	0.053	0.036	0.005	0.001	-0.038	0.076
	Non-adopter	-0.043	-0.045	-0.021	-0.009	-0.003	0.039	-0.02
Disaster mitigation and early warning system (DMEWS)	**Adopter**	**0.052**	**0.036**	**0.022**	**0.013**	**0.000**	**-0.028**	**0.024**
	Non-adopter	**-0.024**	**-0.031**	**-0.013**	**-0.026**	**0.000**	**0.029**	**-0.007**
	Difference	**0.076***(0.025)**	**0.067***(0.023)**	**0.035(0.024)**	**0.04(0.025)**	**0(0.027)**	**-0.06**(0.02)**	**0.03(0.029)**

Absorptive capacity index	**Adopter**	**0.035**	**0.035**	**-0.024**	**0.01**	**-0.005**	**-0.001**	**-0.005**
	Non-adopter	**-0.014**	**-0.028**	**0.016**	**-0.017**	**0.018**	**0.003**	**0.003**
	Difference	**0.049**(0.022)**	**0.062***(0.02)**	**-0.04*(0.021)**	**0.027(0.021)**	**-0.022(0.024)**	**-0.004(0.02)**	**-0.008(0.025)**

Standard errors in parentheses * p < 0.1, ** p < 0.05, *** p < 0.01

5.3.2. Comparison of adaptive capacity of the adoption of CSA innovations

Table 18 shows that adopters of improved variety, crop residue management, compost, row planting, and agroforestry have significantly increased the wealth, income, and food security of households with a greater number of plots, livestock holdings, and farm income ($p<.001$). This concurs with the finding of Mujeyi et al.(2021). Crop rotation households have significantly higher wealth and income ($p<.001$) than SWC households, which have significantly lower food security because they consume less low-quality and low-quantity food. Therefore, (Lasco, 2014; Makate, Makate, Mango, et al., 2019a; Tambo, 2016; Teklewold, 2017) supports our finding that adopters of improved variety, crop residue management, compost, row planting, and agroforestry, households' increased productivity through higher wealth and income that includes more durable assets, a larger farm size, a larger livestock holding, a greater number of plots, farm income as well as improved food security fosters strong adaptive capacity .This finding concurs with the study by Sodokin & Nyatefe (2021), who reported income plays a significant role in the household's resilience building.

Table 18 :Comparison of adaptive capacity of the adoption of CSA innovations

Indicators	Category	Improved variety	Crop residue management	Crop rotation	Compost	Row planting	SWC	Agro forestry
Late sowing of crop	Adopter	-0.047	0.011	0.004	-0.009	-0.010	0.015	-0.054
	Non-adopter	0.021	-0.009	-0.002	0.018	0.033	-0.015	0.014
Use of drought resistant variety	Adopter	0.005	0.041	-0.035	-0.030	-0.038	0.014	-0.097
	Non-adopter	-0.002	-0.035	0.021	0.058	0.122	-0.014	0.025
Use of crop residual for farm	Adopter	0.001	0.011	-0.007	-0.033	-0.002	0.025	-0.084
	Non-adopter	-0.001	-0.009	0.004	0.063	0.007	-0.025	0.022
Use of water harvesting technologies	Adopter	-0.012	0.000	-0.012	-0.004	0.001	0.009	0.000
	Non-adopter	0.005	0.000	0.007	0.007	-0.002	-0.009	0.000
Adaptive strategies	**Adopter**	**-0.014**	**0.016**	**-0.013**	**-0.018**	**-0.013**	**0.016**	**-0.059**
	Non-adopter	**0.006**	**-0.014**	**0.007**	**0.036**	**0.040**	**-0.016**	**0.015**
	Difference	**-0.02(0.03)**	**0.03(0.03)**	**-0.02(0.03)**	**-0.06(0.03)**	**-0.05(0.04)**	**0.03(0.03)**	**-0.07*(0.04)**
Durable asset	Adopter	0.104	0.065	0.094	0.080	0.038	0.072	0.164
	Non-adopter	-0.045	-0.056	-0.055	-0.155	-0.122	-0.074	-0.043
Total Farm size	Adopter	0.146	0.115	0.115	0.052	-0.005	0.035	0.178
	Non-adopter	-0.065	-0.099	-0.066	-0.101	0.017	-0.036	-0.046
Livestock holding	Adopter	0.210	0.082	0.105	0.095	0.046	0.004	0.195
	Non-adopter	-0.092	-0.070	-0.060	-0.183	-0.147	-0.004	-0.051
Number of plots	Adopter	0.169	0.020	0.051	0.043	0.036	-0.025	0.159
	Non-adopter	-0.074	-0.017	-0.030	-0.082	-0.115	0.026	-0.041
Farm income	Adopter	0.242	0.131	0.108	0.094	0.041	-0.037	0.221
	Non-adopter	-0.106	-0.112	-0.062	-0.182	-0.131	0.038	-0.057
Wealth and Income	**Adopter**	**0.175**	**0.083**	**0.094**	**0.072**	**0.031**	**0.009**	**0.184**
	Non-adopter	**-0.076**	**-0.071**	**-0.055**	**-0.141**	**-0.100**	**-0.010**	**-0.048**
	Difference	**0.25***(0.04)**	**0.15***(0.03)**	**0.15***(0.03)**	**0.21***(0.03)**	**0.13***(0.04)**	**0.02(0.03)**	**0.23***(0.04)**
Household Dietary Diversity Score (HDDS)	Adopter	0.196	0.114	0.061	0.100	0.084	-0.053	0.303
	Non-adopter	-0.086	-0.098	-0.036	-0.194	-0.266	0.055	-0.079
Food consumption score (FCS)	Adopter	0.157	0.258	-0.047	0.014	0.040	-0.177	0.048
	Non-adopter	-0.069	-0.221	0.027	-0.026	-0.128	0.181	-0.012
Crop diversity	Adopter	-0.015	0.008	0.014	0.001	0.000	0.009	-0.005
	Non-adopter	0.007	-0.007	-0.007	-0.003	-0.001	-0.009	0.002
Food security	**Adopter**	**0.113**	**0.127**	**0.009**	**0.039**	**0.041**	**-0.073**	**0.115**

	Non-adopter	**-0.050**	**-0.109**	**-0.005**	**-0.074**	**-0.132**	**0.075**	**-0.030**
	Difference	**0.16***(0.04)**	**0.24***(0.04)**	**0.02(0.04)**	**0.11***(0.04)**	**0.17***(0.04)**	**-0.2***(0.04)**	**0.15***(0.04)**
Adaptive capacity index	**Adopter**	**0.079**	**0.068**	**0.025**	**0.025**	**0.016**	**-0.013**	**0.063**
	Non-adopter	**-0.035**	**-0.058**	**-0.015**	**-0.048**	**-0.051**	**0.013**	**-0.017**
	Difference	**0.11***(0.02)**	**0.13***(0.02)**	**0.04*(0.02)**	**0.07***(0.02)**	**0.07***(0.02)**	**-0.025(0.02)**	**0.08***(0.03)**

Standard errors in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

5.3.3 Comparison of transformative capacity of the adoption of CSA innovations

Table 19 shows that adopters of improved variety, crop rotation, compost, row planting, and agroforestry households have a significantly higher information and training index ($p<.001$) due to higher public extension and FTC training scores for adopters of these CSA innovations, while compost adopter households have a marginally poor social network ($p<.1$). Row planting adopters have marginally significant higher score for infrastructure use than non-adopters as the latter have better access to basic services such as access to markets, farmers' training centers (FTC), all-weather roads, water, sanitation, as well as schools. Hence, higher information and training indexes through a strong public agricultural extension system as well as strong infrastructure use led to higher transformative capacity among row-planting adopters. This shows access to basic services is the main source of transformative capacity for smallholder farmers, which concurs with the study by Asmamaw (2019). However, a higher information and training index was offset by a lower social network index among adopters of compost, which showed the influence of social networks on transformative capacity among smallholder farmers, which led to an insignificant difference in transformative capacity between adopters and non-adopters of compost, as the latter needs more labor as a prerequisite for adoption. Similar studies also showed access to extension services, farmers' training centers, as well as infrastructure increases the transformative capacity of smallholder agriculture systems (Jamil et al., 2021; Ketemaw, 2022; Mentire & Gecho, 2017; Yekini, 2019). The result of this study has been theoretically supported by the argument by (Hellin et al., 2021) who argued that there is a need coupling technologies and socio-economics and how they become embedded in ecological systems underpinning smallholder agriculture . Further he supported our argument that a greater focus on transformative adaptation is required to achieve the Paris Agreement because transformative adaptation tackles the root causes of vulnerability by building capacity among farmers (Hellin, 2021).

Table 19: Comparison of transformative capacity of the adoption of CSA innovations

Indicators	Category	Improved variety	Crop residue management	Crop rotation	Compost	Row planting	SWC	Agro forestry
Access to extension	**Adopter**	0.11	-0.08	0.09	0.05	0.06	0.05	0.04
service	**Non-adopter**	-0.05	0.07	-0.05	-0.10	-0.18	-0.05	-0.01
Extension service on farm	**Adopter**	0.48	0.26	0.37	0.32	0.35	0.26	0.35
input	**Non-adopter**	0.20	0.31	0.24	0.22	0.09	0.32	0.27
Extension service on	**Adopter**	0.01	0.03	0.03	0.04	0.03	0.02	0.07
Climate change	**Non-adopter**	0.00	-0.02	-0.02	-0.08	-0.10	-0.02	-0.02
Extension service on	**Adopter**	0.13	0.06	0.04	0.06	0.05	-0.03	0.13
productivity	**Non-adopter**	-0.06	-0.05	-0.03	-0.12	-0.15	0.04	-0.03
Farmers Training	**Adopter**	0.01	-0.01	0.00	0.01	0.00	0.00	0.01
Center(FTC) training	**Non-adopter**	0.00	0.00	0.00	-0.01	0.00	0.00	0.00
Information & Training	**Adopter**	**0.146**	**0.052**	**0.106**	**0.097**	**0.097**	**0.057**	**0.118**
	Non-adopter	**0.018**	**0.063**	**0.03**	**-0.019**	**-0.069**	**0.058**	**0.042**
	Diff	**0.13***(0.03)**	**-0.01(0.03)**	**0.08**(0.038)**	**0.12***(0.03)**	**0.165***(0.033)**	**0(0.029)**	**0.076*(0.036)**
Participation in watershed	**Adopter**	0.031	0.029	0.03	0.03	0.033	0.029	0.036
management	**Non-adopter**	0.05	-0.03	0.05	0.03	0.12	-0.04	0.01
Membership in mahber	**Adopter**	0.04	-0.03	0.09	-0.09	0.00	-0.10	-0.02
	Non-adopter	-0.02	0.03	-0.05	0.18	-0.01	0.11	0.00
Participation in	**Adopter**	-0.01	0.00	-0.01	0.04	0.02	0.05	0.04
debo/wenfel	**Non-adopter**	0.01	0.00	0.01	-0.07	-0.08	-0.05	-0.01
Social Networks	**Adopter**	**-0.029**	**0.003**	**-0.003**	**-0.024**	**-0.003**	**-0.005**	**-0.002**
	Non-adopter	**0.013**	**-0.003**	**0.002**	**0.045**	**0.009**	**0.005**	**0.001**
	Difference	**-0.04(0.04)**	**0.005(0.04)**	**-0.01(0.04)**	**-0.07*(0.03)**	**-0.013(0.043)**	**-0.01(0.036)**	**-0.003(0.045)**
Access to health post	**Adopter**	-0.004	0.01	0.03	-0.01	-0.02	0.02	-0.02
	Non-adopter	0.002	-0.01	-0.02	0.02	0.05	-0.03	0.01
Access to market	**Adopter**	-0.03	-0.02	0.02	0.04	0.01	0.05	-0.01
	Non-adopter	0.02	0.01	-0.01	-0.07	-0.02	-0.05	0.00
Access to FTC	**Adopter**	0.05	0.02	-0.01	-0.004	0.01	-0.06	0.06
	Non-adopter	-0.02	-0.02	0.004	0.01	-0.04	0.06	-0.02
Access to all weather road	**Adopter**	0.03	-0.05	-0.03	-0.01	0.04	-0.06	-0.02
	Non-adopter	-0.01	0.04	0.02	0.01	-0.12	0.06	0.01
Access to water and	**Adopter**	0.04	-0.03	-0.01	0.01	0.02	-0.02	0.02
sanitation	**Non-adopter**	-0.02	0.02	0.01	-0.02	-0.06	0.02	-0.01
Access to school	**Adopter**	-0.01	0.01	0.01	0.01	0.00	0.00	0.03
	Non-adopter	0.01	-0.01	-0.01	-0.01	-0.01	0.00	-0.01
Infrastructure use	**Adopter**	**0.011**	**-0.008**	**0.003**	**0.005**	**0.010**	**-0.010**	**0.009**
	Non-adopter	**-0.005**	**0.007**	**-0.002**	**-0.011**	**-0.032**	**0.010**	**-0.003**
	Diff	**0.02(0.02)**	**-0.02(0.02)**	**0.004(0.02)**	**0.02(0.02)**	**0.042*(0.025)**	**-0.02(0.021)**	**0.012(0.026)**
Transformative capacity	**Adopter**	**0.039**	**0.016**	**0.034**	**0.024**	**0.033**	**0.015**	**0.040**
index	**Non-adopter**	**0.010**	**0.022**	**0.010**	**0.009**	**-0.027**	**0.024**	**0.014**
		0.03(0.02)	**-0.005(0.02)**	**0.02(0.02)**	**0.014(0.021)**	**0.06***(0.022)**	**-0.009(0.02)**	**0.027(0.024)**

Standard errors in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

5.3.4. Comparison of climate resilience capacity of the adoption of CSA innovations

Climate change induced hazards such as drought, floods, hailstorms, and erratic rainfall have been happening in Ethiopia. Such climate shocks disproportionately affect low adaptive capacity households with different severity levels of impacts on across different farmers. The extent of the impact is further magnified when shocks hit households with differences in resilience capacities. This paper used Climate resilience Index (CRi) as a proxy measurement of household climate resilience capacity. Mean comparison of adopters' against non-adopters' CRi of improved variety, crop residue management, crop rotation, compost, row planting, SWC and agroforestry was conducted.

Table 20 shows that households with improved variety, crop residue management, compost, row planting, and agroforestry have a significantly higher climate resilience index (p.001). Therefore, improved variety, crop residue management, compost, row planting, and agroforestry adoption showed significant increases in climate resilience capacities. Similar results supported our finding that improved variety in the form of drought resistance variety (DRV) adoption increased the climate resilience capacity of smallholder households (Rani et al., 2020; Xiong & Tarnavsky, 2020). Moreover, other studies also concur with our finding that adopters of crop residue management as a component of conservation have built climate resilience through mitigating the negative impacts of deviations in rainfall due to drought and rainfall decrease (Michler et al., 2019). Similar findings have been observed by Bedada et al. (2014), who reported that compost alone or in combination with NP fertilizer improved soil properties and crop productivity, which builds climate resilience. Studies also concur with our finding that row planting adopters increased their climate resilience. A study by Adzawla & Alhassan (2021) reported that row planting remained essential adaptation strategy for sustainable food production. Similar studies on row planting by Gelu & Gebre (2022) concur with our finding that the mean yield of row-planted wheat was higher compared to conventional broadcast planting methods, which increases the climate resilience capacity of smallholder wheat farmers. Finally, studies by Gelu (Gelu, 2022) find that reported maintenance and enhancement of locally evolved agroforestry systems, with high resilience and multiple benefits, can contribute to climate resilience.

Table 20 : Comparison of climate resilience capacity of the adoption of CSA innovations

CSA innovations	Category	Absorptive capacity index	Adaptive capacity index	Transformative capacity index	Climate resilience capacity index
Improved variety	**Adopter**	0.035	0.079	0.039	0.055
	Non-adopter	-0.014	-0.035	0.010	-0.016
	Difference	0.049**(0.022)	0.113****(0.022)	0.029(0.021)	0.07**(0.015)
Crop residue management	**Adopter**	0.035	0.068	0.016	0.043
	Non-adopter	-0.028	-0.058	0.022	-0.026
	Difference	0.062***(0.02)	0.126***(0.02)	-0.005(0.02)	0.07***(0.013)
Crop rotation	**Adopter**	-0.024	0.025	0.034	0.014
	Non-adopter	0.016	-0.015	0.010	0.002
	Difference	-0.04*(0.021)	0.04*(0.021)	0.024(0.02)	0.012(0.014)
Compost	**Adopter**	0.01	0.025	0.024	0.020
	Non-adopter	-0.017	-0.048	0.009	-0.022
	Difference	0.027(0.021)	0.072***(0.021)	0.014(0.021)	0.042***(0.02)
Row planting	**Adopter**	-0.005	0.016	0.033	0.016
	Non-adopter	0.018	-0.051	-0.027	-0.024
	Difference	-0.022(0.024)	0.067***(0.024)	0.06***(0.022)	0.04**(0.016)
SWC	**Adopter**	-0.001	-0.013	0.015	-0.002
	Non-adopter	0.003	0.013	0.024	0.013
	Difference	-0.004(0.02)	-0.025(0.02)	-0.009(0.02)	-0.015(0.014)
Agro forestry	**Adopter**	-0.005	0.063	0.040	0.036
	Non-adopter	0.003	-0.017	0.014	-0.002
	Difference	-0.008(0.025)	0.08***(0.025)	0.027(0.024)	0.039**(0.017)

Standard errors in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

5.3.5. Effect of CSA Innovations on climate resilience capacity

Table 8 presents the true average adoption effects of climate resilience capacity under actual and counterfactual conditions. In this table, the climate resilience capacity index (CRi) of farm households who adopted the CSA innovation were compared with the outcome variables that would have been found if the households had not adopted. In order to determine the average adoption effects, the study compared columns A and B of Table 10. Column C presents the impacts of adoption of CSA innovation on the climate resilience capacity, computed as the difference between Columns A and B.

The treatment effect (ATT) result indicated that adoption of improved variety has increased the climate resilience capacity of the adopters by 18.5% while for the non-adopters, climate resilience capacity would have been increased by 13.9% if they had adopted improved variety. However, the negative sign of treatment heterogeneity effect shows that adoption of improved variety is more

pronounced for adopters than non-adopters i.e., some characteristics of non-adopters have made the effect of adoption of improved variety more appropriate for non-adopters than actual adopters ($p< .001$). Hence, the climate resilience capacity of counter factual adopter's households would have increase by 4% if they had adopted improved variety which supports study by (Shikuku, 2019) who reported that drought resistant improved variety has increased climate resilience of smallholder farmers. Adoption of crop residue management has insignificant effect on climate resilience capacity of actual adopters (p=.26) while for the non-adopters of crop residue management climate resilience capacity would have been increased by 6.6% had they adopted crop residue management. The negative effect of adoption of crop residue management shows that some characteristics of non-adopters have made the effect of adoption of crop residue management more appropriate for non-adopters than actual adopters ($p< .001$). The adoption treatment effect (ATT) of crop rotation indicated that adoption has increased the climate resilience capacity of the adopters by 20.5% while for the non-adopters, climate resilience capacity would have been increased by 9.1% if they had adopted crop rotation. Hence, the positive sign of treatment heterogeneity effect shows that adoption of crop rotation has more pronounced effect for adopters than non-adopters ($p< .001$) that supports similar study in China (Tong et al., 2019) who reported that crop rotation by improving technical efficiency creates a stronger agricultural production system that is resilient to climate risks. Hence, the climate resilience capacity of actual as well as counter factual adopter's households would increase by 1.8%. The adoption treatment effect (ATT) of compost showed that adoption has increased the climate resilience capacity of the adopters by 6.0% while for the non-adopters, climate resilience capacity would have been increased by 9.6% if they had adopted compost. The finding concurs with the study by (Yong Liu et al., 2022) who reported soil fertility management technologies increases climate resilience through increased net agricultural income, yield, and productivity. The adoption treatment effect (ATT) of row planting indicated that adoption has increased the climate resilience capacity of the adopters by 6.2% while for the non-adopters, climate resilience capacity would have been increased by 5.3% if they had adopted row planting. Hence, the positive sign of treatment heterogeneity effect shows that adoption of row planting has more pronounced effect for adopters than non-adopters ($p< .001$). Thus, the climate resilience capacity of actual as well as counter factual adopter's households would increase by 3.5%. The treatment effect (ATT) result indicated

that adoption of SWC has reduced the climate resilience capacity of the adopters by 6.2% while for the non-adopters, climate resilience capacity would have been reduced by 23.0% if they had adopted SWC. However, the negative sign of treatment heterogeneity effect shows that adoption of SWC is more pronounced for non-adopters than adopters i.e., some characteristics of non-adopters have made the effect of adoption of SWC more appropriate for non-adopters than actual adopters ($p<$ .001) this may be in line with the study result by (Eze et al., 2022) who reported that SWC increased crop yields and improved the resilience of the agro-ecosystem to environmental stress. Hence, the climate resilience capacity of actual as well as counter factual adopter's households would have reduced by 8.2% if they had adopted SWC. The adoption treatment effect (ATT) of agroforestry indicated that adoption has increased the climate resilience capacity of the adopters by 16.0% while for the non-adopters, climate resilience capacity would have been increased by 12.9% if they had adopted agroforestry. Hence, the climate resilience capacity of actual as well as counter factual adopter's households would increase by 6.9%.

Table 21: Adoption effect of CSA innovations on average expected climate resilience

CSA Innovations	Households	Adoption decision: to adopt (A)	Adoption decision: not to adopt (B)	Impact of CSA innovation on climate resilience capacity index (CRi) (ESR) (C)	Heterogeneity effect
Improved variety	Adopters	0.054	-0.132	ATT= 0.185(0.01)***	-0.040(0.01)***
	Non-adopters	0.123	-0.016	ATU= 0.139(0.009)***	
Crop residue management	Adopters	0.043	0.055	ATT= -0.012(0.01)	-0.041(0.01)***
	Non-adopters	0.041	-0.026	ATU= 0.066(0.009)***	
Crop rotation	Adopters	0.013	-0.192	ATT= 0.205(0.012)***	0.018(0.01)*
	Non-adopters	0.093	0.002	ATU= 0.091(0.01)***	
Compost	Adopters	0.020	-0.040	ATT= 0.06(0.008)***	-0.007(0.007)
	Non-adopters	0.074	-0.022	ATU= 0.096(0.012)***	
Row planting	Adopters	0.015	-0.047	ATT= 0.062(0.008)***	0.035(0.01)***
	Non-adopters	0.029	-0.024	ATU= 0.053(0.015)***	
SWC	Adopters	0.002	0.064	ATT= -0.062(0.008)***	-0.082(0.01)***
	Non-adopters	-0.217	0.013	ATU= -0.230(0.01)***	
Agroforestry	Adopters	0.035	-0.127	ATT= 0.160(0.02)***	0.069(0.01)***
	Non-adopters	0.127	-0.002	ATU= 0.129(0.008)***	

Standard errors in parentheses $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$

Ethiopia's literature on the impact of CSA innovations on climate resilience is limited (Hailemariam, 2017). Hailemariam et al. (2017) investigated the impact of the adoption of improved varieties, chemical fertilizer (a risk multiplier), and water management (a risk-reducing)

on agricultural revenue; however, they did not assess the capacity of smallholder farmers for climate resilience. Even though they evaluated the smallholder farmers' potential for climate resilience through absorptive, adaptive, and transformative capacities, Asmamaw et al. (2019) contrasted the agro-ecology capacity of the agricultural system rather than the effect of technology or innovations the farmers adopted.

5.4. Conclusion

The objective of this paper is to examine the impact of climate-smart agriculture (CSA) innovations on building climate resilience capacity in smallholder agriculture system. A cross-sectional household survey was conducted among multi-stage sampled 424 smallholder farmers selected from five agroecosystem of the Upper Blue Nile Highlands in Ethiopia. The study used an endogenous switching regression (ESR) model to examine the impact of CSA innovations on building climate resilience capacity among smallholder farmers. Principal component analysis was used to generate index of absorptive, adaptive, and transformative capacities.

The principal component analysis of absorptive, adaptive, and transformative capacity showed that the resilience capacity of households were built on the risk management, informal safety net, disaster mitigation, early warning systems, adaptive strategies, wealth, food security, information and training, social network, and infrastructure use. The simple mean comparison of absorptive, adaptive, transformative, and climate resilience capacities among adopters and non-adopters of CSA innovations revealed that improved variety and crop residue management adoption demonstrated a significant increase in absorptive capacity due to their effect on disaster mitigation and early warning systems as well as informal safety net, whereas crop rotation adoption demonstrated a significantly lower absorptive capacity due to lower infrastructural capacity. All CSA innovation adoptions showed a significantly increased adaptive capacity because of their higher value for wealth and food security, while lower wealth and food security status correspond to lower adaptive capacity for adopters of SWC. However, of all the CSA innovation adoptions, only row planting showed a significantly increased transformative capacity due to lower information and training, social network, and infrastructure use. Higher informal safety net support from friends and community during disasters, as well as strong disaster mitigation and early warning systems through strong social communication and access to mobile phone communications resulted in higher absorptive capacity among crop residue management adopters,

whereas crop rotation adopters had lower absorptive capacity. Hence, ensuring strong informal safety nets as well as disaster mitigation and early warning systems builds strong climate resilience capacity among smallholder farmers. Similarly, higher wealth, which includes more durable assets, a larger farm size, a larger livestock holding, a greater number of plots, farm income, and improved food security in terms of quantity and quality of food consumption, fosters strong adaptive capacity in all CSA innovation adoptions except SWC, which has lower food security status than non-adopters. In addition, the strong wealth and food security status of farmers may offset lower adaptive strategies among adopters of agroforestry. Thus, strong wealth and food security build a strong climate resilience farming system in the face of climate change. Furthermore, higher information and training indexes through a strong public agricultural extension system and strong infrastructure use led to higher transformative capacity among row-planting adopters. However, a higher information and training index was offset by a lower social network index among adopters of compost. That led to an insignificant difference in transformative capacity between adopters and non-adopters as compost needs more labor either from higher education or from social networks. Hence, strong information and training through strong public agricultural extension as well as the presence of climate-resilient infrastructure build the climate resilience capacity of smallholder agriculture systems. Strong absorptive, adaptive, and transformative capacity through strong disaster and early warning systems, climate-resilient infrastructure, a strong public agricultural extension system, a strong informal safety net, and social networks build a climate-resilient agriculture system among smallholder farmers. Therefore, improved variety, crop residue management, compost, row planting, and agroforestry adoption showed significant increase in climate resilience capacities.

