Evaluation of Perceptions, Adoption Decisions, and Impact of Climate-Smart Agricultural Practices on Smallholder Maize Farmers' Livelihoods in KwaZulu-Natal Province, South Africa.

by

Minentle Lwando Mnukwa (222094769)

Submitted in fulfilment of the requirements for the degree of Doctor of Philosophy in Agriculture (Agricultural Economics)

in the

School of Agriculture and Sciences

College of Agricultural, Engineering, and Science Discipline

University of KwaZulu-Natal

Pietermaritzburg

South Africa

Promoter (s) : Dr L Mdoda

Prof M Mudhara

July 2025

DEDICATION

To the cherished memory of my beloved parents,

The late Nonkoliso Nothobile Mnukwa & Ackermans Makigwana Mnukwa
Whose unwavering love, sacrificial dedication, and profound belief in the transformative power of education laid the foundation for this achievement. Though you are no longer with us to witness this milestone, your enduring legacy of resilience, wisdom, and commitment to family continues to inspire and guide every step of this journey. This work stands as a testament to the values you instilled and the dreams you nurtured.

Your memory lives on in every page of this thesis.

DECLARATION 1: PLAGIARISM

I, **Minentle Lwando Mnukwa** declare that;

I. The research reported in this thesis, except where otherwise indicated, is my original research.

II. This thesis has not been submitted for any degree or examination at any other university.

III. This thesis does not contain other persons' data, pictures, graphs or other information unless specifically acknowledged as being sourced from other persons.

IV. This thesis does not contain other authors' writing unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:

  a. Their words have been rewritten, but the general information attributed to them has been referenced.

  b. Where their exact words have been used, their writing has been placed in italics, inside quotation marks, and referenced.

V. This thesis does not contain text, graphics or tables copied and pasted from the Internet unless specifically acknowledged, and the source is detailed in the thesis and in the References sections.

Signed: [redacted] 14/07/2025

M.L Mnukwa (Candidate) Date

As the candidate's supervisors, we agree to the submission of this dissertation:

[redacted] 14/07/2025

Dr L. Mdoda (Supervisor) Date

Prof M. Mudhara (Co-supervisor) Date

DECLARATION 2: PUBLICATIONS

The following publications (published and under review) from the research presented in this thesis:

Manuscript 1- Chapter 2 (Published)

Mnukwa, M.L., Mdoda, L. and Mudhara, M., 2025. Assessing the adoption and impact of climate-smart agricultural practices on smallholder maize farmers' livelihoods in Sub-Saharan Africa: A systematic review. *Frontiers in Sustainable Food Systems*, 9, p.1543805. DOI 10.3389/fsufs.2025.1543805

Manuscript 2- Chapter 3 (Under Review)

Mnukwa, M.L., Mdoda, L. and Mudhara, M. Smallholder Maize Farmers' Perceptions and Attitudes Towards Climate-Smart Agricultural Practices in KwaZulu-Natal Province, South Africa. Submitted to International Journal of Agricultural Sustainability.

Manuscript 3- Chapter 4 (Under review)

Mnukwa, M.L., Mdoda, L. and Mudhara, M. The Determinants of Adoption and Intensity of use of Climate-Smart Agricultural Practices among Smallholder Maize Farmers in KwaZulu-Natal Province, South Africa. Submitted to Frontiers in Agronomy.

Manuscript 4- Chapter 5 (Under review)

Mnukwa, M.L., Mdoda, L. and Mudhara, M. The Economic Benefits and Efficiency of Climate-Smart Agricultural Practices Adoption by Smallholder Maize Farmers in KwaZulu-Natal Province, South Africa. Submitted to Climate Risk Management.

Manuscript 5- Chapter 6 (Under review)

Assessing the Impact of Climate-Smart Agricultural Practices on Food Security among Smallholder Maize Farmers in KwaZulu-Natal, South Africa. Submitted to The South African Journal of Agricultural Extension.

ACKNOWLEDGEMENTS

I am deeply grateful to my PhD supervisors, Dr L. Mdoda and Prof. M. Mudhara, for their guidance, support, and belief in my work throughout this journey. Your mentorship has been invaluable in shaping this research and helping me grow as a scholar.

I sincerely thank the National Research Foundation (NRF) for their financial support that made this doctoral study possible. This funding allowed me to focus on my research without financial worries and complete this work successfully.

My heartfelt appreciation goes to the smallholder maize farmers in KwaZulu-Natal Province who participated in this study. Your willingness to share your experiences and time made this research possible. I also thank the field enumerators who helped with data collection and my fellow doctoral students for their friendship, discussions, and support throughout this journey.

To my beloved family - Asanda, Babalo, Zukile, and Busi - thank you for your love, patience, and understanding during the long hours of study and research. Your support has been my greatest strength.

Above all, I give thanks to the Almighty God for His grace and strength that carried me through this journey. I also honour my ancestors, whose spiritual guidance has been a source of comfort and direction throughout this work.

ABSTRACT

Climate change poses significant threats to agricultural systems globally, with smallholder farmers in developing regions particularly vulnerable due to limited adaptive capacity and resource constraints. This study assessed the perceptions, adoption decisions, and effects of Climate-Smart Agricultural Practices (CSAPs) on smallholder maize farmers' livelihoods in KwaZulu-Natal Province, South Africa, where climate change has resulted in substantial agricultural losses and threatens food security. This research explored how CSAPs enhance agricultural productivity, resilience, and food security among smallholder farmers, contributing to climate adaptation and mitigation. The study collected data through structured questionnaires from 378 smallholder maize farmers purposively chosen using a multi-stage sampling technique across Harry Gwala and Ugu District Municipalities. A quantitative approach incorporating descriptive statistics, Tobit regression models, double-hurdle models, stochastic production functions, gross margin analysis, and endogenous switching regression models were employed to analyse the determinants of CSAP adoption and their effects on economic and food security. The study examined four specific CSAPs: drought-tolerant maize varieties, rainwater harvesting, maize-legume intercropping, and crop diversification, investigating their adoption patterns and impacts on farmer livelihoods. Most smallholder farmers were aware of CSAPs and demonstrated moderate uptake, indicating growing acceptance of CSAPs. The most adopted CSAPs included drought-tolerant maize varieties and rainwater harvesting, suggesting their perceived benefits and relative ease of implementation. Key socioeconomic factors such as age, gender, education, household income, access to credit, extension services, and agricultural training significantly influenced the adoption and intensity of CSAP use.

The findings suggest that tailored socioeconomic programmes targeting specific farmer groups can enhance CSAP adoption and agricultural resilience against climate impacts. The analysis further reveals that adopters comprised both male and female farmers, with varying risk tolerance and resource constraints. Marital status, employment status, land ownership, and involvement in agricultural groups also influenced perceptions and adoption of CSAPs. Despite positive perceptions of CSAPs by smallholder farmers, including their potential to improve productivity, food security, and farm income, barriers such as inadequate training, financial constraints, and limited institutional support impede broader adoption of CSAPs. The findings underscore the importance of policy interventions addressing these constraints to promote

CSAP adoption. The results show complementarity between certain CSAPs and highlight significant economic benefits and technical efficiency improvements following adoption. Socioeconomic and institutional factors, including access to credit, extension services, and agricultural training, influenced CSAP adoption and economic outcomes significantly. The findings highlight the need for multi-dimensional interventions encouraging comprehensive CSAP adoption to enhance agricultural resilience and sustainability. The results reveal that CSAP adopters exhibit significantly higher food security and dietary diversity outcomes than non-adopters, indicating that CSAPs positively contribute to household welfare. Education, household income, institutional access, and social capital significantly influenced food security and adoption patterns. These findings support the postulation that adopting CSAPs can substantially enhance the livelihoods of smallholder farmers. However, challenges such as limited access to credit, inadequate agricultural training, and implementation costs remain significant barriers to maximising the potential benefits of CSAPs. The study recommends enhancing access to agricultural training, credit, and extension services, particularly for farmers facing resource constraints, to improve the adoption and effectiveness of CSAPs. Overall, this thesis provides critical insights into the factors influencing CSAP adoption and their role in enhancing economic performance and welfare outcomes for smallholder farmers. The findings emphasise the need for targeted, context-specific interventions to overcome adoption barriers and promote sustainable agricultural practices. By fostering collaboration between farmers, researchers, extension services, and policymakers, this research contributes to developing effective climate-smart strategies that address the unique challenges smallholder farmers face in climate-vulnerable regions.

Keywords: Climate-Smart Agriculture, Smallholder farmers, Technology adoption, Food security, Economic benefits, Agricultural resilience, Climate adaptation.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

ATE	Average Treatment Effect
ATT	Average Treatment Effect on the Treated
ATU	Average Treatment Effect on the Untreated
CA	Conservation Agriculture
CSA	Climate-Smart Agriculture
CSAPs	Climate-Smart Agricultural Practices
DFID	Department for International Development
DIT	Diffusion of Innovations Theory
ESR	Endogenous Switching Regression
FAO	Food and Agriculture Organization
FANTA	Food and Nutrition Technical Assistance
GDP	Gross Domestic Product
GHG	Greenhouse Gas
HDDS	Household Dietary Diversity Score
HFIAS	Household Food Insecurity Access Scale
HGDM	Harry Gwala District Municipality
IMR	Inverse Mills Ratio
IPCC	Intergovernmental Panel on Climate Change
IPM	Integrated Pest Management
KZN	KwaZulu-Natal
MLE	Maximum Likelihood Estimation
MMAT	Mixed Methods Appraisal Tool
NDP	National Development Plan
NBRM	Negative Binomial Regression Model

NRF	National Research Foundation
OECD	Organisation for Economic Co-operation and Development
PRM	Poisson Regression Model
PT	Production Theory
RUT	Random Utility Theory
SDGs	Sustainable Development Goals
SLF	Sustainable Livelihoods Framework
SSA	Sub-Saharan Africa
TAM	Technology Acceptance Model
TPB	Theory of Planned Behaviour
UDM	Ugu District Municipality
UNCTAD	United Nations Conference on Trade and Development
ZINB	Zero-Inflated Negative Binomial
ZIP	Zero-Inflated Poisson
ZAR	South African Rand

PREFACE

This thesis comprises standalone manuscript-based chapters, which may result in minor repetitions across sections.

CHAPTER 1

INTRODUCTION

1.1 Background of the study

Climate change represents one of the most pressing challenges of the 21st century, profoundly threatening global agricultural systems and food security. Agriculture serves as the economic foundation for numerous countries across Sub-Saharan Africa (SSA), playing a vital role in employment generation, livelihood sustenance, and food security provision (Wudil et al., 2022). Over 60% of the regional population relies directly on smallholder farming systems for both subsistence and income generation (Food and Agriculture Organization [FAO], 2022). However, the sector faces significant variability and unprecedented challenges from climate change, with countries experiencing varying degrees of agricultural dependence and vulnerability. While some nations like Chad see agricultural contributions as high as 50% to their Gross Domestic Product, others like South Africa report only 2% (Bontsa et al., 2023). Despite this variation, agricultural growth across SSA stands at 2.6% annually (Organisation for Economic Co-operation and Development [OECD]/FAO, 2023), with this modest expansion influenced by increasing local and international interest in farmland, rural-to-urban migration, population growth, and the escalating impacts of climate change.

The centrality of agriculture to SSA economies and societies positions the sector as critical for achieving multiple Sustainable Development Goals (SDGs). Agricultural development in the region directly impacts SDG 1 (No Poverty) by increasing household incomes and creating sustainable livelihoods, SDG 2 (Zero Hunger) by enhancing food production and accessibility, SDG 8 (Decent Work and Economic Growth) through job creation and economic stabilisation, SDG 12 (Responsible Consumption and Production) by promoting sustainable farming practices, and SDG 15 (Life on Land) through improved land management and biodiversity conservation (Weil et al., 2023; Thornton et al., 2022). Climate variables crucial to food security and agricultural systems are changing rapidly across SSA, with IPCC reports projecting negative impacts on all aspects of food security in the region. Without appropriate interventions, climate change will severely reduce agricultural yields, worsen food insecurity, and exacerbate existing poverty levels (Zougmoré et al., 2018). The vulnerability is especially pronounced in east and southern parts of the region where rainfall-dependent agriculture is dominant (Okoronkwo et al., 2024), with temperature increases of 0.8-2.3°C already recorded over the past five decades (Ziervogel and Taylor, 2023). Climate models predict more intense rainfall events punctuated by longer dry spells, with many areas already reporting decreased yields and increased crop failures due to erratic rainfall patterns and rising temperatures (Rezaei et al., 2023).

Maize (Zea mays L.) stands as a fundamental crop of profound importance for food security, nutrition, and economic stability throughout East and Southern Africa. This staple crop provides approximately 30% of dietary calories across SSA and is predominantly cultivated by smallholder farmers (Sinyolo, 2023). Beyond its nutritional value, maize cultivation represents a critical source of household income, contributing significantly to smallholder farmers' total agricultural income in many regions (Sinyolo and Mudhara, 2018). However, maize productivity is heavily dependent on favourable climate conditions, making it especially vulnerable to climate change impacts (Cairns et al., 2013). The sensitivity of maize to temperature variations and water stress places it at particular risk as climate change intensifies. Maize stands out as a critically important staple crop among the region's agricultural commodities, representing nearly 50% of total cereal production and constituting the primary caloric source for millions of people. Nevertheless, maize cultivation in SSA faces significant threats from climate variability and extreme weather events, including droughts, floods, and unpredictable rainfall patterns (Du and Xiong, 2024). These climatic disruptions not only diminish agricultural yields but also intensify poverty levels and food insecurity, particularly among smallholder farmers who possess limited adaptive capacity to respond to rapidly evolving climatic conditions.

In South Africa, maize represents the most extensively cultivated crop and serves as the foundation of national food security (Mdoda et al., 2025). The country produces approximately 12-16 million tons of maize annually, with smallholder farmers contributing a substantial 4.4% share of total cultivation, concentrated primarily in rural regions (Oduniyi et al., 2022). This farming segment encompasses more than 2.9 million smallholder households that experience disproportionate impacts from climate-related stressors (Sinyolo et al., 2021). Climate change impacts on South African agriculture are already evident, with temperature increases of 1.5-2.0°C recorded over the past four decades and projections indicating further increases of 3-4°C by 2080 (Ngcamu and Chari, 2022). Recurring droughts, such as the severe 2015-2016 El Niño-induced drought that reduced maize production by 30%, have demonstrated the vulnerability of the sector. Land degradation significantly affects South Africa's land area, while declining soil fertility compounds production challenges (Van Huyssteen and du Preez, 2023). These climate-related stressors have resulted in average yield losses of 10-20% for maize over the past decade in South Africa, with some regions experiencing losses exceeding 40% during drought years (Tantoh and McKay, 2023). Furthermore, these challenges are compounded by structural issues such as insecure land tenure, inadequate extension services, and limited access to markets and finance, creating a complex web of constraints that perpetuate vulnerability among smallholder farmers (Barbanente et al., 2024).

KwaZulu-Natal (KZN) Province epitomizes these challenges, experiencing particularly acute climate variability in recent years. The province has recorded temperature increases of 1.8°C since 1960, accompanied by a 15% decline in annual rainfall and increased frequency of extreme weather events (Mthethwa et al., 2022). These changes have resulted in estimated agricultural losses of ZAR 2.8 billion between 2010-2020, with maize production experiencing periodic declines of 10-25% during severe drought years, while maintaining overall growth trends (Kumar et al., 2022). Climate variables crucial to food security and agricultural systems are changing rapidly across the province, creating unprecedented challenges for smallholder farmers who depend on rain-fed agriculture. Moreover, KZN faces high levels of poverty and food insecurity, with approximately 65.3% of households in some districts experiencing food insecurity (Nhlozi, 2023). This situation is exacerbated by various factors, including soil degradation, decreasing farm sizes, limited access to improved technologies, disease, insect pests, and climate variability. The province's diverse agro-ecological conditions, from coastal lowlands to mountainous regions, create varied farming environments some of which are highly susceptible to climate variability. Projected yield reductions of 15-30% by mid-century create an urgent imperative for climate adaptation strategies that can simultaneously enhance productivity and build resilience among smallholder maize farmers (Mangani et al., 2019).

To address these complex and interlinked challenges, Climate-Smart Agriculture (CSA) has gained traction as a strategic framework for transforming and reorienting agricultural systems under the realities of climate change. CSA promotes practices that increase productivity in a sustainable manner, strengthen farmers' resilience to climate-related shocks, and reduce agriculture's carbon footprint (FAO, 2018; Lipper et al., 2014). Climate-Smart Agricultural Practices (CSAPs) represent specific farming techniques and technologies that simultaneously enhance productivity, build resilience to climate variability, and contribute to greenhouse gas mitigation (Zheng et al. 2024). For maize farmers, CSAPs encompass various interventions such as conservation agriculture, crop diversification, planting of drought-tolerant varieties, organic soil amendments, agroforestry, and rainwater harvesting (Mahama et al., 2020; Bongole et al., 2020). These practices have demonstrated significant potential to enhance yield stability, reduce risk exposure, and improve environmental outcomes. Research indicates that drought-tolerant maize varieties can reduce yield losses by 20-30% during drought years, while conservation agriculture practices can improve soil water retention by 15-25% and reduce erosion by up to 90% (Zougmore et al., 2018). CSAPs can simultaneously address climate adaptation, mitigation, and food security objectives, making them particularly valuable for smallholder farmers facing multiple climate-related risks (Kurgat et al., 2020; Wekesa et al., 2018).