The true average adoption effects of climate resilience capacity under actual and counterfactual conditions showed that different CSA innovations have different effect on climate resilience capacity of households. Except SWC adopters, all CSA innovations significantly increased the climate resilience capacity of households. However, improved variety, crop residue management, and SWC have profound effect on the non-adopters than adopters had if non-adopters would have adopted these CSA innovations. Thus, scaling up CSA innovations may expand the benefit of CSA innovation on building the climate resilience capacities of households. Thus, strong risk management, disaster mitigation, early warning systems, adaptive strategies, information and

training, informal safetynet, social network, and infrastructure use may build climate resilience capacity of smallholder farmers by facilitating adoption of CSA innovation. Therefore, policies that strengthen good governance, social cohesion, disaster communication, early warning systems, input supply of drought resistance varieties, climate-smart extension service, and climate-resilient infrastructure are necessary.

Chapter Six: General Discussion, Conclusions and Recommendations

6.1 Introduction

Climate change has necessitated a better understanding of how to incorporate mitigation, adaptation, and sustainable development components into national and international climate and development policies (IPCC, 2014a; Klein et al., 2005; Malley et al., 2021; Pilato et al., 2018). Hence, the interdependence of adaptation and mitigation policies have received increased attention over the last three decades.

However, despite the call from development thinkers and partners, integration of mitigation and adaptation has not been achieved because of three reasons (IPCC, 2014a). First, the effects of climate change and maladaptation may hurt current sustainable development policies, potentially offsetting previously achieved gains. Second, policies and strategies addressing the integration of sustainable development and climate change are cross-cutting and complex (Eriksen et al., 2021; IPCC, 2018). Finally, sustainable development intersects with some of the climate change drivers, particularly agriculture, forests, energy production, and consumption (Denton et al., 2015).

Several global discourses, however, have emerged to improve understanding of the integration of sustainable development and climate change in both the short and long term (Swart & Raes, 2007; Wilbanks & Sathaye, 2007). Science and policy have begun to investigate the feasibility and effectiveness of combining mitigation and adaptation strategies, as well as the costs and benefits of doing so (Zhao et al., 2018). Hence, studies on the links between adaptation and mitigation in both developed and developing countries, including agriculture, have emerged (Denton et al., 2015; Smith & Olesen, 2010).

CSA is one of the initiatives taken by FAO to address the issue of integrating climate change policies with sustainable development. Hence, in 2010 Rome conference of climate change and food security FAO presented the concept of CSA (CSA) as a solution to the problem of integrating climate change adaptation, mitigation, and sustainable development into agriculture (FAO, 2010a). FAO defined CSA as an agricultural approach that sustainably increases productivity and income, improves adaptation and resilience, and, if possible, reduces or removes GHG emissions (FAO, 2010; Zerssa et al., 2021).

Ethiopia's smallholder agriculture suffers from a decline in land productivity, land degradation, shortage of land, low input use, water scarcity, and low adaptive capacity (Ermias et al., 2013;

Gebremicael et al., 2013; Simane et al., 2016). As a result, food insecurity and low adaptive capacity have been the faces of the smallholder agriculture system in the country that hasn't elevated the burden of poverty from millions of smallholder agriculture households (Ayenew, 2015). To make matters worse, climate change has been affecting this fragile agriculture throughout the country, from the lowland to highland areas, by decreasing crop-livestock yield and increasing vulnerability to climate change extremes (Di Falco et al., 2011a).

Climate change extremes, which primarily manifest as increasing intensity of drought, floods, and erratic rainfall, as well as the resulting decrease in crop-livestock yield and environmental degradation, can pose a significant threat to the country's climate-resilient green economy (CRGE) agriculture goal, directly affecting the livelihoods of smallholder farmers and significantly costing the national economy (FDRE, 2019). The challenge is, therefore, how to reconcile the two basic objectives of CRGE, making agriculture not only green but also climate-resilient in the projected future of climate change. This requires a careful assessment of the existing technologies that provide green agriculture and climate resilience simultaneously.

In recent years, much research related to agricultural technology adoption as well as climate change adaptation strategies have been conducted in the country. Yet few studies have systematically addressed the linkage between agricultural greenness and climate resilience and their implications for rural livelihoods in the face of climate change and variability. More importantly, previous research efforts failed to adequately address how CSA innovations affect food security, livelihood vulnerability, GHG emissions, and build climate resilience. Therefore, it is to be recalled that the objective of this research was to investigate adoption of CSA innovations and the impact of these innovations on household food security, climate change adaptation& mitigation, and build climate resilience in the Upper Blue Nile Highlands of Ethiopia.

During the study process, the research investigated farmers' three stages process of adaptation to climate change (perception, selection of CSA innovations, and then adaptation); identified the determinants of multiple adoptions of CSA innovations; examined the synergy and trade-off effects among different CSA innovations; identified the link among CSA innovation adoption decisions; assessed the food security of smallholder farmers; analyzed the livelihood vulnerability of smallholder farmers to climate change; calculated the farm GHGs emissions of households; examined the effect of CSA innovations on food security, climate change adaptation, and

mitigation; as well as investigate how the adoption of CSA innovation build a climate-resilient livelihood. This chapter presents the synthesis of the main findings and their implication for green and climate-resilient smallholder agriculture systems in Ethiopia.

This study aims to contribute to the literature from the micro perspective of the impact of CSA innovations on household food security, livelihood vulnerability, farm GHG emissions, and building a climate-resilient livelihood. The study customized the concept of the *triple win benefit* development objectives (Caron, 2016), to reconcile the three objectives of sustainably increasing production and income, reducing vulnerability and enhancing resilience, reduction or removal of GHGs emissions of smallholder farmers in the reality of climate change. The findings in the study are in line with the core aspects of the notion of the *triple win benefit* and proved that adoption of CSA innovation in the study area indeed result in increased food security, reduced livelihood vulnerability, and low GHGs emission from farm plots and in turn contributes to building climate-resilient livelihood for smallholder farmers. To meet the *triple-win benefit* development objectives in the smallholder highland agriculture system scale-up of a portfolio of CSA innovations is a prior agriculture development agenda.

Theoretical and empirical evidence generally revealed that there is striking heterogeneity regarding the selection of the portfolio of CSA innovations by smallholder farmers. Enhancing the adoption of CSA innovations is a critical aspect in addressing *the triple-win benefit* of smallholder farmers in the study area as evidenced by the effect of the innovation in reducing livelihood vulnerability and building climate-resilient livelihood. However, the effect of the adoption of CSA innovations of the smallholder farmers is a function of endogenous (household endowment related) and exogenous (policies, institutions, and environmental) factors that influence the outcomes (enhanced food security, reduced livelihood vulnerability, and farm GHGs emissions, and building climate-resilient livelihood) as clearly indicated by the conceptual framework of this study, which is customized from the notion of the *triple win benefit and sustainable livelihood framework* of development objectives.

6.2. Perception towards Climate-smart Agriculture innovations

Farmers have different perceptions of CSA innovation's benefits that emanate from their expectation of the livelihood outcome these innovations deliver. To capture the diversity, the perceptions were divided into the three CSA pillars i.e., perception towards food security,

adaptation, and mitigation benefits (**Chapter 2**). Perception towards food security benefits includes the perception of CSA innovations increase productivity and income. Perception of CSA innovations increases productivity significantly differs among agroecosystems (**Chapter 2**). Among perception towards adaptation/resilience, perceptions of CSA innovations increase soil fertility; reduces seeding rate, cost of production, and soil erosion are significantly different among agroecosystems (**Chapter 2**). Similarly, for perception towards mitigation, the perception of CSA reduces chemical fertilizer use and rehabilitates land significantly differs by agroecosystem (**Chapter 2**).

For the perception of food security benefits, farmers who perceive CSA innovations increase productivity are more likely to adopt improved variety, crop residue management, intercropping, and agroforestry (**Chapter 2**). Farmers who perceive that CSA innovations increase productivity are reluctant to adopt SWC because SWC decreases crop yield as it attracts pests and rodents, is difficult to tillage, requires much labour, and reduces farm size (Simeneh, 2015, 2016).

Regarding perceptions towards adaptation benefits, farmers who perceive that CSA innovation increases soil fertility are more likely to adopt crop residue management, crop rotation, and compost as these innovations are part of soil fertility management practices that are proven to enhance soil fertility in the smallholder agriculture systems of different sub-Saharan African countries. Farmers who perceive that CSA innovation's increased diversification of fuel sources is expected to create more of an urge to adopt crop rotation, soil and water conservation, and agroforestry as these practices provide fuel wood for domestic consumption. Farmers who perceive that CSA innovations reduce soil erosion are more likely to adopt crop residue management, crop rotation, intercropping, soil and water conservation, and agroforestry as these practices keep soil erosion by surface runoff. Farmers who perceive that CSA innovations reduce weed infestation are more likely to adopt crop residue, crop rotation, compost, row planting, intercropping, and agroforestry as one of the benefits of these innovations in agronomy is reducing weed infestation. Farmers who perceive that CSA innovations reduce the cost of production cause more likely adoption of row planting. CSA innovations that reduce seeding rates are more likely to adopt improved varieties, compost, row planting, and agroforestry. Thus, a positive perception of farmers towards the implications of CSA innovations on climate change adaptation enhances the

adoption of improved varieties, crop residue management, crop rotation, compost, row planting, soil and water conservation, intercropping, and agroforestry (Abyiot, 2022).

Likewise, the perception that CSA innovation increases soil organic matter and carbon may cause a more likely adoption of crop residue management and compost. Also, farmers' perception that CSA innovations reduce the amount of chemical fertilizer leads to a more probable adoption of improved varieties and compost, and a farmer's perception that CSA innovations rehabilitate land implies a higher expectation to adopt crop rotation. Thus, a positive perception of farmers towards the implications of CSA innovations on climate change mitigation enhances the adoption of crop residue management, crop rotation, and compost (Abyiot, 2022).

As the farmers' perception varies across AES, extension services should focus on awareness of climate-smart innovations' capacity to enhance food security and strengthen climate adaptation in the midland with brown soil (AES3) and the hilly and mountainous agroecosystem zone (AES5). Whereas, extension services should focus on awareness of CSA innovations' capacity to contribute to climate adaptation/resilience in the low land/ Abay gorge agroecosystems zone (AES1) as well as farmers' awareness of the capacity of CSA innovations to deliver climate adaptation (with mitigation co-benefits) in the hilly and mountainous agroecosystem zone (AES5). Hence, designing policies that aim to enhance the information and communication gap of adoption of CSA innovations have a great potential to benefit from the innovations. Programs aimed to reduce the maladaptation of CSA innovations should focus on the bundle of innovations for a particular farmer, not a piecemeal (Chapter 2; (Abyiot, 2022)).

6.3. Multiple adoptions of Climate-Smart Agriculture innovations

Given the warming trend of climate change, farmers tend to adopt multiple climate-smart agriculture practices to reduce multiple climate change risks (Teklewold, 2017). Adaptation to climate change is a three-step process during the adoption of CSA innovations which requires that farmers first perceive climate change and climate-smart agriculture benefits, select multiple CSA innovations that give maximum utility against climate change risks, and respond to the changes in the third step through adaptation (**Chapter 3**).

The economic constraint model demonstrated that farm size, number of plots, and access to financial services influence crop residue management, crop rotation, and agroforestry adoption. Hence, a larger number of plots, a larger total farm size, and access to rural savings and credit

increase the probability of adoption. The diffusion innovation model, on the other hand, asserted that frequent extension visits, market access, access to information communication, social networks, and strong tenure security have no less of an impact on the adoption of CSA innovations such as improved variety, crop residue management, crop rotation, compost, SWC, and agroforestry. Furthermore, farmers' perceived technology-specific characteristics of CSA innovations increase the likelihood of adoption. Hence, formal education, more awareness about climate change and CSA, and the ability of CSA innovations to reduce the impact of climate change risks such as rising temperatures, increased hailstorms, and increasingly erratic rainfall have significantly increased the likelihood of adoption. Therefore, the integrated technology adoption model explains the determinants of adopting multiple CSA innovations simultaneously (**Chapter 3**).

Therefore, scaling up CSA innovations in the study area requires: rural primary education that enables the farmer to raise their awareness about climate change and climate-smart agriculture; improving public extension services, mobile phone accessibility such as agro and climate voice and text message, and improving basic services such as clean water access are important incentives for CSA innovation adoption. Policies must also aim to promote farm-level specific portfolio identification of CSA innovations based on farmers' specific climate change risk perceptions through effective farmer participation (**Chapter 3**).

6.4. Effect of Climate-smart Agriculture Innovation Adoption

Ethiopia's smallholder agriculture suffers from a decline in land productivity, land degradation, shortage of land, low input use, water scarcity, and low adaptive capacity (Ermias et al., 2013; Gebremicael et al., 2013; Simane et al., 2016). When these problems are combined with climate change, the smallholder agriculture system suffers from further productivity loss, increasing water scarcity, and a lack of adaptive capacity to respond to the risk of climate change (Simeneh & Fisseha, 2016; Yibekal et al., 2013). As productivity declines, the shortage of available food for daily consumption intensifies, and smallholder households suffer from malnutrition.

Ethiopia's highlands are more vulnerable to climate change because of their wide variation in topography, climate, and agro ecosystems. Sloping areas are the most fragile lands in the highlands, as they are highly susceptible to erosion as well as agricultural expansion has been carried out toward these areas at the expense of natural resource degradation. The shift of

agricultural areas from more suitable land to marginal and environmentally fragile areas may exacerbate the problem of GHG emissions in three ways. First, degraded and overgrown farmland emits more GHG than cultivated land. Second, the cultivation of grazing land and wetland may release already stored carbon in the area and exacerbate GHGs emissions. Finally, when smallholders deforest the natural forest area for cultivation, they increase the GHG emissions released into the atmosphere.

Several studies have found that smallholder agriculture can improve food security, adapt to climate change or resilience, and reduce GHG emissions by implementing a variety of CSA innovations such as sustainable land management (SLM), intercropping, crop rotation, soil and water conservation, modern input use, and agroforestry. In Ethiopia, although there are no standard criteria to label an agriculture technology as CSA or not, MOA and GIZ have developed a CSA manual that identifies some of the technologies as CSA. According to the manual, crop residue management, crop rotation, compost, soil and water conservation measures, agroforestry, and improved varieties were identified as CSA.

6.4.1 Effect of Climate-smart Agriculture Innovation Adoption on Livelihood Vulnerability

The current vulnerability analysis involved the calculation of a balanced, weighted average LVI (composite index) in which each major component contributes equally to the overall index. The indices used in this study integrated the LVI and the IPCC-LVI. The livelihood vulnerability index (LVI) provides information on the components of livelihood vulnerability. These components include natural disasters and climate change exposure, ecosystem and agriculture sensitivity, wealth, technology, infrastructure use, knowledge, and social networks. On the other hand, the IPCC-LVI identifies which of the exposure, adaptive capacity, and sensitivity factors have a significant impact on agricultural vulnerability to climate change (**Chapter 4**).

The mean comparison of adopters and non-adopters of CSA innovations using the major components of exposure, sensitivity, and adaptive capacity showed that improved varieties have a significantly lower natural disaster and climate change index and a higher ecosystem index but a lower agriculture index than non-adopters. Hence, adopters of improved varieties have a lower climate change exposure index than non-adopters due to their adoption of high-yielding and drought-resistant varieties. In terms of adaptive capacity, adopters of improved varieties have significantly higher wealth and technology indices while having a lower knowledge skill index

than non-adopters. As the productivity of these farmers increases due to the adoption of improved variety, their wealth increases through increased farm income. Hence, adopters of improved varieties have a higher adaptive capacity index than non-adopters. Thus, adopters of improved varieties have a lower climate change exposure index as these farmers mostly live in the midland with black and brown soil agroecosystem zones (AESZ2 and AESZ3) as well as a higher adaptive capacity index than non-adopters. Consequently, adopters of improved varieties are significantly less vulnerable to climate change and enhance adaptation to climate change through the adoption of high-yield, improved wheat varieties and drought-resistant maize varieties among smallholder farmers (**Chapter 4**).

Adopters of crop residue management have a higher climate change exposure index than non-adopters. In terms of the sensitivity of their livelihood, adopters of crop residue management have a lower ecosystem and agriculture index than non-adopters, which results in them having a lower sensitivity index than non-adopters. In terms of adaptive capacity, adopters have a significantly lower wealth index and a lower social network index than non-adopters. Yet, adopters of crop residue management have a higher adaptive capacity index than non-adopters, but there is no difference in the IPCC-LVI among adopters and non-adopters. Crop residue management on farm plots might be considered essential in promoting the physical, chemical, and biological aspects of soil health in smallholder agriculture systems due to the dearth of substitute organic amendments. However, smallholder farmers must make trade-offs when managing crop residues because of several alternative uses, such as livestock feed and fuel sources, which is the case in the study area. One reason for the trade-off effect of crop residue management is the lack of crop residue for farm management. Thus, conclusions about the effect of crop residue management on reducing livelihood vulnerability to climate change in particular and enhancing adaptation to climate change, in general, are inconclusive.

Adopters of crop rotation have a higher natural disaster and climate change exposure index than non-adopters. This shows that areas with variable climates or environmental stress-response characteristics adopt crop rotation. Farmers reported that it allows them to grow products that can be harvested at different times and in different climates, helping weed management and reducing pest and disease infestations. In terms of adaptive capacity, the wealth index and knowledge index of adopters are significantly lower than those of non-adopters. However, the adaptive capacity

index of adopters is significantly higher than that of non-adopters, so technology, infrastructure, and social networks offset the deficits in the wealth and knowledge indices of adopters. However, the adaptive capacity index does not offset the natural disaster and climate change indices. Hence, there is a significantly higher IPCC-LVI for adopters than for non-adopters. Crop rotation makes farmers' livelihoods more vulnerable to climate change because farmers in spatiotemporally climate-change-exposed agroecosystems prefer crop rotation, and their adaptive capacities in terms of technology adoption, wealth, knowledge, infrastructure, and social networks do not offset exposure to climate change (**Chapter 4**).

Compost adopters have a higher ecosystem sensitivity index, which shows that compost is an important organic fertilizer because of its nutrient content and diverse effects on soil fertility and crop productivity, while non-adopters have a lower agricultural sensitivity index. This suggests that the adoption of compost improves soil structure, resulting in greater resistance to erosion, improved water infiltration, and increased water holding capacity, which results in improved crop yield non-adopters have a lower agricultural sensitivity index. This suggests that the adoption of compost improves soil structure, resulting in greater resistance to erosion, improved water infiltration, and increased water holding capacity, which results in improved crop yield. Hence, adopters of compost have a significantly higher sensitivity index than non-adopters because of the higher ecosystem sensitivity of agroecosystems. In terms of adaptive capacity, adopters of compost have significantly lower wealth and infrastructure indexes than non-adopters. However, the adaptive capacity index of adopters of compost is significantly higher than non-adopters. Hence, there is a significantly lower IPCC-LVI for adopters than for non-adopters. Thus, the adoption of compost significantly reduces livelihood vulnerability to climate change (**Chapter 4**).

Farmers adopt row planting not only to reduce seed rates but also to allow more spacing between seedlings, permit easy weeding and reduce competition between seedlings, which increases productivity and reduces vulnerability to climate change. The study shows that adopters of row planting have a lower natural disaster and climate change exposure index than non-adopters. This suggests that adopters of row planting live in less climate change-exposed agroecosystems than non-adopters. Adopters also have a higher ecosystem sensitivity index but a lower agricultural sensitivity index than non-adopters. This suggests that the higher ecosystem sensitivity of adopters of row planting is offset by good crop yield. However, due to the higher ecosystem sensitivity of

the agroecosystem, adopters of row planting have a significantly higher sensitivity index to climate change than non-adopters. In terms of adaptive capacity, though adopters of row planting have significantly lower wealth and knowledge than non-adopters, the overall adaptive capacity index of adopters of row planting is higher than that of non-adopters. The IPCC-LVI result, on the other hand, reveals that the agricultural livelihood vulnerability to climate change of adopters of row planting is significantly lower than that of non-adopters. Hence, the adoption of row planting has the significant impact of reducing agricultural livelihood vulnerability to climate change and enhancing adaptation to climate change in smallholder agriculture systems. This result concurs with studies such as one that reported that row planting enhances food security and adaptation to climate change (**Chapter 4**).

Soil and water conservation (SWC) techniques include soil bunds, stone bunds, bench terraces, vegetative barriers, and tied ridges. SWC adopters have a significantly higher natural disaster and climate change exposure indices than non-adopters. This shows that adopters of SWC are farmers who live in the lowland Abay Gorge (AESZ1), the midland sloping land (AESZ4), and the hilly and mountainous highlands (AESZ5) agroecosystem zones. Hence, the climate change exposure index of SWC adopters is significantly higher than that of non-adopters. Although they have a marginally higher ecosystem index than non-adopters, there is no significant sensitivity index difference between adopters and non-adopters of SWC. In terms of adaptive capacity, the innovation index of adopters of SWC is lower than that of non-adopters. Hence, the IPCC-LVI result shows that adopters of SWC have higher agricultural livelihood vulnerability to the climate change index than non-adopters. Thus, adopters of SWC are more vulnerable to climate change than non-adopters. This result concurs with the finding that the effect of SWC on improving crop yield is dependent on rainfall characteristics, types of crop, slope, and soil. Moreover, the effect of SWC on crop yield is negatively correlated with rainfall for SWC techniques, including level Fanya juu, graded soil bunds, stone bunds, and trash lines, which are the main characteristics of the Choke Mountain watershed (**Chapter 4**).

Agroforestry is a climate-smart agriculture system that diversifies the environmental and socioeconomic benefits of smallholder farmers sustainably, and agroforestry adopters are thought to be more resilient to the increased intensity of extreme weather events caused by climate change. In this study, agroforestry adopters have a higher climate change exposure index than non-

adopters. In terms of the sensitivity index, they have a higher ecosystem index and a lower agricultural sensitivity index than non-adopters. However, they have a significantly higher sensitivity index than non-adopters. In terms of adaptive capacity, they have higher technology adoption and lower wealth and knowledge indices than non-adopters. However, adopters of agroforestry have a significantly higher adaptive capacity index than non-adopters. Unfortunately, the IPCC-LVI result shows that there is no significant difference between the livelihood vulnerability index of adopters and non-adopters of agroforestry. This is due to the marginal adoption of agroforestry as farmland border trees and homestead gardens, as well as wood lots, rather than as an agricultural system that supports their livelihood (**Chapter 4**).

6.4.2 Effect of climate-smart agriculture innovation adoption on food and nutrition security

From the total sample households, less than one-third (33 percent) of the households were food secure (had an acceptable food consumption score), whereas more than two-thirds of the households were food insecure, with 46 and 21 percent of the households having a borderline and poor food consumption score, respectively(**Chapter 4**).

Smallholder farmers adopt CSA innovations for their different CSA benefits, either for food security or climate adaptation, or both. Adopters of SWC have more poor food consumption households than non-adopters, indicating that more SWC adopter households are food insecure than non-adopter households, i.e., they lack daily staple and vegetable consumption, as well as consumption of oil and pulses four times a week, whereas adopters of crop residue management have more acceptable food consumption households than non-adopters (**Chapter 4**).

Adopters of improved varieties and non-adopters have an acceptable food security status, with adopters having a significantly higher FCS value than non-adopters with a positive effect of food security as improved varieties significantly enhance household food security through the adoption of high-yield, improved wheat varieties. Similarly, both adopters of row planting and non-adopters have an acceptable food security status with a positive effect on food security as row planting enhances the food security of adopters. Adopters of crop residue management have acceptable food security and a significantly higher FCS value than non-adopters, who have borderline food security. Likewise, adopters of SWC have borderline food security and a significantly lower FCS value than non-adopters who have acceptable food security, with a negative effect on food security. This result concurs with the finding that the effect of SWC on improving crop yield was

dependent on rainfall characteristics, type of crop, slope, and soil. Moreover, the effect of SWC on crop yield was negatively correlated with rainfall for SWC techniques, including level Fanya juu, graded soil bunds, stone bunds, and trash lines, which are the main characteristics of the Choke mountain watershed. In general, improved varieties, row planting, and crop residue management enhance food availability as well as the food access component of food security for smallholder households, whereas, SWC reduces the food availability as well as the food access component of food security for smallholder households

Adopters of improved varieties have a higher household dietary diversity score (HDDS) than non-adopters; adopters of crop residue management have a higher HDDS than non-adopters; adopters of compost have a higher HDDS than non-adopters; adopters of row planting have a higher HDDS than non-adopters, and adopters of agroforestry have a higher HDDS than non-adopters. Thus, adopters of improved varieties, crop residue management, compost, row planting, and agroforestry consume better-diversified diets of food than non-adopters. Therefore, the adoption of these CSA innovations improves the food utilization component of the food security of smallholder households. However, the effect of the adoption of CSA innovations differs for different food security components. For instance, improved variety, crop residue management, compost, and row planting have significant positive effects on food availability and access to food security, while agroforestry has a significant positive effect on food utilization in the food security component. Moreover, SWC negatively affects the availability and access components of food security (**Chapter 4**).

6.4.3 Effect of Climate-smart Agriculture innovations on-farm greenhouse gas emissions

In terms of biomass, all CSA innovations are sinks, and they have similar GHG sink potential. Soil has the highest GHG sink potential, with the highest sink potential recorded for compost and row-planting adopters. The other source of GHG is enteric fermentation (livestock), which mainly emits CH_4; in this regard, row planting and SWC adopters are the major emitters of GHG from enteric fermentation because they have a high density of livestock and have the largest enteric fermentation emissions with mean values of 2.4 tCO_2 eq ha^{-1} yr-1, while adopters of crop residue management have the lowest enteric fermentation emission (1.8 tCO_2 eq ha^{-1} yr-1Carbon (CO_2) and nitrous oxide (N_2O) emissions from inorganic fertilizer (UREA and NPS) application accounts

show that adopters of improved varieties, row planting, SWC, and agroforestry are the biggest sources of GHG emissions in terms of input use.

C-sequestration in soils and biomass growth, when combined, offset 5 to 52 percent of farm emissions. Woody biomass (above- and belowground) accounts for 5.1 percent of C removals among farm components affecting C-sequestration. Farmers who use row planting and compost have the highest tree density and the highest C fluxes in above- and below-ground biomass, with 0.89 tCO_2 eq ha^{-1} yr-1. The remaining 64–94% of total farm GHG removals (5.7 tCO_2 eq ha^{-1} yr-1) are accounted for by soil C-sequestration. Compost users who apply the most manure to their soils experience soil C-sequestration rates greater than 2.7 tCO_2 eq ha^{-1} yr-1. Among cropping systems, wheat–maize registers the highest rates of carbon sequestration (25% of soil removals), followed by tef–wheat (22%), and potato–barley (20%).

Total emissions per year and intensity per output were calculated for farm-level GHG emissions. These two measurements show a difference in the levels of GHG emissions of CSA innovations for adopters. Hence, adopters of compost and SWC have lower farm GHG emissions per year than non-adopters. Similarly, crop residue management and compost adopters have a lower intensity of GHG emissions (net GHG emissions per yield) than non-adopters. Compost adopters have both lower gross emissions and lower net GHG emissions per yield than non-adopters. As a result, crop residue management(marginally), compost, and SWC are GHG emission sinks, and these CSA innovations can increase farm-level carbon sequestration capacity.

6.4.4 Effect of climate-smart agriculture innovation adoption on triple wins benefits

Adoption of improved varieties results in lower livelihood vulnerability and GHG emissions, as well as higher food security than both actual and counterfactual non-adopters. Hence, the adoption of improved varieties significantly reduces agricultural livelihood vulnerability to climate change, enhances food security, and reduces GHG emissions. Adoption of crop residue management has higher livelihood vulnerability and higher GHG emissions, i.e., maladaptation, with higher food security than actual and counterfactual non-adopters. Adoption of crop residue management improves food security while increasing the vulnerability of agricultural livelihoods to climate change and, against all odds, the GHG emissions from smallholder farms. However, the maladaptation of crop residue management comes more from the competition of crop residue for livestock feed and fuel sources than from soil fertility management. Adoption of crop rotation has

lower agricultural vulnerability to climate change, lower food security (i.e., maladaptation), and lower GHG emissions than actual as well as counterfactual non-adopters. Hence, the adoption of crop rotation reduces the agricultural livelihood's vulnerability to climate change and farm GHG emissions while reducing the food security of smallholder agriculture households, which is maladaptation. Adoption of compost has lower agricultural vulnerability to climate change and GHG emissions but higher food security than actual and counterfactual non-adopters. Hence, the adoption of compost reduces the agricultural livelihood's vulnerability to climate change and farm GHG emissions while enhancing the food security of smallholder agriculture households. Adoption of row planting has a lower agricultural vulnerability to climate change and GHG emissions but a higher FCS than non-adoption. Hence, the adoption of row planting enhances food security while reducing the agricultural livelihood's vulnerability to climate change and GHG emissions from smallholder farms. Adoption of soil and water conservation measures such as soil or stone bunds has lower livelihood vulnerability but higher food security and GHG emissions, i.e., maladaptation, than non-adoption. The adoption of SWC enhances food security and reduces agricultural livelihood vulnerability to climate change, but increases smallholder farm GHG emissions. SWC improves crop productivity and crop yields on terraced fields for tef, barley, and maize. Although the literature on the impact of SWC on food security is limited, a study in Eastern Ethiopia discovered that adopting soil and water conservation not only positively impacts per capita food consumption expenditure but also net crop value. Adoption of agroforestry reduces LVI and GHG emissions while increasing FCS compared to actual and counterfactual non-adopters. Hence, the adoption of agroforestry reduces agricultural livelihood vulnerability to climate change and enhances food security while reducing smallholder farm GHG emissions. Hence, a smallholder agriculture system can enhance food security, adapt to climate change, build resilience, and reduce GHG emissions by implementing a variety of CSA innovations such as sustainable land management (SLM), intercropping, crop rotation, soil and water conservation, modern input use, and agroforestry on farm plots.

6.5. Effect of CSA innovations on the development of climate-resilient livelihoods

Climate change-induced hazards such as drought, floods, hailstorms, and erratic rainfall have been happening in Ethiopia. Such climate shocks disproportionately affect low-adaptive capacity households, with varying degrees of severity across farmers. The extent of the impact is further

magnified when shocks hit households with different resilience capacities. This paper used the Climate Resilience Index (CRi) as a proxy measurement of household climate resilience capacity. A mean comparison of adopters' and non-adopters CRi of improved varieties, crop residue management, crop rotation, compost, row planting, SWC, and agroforestry was conducted.

Households that adopted improved variety, crop residue management, compost, row planting, and agroforestry have a significantly higher climate resilience index. Therefore, improved variety, crop residue management, composting, row planting, and agroforestry adoption showed significant increases in climate resilience capacities. Moreover, other studies also concur with our finding that adopters of crop residue management as a component of conservation have built climate resilience by mitigating the negative impacts of deviations in rainfall due to drought and decreased rainfall. Row-planting adopters increased their climate resilience for sustainable food production by smallholder wheat farmers. Finally, reported maintenance and enhancement of locally evolved agroforestry systems, with their high resilience and multiple benefits, can contribute to climate resilience.

The treatment effect (ATT) result showed that adopting improved varieties increased the adopters' climate resilience capacity by 18.5% while adopting improved varieties would have increased their capacity by 13.9%. However, the adoption of improved variety is more pronounced for adopters than non-adopters; i.e., some characteristics of non-adopters have made the effect of adoption of improved variety more appropriate for non-adopters than actual adopters. Hence, the climate resilience capacity of the households of counterfactual adopter households would have increased by 4% if they had adopted improved varieties through drought-resistant varieties. Adoption of crop residue management has an insignificant effect on the climate resilience capacity of actual adopters, while for the non-adopters of crop residue management, climate resilience would have increased by 6.6% had they adopted crop residue management. Some characteristics of non-adopters have made the effect of the adoption of crop residue management more appropriate for non-adopters than actual adopters. Crop rotation increased adopters' climate resilience capacity by 20.5%, while non-adopters resilience would have increased by 9.1% if crop rotation had been implemented. Hence, adoption of crop rotation has a more pronounced effect on adopters than on non-adopters. Through improved technical efficiency, adopters create a stronger agricultural production system that is resilient to climate risks. Hence, the climate resilience capacity of actual,

as well as counterfactual adopters of composting households would increase by 1.8%. Adoption has increased the climate resilience capacity of the adopters of compost by 6.0%, while for the non-adopters, climate resilience capacity would have increased by 9.6% if they had adopted compost because soil fertility management technologies increase climate resilience through increased net agricultural income, yield, and productivity. Adoption of row planting increased adopters' climate resilience capacity by 6.2% while adoption of row planting would have increased their climate resilience by 5.3%. Hence, the adoption of row planting has a more pronounced effect on adopters than on non-adopters. Thus, the climate resilience capacity of actual as well as counterfactual adopter households would increase by 3.5%. The adoption of SWC has reduced the climate resilience capacity of the adopters by 6.2%, while the climate resilience capacity of the non-adopters would have been reduced by 23.0% if they had adopted SWC. However, the adoption of SWC is more pronounced for non-adopters than adopters; i.e., some characteristics of non-adopters have made the effect of adoption of SWC more appropriate for non-adopters than actual adopters. This may be because SWC increased crop yields and improved the resilience of the agroecosystem to environmental stress. Hence, the climate resilience capacity of actual as well as counterfactual adopter households would have been reduced by 8.2% if they had adopted SWC. Adoption of agroforestry increased adopters' climate resilience capacity by 16.0%, while non-adopters climate resilience capacity would have increased by 12.9% if they had adopted agroforestry. Hence, the climate resilience capacity of actual as well as counterfactual adopter households would increase by 6.9%.

6.6. Conclusions and Recommendations

The *triple-win benefit* analysis provides worthy policy implications for building smallholder farmers' resilience to climate change. The absorptive, adaptive, transformative capacities and overall vulnerability indices generated can provide useful information to set location-specific priorities for interventions that are most needed to cope with the effects of climate change. Based on the indices of livelihood vulnerability, food security status, and level of GHG emissions as well as components of climate resilience, adopters of CSA innovations have different preferences and capacities for different innovations. Hence, the disaster risk management policies of timely provision of climate-specific information and intensive farmer training that leads to enhanced preparedness amid anticipated extreme events Availability of infrastructural facilities that include

input and output markets, water points, communications (mobile phones), human health facilitations, and veterinary services can contribute to enhancing the climate resilience capacity of smallholder farmers.

Since the vulnerability assessment presented in the study followed a household-specific approach, it can provide an indication of vulnerability for the context under consideration among smallholder farmers. Moreover, the directionality of most of the indicators used in any vulnerability assessment is context-specific and arguable. Indicators that revealed increased adaptive capacity or reduced vulnerability to climate impacts in a given context may show a different result in a different context or location. Therefore, there may be a need for more detailed agroecosystem-specific vulnerability analysis through further research.

The factors affecting farmers' perception and adaptation to climate change are directly related to socio-economic, economic, institutional, and environmental factors. Therefore, policy intervention should focus on ensuring institutional services, and infrastructural facilities, and delivering effective adaptation technologies. Ensuring effective and reliable access to climate information and improving farmers' awareness of the potential benefits of autonomous adaptation are suggested areas of policy measures. To address the negative effects of climate change on already vulnerable subsistence agriculture, the availability of adaptation technologies should be aligned with farmer CSA portfolio selection contexts.

6.6.1 Conclusion

Farmers' perceptions of climate change risk and CSA innovations affect the number and combination of innovations adopted. Farmers' perceptions of CSA innovations are determined by their expectations of the triple win (productivity/iincome, climate change adaptation, and mitigation) benefits the innovations can generate in the food system. Different CSA innovations are adopted in three stages of adaptation to climate change (perception, multiple adoptions, and then adaptation); Livelihood assets of the five capitals determine the rate and intensity of CSA innovations adopted; CSA innovations' synergy and trade-off effect determine the type and quantity of innovations adopted; In order to adapt and mitigate climate change, multiple adoption with simultaneous CSA benefits is the only way for CSA innovations to be adopted in the smallholder agriculture system.

CSA innovation adoption improves the quantity and nutritional quality of food consumed in the household. Some CSA innovations enhance the nutritional quality, while others increase the quantity consumed in the smallholder household. Adoption of CSA innovations improves the food security of smallholder farmers through sustainably increased productivity and income. Different CSA innovations have different effects on livelihood vulnerability to climate change components. In terms of increased temperature and drought occurrence, some CSA innovations have a high adaptive capacity and low sensitivity to climate change exposure, whereas others are more sensitive to increased rainfall amounts, floods, and hailstorm occurrence. Some CSA innovations reduce livelihood vulnerability to climate change, while others increase livelihood vulnerability in the smallholder agriculture system. Adoption of CSA innovations has a significant impact on smallholder agriculture systems' adaptation to climate change. CSA innovations adoptions have different effects on the carbon balance components of the smallholder agriculture system. The carbon sequestration and GHG emission potential of each CSA innovation, however, differ, along with the GHG influxes. Some CSA innovations increase farm GHG emissions through input use and investment; others also affect farm GHG emissions through energy consumption; while others reduce farm GHG emissions through annual agriculture and afforestation or woodlots, which are two important sinks of GHG emissions; and livestock and input and investment are the two consistent sources of GHG emissions in the smallholder farming system. In terms of biomass, all CSA innovations are carbon sinks, and they have similar carbon sink potential. The other source of GHG is enteric fermentation (livestock), which mainly emits methane (CH4); row planting and SWC adopters are the major emitters of GHG from enteric fermentation; some CSA innovations increase farm-level GHG emissions, while others sequester carbon or reduce GHG emissions. Except for crop residue management and SWC, all CSA innovations are potential carbon sinks.

Adoption of CSA innovations builds the climate resilience capacity of smallholder farmers through enhanced absorptive, adaptive, or transformative capacities. Disaster risk mitigation and early warning systems, as well as informal safety nets, enhance household absorptive capacity, thereby building the climate resilience capacity of CSA innovators. Households' increased productivity through higher wealth and income, which includes more durable assets, a larger farm size, a larger livestock holding, a greater number of plots, farm income, and improved food security in terms of quantity and quality of food consumption, fosters strong adaptive capacity. Higher information and

training indexes, as well as a strong public agricultural extension system, led to higher transformative capacity among CSA innovators. This demonstrates that smallholder farmers' primary source of transformative capacity is access to basic services. Except for SWC adopters, all CSA innovations significantly increased the climate resilience capacity of households. However, improved variety, crop residue management, and SWC have a more profound effect on the non-adopters than adopters would have had if non-adopters had adopted these CSA innovations. Scaling up CSA innovations may thus broaden the benefits of CSA innovation in terms of building households' climate resilience capacities. Thus, strong risk management, disaster mitigation, early warning systems, adaptive strategies, information and training, an informal safety net, a social network, and infrastructure use may build the climate resilience capacity of smallholder farmers by facilitating the adoption of CSA innovations.

6.6.2. Recommendation

The policy implications and the lessons that are drawn from the empirical results of this study are briefly summarized as follows:

- Enhance farmers' awareness of climate change and climate smart agriculture innovations through FTC training and Farmer to farmer communication;
- Increase the number of farm demonstration on the adoption of CSA innovations;
- Enhance the livelihood asset base of smallholder farmers through asset building programs and projects;
- Identify and develop CSA innovations portfolio in terms of synergy and trade-off effect for a particular agroecosystem zone;
- Encourage multiple adoption of CSA innovations through CSA incentives ;
- Provide farmers with vegetables seed , perennials tree seed, and train them to adopt home garden agroforestry system ;
- Increase the provision of drought resistant and high yield maize and wheat variety
- Reduce chemical fertilizer use and adopt organic farming practices
- Plant trees on a farm boundaries for energy consumption and reduce use of crop residue for fuel ;

- Competition surrounding crop residue utilization for soil fertility management and as a livestock feed source should be resolved by encouraging farmers to plant more forage trees on SWC structures, reducing the burden of crop residue as a livestock feed source.
- Increase afforested and woodlots on degraded farm lands to rehabilitate using acacia decrence tree ;
- Reduce livestock's number and increase their output capacity through adoption of high yield breeds ;
- Enhance disaster risk mitigation and early warning systems through mobile text messaging and agricultural service hotline ;
- Encourage young farmers to rent or share crop more land to secure their food security from vulnerable smallholder farmers such as widowed housewives and elderly people
- Give more agricultural , climate change , and CSA innovation information and training for young and educated farmers;
- Strengthen access to basic services through building climate resilience infrastructure.
- Scaling up CSA innovations may thus broaden the benefits of CSA innovation in terms of building households' climate resilience capacities.

Finally, given the limitations of this study, some implications do deserve further research to make the signified recommendations more robust. These include:

- Policies on CSA governance, social cohesion, disaster communication, early warning systems, and climate-smart extension service should be next research area.
- The requirement for panel data information in order to assess over time, long-term effects, and dynamic linkages among the variables studied in this study;
- The need to make policy analyses of the different CSA innovations in different parts of Ethiopia so as to prioritize them based on their potential benefits and profitability, both at individual and community levels;
- The need to have wider and more diverse coverage of the same issue across the entire Blue Nile River basin

Further research is also recommended regarding constructs of perception using exploratory factor analysis.

References

Abate, T., Shiferaw, B., Menkir, A., Wegary, D., Kebede, Y., Tesfaye, K., Kassie, M., Bogale, G., Tadesse, B., & Keno, T. (2015a). Factors that transformed maize productivity in Ethiopia. *Food Security*, *7*(5), 965–981. https://doi.org/10.1007/s12571-015-0488-z

Abate, T., Shiferaw, B., Menkir, A., Wegary, D., Kebede, Y., Tesfaye, K., Kassie, M., Bogale, G., Tadesse, B., & Keno, T. (2015b). Factors that transformed maize productivity in Ethiopia. *Food Security*, *7*(5), 965–981. https://doi.org/10.1007/s12571-015-0488-z

Abbas, F., Hammad, H. M., Fahad, S., Cerdà, A., Rizwan, M., Farhad, W., Ehsan, S., & Bakhat, H. F. (2017). Agroforestry: a sustainable environmental practice for carbon sequestration under the climate change scenarios—a review. *Environmental Science and Pollution Research*, *24*(12), 11177–11191. https://doi.org/10.1007/s11356-017-8687-0

Abyiot, T., Belay, S., & Bezabih, M. (2022). Effects of perceptions on adoption of climate-smart agriculture innovations: empirical evidence from the upper Blue Nile Highlands of Ethiopia. *International Journal of Climate Change Strategies and Management*, *14*(3), 293–311. https://doi.org/10.1108/IJCCSM-04-2021-0035

Abyiot, T., Belay, S., & Mintewab, A. (2022). Effects of perceptions on adoption of climate-smart agriculture innovations: empirical evidence from the upper Blue Nile Highlands of Ethiopia. *International Journal of Climate Change Strategies and Management*, *14*(3), 293–311. https://doi.org/10.1108/IJCCSM-04-2021-0035

Adego, T., Simane, B., & Woldie, G. A. (2019). The impact of adaptation practices on crop productivity in northwest Ethiopia: an endogenous switching estimation. *Development Studies Research*, *6*(1), 129–141. https://doi.org/10.1080/21665095.2019.1678186

Adesina, A., & Jojo, B.-F. (1995). Farmers' perceptions and adoption of new agricultural technology. *Agircultural Economics*, *13*, 1–9. http://impact.cgiar.org/sites/default/files/pdf/230.pdf

Adesina, A., & Moses, Z. (1993). Technology characteristics, farmers' perceptions and adoption decisions: A Tobit model application in Sierra Leone. *Agricultural Economics*, *9*(4), 297–311. https://doi.org/10.1016/0169-5150(93)90019-9

Adger, W. N. (2005). Social-Ecological Resilience to Coastal Disasters. *Science*, *309*(5737), 1036–1039. https://doi.org/10.1126/science.1112122

Adgo, E., Teshome, A., & Mati, B. (2013). Impacts of long-term soil and water conservation on agricultural productivity: The case of Anjenie watershed, Ethiopia. *Agricultural Water Management*, *117*, 55–61. https://doi.org/10.1016/j.agwat.2012.10.026

Adimassu, Z., Langan, S., Johnston, R., Mekuria, W., & Amede, T. (2017). Impacts of Soil and Water Conservation Practices on Crop Yield, Run-off, Soil Loss and Nutrient Loss in Ethiopia: Review and Synthesis. *Environmental Management*, *59*(1), 87–101. https://doi.org/10.1007/s00267-016-0776-1

Adimassu, Z., Mekonnen, K., Yirga, C., & Kessler, A. (2014). Effect of soil bunds on runoff, soil and nutrient losses, and crop yield in the central highlands of ethiopia. *Land Degradation and Development*, *25*(6), 554–564. https://doi.org/10.1002/ldr.2182

Aditya, B., Amri, I., & Putri, R. F. (2020). Farmer's perception and knowledge on landslide occurrences in Beruk Village, Karanganyar Regency, Central Java. *IOP Conference Series: Earth and Environmental Science*, *451*(1). https://doi.org/10.1088/1755-1315/451/1/012050

Adjimoti, G. O., & Kwadzo, G. T. M. (2018). Crop diversification and household food security status: Evidence from rural Benin. *Agriculture and Food Security*, *7*(1), 1–12. https://doi.org/10.1186/s40066-018-0233-x

Agidie, A., Ayele, B., Wassie, A., Hadgu, K. M., Aynekulu, E., & Mowo, J. (2014). AGROFORESTRY PRACTICES AND FARMERS' PERCEPTION IN KOGA WATERSHED, UPPER BLUE NILE BASIN, ETHIOPIA. *Agriculture and Forestry*, *60*(2), 177–192. http://search.proquest.com/openview/9f836312f60bc0cd8e6ca4d03d630021/1?pq-origsite=gscholar&cbl=1446337

Agriculture, S., Alliance, G., Agriculture, S., Agriculture, C., Agriculture, C. S., Agriculture, C. S., Agriculture, C. S., Smart, C., Smart, C., Alliance, T. G., Agriculture, C. S., Groups, A., & Internationales, R. (2015). *Don ' t be fooled ! Civil society says NO to " Climate Smart Agriculture " and urges decision -makers to support agroecology International organisations (55)* (Issue July).