Despite this promise, the adoption of CSAPs by smallholder maize farmers remains suboptimal and uneven across South Africa, with adoption rates typically ranging between 15-45% across different provinces (Abegunde et al., 2023; Ntshangase et al., 2022). Studies across multiple countries reveal adoption rates typically below 40% despite decades of promotion by various stakeholders (Mizik et al., 2021). Many farmers are either unaware of these practices or lack the means to implement them effectively, creating a significant gap between potential and realized benefits that warrants a comprehensive investigation of adoption barriers and enablers. The importance of mainstreaming CSA is recognized in a global and national development framework. At the global level, CSA aligns with several Sustainable Development Goals (SDGs), particularly SDG 1 (No Poverty), SDG 2 (Zero Hunger), SDG 13 (Climate Action), and SDG 15 (Life on Land), which emphasize the need for resilient agricultural systems and sustainable natural resource management (Tanumihardjo et al., 2020). In the South African context, the National Development Plan (NDP) 2030 highlights the urgency of creating a sustainable and inclusive rural economy through agricultural transformation. The NDP specifically calls for improved support for smallholder farmers, investment in climate-resilient technologies, and sustainable land use practices. Additionally, South Africa's National Climate Change Response Policy (2011) identifies agriculture as a priority sector for both adaptation and mitigation interventions.

Understanding farmers' perceptions and attitudes toward CSAPs is fundamental to promoting adoption, as these psychological factors form the foundation upon which adoption decisions are made and can either facilitate or hinder the widespread uptake of these practices. The CSAP adoption largely depends on farmers' perceptions and attitudes toward these practices (Mkhize and Zwane, 2023). Perception encompasses how farmers view and understand the potential benefits, costs, and risks associated with CSAPs, while attitude reflects their evaluative judgments and predispositions toward implementing these practices. Research by Aryal et al. (2022) demonstrated that farmers' perceptions of the practicality and effectiveness of conservation agriculture strongly predicted adoption rates in the Indo-Gangetic Plains. Similarly, Mpala and Simatele (2024) established that smallholder farmers in Zimbabwe with positive attitudes towards CSAP were more likely to adopt these practices, even when faced with resource constraints. Across SSA, limited research has been conducted to understand smallholder farmers' perceptions and attitudes toward CSAPs, creating a significant knowledge gap. Understanding these psychological factors is critical as they form the foundation upon which adoption decisions are made and can either facilitate or hinder the widespread adoption of CSAPs. Addressing this gap is particularly urgent as the region experiences increasing climate variability that threatens food security and rural livelihoods.

The adoption of CSAPs is a complex process influenced by numerous factors, including socioeconomic characteristics, institutional support, biophysical conditions, and farmers' perceptions (Kpadonou et al., 2017). Understanding these determinants is crucial for designing effective policies and interventions to promote CSAP adoption and address the challenges posed by climate change. Previous research on CSA adoption has primarily focused on specific practices in isolation, such as conservation agriculture, drought-tolerant varieties, or soil and water conservation measures (Marie et al., 2020; Abegunde et al., 2019; Mohammed et al., 2015). However, farmers typically face decisions about adopting multiple interrelated practices simultaneously, which may function as complements or substitutes (Kassie et al., 2015; Teklewold et al., 2013). Furthermore, there is limited understanding of the factors influencing not only the initial adoption decision but also the intensity of adopting CSAPs among smallholder maize farmers. While a growing body of research has examined the general benefits and challenges of CSA, there remains a lack of localized, empirical evidence that explores the full range of factors, social, economic, institutional, and environmental, that shape adoption behaviours among maize farmers in the South African context.

Understanding the economic benefits and efficiency gains from CSAP adoption is crucial for informing policy decisions, extension programs, and financial service provision that can enhance smallholder farmers' livelihoods and agricultural sustainability. The agricultural sector confronts a complex challenge: experiencing vulnerability to climate change impacts while simultaneously contributing substantially to greenhouse gas emissions (OECD, 2016; Smith et al., 2008). Climate change adverse effects pose serious threats to agricultural productivity, food security, and rural livelihoods globally, with particularly severe impacts in developing regions characterized by rain-fed agricultural systems (FAO, 2018; Kassie et al., 2015). Economic analyses demonstrate that CSAPs can simultaneously address climate adaptation and income generation objectives, making them particularly valuable for smallholder farmers facing multiple economic and climate-related risks (Kurgat et al., 2020; Wekesa et al., 2018). Despite this economic promise, CSAP adoption by smallholder maize farmers remains suboptimal across South Africa, with adoption rates typically ranging between 15-45% across different provinces (Abegunde et al., 2019). Many farmers are either unaware of these practices, lack financial means for implementation, or are uncertain about economic returns, creating a significant gap between potential and realized economic benefits. Previous research on CSAP economic impacts has primarily focused on specific practices in isolation without comprehensively examining the economic benefits and efficiency gains of integrated CSAP adoption (Abegunde et al., 2019). Furthermore, there is limited understanding of factors determining the magnitude of economic benefits and efficiency gains from CSAP adoption among smallholder maize farmers. The economic returns from CSAPs are influenced by numerous factors, including farmer characteristics, resource endowments, market access, and institutional support, yet comprehensive analyses examining both economic benefits and production efficiency are scarce (Musafiri., 2020).

Assessing the welfare effects of CSAPs on smallholder farming households represents a critical dimension for understanding the broader development impacts of these agricultural innovations. While numerous studies have documented productivity benefits and adoption patterns, there remains limited empirical evidence on how these practices translate into improved welfare outcomes, particularly food security and dietary diversity (Wekesa et al., 2018). Most existing research has focused primarily on yield improvements and income effects, with insufficient attention to the multidimensional nature of welfare. Furthermore, methodological limitations in previous studies have often failed to address selection bias inherent in technology adoption decisions, potentially leading to biased estimates of welfare impacts (Di Falco et al., 2011). Understanding the welfare effects of CSAPs is crucial for several reasons. First, the ultimate goal of agricultural development interventions is to improve the well-being of farming households. Second, food security and dietary diversity represent critical dimensions of welfare that are particularly relevant for smallholder farmers who often struggle with nutritional adequacy (Nabuuma et al., 2021). Third, evidence on welfare effects is essential for designing effective policies that can maximize the benefits of CSAPs for vulnerable farming communities.

This study addresses these multifaceted challenges through a comprehensive assessment of CSAPs adoption and impacts among smallholder maize farmers in KZN Province, South Africa. The research employs multiple theoretical frameworks and econometric approaches to examine four key dimensions of CSAP adoption: farmer perceptions and attitudes, adoption determinants and intensity, economic benefits and efficiency gains, and welfare impacts on food security and dietary diversity. The study makes several important contributions to the literature of CSAP. First, it provides comprehensive empirical evidence on the multidimensional impacts of CSAP adoption, moving beyond simple productivity measures to examine welfare outcomes that are central to farmer livelihoods. Second, it employs rigorous econometric methods that address selection bias and unobserved heterogeneity, providing more robust estimates of causal impacts than many previous studies. Third, it integrates insights from multiple theoretical frameworks, [including the Theory of Planned Behaviour (TPB), Technology Acceptance Model (TAM), Production Theory (PT), and Random Utility Theory (RUT)] to provide a more complete understanding of farmer decision-making processes. The study focuses on four specific CSAPs that are particularly relevant for smallholder maize farmers in KZN: drought-tolerant maize varieties, rainwater harvesting systems, maize-legume intercropping, and crop diversification strategies. These practices were selected based on their relevance to the local context, their ability to address multiple CSA pillars (productivity, adaptation, and mitigation), their proven effectiveness, scalability, and potential for synergistic effects when combined.

The findings of this study will contribute to the growing body of literature on CSAP adoption and impacts while providing practical recommendations for policymakers, extension services, financial institutions, and other stakeholders working to enhance agricultural resilience and food security in the face of climate change. Ultimately, the study will contribute to enhancing food security, climate resilience, and sustainable development in South Africa's smallholder agricultural sector, while informing policy interventions that can facilitate the transition toward more climate-resilient farming systems in KZN and beyond. As climate change impacts continue to intensify, understanding how to effectively promote and implement adaptation strategies becomes increasingly urgent. This research contributes to that understanding by providing evidence-based insights into one of the most promising approaches for building agricultural resilience while improving farmer livelihoods in one of the world's most climate-vulnerable regions, ultimately supporting the achievement of multiple SDGs including poverty reduction, food security, climate action, and sustainable agriculture.