Akalu, T., Graaff, J. de, & Kassie, M. (2016). Household-Level Determinants of Soil and Water Conservation Adoption Phases: Evidence from North-Western Ethiopian Highlands. *Environmental Management*, *57*(3), 620–636. https://doi.org/10.1007/s00267-015-0635-5

Akalu, T., Rolker, D., & Graaff, J. de. (2013). Financial viability of soil and water conservation technologies in northwestern Ethiopian highlands. *Applied Geography*, *37*(1), 139–149. https://doi.org/10.1016/j.apgeog.2012.11.007

Al-Sari, M. I., Sarhan, M. A. A., & Al-Khatib, I. A. (2018). Assessment of compost quality and usage for agricultural use: a case study of Hebron, Palestine. *Environmental Monitoring and Assessment*, *190*(4). https://doi.org/10.1007/s10661-018-6610-x

Alemu, G. T., Berhanie Ayele, Z., & Abelieneh Berhanu, A. (2017). Effects of Land Fragmentation on Productivity in Northwestern Ethiopia. *Advances in Agriculture*, *2017*. https://doi.org/10.1155/2017/4509605

Alfani, F., Arslan, A., McCarthy, N., Cavatassi, R., & Sitko, N. (2021). Climate resilience in rural Zambia: Evaluating farmers' response to El Niño-induced drought. *Environment and Development Economics*, *26*(5–6), 582–604. https://doi.org/10.1017/S1355770X21000097

Ali, K. A., Muhammad Amin, S., & Abdullah, R. A. (2021). Late sowing date influence on wheat and triticale crop yields as a draught management tool. *Journal of the Saudi Society of Agricultural Sciences*, *20*(6), 353–358. https://doi.org/10.1016/j.jssas.2021.04.002

Amadu, F. O., Miller, D. C., & McNamara, P. E. (2020). Agroforestry as a pathway to agricultural

yield impacts in climate-smart agriculture investments: Evidence from southern Malawi. *Ecological Economics*, *167*(August 2019), 106443. https://doi.org/10.1016/j.ecolecon.2019.106443

Amare, F., & Beyene, A. (2019a). Climate-smart agricultural practices and welfare of rural smallholders in Ethiopia: Does planting method matter? *Land Use Policy*, *85*(April), 387–396. https://doi.org/10.1016/j.landusepol.2019.04.020

Amare, F., & Beyene, A. (2019b). Climate-smart agricultural practices and welfare of rural smallholders in Ethiopia: Does planting method matter? *Land Use Policy*, *85*(5), 387–396. https://doi.org/10.1016/j.landusepol.2019.04.020

Andrieu, N., Sogoba, B., Zougmore, R., Howland, F., Samake, O., Bonilla-Findji, O., Lizarazo, M., Nowak, A., Dembele, C., & Corner-Dolloff, C. (2017). Prioritizing investments for climate-smart agriculture: Lessons learned from Mali. *Agricultural Systems*, *154*, 13–24. https://doi.org/https://doi.org/10.1016/j.agsy.2017.02.008

Arora, N. K. (2019). Impact of climate change on agriculture production and its sustainable solutions. *Environmental Sustainability*, *2*(2), 95–96. https://doi.org/10.1007/s42398-019-00078-w

Arslan, A., McCarthy, N., Lipper, L., Asfaw, S., Cattaneo, A., & Kokwe, M. (2015). *Food security and adaptation impacts of potential climate smart agricultural practices in Zambia* (Issue January). http://www.fao.org/3/a-i4365e.pdf

Aryal, J. P., Farnworth, C. R., Khurana, R., Ray, S., Sapkota, T. B., & Rahut, D. B. (2020). Does women's participation in agricultural technology adoption decisions affect the adoption of climate-smart agriculture? Insights from Indo-Gangetic Plains of India. *Review of Development Economics*, *24*(3), 973–990. https://doi.org/10.1111/rode.12670

Aryal, J. P., Jat, M. L., Sapkota, T. B., Khatri-Chhetri, A., Kassie, M., Rahut, D. B., & Maharjan, S. (2018). Adoption of multiple climate-smart agricultural practices in the Gangetic plains of Bihar, India. *International Journal of Climate Change Strategies and Management*, *10*(3), 407–427. https://doi.org/10.1108/IJCCSM-02-2017-0025

Asfaw, S., Coromaldi, M., & Lipper, L. (2015). Adaptation to climate risk and food security: Evidence from smallholder farmers in Ethiopia. In *FAO* (Issue February). file:///Articles/2015/Asfaw/FAO 2015 Asfaw-2.pdf

Asmamaw, M., Mereta, S. T., & Ambelu, A. (2019). Exploring households' resilience to climate change-induced shocks using Climate Resilience Index in Dinki watershed, central highlands of Ethiopia. *PLoS ONE*, *14*(7), 1–21. https://doi.org/10.1371/journal.pone.0219393

Asmare, F., Teklewold, H., & Mekonnen, A. (2019). The effect of climate change adaptation strategy on farm households welfare in the Nile basin of Ethiopia. *International Journal of Climate Change Strategies and Management*, *11*(4), 518–535. https://doi.org/10.1108/IJCCSM-10-2017-0192

Assefa, A., & Laerhoven, F. Van. (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

Atwoli, L., Erhabor, G. E., Gbakima, A. A., Haileamlak, A., Ntumba, J. M. K., Kigera, J., Laybourn-Langton, L., Mash, R., Muhia, J., Mulaudzi, F. M., Ofori-Adjei, D., Okonofua, F., Rashidian, A., El-Adawy, M., Sidibé, S., Snouber, A., Tumwine, J., Yassien, M. S., Yonga, P., … Zielinski, C. (2022). COP27 Climate Change Conference: urgent action needed for Africa and the world. *The Lancet Healthy Longevity*, *3*(11), e731–e733. https://doi.org/10.1016/S2666-7568(22)00244-6

Aweke, C. S., Hassen, J. Y., Wordofa, M. G., Moges, D. K., Endris, G. S., & Rorisa, D. T. (2021). Impact assessment of agricultural technologies on household food consumption and dietary diversity in eastern Ethiopia. *Journal of Agriculture and Food Research*, *4*(February 2020), 100141. https://doi.org/10.1016/j.jafr.2021.100141

Awoke, H. M. (2021). Member commitment in agricultural cooperatives: Evidence from Ethiopia. *Cogent Business and Management*, *8*(1). https://doi.org/10.1080/23311975.2021.1968730

Ayal, M., Negash, R., & Abebe, A. (2018). Determinants of Adoption of Teff Row Planting Practice: The Case of Baso Liben Woreda, East Gojjam Zone, Amhara Region, Ethopia. *International Journal of Current Research and Academic Review*, *6*(10), 16–22. https://doi.org/10.20546/ijcrar.2018.610.003

Ayele, A. W., Kassa, M., Fentahun, Y., & Edmealem, H. (2020). Prevalence and associated factors for rural households food insecurity in selected districts of east Gojjam zone, northern Ethiopia: Cross-sectional study. *BMC Public Health*, *20*(1), 1–13. https://doi.org/10.1186/s12889-020-8220-0

Aynalem, B. Y., & Melesse, M. F. (2021). Health extension service utilization and associated factors in East Gojjam zone, Northwest Ethiopia: A community-based cross-sectional study. *PLoS ONE*, *16*(8 August), 1–12. https://doi.org/10.1371/journal.pone.0256418

Ayugi, B., Eresanya, E. O., Onyango, A. O., Ogou, F. K., Okoro, E. C., Okoye, C. O., Anoruo, C. M., Dike, V. N., Ashiru, O. R., Daramola, M. T., Mumo, R., & Ongoma, V. (2022). Review of Meteorological Drought in Africa: Historical Trends, Impacts, Mitigation Measures, and Prospects. *Pure and Applied Geophysics*. https://doi.org/10.1007/s00024-022-02988-z

Azam, M. M., & Okitasari, M. (2015). Environmental Governance and National Preparedness towards 2030 Agenda for Sustainable Development : A Tale of Two Countries. *Global Environmental Research*, *19*(2). http://papers.ssrn.com/sol3/Papers.cfm?abstract_id=2682908

Bahta, Y. T., & Myeki, V. A. (2022). The Impact of Agricultural Drought on Smallholder Livestock Farmers: Empirical Evidence Insights from Northern Cape, South Africa. *Agriculture (Switzerland)*, *12*(4). https://doi.org/10.3390/agriculture12040442

Bazzana, D., Foltz, J., & Zhang, Y. (2021). Impact of climate smart agriculture on food security: an agent-based analysis. In *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.3857718

Bedada, W., Karltun, E., Lemenih, M., & Tolera, M. (2014). Long-term addition of compost and

NP fertilizer increases crop yield and improves soil quality in experiments on smallholder farms. *Agriculture, Ecosystems and Environment*, *195*, 193–201. https://doi.org/10.1016/j.agee.2014.06.017

Beddington, J., Asaduzzaman, M., Clark, M. E., Fernandez Bremauntz, A., Guillou, M. D., Howlett, D. J. B., Jahn, M. M., Lin, E., Mamo, T., Negra, C., Nobre, C. a., Scholes, R. J., Van Bo, N., & Wakhungu, J. (2012). What Next for Agriculture After Durban? *Science*, *335*(6066), 289–290. https://doi.org/10.1126/science.1217941

Bekele, A., Aticho, A., & Kissi, E. (2018). Assessment of community based watershed management practices: emphasis on technical fitness of physical structures and its effect on soil properties in Lemo district, Southern Ethiopia. *Environmental Systems Research*, *7*(1). https://doi.org/10.1186/s40068-018-0124-y

Belay, D., & Fekadu, G. (2021). Influence of social capital in adopting climate change adaptation strategies: empirical evidence from rural areas of Ambo district in Ethiopia. *Climate and Development*, 1–12. https://doi.org/10.1080/17565529.2020.1862741

Béné, C. (2020). Resilience of local food systems and links to food security – A review of some important concepts in the context of COVID-19 and other shocks. *Food Security*, *12*(4), 805–822. https://doi.org/10.1007/s12571-020-01076-1

Béné, C., & Doyen, L. (2018). From Resistance to Transformation: A Generic Metric of Resilience Through Viability. *Earth's Future*, *6*(7), 979–996. https://doi.org/10.1002/2017EF000660

Béné, C., Frankenberger, T., & Nelson, S. (2015). Design, Monitoring and Evaluation of Resilience Interventions: Conceptual and Empirical Considerations. *Institute of Development Studies*, *2015*(459), 26. http://www.ids.ac.uk/publication/design-monitoring-and-evaluation-of-resilience-interventions-conceptual-and-empirical-considerations

Béné, C., Headey, D., Haddad, L., & von Grebmer, K. (2016). Is resilience a useful concept in the context of food security and nutrition programmes? Some conceptual and practical considerations. *Food Security*, *8*(1), 123–138. https://doi.org/10.1007/s12571-015-0526-x

Béné, C., Newsham, A., Davies, M., Ulrichs, M., & Godfrey-Wood, R. (2014). Review article: Resilience, poverty and development. In *Journal of International Development* (Vol. 26, Issue 5, pp. 598–623). https://doi.org/10.1002/jid.2992

Béné, C., Wood, R. G., Newsham, A., & Davies, M. (2012). Resilience: New Utopia or New Tyranny? Reflection about the Potentials and Limits of the Concept of Resilience in Relation to Vulnerability Reduction Programmes. In *IDS Working Papers* (Vol. 2012, Issue 405). https://doi.org/10.1111/j.2040-0209.2012.00405.x

Berger, R., Ensor, J., Wilson, K., Phukan, I., & Dasgupta, S. (2014). Adaptive capacity. In *Community-Based Adaptation to Climate Change: Scaling it up* (pp. 22–35). https://doi.org/10.4324/9780203105061

Berhane, Z., & Esayas, B. (2017). Livelihood resilience in the face of recurring floods: an empirical evidence from Northwest Ethiopia. *Geoenvironmental Disasters*, *4*(1).

https://doi.org/10.1186/s40677-017-0074-0

Beyene, A. D., Mekonnen, A., Kassie, M., Falco, S. Di, & Bezabih, M. (2017). Determinants of Adoption and Impacts of Sustainable Land Management and Climate Smart Agricultural Practices (SLM-CSA): Panel Data Evidence from the Ethiopian Highlands. In *Environment for Development* (Issue August). www.efdinitiative.orgorcontactinfo@efdinitiative.org.

Bezabih, M., Di Falco, S., Mekonnen, A., & Kohlin, G. (2021). Land rights and the economic impacts of climatic anomalies on agriculture: evidence from Ethiopia. *Environment and Development Economics*, *26*(5–6), 632–656. https://doi.org/10.1017/S1355770X2100022X

Bhupinderpal-Singh, & Rengel, Z. (2007). The Role of Crop Residues in Improving Soil Fertility. *Soil Biology*, *10*. https://link.springer.com/content/pdf/10.1007%2F978-3-540-68027-7_7.pdf

Birhanu, A. (2014). Environmental Degradation and Management in Ethiopian Highlands: Review of Lessons Learned. *International Journal of Environmental Protection and Policy*, *2*(1), 24. https://doi.org/10.11648/j.ijepp.20140201.14

Bizikova, L., Robinson, J., & Cohen, S. (2007). Linking climate change and sustainable development at the local level. *Climate Policy*, *7*(4), 271–277. https://doi.org/10.1080/14693062.2007.9685655

Bizikova, L., Tyler, S., Moench, M., & Keller, M. (2017). *Climate resilience and food security in Central America : a practical framework*. *5529*(April). https://doi.org/10.1080/17565529.2015.1064806

Bouroncle, C., Imbach, P., Rodríguez-Sánchez, B., Medellín, C., Martinez-Valle, A., & Läderach, P. (2016). Mapping climate change adaptive capacity and vulnerability of smallholder agricultural livelihoods in Central America: ranking and descriptive approaches to support adaptation strategies. *Climatic Change*, 1–15. https://doi.org/10.1007/s10584-016-1792-0

Branca, G., Lipper, L., McCarthy, N., & Jolejole, M. C. (2013). Food security, climate change, and sustainable land management. A review. *Agronomy for Sustainable …*, *33*(4), 635–650. https://doi.org/10.1007/s13593-013-0133-1

Brouder, S. M., & Gomez-Macpherson, H. (2014). The impact of conservation agriculture on smallholder agricultural yields: A scoping review of the evidence. *Agriculture, Ecosystems and Environment*, *187*, 11–32. https://doi.org/10.1016/j.agee.2013.08.010

Campbell, B. M., Thornton, P., Zougmoré, R., van Asten, P., & Lipper, L. (2014). 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

Campesina, L. V. (2015). "Climate Smart Agriculture" Is a Dangerous Hoax. *Green Social Thought*. http://greensocialthought.org/archive/wp-content/uploads/2015/09/gst68-32-34-LaVia-Campesina.pdf

Caron, P. (2016). Climate-smart Agriculture: Emergence of a Concept, Policy and Science Implementation, and Controversies. *Natures Sciences Sociétés*, *24*(2), 147–150.

https://doi.org/10.1051/nss/2016012.

Caron, P., & Treyer, S. (2016). Climate-Smart Agriculture and International Climate Change Negotiation Forums. In *Climate Change and Agriculture Worldwide* (pp. 325–336). Springer Netherlands. https://doi.org/10.1007/978-94-017-7462-8_25

Carter, D., & Milon, J. W. (2005). Price Knowledge in Household Demand for Utility Services. *Land Economics*, *81*(2). https://econpapers.repec.org/RePEc:uwp:landec:v:81:y:2005:i:2:p265-283

Chandra, A., McNamara, K. E., Dargusch, P., Damen, B., Rioux, J., Dallinger, J., & Bacudo, I. (2016). Resolving the UNFCCC divide on climate-smart agriculture. *Carbon Management*, *7*(5–6), 295–299. https://doi.org/10.1080/17583004.2016.1235420

Charles, R., Munishi, P. ., & Nzunda, E. F. (2013). Agroforestry as Adaptation Strategy under Climate Change in Mwanga District, Kilimanjaro, Tanzania. *International Journal of Environmental Protection*, *3*(11), 29–38.

Chaudhuri, S., Roy, M., McDonald, L. M., & Emendack, Y. (2021). Reflections on farmers' social networks: a means for sustainable agricultural development? *Environment, Development and Sustainability*, *23*(3), 2973–3008. https://doi.org/10.1007/s10668-020-00762-6

Chowdhury, A. H., Hambly Odame, H., & Leeuwis, C. (2014). Transforming the Roles of a Public Extension Agency to Strengthen Innovation: Lessons from the National Agricultural Extension Project in Bangladesh. *Journal of Agricultural Education and Extension*, *20*(1), 7–25. https://doi.org/10.1080/1389224X.2013.803990

Christopher, B., & Mark, C. (2014). Toward a theory of resilience for international development applications. *Proceedings of the National Academy of Sciences*, *111*(40), 14625–14630. https://doi.org/10.1073/pnas.1320880111

Clay, N., & Zimmerer, K. S. (2020). Who is resilient in Africa's Green Revolution? Sustainable intensification and Climate Smart Agriculture in Rwanda. *Land Use Policy*, *97*(February), 104558. https://doi.org/10.1016/j.landusepol.2020.104558

Cochran, W. (1977). *Sampling techniques*. https://scholar.google.com.tr/scholar?q=sampling+techniques&btnG=&hl=en&as_sdt=0,5#0

Colomb, V., Touchemoulin, O., Bockel, L., Chotte, J.-L., Martin, S., Tinlot, M., & Bernoux, M. (2013). Selection of appropriate calculators for landscape-scale greenhouse gas assessment for agriculture and forestry. *Environ. Res. Lett*, *8*(1), 15029–10. https://doi.org/10.1088/1748-9326/8/1/015029

Congdon Fors, H., Houngbedji, K., & Lindskog, A. (2019). Land certification and schooling in rural Ethiopia. *World Development*, *115*, 190–208. https://doi.org/10.1016/j.worlddev.2018.11.008

Constas, M., & Barrett, C. (2013). Principles of resilience measurement for food insecurity: metrics, mechanisms, and implementation plans. *Expert Consultation on Resilience*

Measurement Related to Food Security, 15.

Corbeels, M., Andersson, J. A., Mortensen, D., Vanlauwe, B., Kirkegaard, J., Erenstein, O., & Giller, K. E. (2015). Beyond conservation agriculture. *Frontiers in Plant Science*, *6*(October). https://doi.org/10.3389/fpls.2015.00870

De Graaff, J., Aklilu, A., Ouessar, M., Asins-Velis, S., & Kessler, A. (2013). The development of soil and water conservation policies and practices in five selected countries from 1960 to 2010. *Land Use Policy*, *32*, 165–174. https://doi.org/10.1016/j.landusepol.2012.10.018

Deichert, G., Gedamu, A., & Nemomsa, B. (2017). Role of Sustainable Land Management (SLM) in Adapting to Climate Variability Through Agricultural Practices—Experiences from Ethiopian Highlands. In *Climate Change Management* (pp. 475–492). https://doi.org/10.1007/978-3-319-49520-0_29

Delaney, M., Hairiah, K., & Purnomosidhi, P. (2002). Carbon stocks in Indonesian homegarden systems: Can smallholder systems be targeted for increased carbon storage? *American Journal of Alternative Agriculture*, *17*(3), 138–148. https://doi.org/10.1079/AJAA200116

Demenge, J., Alba, R., Welle, K., Manjur, K., Addisu, A., Mehta, L., & Woldearegay, K. (2015). Multifunctional Roads The Potential Effects of Combined Roads and Water Harvesting Infrastructure on Livelihoods and Poverty in Ethiopia. *Journal of Infrastructure Development*, *7*(2), 165–180.

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

Denton, F., Wilbanks, T. J., Abeysinghe, A. C., Burton, I., Gao, Q., Lemos, M. C., Masui, T., O'Brien, K. L., Warner, K., Bhadwal, S., Leal, W., Van Ypersele, J. P., & Wright, S. B. (2015). Climate-resilient pathways: Adaptation, mitigation, and sustainable development. In *Climate Change 2014 Impacts, Adaptation and Vulnerability: Part A: Global and Sectoral Aspects* (pp. 1101–1131). https://doi.org/10.1017/CBO9781107415379.025

Desalew M. & Aklilu A. (2017). Determinants of farmers' perception to invest in soil and water conservation technologies in the North-Western Highlands of Ethiopia. *International Soil and Water Conservation Research*, *5*(1), 56–61. https://doi.org/10.1016/j.iswcr.2017.02.003

Desalew, M., & Aklilu, A. (2017). Determinants of farmers' perception to invest in soil and water conservation technologies in the North-Western Highlands of Ethiopia. *International Soil and Water Conservation Research*, *5*(1), 56–61. https://doi.org/10.1016/j.iswcr.2017.02.003

Di Falco, S., Veronesi, M., & Yesuf, M. (2011). Does adaptation to climate change provide food security? A micro-perspective from Ethiopia. In *American Journal of Agricultural Economics* (Vol. 93, Issue 3, pp. 825–842). https://doi.org/10.1093/ajae/aar006

Di Falco, S., Veronesi, M., Yesuf, M., Falco, S. Di, Veronesi, M., & Yesuf, M. (2011). Does adaptation to climate change provide food security? A micro-perspective from Ethiopia. *American Journal of Agricultural Economics*, *93*(3), 825–842.

https://doi.org/10.1093/ajae/aar006

Dixon, J., & Stringer, L. (2015). Towards a Theoretical Grounding of Climate Resilience Assessments for Smallholder Farming Systems in Sub-Saharan Africa. *Resources*, *4*(1), 128–154. https://doi.org/10.3390/resources4010128

Djalante, R., Holley, C., Thomalla, F., & Carnegie, M. (2013). Pathways for adaptive and integrated disaster resilience. *Natural Hazards*, *69*(3), 2105–2135. https://doi.org/10.1007/s11069-013-0797-5

Dougill, A. J., Hermans, T. D. G., Eze, S., Antwi-Agyei, P., & Sallu, S. M. (2021). Evaluating climate-smart agriculture as route to building climate resilience in african food systems. *Sustainability (Switzerland)*, *13*(17), 1–8. https://doi.org/10.3390/su13179909

EFCCC. (2020). Ethiopia ' s Climate- Resilient Green Economy Strategy Agriculture. In *Federal Democratic Republic of Ethiopia* (Issue December). http://www.uncsd2012.org/content/documents/287CRGE Ethiopia Green Economy_Brochure.pdf

Endris, G. S., Kibwika, P., Obaa, B. B., & Hassan, J. Y. (2020). How social capital can inform targeting formal social safety net interventions in vulnerable communities in eastern Ethiopia: an ethnographic case study. *Journal of International Humanitarian Action*, *5*(1). https://doi.org/10.1186/s41018-020-00075-3

Ermias, T., Woldeamlak, B., Uhlenbrook, S., & Wenninger, J. (2013). Understanding recent land use and land cover dynamics in the source region of the Upper Blue Nile, Ethiopia: Spatially explicit statistical modeling of systematic transitions. *Agriculture, Ecosystems and Environment*, *165*, 98–117. https://doi.org/10.1016/j.agee.2012.11.007

Eshete, G., Assefa, B., Lemma, E., Kibret, G., Ambaw, G., Samuel, S., Seid, J., Tesfaye, K., Tamene, L., Haile, A., Asnake, A., Mengiste, A., Hailemariam, S., Ericksen, P., Mekonnen, K., Amede, T., Haileslassie, A., Hadgu, K., Woldemeskel, E., & Solomon, D. (2020). *Ethiopia CSA Roadmap Final Version*. ww.ccafs.cgiar.org.

Eshete, Y., Alamirew, B., & Bishaw, Z. (2021). Yield and cost effects of plot-level wheat seed rates and seed recycling practices in the east gojam zone, amhara region, ethiopia: Application of the dose–response model. *Sustainability (Switzerland)*, *13*(7). https://doi.org/10.3390/su13073793

Eze, S., Dougill, A. J., Banwart, S. A., Sallu, S. M., Mgohele, R. N., & Senkoro, C. J. (2022). Assessing soil system changes under climate-smart agriculture via farmers' observations and conventional soil testing. *Land Degradation and Development*, *33*(14), 2635–2646. https://doi.org/10.1002/ldr.4339

FAO. (2010a). *"Climate-Smart" Agriculture: Policies, Practices and Financing for Food Security, Adaptation and Mitigation*.

FAO. (2010b). Guidelines for measuring household and individual dietary diversity. In *Fao*. https://doi.org/613.2KEN

FAO. (2013a). *Climate-smart Agriculture Sourcebook*. FAO.

FAO. (2013b). *Resilience Index Measurement and Analysis model*.

FAO. (2018). Climate Smart Agriculture Building Resilience to Climate Change. In *Natural Resource Management and Policy* (Vol. 52). http://www.springer.com/series/6360

FAO. (2020). *Climate-Smart Agriculture (CSA) Globally Through GACSA* (Issue November).

Farnworth, C. R., Baudron, F., Andersson, J. A., Misiko, M., Badstue, L., & Stirling, C. M. (2016). Gender and conservation agriculture in East and Southern Africa: towards a research agenda. *International Journal of Agricultural Sustainability*, *14*(2), 142–165. https://doi.org/10.1080/14735903.2015.1065602

FDRE. (2011). *Ethiopia's Climate-Resilient Green Economy*.

FDRE. (2015). *Intended Nationally Determined Contribution (INDC) of the Federal Democratic Republic of Ethiopia*. http://bit.ly/1GsfaUZ

FDRE. (2019). *Ethiopia's Climate Resilient Green Economy National Adaptation Plan*.

Fentie, A., & Beyene, A. D. (2019). Climate-smart agricultural practices and welfare of rural smallholders in Ethiopia: Does planting method matter? *Land Use Policy*, *85*(May 2018), 387–396. https://doi.org/10.1016/j.landusepol.2019.04.020

Fitawek, W. B., & Legesse, B. (2018). The Role of Potato Seed Cooperative on the Livelihood of Rural Households in Ethiopia. *Journal of Agricultural Studies*, *6*(4), 10. https://doi.org/10.5296/jas.v6i4.11598

Frankenberger, T., Mueller, M., Spangler, T., & Alexander, S. (2013). Community Resilience: Conceptual Framework and Measurement. *Rockville, MD: Westat., October*, 49. https://agrilinks.org/library/community-resilience-conceptual-framework-and-measurement-feed-future-learning-agenda

Fusco, G., Melgiovanni, M., Porrini, D., & Ricciardo, T. M. (2020). How to improve the diffusion of climate-smart agriculture: What the literature tells us. *Sustainability (Switzerland)*, *12*(12), 1–16. https://doi.org/10.3390/su12125168

Fussel. (2007). Vulnerability: A generally applicable conceptual framework for climate change research. *Global Environmental Change*, *17*(2), 155–167. https://doi.org/10.1016/j.gloenvcha.2006.05.002

Füssel & Klein. (2006). Climate change vulnerability assessments: an evolution of conceptual thinking. *Climatic Change*. http://link.springer.com/article/10.1007/s10584-006-0329-3

Füssel, H.-M. (2012). Vulnerability of Coastal Populations. In *Climate Change, Justice and Sustainability: Linking Climate and Development Policy: Vol. Springer N*. https://doi.org/10.1007/978-94-007-4540-7

Gaillard, J. C. (2010). Vulnerability, capacity and resilience: Perspectives for climate and

development policy. *Journal of International Development*, *22*(2), 218–232. https://doi.org/10.1002/jid.1675

Garg, K. K., Singh, R., Anantha, K. H., Singh, A. K., Akuraju, V. R., Barron, J., Dev, I., Tewari, R. K., Wani, S. P., Dhyani, S. K., & Dixit, S. (2020). Building climate resilience in degraded agricultural landscapes through water management: A case study of Bundelkhand region, Central India. *Journal of Hydrology*, *591*, 125592. https://doi.org/10.1016/j.jhydrol.2020.125592

Gaudin, A. C. M., Tolhurst, T. N., Ker, A. P., Janovicek, K., Tortora, C., Martin, R. C., & Deen, W. (2015). Increasing crop diversity mitigates weather variations and improves yield stability. *PLoS ONE*, *10*(2), 1–20. https://doi.org/10.1371/journal.pone.0113261

Gebeyehu T., Poesen, J., Wesemael, B., Vanmaercke, M., T., D., Deckers, J., Goosse, T., Maetens, W., Nyssen, J., Hallet, V., & H., N. (2013). *Effects of land use , slope gradient , and soil and water conservation structures on runoff and soil loss in semi-arid Northern Ethiopia*. *3646*(March 2016). https://doi.org/10.1080/02723646.2013.832098

Gebremicael, T. G., Mohamed, Y. A., Betrie, G. D., van der Zaag, P., & Teferi, E. (2013). Trend analysis of runoff and sediment fluxes in the Upper Blue Nile basin: A combined analysis of statistical tests, physically-based models and landuse maps. *Journal of Hydrology*, *482*, 57–68. https://doi.org/10.1016/j.jhydrol.2012.12.023

Getaneh, Y., Alemu, A., Ganewo, Z., & Haile, A. (2022). Food security status and determinants in North-Eastern rift valley of Ethiopia. *Journal of Agriculture and Food Research*, *8*(August 2021), 100290. https://doi.org/10.1016/j.jafr.2022.100290

Gizaw, B. (2018). Traditional Knowledge on Teff (Eragrostistef) Farming Practice and Role of Crop Rotation to Enrich Plant Growth Promoting Microbes for Soil Fertility in East Showa: Ethiopia. *Agricultural Research & Technology: Open Access Journal*, *16*(5). https://doi.org/10.19080/artoaj.2018.16.556001

Golabi, M. H., Denney, M. J., & Iyekar, C. (2004). Use of Composted Organic Wastes As Alternative To Synthetic Fertilizers for. *Soil Conservation*, *234*, 1–6. http://tucson.ars.ag.gov/isco/isco13/PAPERS F-L/GOLABI.pdf

Gori Maia, A., Silveira, R. L. F. da, Veneo Campos Fonseca, C., Burney, J., & Cesano, D. (2022). Climate resilience programmes and technical efficiency: evidence from the smallholder dairy farmers in the Brazilian semi-arid region. *Climate and Development*, *14*(3), 197–207. https://doi.org/10.1080/17565529.2021.1904812

Greene, W. H. (2003). *Econometric Analysis* (R. Banister, P. J. Boardman, G. Soto, M. McHale, & L. Amato (eds.); 5th ed.). Pearson Education Inc.

Gugissa, D. A., Abro, Z., & Tefera, T. (2022). Achieving a Climate-Change Resilient Farming System through Push–Pull Technology: Evidence from Maize Farming Systems in Ethiopia. *Sustainability (Switzerland)*, *14*(5). https://doi.org/10.3390/su14052648

Hahn, M. B., Riederer, A. M., & Foster, S. O. (2009). The Livelihood Vulnerability Index: A

pragmatic approach to assessing risks from climate variability and change-A case study in Mozambique. *Global Environmental Change*, *19*(1), 74–88. https://doi.org/10.1016/j.gloenvcha.2008.11.002

Haile, G. G., Tang, Q., Hosseini-Moghari, S. M., Liu, X., Gebremicael, T. G., Leng, G., Kebede, A., Xu, X., & Yun, X. (2020). Projected Impacts of Climate Change on Drought Patterns Over East Africa. *Earth's Future*, *8*(7), 1–23. https://doi.org/10.1029/2020EF001502

Hailemariam, T., Alemu, M., & Gunnar, K. (2019). Climate change adaptation: a study of multiple climate-smart practices in the Nile Basin of Ethiopia. *Climate and Development*, *11*(2), 180–192. https://doi.org/10.1080/17565529.2018.1442801

Hailemariam, T., Alemu, M., Gunnar, K., & Salvatore, D. F. (2017). Does Adoption of Multiple Climate-Smart Practices Improve Farmers ' Climate Resilience ? *Climate Change Economics*, *08*(1).

Hanson-Easey, S., Every, D., Hansen, A., & Bi, P. (2018). Risk communication for new and emerging communities: The contingent role of social capital. *International Journal of Disaster Risk Reduction*, *28*(July 2017), 620–628. https://doi.org/10.1016/j.ijdrr.2018.01.012

Harrison, R. D., Thierfelder, C., Baudron, F., Chinwada, P., Midega, C., Schaffner, U., & van den Berg, J. (2019). Agro-ecological options for fall armyworm (Spodoptera frugiperda JE Smith)management: Providing low-cost, smallholder friendly solutions to an invasive pest. *Journal of Environmental Management*, *243*(March), 318–330. https://doi.org/10.1016/j.jenvman.2019.05.011

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 and Food Security*, *7*(1), 1–20. https://doi.org/10.1186/s40066-018-0209-x

Heckman, J., & Navarro-Lozano, S. (2004). Using matching, instrumental variables, and control functions to estimate economic choice models. *Review of Economics and Statistics*. http://www.mitpressjournals.org/doi/abs/10.1162/003465304323023660

Heinkel, S. B., Thiebes, B., Zin Mar Than, Toe Aung, Tin Tin Kyi, Win Lei Mar, Saw Sandar Oo, Miller, C., Willkomm, M., Win Maung, Zin Nwe Myint, Khin Khin Soe, Spohner, R., & Kraas, F. (2022). Disaster preparedness and resilience at household level in Yangon, Myanmar. *Natural Hazards*, *112*(2), 1273–1294. https://doi.org/10.1007/s11069-022-05226-w

Hellin, J., Fisher, E., & Loboguerrero, A. M. (2021). Reflections on Enhancing the Impact of Climate Risk Management Through Transformative Adaptation. *Frontiers in Climate*, *3*(December), 1–7. https://doi.org/10.3389/fclim.2021.751691

Hengsdijk, H., & Verhagen, A. (2013). *Linking climate smart agriculture and good agriculture practices: case studies on consumption potatoes in South Africa, the Netherlands and Ethiopia*.

http://www.researchgate.net/profile/H_Hengsdijk/publication/264346884_Linking_Climate_Smart_Agriculture_and_Good_Agricultural_Practices_Case_studies_on_consumption_potatoes_in_South_Africa_the_Netherlands_and_Ethiopia/links/53d93e7f0cf2631430c3b920.pdf

Huang, J., Nie, F., & Bi, J. (2015). *Comparison of Food Consumption Score (FCS) and Calorie Intake Indicators to Measure Food Security*. *Ssemse*. https://doi.org/10.2991/ssemse-15.2015.296

IPCC. (2006). *2006 IPCC guidelines for national greenhouse gas inventories*. http://www.ipcc-tfi.iges.or.jp/meeting/pdfiles/Washington_Report.pdf

IPCC. (2019). Summary for Policymakers. In *An IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems*. Cambridge University Press.

Jacob, J. M. (2015). *Climate-Smart Agriculture: Farmer's Bane Or Boon?* http://academicworks.cuny.edu/gc_etds/988/

Jaleta, M., Kassie, M., & Erenstein, O. (2015). Determinants of maize stover utilization as feed, fuel and soil amendment in mixed crop-livestock systems, Ethiopia. *Agricultural Systems*, *134*, 17–23. https://doi.org/10.1016/j.agsy.2014.08.010

Jamil, I., Jun, W., Mughal, B., Raza, M. H., Imran, M. A., & Waheed, A. (2021). Does the adaptation of climate-smart agricultural practices increase farmers' resilience to climate change? *Environmental Science and Pollution Research*, *28*(21), 27238–27249. https://doi.org/10.1007/s11356-021-12425-8

Jat, M. L., Rahut, D. B., Kassie, M., Khatri-Chhetri, A., Aryal, J. P., Maharjan, S., & Sapkota, T. B. (2018). Adoption of multiple climate-smart agricultural practices in the Gangetic plains of Bihar, India. *International Journal of Climate Change Strategies and Management*, *42*, 141–158. https://doi.org/10.1108/ijccsm-02-2017-0025

Jerneck, A., & Olsson, L. (2013). More than trees! Understanding the agroforestry adoption gap in subsistence agriculture: Insights from narrative walks in Kenya. *Journal of Rural Studies*, *32*, 114–125. https://doi.org/https://doi.org/10.1016/j.jrurstud.2013.04.004

Jirata, M., Grey, S., & Kilawe, E. (2016). Ethiopia Climate-Smart Agriculture Scoping Study. *FAO, Addis Abab*.

Kaczan, D., Arslan, A., & Lipper, L. (2013). *Climate-Smart Agriculture: A review of current practice of agroforestry and conservation agriculture in Malawi and Zambia*. https://scholar.google.com/scholar?start=40&q=Climate+smart+agriculture&hl=en&as_sdt=0,5#5

Kalele, D. N., Ogara, W. O., Oludhe, C., & Onono, J. O. (2021). Climate change impacts and relevance of smallholder farmers' response in arid and semi-arid lands in Kenya. *Scientific African*, *12*, e00814. https://doi.org/10.1016/j.sciaf.2021.e00814

Kassaye, A. Y., Shao, G., Wang, X., & Belete, M. (2022). Evaluating the practices of climate-

smart agriculture sustainability in Ethiopia using geocybernetic assessment matrix. *Environment, Development and Sustainability*, *24*(1), 724–764. https://doi.org/10.1007/S10668-021-01466-1

Kassie, G. W. (2016). Agroforestry and land productivity: Evidence from rural Ethiopia. *Cogent Food & Agriculture*, *2*(1), 1–17. https://doi.org/10.1080/23311932.2016.1259140

Kassie, M., Jaleta, M., Shiferaw, B., Mmbando, F., & Mekuria, M. (2013). Adoption of interrelated sustainable agricultural practices in smallholder systems: Evidence from rural Tanzania. *Technological Forecasting and Social Change*, *80*(3), 525–540. https://doi.org/10.1016/j.techfore.2012.08.007

Kassie, M., Köhlin, G., Bluffstone, R., & Holden, S. (2011). *Are soil conservation technologies " win-win ?" A case study of Anjeni in the north-western Ethiopian highlands*. *35*, 89–99.

Kato, E., Ringler, C., Yesuf, M., & Bryan, E. (2011). Soil and water conservation technologies: a buffer against production risk in the face of climate change? Insights from the Nile basin in Ethiopia. *Agricultural Economics*, *42*, 593–604. http://onlinelibrary.wiley.com/doi/10.1111/j.1574-0862.2011.00539.x/full

Kebede, A. (2020). Smallholder Farmers' Perception and Adaptation Strategies to Climate Change and Variability in Ankesha Guagusa District of Awi Zone, North Western Ethiopia. *Journal of Economics and Sustainable Development*, *11*(1). https://doi.org/10.7176/jesd/11-1-05

Kerr, R. B., Hasegawa, T., & Rodel, L. (2022). IPCC WGII Sixth Assessment Report : Food , Fibre and Ecosystem. In *Climate change 2022*.

Ketemaw, M., Tsehay, A. S., & Lemma, S. E. (2022). Training at farmers training centers and its impact on crop productivity and households' income in Ethiopia: A propensity score matching (PSM) analysis. *Heliyon*, *8*(7), e09837. https://doi.org/10.1016/j.heliyon.2022.e09837

Khatri-Chhetri, A., Aryal, J. J. P., Sapkota, T. T. B., & Khurana, R. (2016). Economic benefits of climate-smart agricultural practices to smallholder farmers in the Indo-Gangetic Plains of India. *Current Science*, *110*(7), 1251–1256. https://doi.org/10.18520/cs/v110/i7/1251-1256

Kindie, T., Kassie, M., Cairns, J. E., Michael, M., Stirling, C., Abate, T., Prasanna, B. M., Mekuria, M., Hailu, H., Rahut, D. B., Erenstein, O., & Gerard, B. (2017). Potential for Scaling up Climate Smart Agricultural Practices: Examples from Sub-Saharan Africa. In *Climate Change Management* (pp. 185–203). https://doi.org/10.1007/978-3-319-49520-0_12

Knowler, D., & Bradshaw, B. (2007). Farmers' adoption of conservation agriculture: A review and synthesis of recent research. *Food Policy*, *32*(1), 33. https://doi.org/10.1016/j.foodpol.2006.01.003

Komarek, A. M., Thurlow, J., Koo, J., & De Pinto, A. (2019). Economywide effects of climate-smart agriculture in Ethiopia. *Agricultural Economics (United Kingdom)*, *50*(6), 765–778. https://doi.org/10.1111/agec.12523

Kombat, R., Sarfatti, P., & Fatunbi, O. A. (2021). A Review of Climate-Smart Agriculture Technology Adoption by Farming Households in Sub-Saharan Africa. *Sustainability*, *13*(21), 12130. https://doi.org/10.3390/su132112130

Kosmowski, F. (2018). Soil water management practices (terraces) helped to mitigate the 2015 drought in Ethiopia. *Agricultural Water Management*, *204*(April), 11–16. https://doi.org/10.1016/j.agwat.2018.02.025

Kpadonou, R., Owiyo, T., Barbier, B., Denton, F., Rutabingwa, F., & Kiema, A. (2017). Advancing climate-smart-agriculture in developing drylands: Joint analysis of the adoption of multiple on-farm soil and water conservation technologies in West African Sahel. *Land Use Policy*, *61*, 196–207. https://doi.org/10.1016/j.landusepol.2016.10.050

Kumar, R., Bhatnagar, P. R., Kakade, V., & Dobhal, S. (2020). Tree plantation and soil water conservation enhances climate resilience and carbon sequestration of agro ecosystem in semi-arid degraded ravine lands. *Agricultural and Forest Meteorology*, *282–283*(November 2019), 107857. https://doi.org/10.1016/j.agrformet.2019.107857

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*(3). https://doi.org/10.3389/fsufs.2020.00055

Lasco, R. D., Delfino, R. J. P., & Espaldon, M. L. O. (2014). Agroforestry systems: Helping smallholders adapt to climate risks while mitigating climate change. *Wiley Interdisciplinary Reviews: Climate Change*, *5*(6), 825–833. https://doi.org/10.1002/wcc.301

Leal Filho, W., Esilaba, A. O., Rao, K. P., & Sridhar, G. (2015). Adapting African Agriculture to Climate Change: Transforming rural livelihoods. In *Adapting African agriculture to climate change*. Springer. https://doi.org/10.1007/978-3-319-13000-2

Lemlem, A., & Darnhofer, I. (2015). *Enhancing social-ecological resilience through social learning : A case study of communal pasture management in the Highlands of Ethiopia*. *10*(51), 4681–4698. https://doi.org/10.5897/AJAR2015.10318

Lemlem, A., Darnhofer, I., Tegegne, A., Hoekstra, D., & Wurzinger, M. (2016). The impact of gender-blindness on social-ecological resilience: The case of a communal pasture in the highlands of Ethiopia. *AMBIO: A Journal of the Human Environment*, *45*, 287–296. https://doi.org/10.1007/s13280-016-0846-x

Linkov, I., Bridges, T., Creutzig, F., Decker, J., Fox-Lent, C., Kröger, W., Lambert, J. H., Levermann, A., Montreuil, B., Nathwani, J., Nyer, R., Renn, O., Scharte, B., Scheffler, A., Schreurs, M., & Thiel-Clemen, T. (2014). Changing the resilience paradigm. *Nature Climate Change*, *4*(6), 407–409. https://doi.org/10.1038/nclimate2227

Lipper, L., Thornton, P. K., Campbell, B. M., Baedeker, T., Braimoh, A., Bwalya, M., Caron, P., Cattaneo, A., Garrity, D., Henry, K., Hottle, R., Jackson, L., Jarvis, A., Kossam, F., Mann, W., McCarthy, N., Meybeck, A., Neufeldt, H., Remington, T., … Torquebiau, E. F. (2014). Climate-smart agriculture for food security. *Nature Climate Change*, *4*(12), 1068–1072.

https://doi.org/10.1038/nclimate2437

Liu, K., Harrison, M. T., Wang, B., Yang, R., Yan, H., Zou, J., Liu, D. L., Meinke, H., Tian, X., Ma, S., Zhang, Y., Man, J., Wang, X., & Zhou, M. (2022). Designing high-yielding wheat crops under late sowing: a case study in southern China. *Agronomy for Sustainable Development*, *42*(2). https://doi.org/10.1007/s13593-022-00764-w

Liu, Y., Ruiz-Menjivar, J., & Zhang, J. (2022). Do soil nutrient management practices improve climate resilience? Empirical evidence from rice farmers in central China. *Environment, Development and Sustainability*. https://doi.org/10.1007/s10668-022-02475-4

Lokshin, M., & Sajaia, Z. (2004). Maximum likelihood estimation of endogenous switching regression models. *The Stata Journal*, *4*(3), 282–289.

Lokshin, M., & Sajaia, Z. (2010). The Stata Journal. In *Stata Journal* (Vol. 4, Issue 3). https://doi.org/The Stata Journal

Long, T. T. B., Blok, V., & Coninx, I. (2016). Barriers to the adoption and diffusion of technological innovations for climate-smart agriculture in Europe: Evidence from the Netherlands, France, Switzerland and Italy. *Journal of Cleaner Production*, *112*, 9–21. https://doi.org/10.1016/j.jclepro.2015.06.044

Lovon, M., & Mathiassen, A. (2014). Are the World Food Programme's food consumption groups a good proxy for energy deficiency? *Food Security*, *6*(4), 461–470. https://doi.org/10.1007/s12571-014-0367-z

Madhuri, Tewari, H. R., & Bhowmick, P. K. (2014). Livelihood vulnerability index analysis: An approach to study vulnerability in the context of Bihar. *Jàmbá: Journal of Disaster Risk Studies*, *6*(1), 1–13. https://doi.org/10.4102/jamba.v6i1.127

Makate, C. (2019). Effective scaling of climate smart agriculture innovations in African smallholder agriculture: A review of approaches, policy and institutional strategy needs. In *Environmental Science and Policy* (Vol. 96, Issue January, pp. 37–51). Elsevier. https://doi.org/10.1016/j.envsci.2019.01.014

Makate, C., Makate, M., Mango, N., & Siziba, S. (2019a). 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*, 858–868. https://doi.org/10.1016/j.jenvman.2018.10.069

Makate, C., Makate, M., Mango, N., & Siziba, S. (2019b). 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*, 858–868. https://doi.org/10.1016/j.jenvman.2018.10.069

Makate, C., Makate, M., Mutenje, M., Mango, N., & Siziba, S. (2019). Synergistic impacts of agricultural credit and extension on adoption of climate-smart agricultural technologies in southern Africa. *Environmental Development*, *32*, 100458. https://doi.org/https://doi.org/10.1016/j.envdev.2019.100458

Mango, N., Makate, C., Tamene, L., Mponela, P., & Ndengu, G. (2018). Adoption of small-scale irrigation farming as a climate-smart agriculture practice and its influence on household income in the Chinyanja Triangle, Southern Africa. *Land*, *7*(2), 1–19. https://doi.org/10.3390/land7020049

Mango, N., Siziba, S., & Makate, C. (2017). The impact of adoption of conservation agriculture on smallholder farmers' food security in semi-arid zones of southern Africa. *Agriculture & Food Security*, *6*(1), 4–11. https://doi.org/10.1186/s40066-017-0109-5

Mare, F., Bahta, Y. T., & Van Niekerk, W. (2018). The impact of drought on commercial livestock farmers in South Africa. *Development in Practice*, *28*(7), 884–898. https://doi.org/10.1080/09614524.2018.1493091

Marivoet, W., Becquey, E., & Van Campenhout, B. (2019). How well does the Food Consumption Score capture diet quantity, quality and adequacy across regions in the Democratic Republic of the Congo (DRC)? *Food Security*, *11*(5), 1029–1049. https://doi.org/10.1007/s12571-019-00958-3

Martin, N., Stefan, S., & Qaim, M. (2011). Knowledge-Based Agricultural Innovations in Asia : The System of Rice Intensification (SRI) in Timor Leste. *Pacific News*, *February*, 6.

Maru, H., Haileslassie, A., Zeleke, T., & Esayas, B. (2021). Analysis of smallholders' livelihood vulnerability to drought across agroecology and farm typology in the upper awash sub-basin, ethiopia. *Sustainability (Switzerland)*, *13*(17). https://doi.org/10.3390/su13179764

Mashingaidze, N., & Twomlow, S. (2017). Weed growth and crop yield responses to tillage and mulching under different crop rotation sequences in semi-arid conditions. *Soil Use And*. http://onlinelibrary.wiley.com/doi/10.1111/sum.12338/full

Maxwell, D., Vaitla, B., Tesfay, G., & Abadi, N. (2013). *Resilience , Food Security Dynamics , and Poverty Traps in Northern Ethiopia Analysis of a Biannual Panel Dataset , 2011 – 2013* (Issue October).

Mbow, C., Van Noordwijk, M., Luedeling, E., Neufeldt, H., Minang, P. A., & Kowero, G. (2014). Agroforestry solutions to address food security and climate change challenges in Africa. *Current Opinion in Environmental Sustainability*, *6*(1), 61–67. https://doi.org/10.1016/j.cosust.2013.10.014

McCarthy, N., Lipper, L., Branca, G., & Security, F. (2011). Climate-Smart Agriculture : Smallholder Adoption and Implications for Climate Change Adaptation and Mitigation. *Organization*, *May*, 1–37. https://doi.org/FAO Mitigatiion of Climate Change in Agriculture Series 4

Meijer, S. S., Catacutan, D., Ajayi, O. C., Sileshi, G. W., & Nieuwenhuis, M. (2015). The role of knowledge, attitudes and perceptions in the uptake of agricultural and agroforestry innovations among smallholder farmers in sub-Saharan Africa. *International Journal of Agricultural Sustainability*, *13*(1), 40–54. https://doi.org/10.1080/14735903.2014.912493

Mekonnen, D. A., Gerber, N., & Matz, J. A. (2018). Gendered Social Networks, Agricultural

Innovations, and Farm Productivity in Ethiopia. *World Development*, *105*, 321–335. https://doi.org/https://doi.org/10.1016/j.worlddev.2017.04.020

Melak, M., & Birgit, K. (2014). Food Insecurity in Ethiopia: Population, Food Production and Market. *32nd International Conference of the System Dynamics Society*, 1–29.

Melese, M., Tilahun, M., & Alemu, M. (2021). Household food insecurity and coping strategies in Southern Ethiopia. *Agriculture and Food Security*, *10*(1), 1–12. https://doi.org/10.1186/s40066-021-00296-8

Melisse, B. (2018). A Review on Factors Affecting Adoption of Agricultural New Technologies in Ethiopia. *Journal of Agricultural Science and Food Research*, *9*(3), 1–6.

Menale Kassie, Teklewold, H., Jaleta, M., Marenya, P., & Erenstein, O. (2015). Understanding the adoption of a portfolio of sustainable intensification practices in eastern and southern Africa. *Land Use Policy*, *42*, 400–411. https://doi.org/10.1016/j.landusepol.2014.08.016

Mentire, W., & Gecho, Y. (2017). Factors Affecting Adoption of Wheat Row Planting Technology: The Case of Sodo Zuriya Woreda, Wolaita Zone, Southern Ethiopia. December, 2016. *Innovative Systems Design and Engineering*, *8*(1), 2222–1727.

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

Mihretie, A. A., Misganaw, G. S., & Siyum Muluneh, N. (2022). Adoption Status and Perception of Farmers on Improved Tef Technology Packages: Evidence from East Gojjam Zone, Ethiopia. *Advances in Agriculture*, *2022*, 1–15. https://doi.org/10.1155/2022/6121071

Mittal, S., & Mehar, M. (2012). How mobile phones contribute to growth of small farmers? evidence from India. *Quarterly Journal of International Agriculture*, *51*(3), 227–244.

Mlenga, D. H. (2015). Factors Influencing Adoption of Conservation Agriculture : A Case for Increasing Resilience to Climate Change and Variability in Swaziland. *Journal of Environment and Earth Science*, *5*(22), 16–25. https://www.researchgate.net/profile/Daniel_Mlenga2/publication/290296792_Factors_Influencing_Adoption_of_Conservation_Agriculture_A_Case_for_Increasing_Resilience_to_Climate_Change_and_Variability_in_Swaziland/links/5695fc9f08ae425c689868ea.pdf

MoA. (2011). *Agriculture Sector Programme of Plan on Adaptation to Climate Change* (Issue September).

Montes de Oca Munguia, O., Pannell, D. J., & Llewellyn, R. (2021). Understanding the adoption of innovations in agriculture: A review of selected conceptual models. *Agronomy*, *11*(1), 1–20. https://doi.org/10.3390/agronomy11010139

Mupangwa, W., Mutenje, M., Thierfelder, C., & Nyagumbo, I. (2016). Are conservation agriculture (CA) systems productive and profitable options for smallholder farmers in different agro-ecoregions of Zimbabwe? *Renewable Agriculture and Food Systems*, 1–17.

https://doi.org/10.1017/S1742170516000041

Murage, A. W., Obare, G., Chianu, J., Amudavi, D. M., & Khan, Z. R. (2012). THE EFFECTS OF DISSEMINATION PATHWAYS ON THE SPEED OF PUSH- PULL TECHNOLOGY ADOPTION IN WESTERN KENYA. *Quarterly Journal of International AgricultureJournal of International Agriculture*, *51*(1), 51–71.

Murray, U., Gebremedhin, Z., Brychkova, G., & Spillane, C. (2016). Smallholder Farmers and Climate Smart Agriculture: Technology and Labor-productivity Constraints amongst Women Smallholders in Malawi. *Gender, Technology and Development*, *20*(2), 117–148. https://doi.org/10.1177/0971852416640639

Mutenje, M. J., Farnworth, C. R., Stirling, C., Thierfelder, C., Mupangwa, W., & Nyagumbo, I. (2019). A cost-benefit analysis of climate-smart agriculture options in Southern Africa: Balancing gender and technology. *Ecological Economics*, *163*(March 2018), 126–137. https://doi.org/10.1016/j.ecolecon.2019.05.013

Mwaura, G. G., Kiboi, M. N., Bett, E. K., Mugwe, J. N., Muriuki, A., Nicolay, G., & Ngetich, F. K. (2021). Adoption Intensity of Selected Organic-Based Soil Fertility Management Technologies in the Central Highlands of Kenya. *Frontiers in Sustainable Food Systems*, *4*(January), 1–17. https://doi.org/10.3389/fsufs.2020.570190

Mwungu, C. M., Mwongera, C., Shikuku, K. M., Acosta, M., & Läderach, P. (2020). Determinants of Adoption of Climate-Smart Agriculture Technologies at Farm Plot Level: An Assessment from Southern Tanzania. In *Handbook of Climate Change Resilience* (pp. 1647–1660). https://doi.org/10.1007/978-3-319-93336-8_78

Ndlovu, S., Mathe, B., Phiri, K., & Nyathi, D. (2020). Factoring water harvesting into climate change adaptation: Endogenous responses by smallholder farmers in Gwanda district, Zimbabwe. *Cogent Social Sciences*, *6*(1). https://doi.org/10.1080/23311886.2020.1784652

Negash, W. (2017). Effect of Row Spacing on Yield and Yield Components of Teff [Eragrostis tef (Zucc .) Trotter] Varieties in Gonji Kolela District , North Western Ethiopia. *Journal of Biology, Agriculture and Healthcare*, *7*(23), 35–43.