1.2 Problem statement

In SSA, agriculture is the linchpin of economic stability and sustenance, with around 70% of smallholder farmers relying on it as their primary source of income (Kom, 2022). Among these, maize is a staple crop critical to food security and economic stability, particularly in South Africa, where it plays a vital role in the livelihoods of many smallholder farmers (Mbuli et al., 2021). Despite its importance, maize cultivation is beleaguered by persistent challenges, including low yields, food insecurity, and vulnerability to environmental stressors. These issues are compounded by the adverse impacts of climate change, inefficient farming practices, and limited access to resources (Zhang et al., 2023; Mthethwa et al., 2022). Climate change has emerged as a major threat to agricultural productivity, characterized by rising temperatures, erratic rainfall, and increased frequency of extreme weather events such as droughts and floods. These climatic shifts exacerbate agricultural issues, including soil degradation, pest infestations, and water scarcity, severely affecting maize yields and farm returns. The situation is dire, with approximately 28% of the African population experiencing severe hunger, highlighting the urgent need to address these agricultural challenges to ensure food security and improve livelihoods (Mbuli et al., 2021).

CSAPs have emerged as a promising strategy to address challenges in agriculture, particularly for smallholder maize farmers. CSAPs aim to enhance agricultural productivity and resilience while reducing greenhouse gas emissions, offering a sustainable approach to farming in the face of climate change (Steiner et al., 2020). These practices include crop rotation, agroforestry, improved water management, conservation agriculture, and the use of drought-resistant crop varieties. The potential benefits of CSAPs are significant and well-documented in recent literature. A meta-analysis by Arslan et al. (2022) covering 235 studies across SSA found that CSAPs implementation led to an average yield increase of 23% for maize, with soil carbon sequestration improving by 19%. In South Asia, Aryal et al. (2022) reported that integrated adoption of multiple CSAPs resulted in a 31% increase in farm income and a 17% reduction in production risk. Furthermore, a global study by Loboguerrero et al. (2023) demonstrated that CSAPs could potentially mitigate up to 7% of agricultural greenhouse gas emissions while simultaneously improving food security for an estimated 78 million people in low-income countries by 2030.

Despite their proven benefits, the adoption of CSAPs among smallholder farmers remains disappointingly low across SSA, with this trend persisting in South Africa and KZN Province. This low adoption rate represents a significant challenge to improving agricultural sustainability, food security, and economic stability in the region. At the broader SSA level, Mutenje et al. (2023) reported CSAP adoption rates ranging from 28% to 45% across six countries, highlighting the widespread nature of this issue. Focusing on Southern Africa, Thierfelder et al. (2022) noted that despite two decades of promotion, adoption rates of conservation agriculture, a key component of CSAPs, remained below 40% across the region. In a comprehensive study of East and Southern Africa, Nyagumbo et al. (2020) corroborated these findings, reporting that conservation agriculture adoption stayed below 40% in most countries studied, including South Africa. Narrowing down to South Africa specifically, Senyolo et al. (2022) found that only 37% of smallholder farmers in Limpopo Province had adopted CSAPs, with adoption rates varying significantly across different techniques. While specific recent data for KZN Province is limited, these studies suggest that the province likely faces similar challenges, given the broader regional trends. The consistently low adoption rates across these geographical scales underscore the persistent challenge of CSAP implementation among smallholder farmers, highlighting the need for more effective, locally-tailored strategies to promote these practices.

The first critical knowledge gap relates to understanding farmer perceptions and attitudes toward CSAPs, which represent fundamental psychological barriers that have received insufficient attention in the literature. Research demonstrates that farmers' willingness to adopt new agricultural technologies is fundamentally shaped by their understanding of potential benefits, costs, and risks, as well as their confidence in implementation capacity (Aryal et al., 2022). However, there remains limited understanding of how smallholder maize farmers in KZN perceive CSAPs and what factors influence their attitudes toward these practices. The low uptake of CSAPs can be attributed to several interconnected barriers, including economic constraints where many smallholder farmers lack financial resources to invest in new agricultural practices or technologies (Olabanji and Chitakira , 2025; McCarthy et al., 2011), limited access to credit with only 23% of smallholder farmers in KZN having access to formal credit services (Ogisi and Begho, 2023; Sinyolo and Mudhara, 2018), and information barriers where only 45% of smallholder farmers had received information about CSAPs from extension services in the past year (Ngcoya and Kumarakulasingam, 2017). These barriers fundamentally shape farmer perceptions and attitudes, yet comprehensive analysis of these psychological factors using appropriate theoretical frameworks such as TPB remains absent from the literature.

The second major knowledge gap concerns the determinants of CSAP adoption decisions and intensity among smallholder farmers. The adoption decision itself represents a complex process influenced by multiple interacting factors that extend beyond simple awareness or economic capacity. While previous research has examined individual CSAPs in isolation, farmers typically face decisions about adopting multiple, potentially complementary practices simultaneously (Kassie et al., 2015; Teklewold et al., 2013). There is insufficient understanding of the factors that influence not only the initial decision to adopt but also the intensity of adoption, the extent to which farmers implement multiple practices or expand their use across their farming operations. This dual-stage decision-making process requires more sophisticated analytical approaches such as TAM that can account for the different factors operating at each stage and the potential selection bias inherent in comparing adopters with non-adopters.

The third significant knowledge gap relates to the actual economic benefits and efficiency gains from CSAP adoption among smallholder farmers operating under real-world conditions. Even among farmers who do adopt CSAPs, there remains significant uncertainty about the economic returns and efficiency improvements from implementation. While experimental and demonstration plot studies have shown promising results, there is limited empirical evidence on the real-world economic benefits experienced by smallholder farmers operating under resource constraints and market imperfections. The economic impacts of CSAP adoption are influenced by numerous factors, including farmer characteristics, resource endowments, market access, and institutional support, yet comprehensive analyses examining both direct economic benefits and production efficiency improvements using frameworks such as Production Theory are scarce (Musafiri, 2020). This evidence gap creates challenges for farmers trying to make informed investment decisions and for policymakers seeking to design effective support programs.

The fourth critical knowledge gap involves understanding how CSAP adoption translates into improved food security for smallholder farming households. There is insufficient understanding of how CSAP adoption affects food security, dietary diversity, and overall livelihood outcomes. While productivity improvements are important, the ultimate goal of agricultural development interventions is to enhance farmer well-being through improved welfare indicators. Most existing research has focused primarily on yield and income effects, with inadequate attention to the multidimensional nature of welfare impacts. Understanding these welfare effects is essential for designing policies that maximize the development benefits of CSAPs for vulnerable farming communities, yet methodological limitations in previous studies have often failed to address selection bias inherent in technology adoption decisions, potentially leading to biased estimates of impact (Di Falco et al., 2011). Rigorous analytical frameworks such as RUT through ESR models are needed to provide unbiased estimates of welfare impacts.

The consequences of not addressing the low adoption of CSAPs are severe and far-reaching, extending well beyond individual farm-level impacts to affect broader community resilience and regional food security. Continued low uptake leaves smallholder farmers vulnerable to the escalating impacts of climate change, perpetuates low yields, and exacerbates food insecurity in the region. In KZN, where smallholder farmers account for approximately 60% of agricultural production (Sinyolo & Mudhara, 2018), the implications extend beyond individual farmers to affect the broader community and regional economy. The province has experienced significant climate variability in recent years, with a 1.2°C increase in average temperatures and a 10% decrease in annual rainfall over the past three decades (Touré et al., 2022). These changes have led to a 30% reduction in maize productivity in some areas (Mbatha & Masuku, 2018), underscoring the urgent need for widespread adoption of CSAPs.

The vulnerability of smallholder farmers to climate change impacts is particularly concerning, with non-adopters facing disproportionate risks compared to those who have implemented climate-smart practices. A study by Sinyolo et al. (2020) found that non-adopters of CSAPs were 40% more likely to experience significant crop losses during drought years compared to adopters. This vulnerability not only affects individual households but also contributes to broader food insecurity and economic instability in the region. Moreover, the low adoption of CSAPs hampers efforts to achieve SDGs and improve rural livelihoods. The potential of these practices to increase agricultural productivity, enhance food security, and promote environmental sustainability remains largely untapped. The persistence of low adoption rates also represents a significant lost opportunity for climate change mitigation, as widespread implementation of CSAPs could contribute substantially to reducing agricultural greenhouse gas emissions while building resilience to climate impacts.

The complex and multifaceted nature of the CSAP adoption challenge demands a comprehensive research approach that examines multiple dimensions of farmer decision-making and impact pathways. This research aims to comprehensively evaluate how smallholder maize farmers in KZN perceive, decide to adopt, and are impacted by CSAPs through four interrelated analytical frameworks. By examining farmers' perceptions and attitudes using TPB, investigating adoption determinants and intensity through TAM, measuring economic benefits and efficiency gains within Production Theory, and assessing welfare impacts via RUT, this study seeks to provide crucial insights for developing targeted interventions that address the full spectrum of adoption barriers and maximize development outcomes.