Negra, C., Vermeulen, S., Barioni, L. G., Mamo, T., Melville, P., & Tadesse, M. (2014). Brazil, Ethiopia, and New Zealand lead the way on climate-smart agriculture. *Agriculture & Food Security*, *3*(1), 19. https://doi.org/10.1186/s40066-014-0019-8

Ng'ang'a, S. K., Jalang'o, D. A., & Girvetz, E. H. (2019). Adoption of technologies that enhance soil carbon sequestration in East Africa. What influence farmers' decision? *International Soil and Water Conservation Research*, *xxxx*, 1–12. https://doi.org/10.1016/j.iswcr.2019.11.001

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

Ngwira, A., Aune, J., & Thierfelder, C. (2014). On-farm evaluation of the effects of the principles and components of conservation agriculture on maize yield and weed biomass in malawi.

Experimental Agriculture, *50*(4), 591–610. https://doi.org/10.1017/S001447971400009X

Ngwira, A., Sleutel, S., & de Neve, S. (2012). Soil carbon dynamics as influenced by tillage and crop residue management in loamy sand and sandy loam soils under smallholder farmers' conditions in Malawi. *Nutrient Cycling in Agroecosystems*, *92*(3), 315–328. https://doi.org/10.1007/s10705-012-9492-2

Niang, I., Oliver, R., Mohamed, A., Amma, E., Lennard, C., Jonathan, P., & Penny, U. (2014a). Africa. *Climate Change 2014: Impacts, Adaptation and Vulnerability - Contributions of the Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.*, 1199–1265. https://doi.org/10.1017/CBO9781107415386.002

Niang, I., Oliver, R., Mohamed, A., Amma, E., Lennard, C., Jonathan, P., & Penny, U. (2014b). Climate Change 2014: Africa. In and L. L. W. Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea (Ed.), *Africa. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 1199–1265). Cambridge University Press.

Noulekoun, F., Birhane, E., Chude, S., & Zenebe, A. (2016). Characterization of Faidherbia albida (Del.) A. Chev. population in agroforestry parklands in the highlands of Northern Ethiopia: impact of conservation, environmental factors and human disturbances. *Agroforestry Systems*, 1–13. https://doi.org/10.1007/s10457-016-9910-6

Ntshangase, N. L., Muroyiwa, B., & Sibanda, M. (2018). Farmers' perceptions and factors influencing the adoption of no-till conservation agriculture by small-scale farmers in Zashuke, KwaZulu-Natal province. *Sustainability (Switzerland)*, *10*(2). https://doi.org/10.3390/su10020555

Nyanga, H. (2012). Food Security, Conservation Agriculture and Pulses: Evidence from Smallholder Farmers in Zambia. *Journal of Food Research*, *1*(2), p120. https://doi.org/10.5539/jfr.v1n2p120

Ojo, T. O., Baiyegunhi, L. J. S., Adetoro, A. A., & Ogundeji, A. A. (2021). Adoption of soil and water conservation technology and its effect on the productivity of smallholder rice farmers in Southwest Nigeria. *Heliyon*, *7*(3), e06433. https://doi.org/10.1016/j.heliyon.2021.e06433

Ouédraogo, M., Houessionon, P., Zougmoré, R. B., & Partey, S. T. (2019). Uptake of climate-smart agricultural technologies and practices: Actual and potential adoption rates in the climate-smart village site of Mali. *Sustainability (Switzerland)*, *11*(17). https://doi.org/10.3390/su11174710

Paulos, A., & Belay, S. (2017). Adaptation Benefits of Climate-Smart Agricultural Practices in the Blue Nile Basin: Empirical Evidence from North-West Ethiopia. In *Climate Change Adaptation in Africa*. https://doi.org/10.1007/978-3-319-49520-0

Pender, J., & Ehui, S. (2006). Strategies for sustainable land management in the East African

highlands. In and S. E. Pender, J., F. Place (Ed.), *Food Policy*. International Food Policy Research Institute. http://books.google.com/books?hl=en&lr=&id=9pzrraDIF-wC&oi=fnd&pg=PR11&dq=Strategies+for+Sustainable+Land+Management+in+the+East+African+Highlands&ots=ddo4GR6GNT&sig=muizJyZ0Ftbl-HKQ0ZgQDNA32GI

Peng, W., Dernini, S., & Berry, E. M. (2018). Coping With Food Insecurity Using the Sociotype Ecological Framework. *Frontiers in Nutrition*, *5*(November). https://doi.org/10.3389/fnut.2018.00107

Porter, J. R., Soussana, J.-F., Fereres, E., Long, S. P., Mohren, F. G., Pandya-Lorch, R., Peltonen-Sainio, P., Rosswall, T., & J., V. B. (2013). European perspectives: An agronomic science plan for food security in a changing climate. In *Handbook of Climate Change and Agroecosystems: Global and Regional Aspects and Implications* (Vol. 2, pp. 73–84). https://books.google.com/books?hl=en&lr=&id=EmOes-iIaeAC&oi=fnd&pg=PA73&dq=%22climate+smart+agriculture%22&ots=AQFL9ikdOb&sig=YyYWLlE5MRUoZ_6v2BL1EvQiIss

Prager, K., & Posthumus, H. (2010). Socio-economic factors influencing Farmers' adoption of soil conservation practices in Europe. In P. Ted L. Napier (Ed.), *Human Dimensions of Soil and Water Conservation* (Issue January, pp. 203–223).

Qaswar, M., Huang, J., Ahmed, W., Liu, S., & Li, D. (2019). Substitution of Inorganic Nitrogen Fertilizer with Green Manure (GM) Increased Yield Stability by Improving C Input and Nitrogen Recovery E ffi ciency in Rice Based Cropping System. *Agronomy*, *9*(609).

Rani, A., Devi, P., Jha, U. C., Sharma, K. D., Siddique, K. H. M., & Nayyar, H. (2020). Developing Climate-Resilient Chickpea Involving Physiological and Molecular Approaches With a Focus on Temperature and Drought Stresses. *Frontiers in Plant Science*, *10*(February), 1–29. https://doi.org/10.3389/fpls.2019.01759

Räsänen, A., Lein, H., Bird, D., & Setten, G. (2020). Conceptualizing community in disaster risk management. *International Journal of Disaster Risk Reduction*, *45*(January). https://doi.org/10.1016/j.ijdrr.2020.101485

Reppin, S., Kuyah, S., de Neergaard, A., Oelofse, M., & Rosenstock, T. S. (2020). Contribution of agroforestry to climate change mitigation and livelihoods in Western Kenya. *Agroforestry Systems*, *94*(1), 203–220. https://doi.org/10.1007/s10457-019-00383-7

Rimhanen, K., & Kahiluoto, H. (2014). Management of harvested C in smallholder mixed farming in Ethiopia. *Agricultural Systems*, *130*, 13–22. https://doi.org/10.1016/j.agsy.2014.06.003

Rimhanen, K., Kahiluoto, H., Ketoja, E., & Yli-halla, M. (2012). Carbon sequestration by climate smart agriculture in Ethiopia. *ECosummit 2012*, 2012.

Salehu, A., Sebeko, B., Miftah, N., Sebuh, S., MOA, Salehu, A., Sebeko, B., Miftah, N., & Sebuh, S. (2011). *Agriculture Sector Programme of Plan on Adaptation to Climate Change* (Issue September).

Samiee, S., & Rezaei-Moghaddam, K. (2017). The proposed alternative model to predict adoption of innovations: The case of no-till technology in Iran. *Journal of the Saudi Society of Agricultural Sciences*, *16*(3), 270–279. https://doi.org/10.1016/j.jssas.2015.09.002

Samuel, G. (2006). Land, Land Policy and Smallholder Agriculture in Ethiopia: Options and Scenarios. In *Future Agricultures Consortium meeting at the Institute of Development Studies 20-22 March 2006* (Issue March). http://r4d.dfid.gov.uk/Output/178530/Default.aspx

Shackleton, S., Ziervogel, G., Sallu, S., Gill, T., & Tschakert, P. (2015). Why is socially-just climate change adaptation in sub-Saharan Africa so challenging? A review of barriers identified from empirical cases. In *Wiley Interdisciplinary Reviews: Climate Change* (Vol. 6, Issue 3, pp. 321–344). https://doi.org/10.1002/wcc.335

Shah, K. K., Modi, B., Pandey, H. P., Subedi, A., Aryal, G., Pandey, M., & Shrestha, J. (2021). Diversified Crop Rotation: An Approach for Sustainable Agriculture Production. *Advances in Agriculture*, *2021*, 1–9. https://doi.org/10.1155/2021/8924087

Shekuru, A. H., Berlie, A. B., & Bizuneh, Y. K. (2022). Rural household livelihood strategies and diet diversification in North Shewa, Central Ethiopia. *Journal of Agriculture and Food Research*, *9*(July), 100346. https://doi.org/10.1016/j.jafr.2022.100346

Shiferaw, B., Jaleta, M., Norton, G., Yirga, C., Zeng, D., & Alwang, J. (2017). Land ownership and technology adoption revisited: Improved maize varieties in Ethiopia. *Land Use Policy*, *72*(March 2016), 270–279. https://doi.org/10.1016/j.landusepol.2017.12.047

Shiferaw, B., Kassie, M., Jaleta, M., & Yirga, C. (2014a). Adoption of improved wheat varieties and impacts on household food security in Ethiopia. *Food Policy*, *44*(2014), 272–284. https://doi.org/10.1016/j.foodpol.2013.09.012

Shiferaw, B., Kassie, M., Jaleta, M., & Yirga, C. (2014b). Adoption of improved wheat varieties and impacts on household food security in Ethiopia. *Food Policy*, *44*, 272–284. https://doi.org/10.1016/j.foodpol.2013.09.012

Shikuku, K. M., Mwungu, C. M., & Mwongera, C. (2019). Impact of drought-tolerant maize and maize–legume intercropping on the climate resilience of rural households in Northern Uganda. In *Elsevier* (pp. 221–234). https://doi.org/10.1016/b978-0-12-814820-4.00015-8

Sileshi, M., Kadigi, R., Mutabazi, K., & Sieber, S. (2019). Impact of soil and water conservation practices on household vulnerability to food insecurity in eastern Ethiopia: endogenous switching regression and propensity score matching approach. *Food Security*, *11*(4), 797–815. https://doi.org/10.1007/s12571-019-00943-w

Silici, L., Rowe, A., Suppiramaniam, N., & Knox, J. W. (2021). Building adaptive capacity of smallholder agriculture to climate change: evidence synthesis on learning outcomes. *Environmental Research Communications*, *3*(12), 122001. https://doi.org/10.1088/2515-7620/ac44df

Simane, B. (2013). The Sustainability of Community-Based Adaptation in the Choke Mountain Watersheds, Blue Nile Highlands, Ethiopia. *Sustainability*, *5*, 1–37.

https://doi.org/10.3390/su50x000x

Simane, B., & Asrat, P. (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

Simane, B., Benjamin F., Z., & Jeremy, D. F. (2016). Agroecosystem specific climate vulnerability analysis : application of the livelihood vulnerability index to a tropical highland region. *Mitigation and Adaptation Strategies for Global Change*, *21*, 39–65. https://doi.org/10.1007/s11027-014-9568-1

Simane, B., Zaitchik, B. F., & Mesfin, D. (2012). Building Climate Resilience in the Blue Nile/Abay Highlands: A Framework for Action. *International Journal of Environmental Research and Public Health*, *9*(2), 610–631. https://doi.org/10.3390/ijerph9020610

Simane, B., Zaitchik, B., & Ozdogan, M. (2013). Agroecosystem analysis of the choke mountain watersheds, Ethiopia. *Sustainability*, *5*(2), 602–603. https://doi.org/10.3390/su5020592

Simeneh, D. (2015). Perception of Farmers Toward Physical Soil and Water Conservation Structures in Wyebla Watershed, Northwest Ethiopia. *Academic Journal of Plant Sciences*, *7*(3), 34–40. https://doi.org/10.5829/idosi.ajps.2015.7.3.12822

Simeneh, D., & Fisseha, G. (2016). Perception of Farmers Toward Physical Soil and Water Conservation Structures in Wyebla Watershed, Northwest Ethiopia. *World Journal of Agricultural Sciences*, *1*(12), 57–63. https://doi.org/10.5829/idosi.ajps.2015.7.3.12822

Soussana, J.-F., Barioni, L. G., Ben Ari, T., Conant, R., Gerber, P., Havlík, P., Ickowicz, A., & G, M. H. (2013). Managing grassland systems in a changing climate: the search for practical solutions. *Revitalising Grasslands to Sustain Our Communities, 22nd International Grasslands Congress, 15 - 19 September 2013, SEPTEMBER*, 1–18. https://agritrop.cirad.fr/573349/1/document_573349.pdf

Srinivasarao, C., Rani, Y., & Veni, V. (2016). Assessing village-level carbon balance due to greenhouse gas mitigation interventions using EX-ACT model. *International Journal of Environmental Technology*. http://link.springer.com/article/10.1007/s13762-015-0788-z

T. Bradley, D., Mcfarland, M., & Clarke, M. (2016). Chapter 3 The Effectiveness of Disaster Risk Communication A Systematic Review of Intervention Studies. In *Effective Communication During Disasters* (Issue August, pp. 55–94). Apple Academic Press Inc. https://doi.org/10.1201/9781315365640-4

Tambo, J. A. (2016). Adaptation and resilience to climate change and variability in north-east Ghana. *International Journal of Disaster Risk Reduction*, *17*, 85–94. https://doi.org/10.1016/j.ijdrr.2016.04.005

Tamirat, N. (2020). Impact Analysis of Row Planting Teff Crop Technology on Household Welfare:A Case Study of Smallholder Farmers of Duna District in Hadiya Zone, Ethiopia. *Journal of Economics and Sustainable Development*, *11*(5), 4–9. https://doi.org/10.7176/jesd/11-5-02

Teklewold, H., Gebrehiwot, T., & Bezabih, M. (2019). Climate smart agricultural practices and gender differentiated nutrition outcome: An empirical evidence from Ethiopia. *World Development*, *122*, 38–53. https://doi.org/10.1016/j.worlddev.2019.05.010

Teklewold, H., Mekonnen, A., & Kohlin, G. (2019). Climate change adaptation: a study of multiple climate-smart practices in the Nile Basin of Ethiopia. *Climate and Development*, *11*(2), 180–192. https://doi.org/10.1080/17565529.2018.1442801

Teklewold, H., Mekonnen, A., Kohlin, G., & Di falco, S. (2017). Does adoption of multiple Climate-Smart practices improve farmers' Climate Resilience? Empirical Evidence from the Nile Basin of Ethiopia. *Climate Change Economics*, *08*(01), 1750001. https://doi.org/10.1142/S2010007817500014

Teklewold, H., Minale, K., & Beklee, S. (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

Temesgen & Rashid. (2009). Economic impact of climate change on crop production in ethiopia: Evidence from cross-section measures. *Journal of African Economies*, *18*(4), 531. https://doi.org/10.1093/jae/ejp002

Temesgen, D., Hassan, R. M., & Ringler, C. (2011). Assessing Household Vulnerability to Climate Change The Case of Farmers in the Nile Basin of Ethiopia. *International Food and Policy Research Institute*, 1–2.

Tenge, A. J., De Graaff, J., & Hella, J. P. (2005). Financial efficiency of major soil and water conservation measures in West Usambara highlands, Tanzania. *Applied Geography*, *25*(4), 348–366. https://doi.org/10.1016/j.apgeog.2005.08.003

Tesfaye, W., Blalock, G., & Tirivayi, N. (2021). Climate-Smart Innovations and Rural Poverty in Ethiopia: Exploring Impacts and Pathways. *American Journal of Agricultural Economics*, *103*(3), 878–899. https://doi.org/10.1111/ajae.12161

Tesfaye, W., & Seifu, L. (2016). Climate change perception and choice of adaptation strategies: Empirical evidence from smallholder farmers in east Ethiopia. *International Journal of Climate Change Strategies and Management*, *8*(2), 253–270. https://doi.org/10.1108/IJCCSM-01-2014-0017

Teshome, A., & Abate, E. (2013). Wheat technologies from where to where ? The case of East Gojam zone of Amhara region , Ethiopia. *Journal of Agricultural Economics and Development*, *2*(6), 226–236. https://www.researchgate.net/profile/Ermias_Abate/publication/265797731_Wheat_technologies_from_where_to_where_The_case_of_East_Gojam_zone_of_Amhara_region_Ethiopia/links/555da22308ae9963a1127d00/Wheat-technologies-from-where-to-where-The-case-of-East-Goj

Teshome, A., Graaff, J. de, Ritsema, C., & Kassie, M. (2014). Farmers' perceptions about the influence of land quality, land fragmentation and tenure systems on sustainable land

management in the north western ethiopian highlands. *Land Degradation and Development*. https://doi.org/10.1002/ldr.2298

Teshome, H., Tesfaye, K., Dechassa, N., Tana, T., & Huber, M. (2021). Smallholder farmers' perceptions of climate change and adaptation practices for maize production in eastern Ethiopia. *Sustainability (Switzerland)*, *13*(17), 1–21. https://doi.org/10.3390/su13179622

Thierfelder, C., Chivenge, P., Mupangwa, W., Rosenstock, T. S., Lamanna, C., & Eyre, J. X. (2017). How climate-smart is conservation agriculture (CA)? – its potential to deliver on adaptation, mitigation and productivity on smallholder farms in southern Africa. *Food Security*, *9*(3), 537–560. https://doi.org/10.1007/s12571-017-0665-3

Thierfelder, C., Rusinamhodzi, L., Setimela, P., Walker, F., & Eash, N. S. (2016). Conservation agriculture and drought-tolerant germplasm: Reaping the benefits of climate-smart agriculture technologies in central Mozambique. *Renewable Agriculture and Food Systems*, *31*(5), 414–428. https://doi.org/10.1017/S1742170515000332

Tittonell, P., Gérard, B., & Erenstein, O. (2015). Tradeoffs around crop residue biomass in smallholder crop-livestock systems - What's next? *Agricultural Systems*, *134*, 119–128. https://doi.org/10.1016/j.agsy.2015.02.003

Tofa, A. I., Kamara, A. Y., Babaji, B. A., Akinseye, F. M., & Bebeley, J. F. (2021). Assessing the use of a drought-tolerant variety as adaptation strategy for maize production under climate change in the savannas of Nigeria. *Scientific Reports*, *11*(1), 8983. https://doi.org/10.1038/s41598-021-88277-6

Tofu, D. A., Woldeamanuel, T., & Haile, F. (2022). Smallholder farmers' vulnerability and adaptation to climate change induced shocks: The case of Northern Ethiopia highlands. *Journal of Agriculture and Food Research*, *8*(September 2021), 100312. https://doi.org/10.1016/j.jafr.2022.100312

Tong, Q., Swallow, B., Zhang, L., & Zhang, J. (2019). The roles of risk aversion and climate-smart agriculture in climate risk management: Evidence from rice production in the Jianghan Plain, China. *Climate Risk Management*, *26*. https://doi.org/10.1016/j.crm.2019.100199

Traore, B., Birhanu, B. Z., Sangaré, S., Gumma, M. K., Tabo, R., & Whitbread, A. M. (2021). Contribution of climate-smart agriculture technologies to food self-sufficiency of smallholder households in mali. *Sustainability (Switzerland)*, *13*(14), 1–17. https://doi.org/10.3390/su13147757

Trisos, C. H., Adelekan, I. O., & Edmond, T. (2022). IPCC WGII Sixth Assessment Report : Africa. In *Climate change 2022*.

Tsegaye, A. T., Tariku, A., Worku, A. G., Abebe, S. M., Yitayal, M., Awoke, T., Alemu, K., & Biks, G. A. (2018). Reducing amount and frequency of meal as a major coping strategy for food insecurity. *Archives of Public Health*, *76*(1), 1–9. https://doi.org/10.1186/s13690-018-0303-3

Tsige, M., Synnevåg, G., & Aune, J. B. (2020). Gendered constraints for adopting climate-smart

agriculture amongst smallholder Ethiopian women farmers. *Scientific African*, *7*. https://doi.org/10.1016/j.sciaf.2019.e00250

Turmel, M. S., Speratti, A., Baudron, F., Verhulst, N., & Govaerts, B. (2015). Crop residue management and soil health: A systems analysis. *Agricultural Systems*, *134*, 6–16. https://doi.org/10.1016/j.agsy.2014.05.009

Uchimura, T., Towhata, I., Wang, L., Nishie, S., Yamaguchi, H., Seko, I., & Qiao, J. (2015). Precaution and early warning of surface failure of slopes using tilt sensors. *Soils and Foundations*, *55*(5), 1086–1099. https://doi.org/10.1016/j.sandf.2015.09.010

UNFCC. (2015). *Paris agreement*.

Usman, M. A., & Callo-Concha, D. (2021). Does market access improve dietary diversity and food security? Evidence from Southwestern Ethiopian smallholder coffee producers. *Agricultural and Food Economics*, *9*(1). https://doi.org/10.1186/s40100-021-00190-8

van Ginkel, M., & Biradar, C. (2021). Drought early warning in agri-food systems. *Climate*, *9*(9). https://doi.org/10.3390/cli9090134

van Noordwijk, M., Bayala, J., Hairiah, K., Lusiana, B., Muthuri, C., Khasanah, N., & Mulia, R. (2014). Agroforestry solutions for buffering climate variability and adapting to change. In *Climate change Impact and Adaptation in Agricultural Systems* (pp. 216–232). https://doi.org/10.1079/9781780642895.0216

Vancampenhout, K., Nyssen, J., Gebremichael, D., Deckers, J., Poesen, J., Haile, M., & Moeyersons, J. (2006). Stone bunds for soil conservation in the northern Ethiopian highlands: Impacts on soil fertility and crop yield. *Soil and Tillage Research*, *90*(1–2), 1–15. https://doi.org/10.1016/j.still.2005.08.004

Vandercasteelen, J., Dereje, M., Minten, B., & Taffesse, A. S. (2018). Labour, profitability and gender impacts of adopting row planting in Ethiopia. *European Review of Agricultural Economics*, *45*(4), 471–503. https://doi.org/10.1093/erae/jby001

Warnars, L. M. E., & Hivos. (2014). Bioslurry: a supreme fertiliser Positive effects of bioslurry on crops. *Practitioners' Track, IFOAM Organic World Congress 2014, 'Building Organic Bridges*, 13–15.

Webb, N. P., Marshall, N. A., Stringer, L. C., Reed, M. S., Chappell, A., & Herrick, J. E. (2017). Land degradation and climate change: building climate resilience in agriculture. *Frontiers in Ecology and the Environment*, *15*(8), 450–459. https://doi.org/10.1002/fee.1530

Wekesa, B. M., Ayuya, O. I., & Lagat, J. K. (2018). 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, Z. B., & Prowse, M. (2013). Climate-Change Adaptation in Ethiopia : To What Extent Does Social Protection Influence Livelihood Diversification ? *Development Policy*

Review, *31*(October 2012), 35–56.

WFP. (2009). Comprehensive Food Security & Vulnerability Analysis Guidelines. *Africa*, *April*, 27. https://doi.org/http://dx.doi.org/10.1016/S0169-8141(08)00187-X

Wilbanks, T. J., & Sathaye, J. (2007). Integrating mitigation and adaptation as responses to climate change: A synthesis. *Mitigation and Adaptation Strategies for Global Change*, *12*(5), 957–962. https://doi.org/10.1007/s11027-007-9108-3

Woldeamlak, B. (2012). Climate change perceptions and adaptive responses of smallholder farmers in central highlands of Ethiopia. *International Journal of Environmental Studies*, *69*(June), 507–523. https://doi.org/10.1080/00207233.2012.683328

Woldeamlak, B., Maren, R., & Catherine, M. (2015). *Agricultural Adaptation and Institutional Responses to Climate Change Vulnerability in Ethiopia* (No. 106; Issue 106). https://cgspace.cgiar.org/handle/10568/56997

Woldeamlak Bewekt. (2007). Soil and water conservation intervention with conventional technologies in northwestern highlands of Ethiopia: Acceptance and adoption by farmers. *Land Use Policy*, *24*(2), 404–416. https://doi.org/10.1016/j.landusepol.2006.05.004

Wolka, K., Mulder, J., & Biazin, B. (2018). Effects of soil and water conservation techniques on crop yield, runoff and soil loss in Sub-Saharan Africa: A review. *Agricultural Water Management*, *207*(January), 67–79. https://doi.org/10.1016/j.agwat.2018.05.016

Wordofa, M. G., Hassen, J. Y., Endris, G. S., Aweke, C. S., Moges, D. K., & Rorisa, D. T. (2021). Adoption of improved agricultural technology and its impact on household income: a propensity score matching estimation in eastern Ethiopia. *Agriculture and Food Security*, *10*(1), 1–12. https://doi.org/10.1186/s40066-020-00278-2

Wordofa, M. G., Okoyo, E. N., & Erkalo, E. (2020). Factors influencing adoption of improved structural soil and water conservation measures in Eastern Ethiopia. *Environmental Systems Research*, *9*(1). https://doi.org/10.1186/s40068-020-00175-4

Workneh, N., & Parikh, A. (1999). The impact of perception and other factors on the adoption of agricultural technology in the Moret and Jiru Woreda (district) of Ethiopia. *Agricultural Economics*, *21*(2), 205–216. https://doi.org/10.1016/s0169-5150(99)00020-1

World Food Programme. (2008). Food consumption analysis - calculation and use of the food consumption score in food security analysis. In *Technical Guidance Sheet*. https://doi.org/10.1017/CBO9781107415324.004

Wudad, A., Naser, S., & Lameso, L. (2021). The impact of improved road networks on marketing of vegetables and households' income in Dedo district, Oromia regional state, Ethiopia. *Heliyon*, *7*(10), e08173. https://doi.org/10.1016/j.heliyon.2021.e08173

Xiong, W., & Tarnavsky, E. (2020). Climate Resilience of Maize To Drought in. *Atmosphere*, *11*, 982.