The study's objectives are strategically designed to address the multifaceted nature of the low CSAP adoption problem through complementary analytical approaches that build upon each other to provide comprehensive understanding. Examining perceptions and attitudes toward CSAPs will shed light on the psychological and cultural factors influencing adoption decisions, while controlling for the censored nature of perception data through appropriate econometric techniques. Investigating the determinants of both initial adoption decisions and adoption intensity will provide valuable insights into the socio-economic, institutional, and environmental factors that influence farmers' choices at different stages of the adoption process. Measuring the economic benefits and technical efficiency improvements from CSAPs is essential for demonstrating their tangible value to farmers and policymakers while identifying the key determinants of successful economic outcomes. Assessing welfare impacts on food security and dietary diversity will reveal how CSAPs translate into meaningful improvements in farmer well-being while addressing potential selection bias through appropriate impact evaluation methods.

Previous studies have shown that CSAP adoption can lead to significant improvements, with some farmers experiencing up to a 25% increase in maize yields and a 20% improvement in household food security status (Ngcoya & Kumarakulasingam, 2017; Sinyolo et al., 2020). However, these findings are often based on simple comparisons between adopters and non-adopters without adequately controlling for selection bias or examining the heterogeneous effects across different farmer groups. This study addresses these methodological limitations through rigorous econometric approaches that provide more robust and policy-relevant estimates of CSAP impacts.

Addressing the low adoption rates of CSAPs in KZN is crucial for improving food security, economic stability, and the overall quality of life for rural communities amidst ongoing climate change challenges. The findings from this study will provide valuable insights for developing effective policies and strategies that align with the needs and contexts of smallholder maize farmers, ultimately fostering sustainable agricultural practices and resilient livelihoods. Moreover, this research will contribute to closing the gap between the theoretical benefits of CSAPs and their practical application, exploring how local knowledge, practices, and perceptions shape the effectiveness of CSA interventions while providing actionable recommendations for extension services, financial institutions, and development organizations.

The potential impact of this study extends beyond KZN, offering scalable solutions for other regions in SSA facing similar challenges. By contributing to a deeper understanding of the socio-economic and cultural factors influencing CSAP adoption, the study will play a pivotal role in shaping future agricultural policies and practices. This research has the potential to inform the development of more effective extension services, tailored financial support mechanisms, and culturally appropriate education programs that can accelerate the adoption of CSAPs across the continent while ensuring that these interventions translate into meaningful welfare improvements for smallholder farming communities.

The low adoption of CSAPs among smallholder maize farmers in KZN represents a significant challenge with far-reaching implications for food security, economic stability, and environmental sustainability. By providing a comprehensive understanding of the factors influencing CSAP adoption and their multidimensional impacts through rigorous theoretical and empirical frameworks, this research aims to catalyse positive change in agricultural practices, ultimately fostering a more food-secure and climate-resilient future for smallholder farmers across SSA. The urgency of addressing this challenge cannot be overstated, as climate change impacts continue to intensify and the window for effective adaptation narrows, making the need for evidence-based solutions to promote widespread CSAP adoption increasingly critical for the livelihoods and food security of millions of smallholder farmers across the region.

1.3 Aim and objectives

Thus, the study aimed to assess the perceptions, adoption decisions, and effects of CSAPs on the welfare of smallholder maize farmers in KZN Province.

Specific objectives were as follows:

I. To examine the perceptions and attitudes toward CSAPs among smallholder maize farmers
II. To investigate the determinants of the decision to adopt and intensity of use of CSAPs by smallholder maize farmers
III. To measure the economic benefits (maize production/farm income) and efficiency of adopting CSAPs by smallholder maize farmers
IV. To assess the effect of CSAPs on the welfare (food security) of smallholder maize farmers

1.4 Research questions

I. What are the perceptions and attitudes of smallholder maize farmers toward CSAPs?
II. What are the determinants of the decision to adopt and the intensity of use of CSAPs by smallholder maize farmers?
III. What are the economic benefits (maize production/farm income) and efficiency of adopting CSAPs by smallholder maize farmers?
IV. What is the effect of CSAPs on the welfare (food security) of smallholder maize farmers?

1.5 Significance of the study

This study addressed a critical gap in the existing literature by providing a comprehensive, micro-level analysis of CSAPs in the context of smallholder maize farming in KZN Province, South Africa. From a theoretical perspective, this research contributed to the growing body of literature on CSAPs and their impacts on smallholder farmers' welfare. By examining the complex interplay between farmers' perceptions, adoption decisions, and the subsequent impacts of these practices, the study enhanced understanding of the cognitive, social, and economic factors that influence the uptake and effectiveness of innovative agricultural practices through the application of multiple theoretical frameworks including TPB, TAM, Production Theory, and RUT. The focus on smallholder maize farmers in KZN Province provided a unique opportunity to examine CSAPs in a specific agro-ecological and socio-economic context. This localized approach was significant because it allowed for a detailed understanding of how global concepts of CSA translate into practice in a particular setting. By providing in-depth, context-specific analyses, this research contributed to filling a gap in the literature, which often lacks detailed regional studies. The findings are valuable for local policymakers and practitioners while contributing to the broader understanding of regional variations in CSA adoption and impacts across SSA.

This research was significant in its comprehensive approach to studying CSAPs. By combining analyses of perceptions, adoption decisions, economic benefits, and welfare impacts, the study provided a holistic view of the CSA landscape in KZN. This multifaceted approach is relatively rare in the existing literature, which often focuses on either adoption or impacts in isolation. The integration of these different aspects allowed for a more nuanced understanding of the challenges and opportunities associated with promoting CSAPs among smallholder maize farmers. Furthermore, by evaluating both economic benefits and welfare effects, the study acknowledged the multidimensional nature of agricultural interventions and their impacts on rural livelihoods (Barrett et al., 2020). From a methodological perspective, this study made significant contributions by employing rigorous econometric approaches that addressed selection bias and unobserved heterogeneity in CSAP adoption decisions. The use of ESR models for welfare impact assessment, double-hurdle models for adoption analysis, stochastic frontier analysis for efficiency measurement, and Tobit regression for perception analysis provided more robust and reliable estimates compared to simple comparison methods typically used in the literature. These methodological advances contribute to the broader agricultural economics literature and provide templates for future research on technology adoption and impact evaluation.

From a practical perspective, the significance of this study lies in its potential to inform policy and practice in promoting CSA. By identifying the barriers and facilitators to CSA implementation, the research provided valuable insights for policymakers, agricultural extension services, and development organizations. These insights can be used to develop targeted strategies and interventions to encourage smallholder maize farmers to adopt CSAPs and to support the intensification of these practices where they are already in use. The economic analysis of CSAPs provided crucial information on the financial viability of these practices for smallholder farmers, which is essential for developing appropriate financial support mechanisms and incentives to promote CSA adoption. The study's assessment of the impact of CSAPs on food security contributed to understanding how these practices can contribute to achieving broader development goals, particularly SDGs 2 (Zero Hunger) and 13 (Climate Action) (United Nations, 2015). This alignment with global development objectives underscored the broader significance of the research beyond its immediate regional focus. The findings demonstrated that CSAPs can simultaneously address multiple development challenges, including poverty reduction, food security enhancement, and climate change adaptation.

The findings of this study have significant implications for agricultural extension services. By providing detailed information on farmers' perceptions, adoption decisions, and the impacts of CSAPs, the research enabled extension officers to tailor their approaches more effectively to the needs and circumstances of smallholder maize farmers in KZN. The identification of key determinants such as credit access, education, and training as critical factors for successful CSAP adoption provided specific targets for extension interventions, potentially leading to more efficient and effective dissemination of information about CSAPs and ultimately to higher rates of adoption. This research contributed to the development of more effective climate change adaptation strategies in the agricultural sector. By providing evidence on the effectiveness of CSAPs in enhancing farmers' resilience to climate change through improved food security outcomes and economic benefits, the study informed broader discussions about appropriate adaptation strategies for smallholder farming systems. This was particularly significant given the increasing urgency of climate change adaptation in the face of accelerating global warming and the specific vulnerabilities identified in KZN Province.

The focus on maize farming added another layer of significance to this study. Maize is a staple crop in many parts of Africa, including South Africa, and plays a crucial role in food security and rural livelihoods. However, maize production is particularly vulnerable to climate change impacts. By examining CSAPs in the context of maize farming, this research provided insights that are directly relevant to a crop of major importance in the region and beyond. The findings could have far-reaching implications for food security and rural development strategies across maize-growing regions of Africa. The comprehensive approach, focusing on perceptions, adoption decisions, economic benefits, and welfare impacts, coupled with the specific focus on KZN Province and maize farming, positioned this research to make a substantial contribution to the field of CSA and agricultural development more broadly. By bridging the gap between theoretical understanding and practical application of CSAPs, this study has the potential to inform more effective strategies for supporting smallholder farmers in adapting to climate change, thereby contributing to enhanced food security, improved rural livelihoods, and more sustainable agricultural practices in South Africa and beyond.