Yalew, S., Teferi, E., Van Griensven, a, Uhlenbrook, S., Mul, M., Van Der Kwast, J., & Van Der Zaag, P. (2012). Land use change and suitability assessment in the Upper Blue Nile basin under water resources and socio-economic constraints: A drive towards a decision support system. *IEMSs 2012 - Managing Resources of a Limited Planet: Proceedings of the 6th Biennial Meeting of the International Environmental Modelling and Software Society*, 2124–2131. http://www.scopus.com/inward/record.url?eid=2-s2.0-84894179758&partnerID=40&md5=aa8d99368ff9ba84c59d1cacc87c37c4

Yekini, O. T., Ladigbolu, T. A., Adeniyi, R. T., & Adebisi, G. L. (2019). Determinants of Participation in Farmers Training Centre Based Extension Training in Ethiopia. *Journal of Agricultural Extension*, *23*(3), 117–125.

Yesuf, M., & Ringler, C. (2008). *The Impact of Climate Change and Adaptation on Food Production in Low-Income Countries Evidence from the Nile Basin , Ethiopia*. *December*.

Yibekal, T., Chanyalew, A., & Getachew, E. (2013). Understanding the process of adaptation to climate change by small-holder farmers: the case of east Hararghe Zone, Ethiopia. *Agricultural and Food Economics*, *1*(1), 13. https://doi.org/10.1186/2193-7532-1-13

Zakari, S., Ouédraogo, M., Abasse, T., & Zougmoré, R. (2019). Farmer's Prioritization and Adoption of Climate-Smart Agriculture (CSA) Technologies and Practices. *Journal of Agriculture and Environmental Sciences*, *8*(1). https://doi.org/10.15640/jaes.v8n1a17

Zakaria, A., Alhassan, S. I., Kuwornu, J. K. M., Azumah, S. B., & Derkyi, M. A. A. (2020). Factors Influencing the Adoption of Climate-Smart Agricultural Technologies Among Rice Farmers in Northern Ghana. *Earth Systems and Environment*, *4*(1), 257–271. https://doi.org/10.1007/s41748-020-00146-w

Zerihun, M. F., Muchie, M., & Worku, Z. (2014). Determinants of agroforestry technology adoption in Eastern Cape Province, South Africa. *Development Studies Research*, *1*(1), 382–394. https://doi.org/10.1080/21665095.2014.977454

Zerssa, G., Feyssa, D., Kim, D. G., & Eichler-Löbermann, B. (2021). Challenges of smallholder farming in Ethiopia and opportunities by adopting climate-smart agriculture. *Agriculture (Switzerland)*, *11*(3), 1–26. https://doi.org/10.3390/agriculture11030192

Zeweld, W. (2015). *Food Security through Small Scale Irrigation : Case Study from Northern Ethiopia*. *September 2013*. https://doi.org/10.13140/2.1.1292.1129

Zeweld, W., Van Huylenbroeck, G., Tesfay, G., Azadi, H., & Speelman, S. (2018). Impacts of socio-psychological factors on actual adoption of sustainable land management practices in dryland andwater stressed areas. *Sustainability (Switzerland)*, *10*(9), 1–23. https://doi.org/10.3390/su10092963

Zeweld, W., Van Huylenbroeck, G., Tesfay, G., Azadi, H., & Speelman, S. (2020). Sustainable agricultural practices, environmental risk mitigation and livelihood improvements: Empirical evidence from Northern Ethiopia. *Land Use Policy*, *95*(December 2018), 1–13. https://doi.org/10.1016/j.landusepol.2019.01.002

Zeweld, W., Van Huylenbroeck, G., Tesfay, G., & Speelman, S. (2017). Smallholder farmers' behavioural intentions towards sustainable agricultural practices. *Journal of Environmental Management*, *187*, 71–81. https://doi.org/10.1016/j.jenvman.2016.11.014

Zilberman, D., Goetz, R., Garrido, A., Lipper, L., Mccarthy, N., Asfaw, S., & Editors, G. B. (2017). *Identifying Strategies to Enhance the Resilience of Smallholder Farming Systems: Evidence from Zambia*. 425–441. https://doi.org/10.1007/978-3-319-61194-5

Annex A

Survey on "CSA for a Resilient Agriculture among smallholder farmers in the upper Blue Nile Basin of Ethiopia"

The purpose of this survey is to collect information on the implications of CSA for climate resilience in the upper Blue Nile Highlands of Ethiopia. Hence, your participation is very much valuable to achieve the objectives of the study. I would like to assure you that your responses will be kept confidential and used only for the research purpose. Would you mind to respond to the questions? [*If the potential respondent is willing*],

Questionnaire ID_____ Name of the interviewer:_____

Date of Interview : _____

Starting time: _____

Section 1: Socio- demographic and economic characteristics			
S/N	Question	List of responses	
100	Woreda	1. Machakel ☐ 2. Awabel ☐ 3. Dejen ☐ 4. Basoliben ☐ 5. Sinan ☐	
101	Kebele	1. Debre Kelemua ☐ 2. Enebi ☐ 3. Gelgele ☐ 4. Limichi ☐ 5. Yeted ☐	
102	Gott		
103	Agro-ecological zone	1. Dega ☐ 2. Woina-dega ☐ 3. Kolla ☐	
104	Name of household head	_____	
105	Sex of household head	1. Male ☐ 2. Female ☐	
106	Age of the household head	_____ years	
107	Marital status of household head	1. Married ☐ 2. Single ☐ 3. Divorced ☐ 4. Widow ☐ 5. Separated ☐	
108	How long have you been living continuously in this place?	For _____ years	

109	What is your educational level?	1. Not read and write ☐ 2. Read and write ☐ 3. Primary ☐ : Grade: _____ 4. Secondary ☐ : Grade: _____ 5. TVET ☐ Level: _____ 6. Tertiary ☐ : Level: _____			
110	What is the total number of household members including you (the head)?	Total: _____ Male: _____ Female: _____			
111	Do your household owned the following farm equipment and other durable assets ?	No	Assets	1. Yes 2. No	
		1	Maresha		
		2	Spade/Akafa		
		3	Sickle		
		4	Axe		
		5	Cart		
		6	Hoe/doma		
		7	Radio		
		8	Television		
		9	Mobile		
		10	Table /Sofa set		
		11	Mozbold		
		12	Improved stove		
		13	Solar		

Section 2 – Pro environmental behavior						
	Value & Self efficacy	**1**	**2**	**3**	**4**	**5**
201	I will always make an effort to use sustainable soil, water ,and grazing management agricultural practices					
202	I plan to purchase sustainable soil, water ,and grazing management agricultural inputs although these may be more expensive					
203	I am willing to use sustainable soil, water ,and grazing management agricultural practices although this might take more time to get benefit from it					
204	I am willing to use sustainable soil, water ,and grazing management agricultural practices although this might be more expensive					
205	As a farmer I can help protect the wildlife and natural habitats in my area					
206	By choosing sustainable soil, water ,and grazing management agricultural practices, I can help the earth					
207	By using knowledge , I can make an important contribution to preserve the environment in my area					
208	By practicing sustainable soil, water ,and grazing management agricultural practices , I can encourage others to do the same					
209	By not using practices that degrading the land in my area, I can encourage others to do the same					
210	I am con*fi*dent that we as farmers can together contribute to solving the problem of land degradation					
211	We as farmers can come up with creative ideas to help solve environmental problems effectively, even if the external conditions are unfavorable					
212	I am con*fi*dent that we as farmers can together help mitigate global climate change					
213	I am con*fi*dent that we as farmers can together encourage more and more people to practice in					

	sustainable soil, water ,and grazing management practices					
214	I am willing pay more in my agricultural practices if this helps protect the environment					
	New Ecological Paradigm (NEP)					
215	We are approaching the limit of the number of people the earth can support					
216	Humans have the right to modify the natural environment to suit their needs					
217	When humans interfere with nature it often produces disastrous consequences					
218	Human ingenuity will insure that we do NOT make the earth unlivable					
219	Humans are severely abusing the environment					
220	The earth has plenty of natural resources if we just learn how to develop them					
221	Plants and animals have as much right as humans to exist					
222	The balance of nature is strong enough to cope with the impacts of modern industrial nations					
223	Despite our special abilities humans are still subject to the laws of nature					
224	The so-called "ecological crisis" facing humankind has been greatly exaggerated					
225	The earth is like a spaceship with very limited room and resources					
226	Humans were meant to rule over the rest of nature					
227	The balance of nature is very delicate and easily upset					
	Social role					
228	People can be both destructive and nurturing to the environment regardless of their social status					
229	People should be treated the same regardless of their social status					
230	Environmental protection tasks around should not be regardless of social status					
231	We should stop thinking about whether people are higher than us in social status and focus on other characteristics					
232	Major responsibility of the Kebeles authority is to provide security for all farmers in the kebele.					
233	Men practice more sustainable soil, water ,and grazing management practices than women.					
234	Some types of environmental practices like building terrace are just not appropriate for respected people in our village.					
235	Elders should make most decisions about how environment is protected.					
236	Elders should work on environmental protection practices only if necessary					
237	Development agent should be more concerned about the environment than me.					
238	Only I have called for work that I should be available to protect the environment					
239	For many important environmental tasks , it is better to call the development agent					

Section 3- CSApractices and preference

301 Which of the CSA practices have you used on [FIELD]? [Multiple responses expected]

	No	CSA practices	1. Yes 2. No	In hectare
	1	Plant dual purpose crops		
	2	Plant cover crops		
	3	Crop residue as mulch		
	4	Compost		
	5	Row planting		
	6	Crop rotations		
	7	Intercropping		
	8	water harvesting		

	9	Physical soil and water conservation structures					
	10	Plant Forage species					
	11	Planting perennial crops					
	12	Planting eucalyptus tree					
	13	Planting acacia decurrens					
	14	Agro forestry					
	15	Income generating activities					
	16	Crop insurance					
	17	Climate information services					

302	[*If the response to question 3011 is yes*], what advantages do you get from planting dual purpose crops? [Multiple responses expected]						
	No	Advantages	**1**	**2**	**3**	**4**	**5**
	1	used as animal feed					
	2	used as a fuel					
	3	reduce soil erosion					
	4	increases soil fertility					
	5	aesthetically pleasing					
303	[*If the response to question 3012 is yes*], what advantages do you get from planting cover crops? [Multiple responses expected]						
	No	Advantages	1	2	3	4	5
	1	reduce soil erosion					
	2	reduce weed pressure					
	3	increase soil fertility					
	4	increase income					
	5	used as animal feed					
	6	aesthetically pleasing					
	7	Reduce cost of production					
304	[If the response to question 3013 is yes], what advantages do you get from using crop residue as mulch? [Multiple responses expected]						
	No	Advantages	1	2	3	4	5
	1	Increase soil fertility for succeeding grain crops					
	2	reduce soil erosion					
	3	reduce weed pressure					
	4	increase soil organic matter(SOC)					
	5	it is cheap input/easily available					
	6	increase productivity					
	7	decreases the amount of inorganic fertilizer used					
305	[If the response to question 3014 is yes], what advantages do you get from using compost as fertilizer? [Multiple responses expected]						
	No	Advantages	1	2	3	4	5
	1	I have enough livestock for compost making					
	2	increase soil fertility					
	3	increase soil organic matter(SOC)					
	4	it is cheap input/easily available					
	5	increase productivity					
	6	decreases the amount of inorganic fertilizer used					
306	[If the response to question 3015 is yes], what advantages do you get from row planting ? [Multiple responses expected]						
	No	Advantages	1	2	3	4	5
	1	saves seed					
	2	easy weeding					
	3	increase productivity					

	4	decreases the amount of inorganic fertilizer used					
	5	aesthetically pleasing.					
307	[If the response to question 3016 is yes], what advantages do you get from crop rotation ? [Multiple responses expected]						
	No	Advantages	1	2	3	4	5
	1	Increase soil fertility for succeeding grain crops					
	2	reduce soil erosion					
	3	reduce weed pressure					
	4	pest control					
	5	increase productivity					
	6	decreases the amount of inorganic fertilizer used					
	7	aesthetically pleasing					
308	[If the response to question 3017 is yes], what advantages do you get from intercropping ? [Multiple responses expected]						
	No	Advantages	1	2	3	4	5
	1	reduce crop failure					
	2	increase productivity					
	3	increase income					
	4	reduce the amount of fertilizer used					
	5	increase soil fertility					
	6	increase feed for animals					
	7	reduce weed pressure					
	8	pest control					
309	[If the response to question 3018 is yes], what advantages do you get from water harvesting ? [Multiple responses expected]						
	No	Advantages	1	2	3	4	5
	1	improves farm income;					
	2	reduce crop failure					
	3	improves social networking;					
	4	improves livestock holding					
	5	rehabilitates land					
	6	increases crop harvesting frequency					
	7	increases agro biodiversity					
310	[If the response to question 3019 is yes], what advantages do you get from SWC structures? [Multiple responses expected]						
	No	Advantages	1	2	3	4	5
	1	reduce soil erosion					
	2	increase soil fertility					
	3	increase productivity					
	4	increase water infiltration					
	5	aesthetically pleasing					
	6	increase soil organic matter					
	7	easy to construct					
	8	reclaim land					
311	[If the response to question 30110 is yes], what advantages do you get from planting forage species? [Multiple responses expected]						
	No	Advantages	1	2	3	4	5
	1	increase productivity					
	2	increase soil fertility					
	3	increase feed for animals					
	4	reduce soil erosion					
	5	rehabilitate land					
	6	aesthetically pleasing					
312	[If the response to question 30111 is yes], what advantages do you get from planting perennial crops ? [Multiple responses expected]						

	No	Advantages	1	2	3	4	5
	1	Improves farm income;					
	2	reduce crop failure					
	3	rehabilitates land					
	4	increases productivity					
	5	increases agro biodiversity					
	6	aesthetically pleasing					
313	[If the response to question 30112 is yes], what advantages do you get from planting eucalyptus ? [Multiple responses expected]						
	No	Advantages	1	2	3	4	5
	1	improves income					
	2	rehabilitates land					
	3	diversify fire wood source					
	4	reduce soil erosion					
	5	increased biomass					
	6	aesthetically pleasing					
	7	Reduces agricultural labour					
	8	Reduces cost of production					
314	[If the response to question 30113 is yes], what advantages do you get from planting acacia decurrens ? [Multiple responses expected]						
	No	Advantages	1	2	3	4	5
	1	improves income;					
	2	rehabilitates land					
	3	diversify fire wood source					
	4	reduce soil erosion					
	5	increased biomass					
	6	increase productivity					
	7	increase soil fertility					
	8	increase feed for animals					
	9	aesthetically pleasing					

3 Point Likert Scale : 1.Strongly disagree 2. disagree 3. neutral 4. agree 5. Strongly agree

Section 4: Crop Production						
401	How many plots of land did you farm in the last[2009] rainy season?					Skip Rule
402	What was the size of [FIELD] in ha?					
403	What was the land holding status of the [FIELD]?					
	No	Holding status	1. Yes 2. N0			
	1	own land under cultivation				
	2	own land rented out				
	3	own land under sharecropping				
	4	rented in land				
	5	land acquired under sharecropping				
404	What crops were grown in the last [2009] rainy season on the [FIELD]?					
	No	**Crop**	**Size in Ha**	**Amount harvested in quintal**		
	1	Tef				
	2	Wheat				
	3	Barley				

	4	Potato				
	5	Maize				
	6	Engido				
	7	Millet				
	8	Tricale				
	9	Gibeto/Lupin				
	10	Eucalyptus (in Birr)				
	11	Acacia decrence(in Birr				
	12	Other specify				
405	How many times did you plough the [FIELD] during planting [CROP]?					
406	Did you used chemical fertilizer on [FIELD] during planting [CROP]?				1. Yes ☐ 2. No ☐	
407	Did you used fig/compost on the field [FIELD] during planting [CROP]?				1. Yes ☐ 2. No ☐	
408	How much of the following fertilizers used in the [FIELD] during planting [CROP]?					
	No	Fertilizer	Quantity in Kg	In Birr		
	1	UREA				
	2	DAP				
	3	NPS/mitin				
	4	Other				
409	How do you obtain/purchase the fertilizers for the [FIELD] during planting [CROP]?					
	No	Fertilizer	1. Gift 2. Cash 3. Credit			
	1	UREA				
	2	DAP				
	3	NPS/mitin				
410	Did you used improved seed on the [FIELD] during planting [CROP]?				1. Yes ☐ 2. No ☐	
411	How much did the improved seed cost you in Birr for [CROP]?					
412	Did you used labor other than your family labor during planting or harvesting [CROP]?				1. Yes ☐ 2. No ☐	
413	Did you used wonfel or debo during planting or harvesting [CROP]?				1. Yes ☐ 2. No ☐	
414	How much did the labor cost you?					
415	Did you used pesticide/herbicide in the [FIELD] ?				1. Yes ☐ 2. No ☐	
416	How much did it cost you?					
417	Have you encountered crop damage in the [FIELD]?				1. Yes ☐ 2. No ☐	
418	What is the cause of the damage of [CROP]?					
	S/N	Cause of damage	1. Yes 2. No			
	1	TOO MUCH RAIN				
	2	TOO LITTLE RAIN				
	3	INSECTS				
	4	CROP DISEASE				
	5	WEEDS				
	6	HAIL				
	7	FROST				
	8	FLOOD				
	9	WILD ANIMALS				
	10	LOCUST				
	11	BIRDS				
	12	Other specify_____				
419	What is the percentage share of damage for [CROP] on this field?				Percent_____	
420	How often is annual crop the [FIELD] used in [2009]productions season				1. Once ☐ 2. Twice ☐ → Q.406 3. Three times ☐ → Q.406	

Section 5 – Livelihood Vulnerability								
Adaptation			**1**	**2**	**3**	**4**	**5**	
501	How many times have you got agricultural extension services in your area during the last 12 months?							
502	How many times, did you got agricultural extension service on agricultural technology and inputs use ?							
503	How many times, have you ever heard about climate related information from agricultural extension services source(s)?							
504	How many times ,do you use the agricultural extension services information for productivity improvement?							
505	How many times ,do you and family member suffer from chronic illness ?							
506	How many times ,do you and your family use toilet facilities ?							
507	How many times ,do you use the credit service in your area?							
508	How many times have you returned the loan you borrowed from credit service?							
509	How many times ,did you used the credit service to buy agricultural inputs /seed ,fertilizer and feed?							
510	How many times do you save in cash or kind ?							
511	How many times did you receive remittance (in the form of cash or kind) during the last 12 months?							
512	How many times ,do you use veterinary service in your area ?							
513	**In your opinion, compared to the last 20 to 30 years**							
	1	The number of hot days increased						
	2	The amount of precipitation decreased						
	3	The amount of precipitation increased						
	4	Number of climate related disasters encountered increased						
	5	Drought						
	6	Flooding						
	7	Hail						
	8	Erratic rainfall						
514	Which of the changes have you observed in precipitation pattern over the last 20-30 years							
	No	Changes						
	1	Early onset of rain season						
	2	Late onset of rain season						
	3	No rain when the crops need it						
	4	Rain when it is not needed						
	5	Early withdrawal of rain						
	6	Too little rain						
	7	Too much rain						

515	Do you have land of your own?			1. Yes☐ 2. N☐	
516	Do you have grazing land for your livestock in your area?			1. Yes☐ 2. N☐	
517	Is your grazing land enough to feed your livestock ?			1. Yes☐ 2. N☐	
518	Is there forest in your area?			1. Yes☐ 2. N☐	
519	Do you use the forest for source of fire wood			1. Yes☐ 2. N☐	
520	What are the main sources of water for domestic use in your household?				
	No	**Source**	**1. Yes 2. No**		
	1	Public tap/Public water tap			
	2	Hand pump well/borehole			
	3	Unprotected spring			
	4	Unprotected dug well			
	5	Surface water			
521	Has the head of household suffered any serious health problem during the last 6 months?			1. Yes☐ 2. N☐	
522	How many days did head of the household stop agricultural activity due to this last 6 months?				
523	Do health post or station do exist in your locality?			1. Yes☐ 2. N☐	
524	How far is the health post or health station in minutes from your home ?				
525	Have you get the needed service from ?			1. Yes☐ 2. N☐	

Section 6 – Climate Change mitigation					
	Land use change(deforestation)				
601	Do you have eucalyptus plantation?			1. Yes ☐ 2. No ☐	
602	How many hectares of eucalyptus plantation do you have?				
603	After how many years do you plan to cut eucalyptus plantation for sale ?				
604	After you cut it do you plan change the land use of the plantation?			1. Yes ☐ 2. No ☐	
605	Do you have acacia decerrens plantation?			1. Yes ☐ 2. No ☐	
606	How many hectares of acacia decerrens plantation do you have?				
607	After how many years do you plan to cut acacia decerrens for sale ?				
608	After you cut it do you plan change the land use of the plantation?			1. Yes ☐ 2. No ☐	
	Land use change(afforestation)				
609	In the future, do you plan to plant eucalyptus or acacia decerrens on your				
	Land use	**1. Yes 2. No**	**In Hectares**		
	Crop land				
	Set aside land				
	Degraded land				
	Grass land				
	Perennial crop land				
610	Do you plan to change your crop land to house in the next five years?			1. Yes ☐ 2. No ☐	
611	How much hectare of your crop land do you want to change to house?				
612	Do you use manure management on this field?			1. Yes ☐ 2. No ☐	
613	Do you plan to change your crop land to perennial crop field?			1. Yes ☐ 2. No ☐	
614	How many hectares do you plan to change to perennial ?				
615	Did you drained grassland area for crop land ?			1. Yes ☐ 2. No ☐	
616	How many hectares of grassland area did you drained for crop production?				
617	Did you use lime on your crop land?			1. Yes ☐ 2. No ☐	
618	How many kilogram of lime did you used?				
619	Do you use firewood for cooking your food?			1. Yes ☐ 2. No ☐	
620	How many kilogram of firewood do you use in a month?				

622	How many head livestock do you posses ?				
	S/N	Livestock	Heads of livestock		
	1	Ox/Oxen			
	2	Cow/Cows			
	3	Bull/Bulls			
	4	Heifer/Heifers			
	5	Calf/Calves			
	6	Goat/Goats			
	7	Sheep			
	8	Poultry			
	9	Horse/Horses			
	10	Mule/Mules			
	11	Donkey/Donkeys			
	12	Bee colony			
623	Livestock Products in a year				

	S/N	Livestock	Value in Birr	Amount in Kg	
	1	Milk			
	2	Butter			
	3	Cheese			
	4	Oxen			
	5	Sheep			
	6	Goat			
	7	Poultry			
	8	Egg			
	9	Honey			

Section 7 – Food Security

701 I would like to ask you about all the different foods that your household members have eaten in the **last 7 days**. Could you please tell me **how many days** in the past week your household has eaten the following foods? (for each food, ask what the primary source of each food item eaten that week was, as well as the second main source of food, if any)

	Food item	**Number of days**	**Food sources ***	*** Food source codes:**
	Enjera /Tef, Maize, Millet, Sorghum, wheat, Engedo			Purchase =1 Own production =2 Traded goods/services, barter =3 Borrowed = 4 Received as gift= 5 Food aid =6 Other (specify) =7
	Potatoes as main food			
	Potatoes used in' wett'			
	Groundnuts & Pulses/Beans, Peas, niger seed, linseed			
	Pulses used as 'wett'			
	Vegetables and leaves			
	Fruits			
	Red meat (sheep/goat/beef)			
	Poultry			
	Eggs			
	Fish			
	Milk and other dairy			
	Sugar and sugar products,			
	Vegetable oil and butter			

Section 8 – Climate Resilience

Absorptive capacity

801 What coping mechanisms do you use before and after drought occur?

No	**Coping strategies**	**1. Yes** **2. No**
1	Late(early) sowing of crops	
2	Use drought resistant crop variety	
3	Use crop residue as mulching	
4	Use water harvesting for crop cultivation	
5	Decreased quantity of meal	
6	Decreased diversity of meal	
7	Borrowed grains	
8	Sought support from NGOs and government	
9	Borrowed cash	
10	Sought support from friends/ relatives	

	11	Sales of livestock/oxen		
	12	Sought additional labor work		
	13	Sales of farm land		
	14	Distressed sale farm equipment		
	15	Distressed sale of household assets		
	16	Distressed migration of HH members		
	17	Engaged in the extraction and sale of natural resources		
	18	Sales of perennial crops		

802	What coping mechanisms do you use before and after flood occur?				
	No	Coping strategies	1. Yes 2. No		
	1	Borrowing seeds			
	2	Selling household assets			
	3	Changing crops			
	4	Using BBM			
	5	Informal social transfers			
	Transformative capacity				
803	Do you get food aid from government or NGO?			1. Yes ☐ 2. No ☐	
804	Do you use local market for agricultural input/fertilizer or improved seed?			1. Yes ☐ 2. No ☐	
805	Do you use local market for agricultural output/ sale product and buy food ?			1. Yes ☐ 2. No ☐	
806	Do use these facilities in your locality?[Multiple responses are possible]				
	No	**Facilities**	**1. Yes 2. NO**	**How far are they in Minutes?**	
	1	Health post			
	2	Main market center			
	4	Local Shop			
	3	Farmer training center			
	4	All weather road			
	5	Potable Water for domestic use			
	6	Water source for irrigation			
	7	Primary school			
	8	Grain mill			
	9	Dry weather road			
807	Did you participate in the following community based organizations during the last 12 months?				
	No	**Community Based Organization**	**1. Yes 2. No**		
	1	Debo/Wonfel			
	2	Idir			
	3	Iqub			
	4	Mahiber			

I have finished my question, I thank you very much for your willingness to participate in the study.