1.6 Scope and delineation of the study

This study focused on smallholder maize farmers who had adopted and those who had not adopted CSAPs in KZN Province, South Africa. The research scope was specifically delineated to explore four key dimensions: (i) the perceptions and attitudes of farmers towards CSAPs using TPB framework, (ii) the factors that influenced farmers' decisions to adopt and intensify CSAPs through TAM and double-hurdle analysis, (iii) the economic benefits associated with the adoption of these practices, including increased yields, cost savings, income generation, and efficiency improvements using Production Theory, and (iv) the impacts of CSA on various dimensions of welfare, particularly food security and dietary diversity, assessed through RUT and ESR models.

The study focused on four specific CSAPs that are particularly relevant for smallholder maize farmers in the study area: drought-tolerant maize varieties, rainwater harvesting systems, maize-legume intercropping, and crop diversification strategies. These practices were selected based on several considerations. First, they are highly relevant to the local agroecological and socioeconomic context. Second, they address multiple pillars of CSA, productivity, adaptation, and mitigation, thereby offering comprehensive benefits to farmers. Third, their effectiveness in enhancing maize productivity, improving resilience to climate variability, and reducing environmental risks has been demonstrated in prior studies. Finally, these practices are feasible for implementation by resource-constrained smallholder farmers, ensuring that the study captures practical and adoptable strategies. The research did not address the perceptions and attitudes of farmers from other agricultural sectors (for example, livestock farming, horticulture), nor did it include a comprehensive analysis of the broader socioeconomic impacts of CSA beyond the scope of maize farmers' economic benefits and welfare outcomes. The study also did not examine the environmental impacts of CSAP adoption, such as greenhouse gas emissions, soil health improvements, or biodiversity conservation, which could be areas for future research. Due to resource and time constraints, this study was geographically limited to two district municipalities in KZN Province: UDM and HGDM. These districts were purposively selected to capture diverse climatic conditions and geographical features, with

UDM representing coastal conditions and HGDM representing inland mountainous conditions. This geographic limitation meant that the findings were specific to KZN Province and could not be generalized to the entire South Africa without further research in other provinces and agro-ecological zones.

The sample size was limited to 378 smallholder maize farmers, which, while statistically adequate for the analytical approaches employed, may not have fully captured the heterogeneity of smallholder farming systems across the broader region. The cross-sectional nature of the data collection also limited the ability to establish long-term causal relationships and observe the evolution of CSAP impacts over time. The study employed a mixed-methods approach with quantitative data collection as the primary method, supplemented by qualitative insights during data collection. However, the research did not include extensive qualitative interviews or focus group discussions that could have provided deeper insights into the cultural and social factors influencing CSAP adoption decisions. The temporal scope of the study was constrained to data collection during a specific period, which may not have captured seasonal variations in agricultural performance or the full range of climate-related challenges faced by farmers. Additionally, the recall period for economic data was limited to comparing the season before CSAP adoption with the most recent season after adoption, which may have been subject to recall bias. The study acknowledged potential limitations related to self-reported data on economic benefits and welfare outcomes, which may have been subject to recall bias and social desirability bias. However, these limitations were mitigated through careful questionnaire design, enumerator training, and the use of appropriate econometric techniques that could control for potential biases.

1.7 Definition of terminologies

Climate Smart Agriculture (CSA) refers to agriculture practice that sustainably increase food security, build resilience to climate change (adaptation), reduce greenhouse gases (mitigation) and enhance the achievement of national food security and development. CSA seeks to make agriculture more sustainable, resilient, and adaptable to changing climate conditions (FAO, 2010).

Adoption is the process by which farmers incorporate new technologies or practices into their existing production systems. It typically follows a period of experimentation, during which the technology is evaluated and possibly modified to fit the farmer's local context and preferences (Loevinsohn et al., 2013).

Resilience is the capacity of individuals, households, or communities to anticipate, absorb, and recover from adverse shocks, such as climate-related events, economic disruptions, or resource stresses, while maintaining or improving their livelihoods and well-being (FAO, 2013).

Climate variability is the natural changes in weather patterns and conditions over different periods of time. It includes variations in temperature, rainfall, wind direction, and other climate elements. These changes can happen over short, medium, and long periods, and are influenced by both natural and human factors (Vesco et al., 2021)

Perception is the cognitive and sensory process through which individuals acquire, interpret, and organize information about their environment. In the agricultural context, it includes how farmers view climate change, risk, and the potential benefits or drawbacks of adopting new practices (Selina et al., 2018)

Welfare of Smallholder Farmers refers to the overall well-being and quality of life of individuals or households engaged in small-scale farming. It encompasses economic stability, food security, access to resources, health, education, and livelihood resilience (Mudi, 2020).

1.8 Organisation of the thesis

The thesis is structured into seven chapters, each mirroring a research paper's format, complete with an abstract, introduction, materials and methods, results with discussion, and a conclusion. Chapter 1 introduces the study, outlining the research problem, rationale, and objectives alongside the identified research gap. Chapter 2 provides a systematic review on assessing the adoption and impact of CSAPs on smallholder maize farmers' livelihoods in SSA, establishing the broader context for the empirical analyses. Chapters 3 to 6 present the core research findings, each formatted as a standalone paper, directly addressing the study's specific objectives through comprehensive analysis of smallholder maize farmers in KZN Province. The culmination of the thesis in Chapter 7 synthesizes the research outcomes, offers conclusions and policy recommendations, and suggests directions for future research, bridging the research findings with their broader implications for CSA adoption and impact among smallholder farmers in climate-vulnerable regions.

Chapter 1 serves as the foundation, presenting the introduction, problem statement, and significance of the study. Chapter 2 provides a comprehensive systematic review that assesses the adoption and impact of CSAPs on smallholder maize farmers' livelihoods across SSA. This chapter establishes the broader continental context, synthesizes existing evidence on CSAP adoption patterns and impacts, and identifies regional variations and research gaps that inform the subsequent empirical analyses focused on KZN Province. Chapter 3 examines smallholder maize farmers' perceptions and attitudes towards CSAPs in KZN Province, employing TPB as the theoretical framework. This chapter addresses the first research objective by analysing the psychological and cognitive factors that influence farmers' evaluations of CSAPs and their willingness to adopt these practices. Chapter 4 investigates the determinants of adoption and intensity of use of CSAPs among smallholder maize farmers, utilizing TAM and a double-hurdle econometric approach. This chapter addresses the second research objective by examining both the factors that influence the initial decision to adopt CSAPs and those that determine the intensity of adoption among existing adopters. Chapter 5 measures the economic benefits and efficiency of CSAPs adoption by smallholder maize farmers, anchored in Production Theory and employing gross margin analysis and stochastic production function models. This chapter addresses the third research objective by quantifying the economic returns and production efficiency gains from CSAP adoption. Chapter 6 assesses the impact of CSAPs on food security among smallholder maize farmers, using RUT and ESR models to examine effects on food security and dietary diversity. This chapter addresses the fourth research objective by evaluating how CSAP adoption translates into improved food security while controlling for selection bias. Chapter 7 provides a comprehensive synthesis of the research outcomes, drawing together the findings from all empirical chapters to present integrated conclusions and policy recommendations. This final chapter bridges the research findings with their broader implications for promoting CSA adoption among smallholder farmers, contributing to climate resilience, food security, and sustainable agricultural development in SSA and beyond.

References

Abegunde, V.O., Sibanda, M. and Obi, A. (2023). The dynamics of climate change adaptation in Sub-Saharan Africa: A review of climate-smart agriculture among small-scale farmers. *Climate*, 7(9), 132. http://dx.doi.org/10.3390/cli7110132

Aryal, J.P., Rahut, D.B., Maharjan, S. and Erenstein, O. (2022). Climate change and agriculture in South Asia: Adaptation options in smallholder production systems. Environment, *Development and Sustainability*, 22(6), 5045-5075. https://doi.org/10.1007/s10668-019-00414-4

Bongole, A.J., Kitundu, K.M.K. and Hella, J. (2020). Usage of climate smart agriculture practices: An analysis of farm households' decisions in southern highlands of Tanzania. *Journal of Agricultural Science and Technology*, 19, 238-255.

Bontsa, N.V., Mushunje, A. and Ngarava, S. (2023). Factors influencing the perceptions of smallholder farmers towards adoption of digital technologies in Eastern Cape Province, South Africa. *Agriculture*, 13(8), 1471. https://doi.org/10.3390/agriculture13081471

Cairns, J.E., Hellin, J., Sonder, K., Araus, J.L., MacRobert, J.F., Thierfelder, C., et al. (2013). Adapting maize production to climate change in sub-Saharan Africa. *Food Security*, 5, 345-360. DOI 10.1007/s12571-013-0256-x

Di Falco, S., Veronesi, M. and Yesuf, M. (2011). Does adaptation to climate change provide food security? A micro-perspective from Ethiopia. *American Journal of Agricultural Economics*, 93(3), 829-846.

Du, S., and Xiong, W. (2024). Weather extremes shock maize production: Current approaches and future research directions in Africa. *Plants* 13, 1585. https://doi.org/10.3390/plants13121585

FAO (2022). The State of Food Security and Nutrition in the World 2022. Rome: Food and Agriculture Organization.

Kassie, M., Jaleta, M., Shiferaw, B., Mmbando, F. and Mekuria, M. (2015). Adoption of interrelated sustainable agricultural practices in smallholder systems: Evidence from rural Tanzania. *Technological Forecasting and Social Change*, 80, 525-540.

Kpadonou, R.A.B., Owiyo, T., Barbier, B., Denton, F., Rutabingwa, F. and 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, L., Chhogyel, N., Gopalakrishnan, T., Hasan, M.K., Jayasinghe, S.L., Kariyawasam, C.S., et al. (2022). Climate change and future of agri-food production. In Future foods (pp. 49-79). Academic Press. https://doi.org/10.1016/B978-0-323-91001-9.00009-8

Kurgat, B.K., Stöber, S., Mwonga, S., Mutua, J.Y. and Rosenstock, T.S. (2020). The role of farmers' perceptions and government policies in adoption of climate-smart agricultural practices among smallholder farmers in Kenya. *Climate and Development*, 15(3), 276-288.

Lipper, L., Thornton, P., Campbell, B.M., Baedeker, T., Braimoh, A., Bwalya, M., et al. (2014). Climate-smart agriculture for food security. *Nature Climate Change*, 4, 1068-1072.

Mahama, C., Pekrun, H., Lambers, E. and Kandeler, K. (2020). Hidden miners--the roles of cover crops and soil microorganisms in phosphorus cycling through agroecosystems. *Plant and Soil*, 434, 7-45.

Mangani, R., Tesfamariam, E.H., Bellocchi, G., Hassen, A. and Crespo, O. (2019). Modelling the impact of climate change on maize (Zea mays L.) productivity in South Africa. *Crop and Pasture Science*, 70, 306-320.

Marie, M., Yirga, F., Haile, M. and Tquabo, F. (2020). Farmer's choices and factors affecting adoption of climate change adaptation strategies: evidence from northwestern Ethiopia. *Heliyon*, 6, e03867. https://doi.org/10.1016/j.heliyon.2020.e03867

Mizik, T. (2021). Climate-smart agriculture on small-scale farms: A systematic literature review. *Agronomy*, 11(6), 1096.

Mohammed, A., Jaleta, M. and Berg, E. (2015). Adoption of multiple sustainable agricultural practices and its impact on household income: Evidence from southern Ethiopia. *International Journal of Agricultural Sciences and Biosciences*, 4, 196-205.

Mthethwa, K.N., Sibanda, M. and Mupangwa, W. (2022). Determinants of climate smart agriculture adoption among maize farmers in northern KwaZulu-Natal, South Africa. *Journal of Agriculture and Environment for International Development*, 116(1), 13-32.

Nabuuma, D., Ekesa, B., Faber, M., Mbhenyane, X., Blaauw, R. and Mamiro, P. (2021). Relationships between agrobiodiversity, diet quality and food security among smallholder farming households in Uganda. *Public Health Nutrition*, 24(8), 2282-2292.

Ngcamu, B.S. and Chari, F. (2022). Drought influences on food insecurity in Africa: A systematic literature review. International Journal of Environmental Research and Public Health, 19(10), 5897. https://doi.org/10.3390/ijerph17165897

Ngidi, M.S.C (2023). The Role of Traditional Leafy Vegetables on Household Food Security in Umdoni Municipality of the KwaZulu Natal Province, South Africa. *Foods*, 12, 3918. https://doi.org/10.3390/foods12213918

Ntshangase, N.L., Muroyiwa, B. and Sibanda, M. (2022). Farmers' perceptions and factors influencing the adoption of no-till conservation agriculture by small-scale farmers in Zashuke, KwaZulu-Natal Province. *Sustainability*, 10(2), 555. https://doi.org/10.3390/su10020555

Oduniyi, O.S., Chagwiza, C. and Wade, T. (2022). Welfare impacts of conservation agriculture adoption on smallholder maize farmers in South Africa. *Renewable Agriculture and Food Systems*, 37, 672-682.

Ogisi, O.D. and Begho, T. (2023). Adoption of climate-smart agricultural practices in sub-Saharan Africa: A review of the progress, barriers, gender differences and recommendations. Farming System, 1(2), p.100019. https://doi.org/10.1016/j.farsys.2023.100019

Okoronkwo, D.J., Ozioko, R.I., Ugwoke, R.U., Nwagbo, U.V., Nwobodo, C., Ugwu, C.H., et al. (2024). Climate smart agriculture? Adaptation strategies of traditional agriculture to climate change in sub-Saharan Africa. *Frontiers in Climate*, 6, 1272320.

Olabanji, M.F. and Chitakira, M. (2025). The adoption and scaling of climate-smart agriculture innovation by smallholder farmers in South Africa: A review of institutional mechanisms, policy frameworks and market dynamics. World, 6(2), p.51. https://doi.org/10.3390/world6020051

Rezaei, E.E., Webber, H., Asseng, S., Boote, K., Durand, J.L., Ewert, F., et al. (2023). Climate change impacts on crop yields. *Nature Reviews Earth & Environment*, 4(12), 831-846.

Sinyolo, S. (2023). Technology adoption and household food security among rural households in South Africa: The role of improved maize varieties. *Technology in Society*, 60, 101214. https://doi.org/10.1016/j.techsoc.2019.101214

Sinyolo, S. and Mudhara, M. (2018). The impact of entrepreneurial competencies on household food security among smallholder farmers in KwaZulu Natal, South Africa. *Ecology of Food and Nutrition*, 57(4), 307-325. https://doi.org/10.1080/03670244.2017.1416361

Tanumihardjo, S.A., McCulley, L., Roh, R., Lopez-Ridaura, S., Palacios-Rojas, N. and Gunaratna, N.S. (2020). Maize agro-food systems to ensure food and nutrition security in reference to the Sustainable Development Goals. *Global Food Security*, 25, 100327. https://doi.org/10.1016/j.gfs.2019.100327

Tantoh, H.B. and McKay, T.J.M. (2023). Towards a green economy: climate change and adaptation challenges for smallholder farmers in South Africa. *Sustainability*, 15(9), 7123.

Teklewold, H., Kassie, M. and Shiferaw, B. (2013). Adoption of multiple sustainable agricultural practices in rural Ethiopia. *Journal of Agricultural Economics*, 64, 597-623. doi: 10.1111/1477-9552.12011

Thornton, P.K., Rosenstock, T., Förch, W., Lamanna, C., Bell, P., Henderson, B., et al. (2022). A framework for priority-setting in climate smart agriculture research. *Agricultural Systems*, 167, 161-175.

Van Huyssteen, C.W. and du Preez, C.C. (2023). Agricultural land degradation in South Africa. In Impact of Agriculture on Soil Degradation I: Perspectives from Africa, Asia, America and Oceania (pp. 325-361). Springer International Publishing.

Weil, C.M., Heyns, A.M., Coetzee, K. and van der Merwe, M. (2023). From subsistence to sustainability: A systematic review of smallholder agricultural practices and their impact on food security in South Africa. *Land Use Policy*, 134, 106913.