Ending time: _____

Take GPS reading of the interview place

Annex A

Table A1: Determinants of CSA innovation adoption

Explanatory variables	Crop residue			Improved variety			Crop rotation			Compost		
	Adopter	Non adopter	t-test (chi2)	Adopter	Adopter	Adopter	Adopter	Non adopter	t-test (chi2)	Adopter	Non adopter	t-test (chi2)
Personal Factors												
Household head sex	0.98	0.91	9.62***	0.94	0.94	0.94	0.97	0.93	3.14*	0.94	0.94	0.06
Household head age(in Year)	44.39	47.55	-2.58**	46.9	46.9	46.9	46.37	45.94	0.34	46.9	44.6	1.8*
Household head education level	1.96	1.54	5.64***	1.72	1.72	1.72	1.79	1.70	1.22	1.72	1.75	2.5
Household head farm experience (in Year)	9.46	11.78	-2.94***	10.7	10.7	10.7	10.45	10.87	-0.50	10.7	10.8	-0.19
Household size	5.38	5.22	0.89	5.6	5.6	5.6	5.54	5.15	2.11**	5.6	4.7	5.14***
Climate change awareness	0.27	0.1	18.76***	0.23	0.23	0.23	0.19	0.17	0.1	0.23	0.09	12.02***
CSA awareness	0.32	0.1	31.09	0.27	0.27	0.27	0.21	0.20	0.05	0.27	0.08	21.35***
Economic Factors												
Number of Plots	1.73	1.38	5.06***	4.00	4.98	-0.99***	1.73	1.43	4.1***	1.63	1.37	3.37***
Total farm size	4.38	4.23	0.91	1.43	1.79	-0.35***	4.50	4.18	1.88*	4.5	4.0	2.9***
Livestock holding	5.44	4.38	3.36***	4.23	6.33	-2.11***	5.60	4.45	3.6***	5.5	3.6	6.01***
Access to credit	0.5	0.52	0.13	0.56	0.40	9.25***	0.54	0.49	0.78	0.51	0.5	0.01
Access to saving	0.16	0.2	1.24	0.21	0.12	4.13**	0.26	0.14	9.61***	0.19	0.17	0.13
Remittance	0.84	0.86	0.69	0.85	0.86	0.12	0.87	0.84	0.73	0.84	0.88	1.04
Institutional Factors												
Agricultural extension service	3.5	3.69	- 2.78***	3.7	3.7	3.7	3.72	3.54	0.17**	3.7	3.5	2.73***
Market distance (in minutes)	60.24	63.46	-0.77	66.5	66.5	66.5	64.83	60.34	1.04	66.5	53.3	3.04***
Mobile phone	0.46	0.38	3.21*	0.5	0.5	0.5	0.38	0.43	1.19	0.5	0.26	23.21***
Stand pipe water infrastructure	0.37	0.31	1.91	0.3	0.3	0.3	0.36	0.32	0.76	0.3	0.4	4.2**
Hand pump well water infrastructure	0.3	0.23	3.11*	0.22	0.22	0.22	0.19	0.30	5.89**	0.22	0.35	7.86***
Solar(energy infrastructure)	0.39	0.38	0.1	0.41	0.41	0.41	0.43	0.36	1.57	0.41	0.35	1.64
Improved stove(energy infrastructure)	0.36	0.3	2.2	0.41	0.41	0.41	0.41	0.28	8.02***	0.41	0.18	22.06***
Community work	0.61	0.56	0.96	0.57	0.57	0.57	0.52	0.62	3.91**	0.57	0.61	0.44
Wenfel	0.4	0.45	1.07	0.35	0.35	0.35	0.50	0.39	4.88**	0.35	0.57	17.31***
Mahber	0.86	0.86	0.03	0.9	0.9	0.9	0.85	0.87	0.36	0.9	0.77	13.44***
Informal aid from fiends	2.99	2.21	3.48***	2.7	2.7	2.7	2.43	2.65	0.94	2.7	2.4	1.01
Own farm plot	0.82	0.76	2.32	0.81	0.81	0.81	0.82	0.77	1.46	0.81	0.75	2.43
Environmental Factors												
Degraded farm land	0.15	0.19	1.07	0.15	0.15	0.15	0.22	0.15	3.41*	0.15	0.23	4.31**
Erosion prone farm land	0.05	0.02	3.77*	0.04	0.04	0.04	0.05	0.02	2.65	0.04	0.03	0.2
prolonged dry spell	0.84	0.69	12.85***	0.76	0.76	0.76	0.84	0.71	9.31	0.76	0.74	0.35
Precipitation decreased	0.73	0.62	5.69**	0.65	0.65	0.65	0.68	0.67	0.1	0.65	0.72	1.83
Drought increased	0.7	0.66	0.73	0.66	0.66	0.66	0.75	0.64	5.02**	0.66	0.72	1.84
Flooding increased	0.51	0.48	0.22	0.52	0.52	0.52	0.51	0.49	0.2	0.52	0.45	1.95
Hailstorm increased	0.53	0.45	2.64	0.49	0.49	0.49	0.50	0.48	0.16	0.49	0.48	0.05
Erratic rainfall increased	0.77	0.76	0.12	0.75	0.75	0.75	0.76	0.77	0.04	0.75	0.8	1.38
Agroecosystem zones												

Dejen(AESZ1)	0.51	0.49	0.07	0.93	0.42	0.58	0.45	0.55
Awobel(AESZ2)	0.56	0.44	0.15	0.85	0.44	0.56	0.29	0.71
Basoliben (AESZ3)	0.67	0.33	0.64	0.36	0.41	0.41	0.89	0.11
The midland with slopping land (AESZ4)	0.35	0.65	0.38	0.62	0.37	0.63	0.84	0.16
The hilly and mountainous highland (AESZ5)	0.27	0.73	0.20	0.80	0.27	0.73	0.67	0.33

Standard errors in parentheses* p < 0.1, ** p < 0.05, *** p < 0.01

Table A1: Continued

Explanatory variables	Row planting			Soil and water conservation (SWC)			Agroforestry		
	Adopter	Non adopter	t-test (chi2)	Adopter	Non adopter	t-test (chi2)	Adopter	Non adopter	t-test (chi2)
Personal Factors									
Household head sex	0.94	0.94	0.0	0.94	0.94	0.03	0.99	0.93	4.45**
Household head age(in Year)	46.71	44.16	1.79*	46.12	46.07	0.04	48.05	45.59	1.62
Household head education level	1.69	1.86	-1.92*	1.80	1.66	1.9*	1.86	1.70	1.73*
Household head farm experience (in Year)	11.24	9.05	2.37**	10.78	10.65	0.16	11.20	10.59	0.61
Family size	5.50	4.63	4.24***	5.37	5.21	0.86	6.06	5.09	4.4***
Climate change awareness	0.18	0.17	0.14	0.15	0.21	2.59	0.25	0.16	4.03**
CSA awareness	0.21	0.18	0.48	0.21	0.19	0.26	0.32	0.17	10.1***
Economic Factors									
Total farm size	1.53	1.57	-0.42	1.60	1.48	1.6	1.84	1.46	4.28***
Number of Plots	4.44	3.83	3.2***	4.20	4.40	-1.22	4.94	4.13	4.01***
Livestock holding	5.19	3.84	3. 7***	4.90	4.83	0.21	6.22	4.52	4.44***
Credit	0.49	0.56	-1.4	0.61	0.40	17.43***	0.49	0.51	0.07
Save	0.18	0.19	-0.02	0.21	0.15	2.39	0.16	0.19	0.32
Remittance	0.83	0.92	-5.22**	0.84	0.87	0.76	0.76	0.88	7.45***
Institutional Factors									
Agricultural extension service	3.68	3.38	3.7***	3.66	3.55	1.68*	3.66	3.59	0.72
Market distance (in minutes)	62.83	59.29	0.73	67.93	55.92	2.9***	60.93	62.25	0.26
Mobile phone	0.43	0.37	1.0	0.56	0.27	35.37***	0.47	0.40	1.42
Stand pipe water source	0.27	0.55	27.64***	0.42	0.25	12.72***	0.23	0.36	5.42**
Hand pump well water source	0.26	0.25	-0.03	0.15	0.37	25.87***	0.25	0.26	0.05
Solar	0.41	0.30	3.89**	0.42	0.36	1.54	0.47	0.36	3.29*
Improved stove	0.35	0.25	3.24*	0.35	0.31	0.63	0.47	0.29	10.2***
Community land restoration	0.56	0.67	3.7*	0.61	0.56	0.91	0.56	0.59	0.21
Wenfel	0.43	0.42	0.02	0.35	0.51	11.6***	0.41	0.43	0.08
Mahber	0.89	0.76	9.72***	0.93	0.79	15.84***	0.91	0.85	2.21
Informal aid from fiends	2.60	2.50	0.36	2.52	2.62	-0.44	2.83	2.51	1.14
Own farm plot	0.80	0.75	0.87	0.79	0.78	0.12	0.90	0.76	7.75***
Environmental Factors									
Degraded farm land	0.18	0.15	0.7	0.19	0.16	0.46	0.20	0.17	0.33
Erosion prone farm land	0.03	0.05	-1.07	0.05	0.01	4.57**	0.01	0.04	1.58
prolonged dry spell	0.73	0.82	3.44*	0.80	0.70	5.61**	0.83	0.74	3.14*
Precipitation decreased	0.64	0.78	7.37***	0.64	0.70	1.73	0.69	0.67	0.11
Drought increased	0.67	0.72	0.72	0.69	0.68	0.06	0.72	0.67	0.91

Flooding increased	0.51	0.46	0.64	0.54	0.45	3.78*	0.59	0.47	3.62*
Hailstorm increased	0.48	0.54	1.27	0.60	0.38	21.8***	0.54	0.48	1.08
Erratic rainfall increased	0.77	0.76	0	0.80	0.73	3.35*	0.77	0.77	0.01
Agroecosystem zones									
Dejen(AESZ1)	0.32	0.68		0.78	0.22		0.01	0.99	
Awobel(AESZ2)	0.30	0.70		0.27	0.73		0.05	0.95	
Basoliben (AESZ3)	0.98	0.02		0.34	0.66		0.42	0.58	
The midland with slopping land (AESZ4)	0.97	0.03		0.65	0.35		0.18	0.82	
The hilly and mountainous highland (AESZ5)	0.94	0.06		0.51	0.49		0.23	0.77	

Standard errors in parentheses* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Annex B

Table B1 : Estimates of the multivariate probit model

VARIABLES	Improve crop variety	Crop residue Management	Crop rotation	Compost	Row planting	SWC	Agroforestry
Personal factors							
Gender	-0.01(0.35)	1.03(0.38)***	0.50(0.32)	-0.34(0.33)	-0.03(0.34)	-0.37(0.3)	0.86(0.49)*
Age	-0.01(0.01)	-0.012(0.01)*	0.004(0.01)	-0.002(0.01)	-0.003(0.01)	-0.003(0.01)	0.004(0.01)
Education	0.013(0.11)	0.33(0.1)***	0.06(0.09)	-0.011(0.1)	-0.06(0.1)	0.229(0.1)**	0.10(0.1)
Farm experience	0.015(0.01)*	-0.01(0.01)	-0.003(0.01)	-0.01(0.01)	0.02(0.01)	0.01(0.01)	0.01(0.01)
Climate Change know	0.58(0.33)*	-0.4(0.35)	0.13(0.35)	-0.24(0.45)	-0.08(0.41)	-1.2(0.39)***	-0.4(0.36)
CSA know	-0.34(0.32)	1.2(0.34)***	-0.1(0.32)	1.32(0.44)***	0.12(0.39)	0.86(0.37)**	0.65(0.34)*
Economic factors							
Land fragmentation	0.14(0.05)**	-0.10(0.05)*	0.030(0.05)	0.03(0.06)	0.13(0.06)**	-0.11(0.05)**	0.13(0.05)**
Farm size	0.06(0.13)	0.37(0.13)***	0.26(0.13)***	0.12(0.14)	-0.32(0.13)**	0.30(0.13)*	0.12(0.13)
Livestock	0.09(0.03)***	0.06(0.03)*	0.03(0.03)	0.11(0.03)***	0.05(0.03)	0.01(0.03)	0.02(0.02)
Credit	-0.16(0.17)	-0.17(0.17)	0.181(0.17)	-0.18(0.18)	-0.09(0.18)	0.15(0.16)	0.06(0.20)
Saving	0.09(0.23)	0.07(0.22)	0.66(0.21)***	0.49(0.24)**	0.19(0.23)	0.38(0.22)*	0.15(0.26)
Remittance	0.25(0.22)	0.06(0.22)	0.28(0.23)	0.21(0.24)	-0.59(0.28)**	-0.12(0.21)	-0.14(0.22)
Institutional factors							
Extension Service	0.2(0.09)**	-0.2(0.1)*	0.27(0.09)***	0.22(0.11)**	0.26(0.11)**	0.18(0.09)*	0.02(0.11)
Market distance	0.002(0.002)	-0.002(0.002)	0.002(0.002)	0.01(0.003)***	0.001(0.002)	0.003(0.002)	0.0001(0.002)
Mobile	-0.37(0.19)*	0.3(0.18)*	-0.3(0.18)*	0.41(0.2)**	0.11(0.19)	0.67(0.18)***	0.01(0.21)
Standpipe(water infrastructure)	0.01(0.21)	0.5(0.2)**	0.14(0.2)	-0.23(0.22)	-0.6(0.21)***	0.42(0.2)**	-0.23(0.22)
Tube well(water infrastructure)	0.46(0.2)**	0.57(0.2)***	-0.42(0.2)**	-0.4(0.22)*	-0.34(0.23)	-0.41(0.2)**	-0.15(0.2)
Solar	0.2(0.17)	-0.14(0.18)	0.2(0.17)	-0.23(0.19)	0.18(0.19)	0.2(0.18)	0.21(0.19)
Improved stove	-0.07(0.19)	-0.02(0.18)	0.32(0.18)*	0.5(0.2)**	-0.1(0.2)	-0.05(0.18)	0.14(0.20)
Community work	-0.49(0.18)***	0.03(0.18)	-0.39(0.18)**	-0.1(0.2)	-0.5(0.19)**	0.03(0.18)	-0.45(0.2)**
Wenfel(social network)	-0.07(0.17)	-0.4(0.17)**	0.5(0.17)***	-0.7(0.2)***	0.12(0.2)	-0.24(0.17)	-0.17(0.19)
Mahber(social network)	0.02(0.23)	0.03(0.22)	-0.5(0.22)**	0.52(0.23)**	0.46(0.22)**	0.65(0.23)***	0.14(0.27)
Informal aid support	0.07(0.04)**	0.03(0.03)	-0.06(0.04)	-0.07(0.04)	0.01(0.04)	-0.04(0.03)	0.05(0.04)

Strong tenure security	0.45(0.23)**	0.61(0.22)***	0.03(0.21)	-0.18(0.22)	0.16(0.22)	0.06(0.2)	0.67(0.3)**
Environmental factors							
Degraded land	0.76(0.22)***	-0.33(0.23)	0.23(0.21)	-0.33(0.24)	0.56(0.25)**	0.18(0.23)	0.5(0.25)**
Erosion prone land	-1.3(0.9)	1.8(0.6)***	0.48(0.4)	0.8(0.55)	-0.4(0.48)	0.02(0.5)	
Temperature increased	-0.07(0.19)	0.49(0.19)**	0.43(0.20)**	-0.07(0.2)	-0.19(0.2)	0.16(0.19)	0.33(0.24)
Rainfall decreased	-0.44(0.19)**	0.2(0.18)	0.1(0.17)	0.04(0.2)	-0.24(0.2)	-0.25(0.18)	-0.1(0.2)
Drought increased	0.15(0.19)	-0.08(0.18)	0.21(0.18)	-0.2(0.2)	0.02(0.2)	-0.09(0.18)	0.17(0.2)
Flood increased	-0.2(0.17)	-0.1(0.17)	-0.05(0.16)	0.06(0.18)	0.05(0.18)	-0.07(0.16)	0.33(0.19)*
Hailstorm increased	-0.48(0.18)***	0.27(0.18)	-0.03(0.17)	-0.14(0.2)	-0.1(0.2)	0.25(0.17)	0.04(0.2)
Erratic rainfall increased	0.34(0.2)*	-0.26(0.18)	0.02(0.19)	-0.27(0.21)	-0.05(0.21)	0.4(0.18)**	-0.06(0.21)
AESZ1	-0.32(0.45)	-0.37(0.32)	-0.330(0.29)	0.15(0.34)	-0.14(0.38)	1.61(0.35)***	-1.32(0.69)*
AESZ3	1.78(0.36)***	0.98(0.3)***	-0.392(0.27)	2.15(0.34)***	2.94(0.43)***	-0.06(0.31)	1.89(0.42)***
AESZ4	1.7(0.42)***	-0.51(0.34)	-0.32(0.32)	1.07(0.37)***	3.03(0.58)***	0.7(0.35)**	0.56(0.46)
AESZ5	1.1(0.37)***	-0.52(0.28)*	-0.6(0.27)**	1.03(0.30)***	2.41(0.36)***	0.27(0.29)	1.00(0.4)**
Constant	-2.66(0.7)***	-2.13(0.7)***	-3.73(0.7)***	-0.92(0.7)	0.24(0.7)	-1.68(0.6)**	-4.36(0.9)***
Log likelihood =				-1353.77			
Wald chi2(96) =				581.46			
Probability >chi2 =				0.0000			
Sample size =				423			

Standard errors in parentheses ***, **, * are significant at 1%, 5%, and 10%, respectively

Annex C :

Table C1 Comparison among CSA innovations on major components of livelihood vulnerability

CSA Innovations	Improved variety			Crop residue management			Crop rotation			Compost		
	Adopter	**Non adopter**	**t value**	**Adopter**	**Non adopter**	**t value**	**Adopter**	**Non adopter**	**t value**	**Adopter**	**Non adopter**	**t value**
Natural disaster	0.52	0.61	-3.7***	0.57	0.59	-1.2	0.62	0.56	3.1***	0.57	0.60	-1.2
Climate change	0.65	0.72	-3.7***	0.73	0.67	3.2***	0.75	0.67	3.9***	0.69	0.71	-0.7
Exposure index	**0.58**	**0.67**	**-4.54*** **	**0.64**	**0.63**	**-0.76**	**0.68**	**0.61**	**4.18*** **	**0.63**	**0.65**	**-1.2**
Ecosystem	0.34	0.31	3.3***	0.38	0.40	-2.3**	0.32	0.32	0.7	0.33	0.29	4.4***
Agriculture	0.3	0.35	-4.6***	0.33	0.34	-0.5	0.33	0.34	-1.4	0.31	0.37	-6.9***
Sensitivity index	**0.38**	**0.37**	**1.66**	**0.36**	**0.38**	**-2.53*** **	**0.37**	**0.37**	**0.2**	**0.38**	**0.36**	**2.96*** **
Wealth	0.71	0.62	6.9***	0.65	0.71	-5.25***	0.64	0.71	-4.7***	0.65	0.74	-6.7***
Technology/ innovation	0.90	0.76	19.2***	0.81	0.80	0.5	0.81	0.80	0.7	0.82	0.79	3.0***
Infrastructure	0.16	0.15	0.4	0.15	0.16	-0.35	0.16	0.15	1.1	0.16	0.14	-2.1**
Knowledge	0.75	0.79	-2.7**	0.77	0.78	-0.1	0.75	0.79	-2.2**	0.77	0.79	-1.8
Social Network	0.74	0.75	-1.7	0.73	0.76	-2.7**	0.75	0.75	0.6	0.74	0.76	-1.4
Adaptive capacity index	**0.36**	**0.33**	**5.66*** **	**0.35**	**0.33**	**3.88*** **	**0.35**	**0.33**	**3.44*** **	**0.34**	**0.32**	**3.9*** **
IPCC-LVI=(E-AC)*S/100	**0.09**	**0.12**	**-6.96*** **	**0.106**	**0.112**	**-0.8**	**0.12**	**0.10**	**3.16*** **	**0.106**	**0.115**	**-1.33**

* p < 0.1, ** p < 0.05, *** p < 0.01

Table 1 **Continued**

CSA innovations	Row planting			SWC			Agroforestry		
	Adopter	Non adopter	t value	Adopter	Non adopter	t value	Adopter	Non adopter	t value
Natural disaster	0.57	0.62	-1.9*	0.63	0.53	4.4***	0.63	0.57	2.4**
Climate change	0.68	0.76	-3.5***	0.73	0.66	3.55***	0.73	0.69	1.6
Exposure index	0.62	0.68	**3.1*** **	0.67	0.59	**4.98*** **	0.67	0.62	**2.45** **
Ecosystem	0.33	0.27	7.9***	0.32	0.31	1.7*	0.35	0.31	4.8***
Agriculture	0.32	0.39	-7.9***	0.33	0.34	1.2	0.30	0.34	-4.5***
Sensitivity index	0.38	0.34	**4.61*** **	0.37	0.37	**0.2**	0.38	0.37	**2.39** **
Wealth	0.67	0.72	-3.2***	0.67	0.69	1.15	0.61	0.70	-5.7***
Technology / innovation	0.82	0.76	5.1***	0.79	0.82	-3.4***	0.83	0.80	2.6**
Infrastructure	0.16	0.14	1.5	0.16	0.15	-1.0	0.16	0.15	1.3
Knowledge	0.76	0.81	-3.1***	0.76	0.79	-1.9*	0.75	0.78	-1.9*
Social Network	0.74	0.76	-1.6	0.74	0.75	-1.1	0.73	0.75	-1.7
Adaptive capacity index	0.34	0.32	**2.87*** **	0.34	0.33	**1.8***	0.35	0.33	**3.6*** **
IPCC-LVI=(E-AC)*S/100	0.106	0.123	**-3.47*** **	0.123	0.097	**2.2** **	0.123	0.107	**0.16**

* p < 0.1, ** p < 0.05, *** p < 0.01

Table C2. Indicators of farm level GHG emissions and adoption of CSA innovations

Indicators	Improved Variety	Crop Residue Management	Crop Rotation	Compost	Row planting	SWC	Agrofores
Wood lot (in ha)	15	15	13	29	33	19	12
Area of tef (in ha)	154	243	197	323	361	253	107
Tef yield(in qt/ha)	21.1	27.8	20.7	42.0	47.8	26.8	13.6
Area of maize (in ha)	130	209	156	276	296	219	97
Maize yield(in qt/ha)	18.2	25.1	19.9	38.0	44.5	24.7	14.6
Area of wheat (in ha)	158	239	193	317	333	232	112
Wheat yield(in qt/ha)	22.2	27.3	22.1	41.5	47.7	26.2	16.5
Area of Potato (in ha)	59	70	74	111	122	87	37
Potato yield(in qt/ha)	8.5	8.8	9.2	16.1	18.8	11.2	6.1
Area of faba bean (in ha)	28	37	31	50	54	40	17
Faba bean yield(in qt/ha)	4.5	4.7	4.6	8.1	9.1	5.1	2.6
Area of barley (in ha)	24	38	31	55	62	44	22
Barley yield(in qt/ha)	2.7	4.2	3.8	7.2	9.3	4.6	2.9
Dairy cattle(in number)	235	339	289	493	566	402	159
Other cattle (in number)	251	388	319	566	645	438	158
Sheep (in number)	304	480	398	760	883	607	203
Goat (in number)	60	63	50	94	109	60	37
Horse (in number)	44	86	60	113	129	101	28
Poultry (in number)	249	303	269	504	650	399	145
Milk (in ton)	7	15	9	20	20	15	6
Meat (in ton)	15	23	18	33	39	25	9
Lime (in ton)	15	22	19	34	34	192	10
UREA (in ton)	23.2	32.2	23.8	40.1	44.5	25.4	16.2
NPS (in ton)	51	61.2	44.5	93.8	103.8	48	45.1
Fire wood(in ton)	489.9	716.0	584.7	1,062.4	1,192.5	803.4	363.5