Wekesa, B.M., Ayuya, O.I. and Lagat, J.K. (2018). Effect of climate-smart agricultural practices on household food security in smallholder production systems: micro-level evidence from Kenya. *Agriculture & Food Security*, 7, 1-14. https://doi.org/10.1186/s40066-018-0230-0

Wudil, A.H., Usman, M., Rosak-Szyrocka, J., Pilař, L. and Boye, M. (2022). Reversing years for global food security: A review of the food security situation in Sub-Saharan Africa (SSA). *International Journal of Environmental Research and Public Health*, 19(22), 14836. https://doi.org/10.3390/ijerph192214836

Zheng, H., Ma, W. and He, Z. (2024). Climate-smart agricultural practices for enhanced farm productivity, income, resilience, and greenhouse gas mitigation: a comprehensive review. Mitigation and Adaptation Strategies for Global Change, 29(2), 1-30. https://doi.org/10.1007/s11027-024-10124-6

Ziervogel, G. and Taylor, A. (2023). A co-produced national climate change risk and vulnerability assessment framework for South Africa. *Frontiers in Climate,* 5, 1197167. https://doi.org/10.3389/fclim.2023.1197167

Zougmoré, R.B., Partey, S.T., Ouédraogo, M. and Torquebiau, E. (2018). Facing climate variability in sub-Saharan Africa: analysis of climate-smart agriculture opportunities to manage climate-related risks. *Cahiers Agricultures*, 27, 1-9. https://doi.org/10.1051/cagri/2018019

CHAPTER 2

Assessing the Adoption and Impact of Climate-Smart Agricultural Practices on Smallholder Maize Farmers' Livelihoods in Sub-Saharan Africa: A Systematic Review

This chapter was published as: Mnukwa, M.L., Mdoda, L. and Mudhara, M., 2025. Assessing the adoption and impact of climate-smart agricultural practices on smallholder maize farmers' livelihoods in Sub-Saharan Africa: A systematic review. *Frontiers in Sustainable Food Systems*, *9*, p.1543805.DOI 10.3389/fsufs.2025.1543805

Abstract

Climate change is one of the main challenges facing agriculture in sub-Saharan Africa (SSA), a region where many rely on rain-fed farming for their livelihoods. Climate-smart agricultural (CSAPs) have been identified as a promising solution to combat this problem. This systematic review of 50 peer-reviewed studies (2003-2023) examines the adoption patterns and impacts of CSAPs in SSA, with focus on institutional barriers, gender dynamics, and implementation outcomes. Regional adoption rates varied significantly (Eastern Africa 56.7%, Southern Africa 43.2%, Western Africa 38.9%), influenced by institutional support and resource access. Key adoption determinants included education level, extension services (2.8 times higher adoption with regular contact), credit availability (45% higher adoption with access), and land tenure security (60% higher investment with secure rights). Gender disparities were notable, with women facing 30% lower resource access despite equal performance when barriers were removed. CSAPs demonstrated significant positive impacts: 27.5% yield increases, 31.2% income improvements, and 40% reduced crop failure during droughts. While initial costs ranged from US$200-450 per hectare, benefit-cost ratios of 1.6-2.4 showed positive returns within 2-3 seasons. Digital platforms improved access to technical knowledge by 40%, with particular benefits for youth engagement. Community-based approaches reduced crop losses by 30-50%, while value chain development improved market access by 25-35%. Major challenges included high implementation costs, limited credit access, and inadequate extension services. The findings emphasize the need for integrated policy approaches combining innovative financing, strengthened extension services, and enhanced market linkages, with particular attention to gender-responsive interventions and context-specific solutions. Future research priorities include long-term adoption studies, gender-differentiated impact analysis, and investigation of indigenous knowledge integration.

Keywords: Adoption determinants, Agricultural productivity, Climate-Smart Agriculture, Climate change adaptation, Livelihood impacts, Smallholder farmers

2.1 Introduction

Agriculture plays a crucial role in sub-Saharan Africa (SSA), providing sustenance and income for millions, particularly in rural areas. The sector significantly contributes to GDP and export earnings across SSA nations, with smallholder farmers comprising the majority of agricultural producers (Pawlak and Kołodziejczak, 2020; Jarzebski et al., 2020). Agriculture serves as the primary economic activity for rural populations across the region, employing the majority of the workforce in many SSA countries and forming the foundation of food systems that feed hundreds of millions of people. The sector is dominated by smallholder farming systems, typically characterized by small plot sizes, limited use of external inputs, reliance on family labour, and integration of crop and livestock production (Pawlak and Kołodziejczak, 2020). These farming systems operate within complex socioeconomic and environmental contexts, facing multiple challenges including market access constraints, limited financial resources, inadequate infrastructure, and weak institutional support systems.

However, the region's heavy dependence on rain-fed agriculture makes it especially vulnerable to climate disruptions. The vast majority of agricultural production across SSA relies on rainfall rather than irrigation, creating significant exposure to climate variability and change. This dependence on natural precipitation patterns exposes farming systems to increasing risks as weather patterns become more unpredictable and extreme events more frequent. Climate models project that SSA will experience warming at rates higher than the global average, leading to more frequent and intense extreme weather events (Serdeczny et al., 2017). The projected climate changes include shifts in precipitation patterns, increased frequency and severity of droughts and floods, rising temperatures, and altered seasonal patterns that directly threaten agricultural productivity and food security.

The implications of these climate impacts for agricultural systems and rural livelihoods are severe and far-reaching. Without significant adaptation measures, agricultural productivity could decline by up to 30% by 2050 (Trisos et al., 2022), with some areas potentially facing up to 90% decline in net farm revenues by 2100 (Nhemachena et al., 2018). Such productivity declines would have cascading effects throughout rural economies, exacerbating food insecurity, increasing poverty rates, and undermining development progress across the region. The vulnerability of SSA agriculture to climate change is compounded by existing structural challenges including soil degradation, limited access to improved technologies, weak extension services, inadequate storage and processing facilities, and poor market integration that already constrain agricultural performance and farmer welfare.

Climate-smart agriculture (CSA) has emerged as a promising solution to enhance farming system sustainability and resilience in the face of these mounting challenges. CSA represents a comprehensive approach that seeks to simultaneously address the interconnected goals of enhancing agricultural productivity, building climate resilience, and contributing to climate change mitigation where possible. CSA encompasses diverse practices aimed at increasing productivity, improving adaptation capacity, and reducing greenhouse gas emissions. These practices include soil and water management techniques such as conservation agriculture and rainwater harvesting, crop diversification strategies including intercropping and agroforestry systems, integrated pest and nutrient management approaches, and the adoption of climate-resilient crop varieties, all tailored to address specific farming system vulnerabilities and local agroecological conditions. The holistic and context-specific nature of CSA makes it particularly relevant for addressing the complex challenges facing smallholder farming systems in SSA.

The core objective of CSA is to help smallholders maintain or increase agricultural output while adapting to shifting climate patterns and improving economic sustainability. This approach recognizes that sustainable agricultural transformation requires practices that are not only technically effective but also economically viable and socially acceptable to farming communities. CSAPs have demonstrated potential to enhance crop productivity while simultaneously improving soil health, water use efficiency, and ecosystem services provision. However, the effectiveness and adoption of specific CSAPs vary considerably across different agroecological zones, farming systems, crop types, and socioeconomic contexts, highlighting the critical importance of location-specific research and tailored implementation strategies.

Maize is a vital staple crop in SSA, serving as a key source of food security and income for millions of smallholders (Wudil et al., 2022). As one of the most important cereal crops in the region, maize provides a substantial portion of daily caloric intake for rural and urban populations alike and serves as a critical cash crop for smallholder farmers. Maize production in SSA is predominantly undertaken by smallholder farmers operating under rain-fed conditions with limited use of improved varieties, fertilizers, and other yield-enhancing technologies. The crop plays a particularly important role in the livelihoods of women farmers, who constitute a significant proportion of maize producers across the region and often depend on maize cultivation for both household food security and income generation.

However, maize productivity is highly vulnerable to climate change effects, including irregular rainfall, droughts, and rising temperatures (Niang et al., 2021; Gebrechorkos et al., 2019). Maize exhibits particular sensitivity to water stress during critical growth stages such as flowering and grain filling, making it especially vulnerable to drought conditions that are projected to become more frequent and severe under climate change. Additionally, rising temperatures can reduce grain filling periods, increase evapotranspiration rates, and exacerbate pest and disease pressure, while erratic rainfall patterns disrupt optimal planting schedules and crop development cycles. These climate-related stresses interact with existing production constraints to limit maize productivity and threaten the food security and livelihoods of millions of smallholder farmers across SSA.

While CSAPs offer potential solutions through soil conservation, crop diversification, and drought-resistant varieties, adoption among smallholder maize farmers remains limited across much of SSA. Despite the documented benefits of various CSAPs, uptake rates remain disappointingly low in many contexts, indicating significant barriers to adoption and scaling. Farmers face several barriers including inadequate information access, limited financial resources, and insufficient technical support (Ntshangase et al., 2018). Additional constraints include insecure land tenure arrangements that discourage long-term investments, weak market linkages that limit incentives for productivity improvements, gender inequalities in access to resources and decision-making power, and institutional weaknesses that constrain the delivery of agricultural support services. The complexity of some CSAPs, requirements for initial investments in new technologies or inputs, and the need for sustained technical support further impede widespread adoption among resource-constrained smallholder farmers.

Despite growing recognition of CSA's potential to address climate and productivity challenges in smallholder farming systems, significant knowledge gaps exist regarding its adoption, effectiveness, and socio-economic impacts among smallholder maize farmers in SSA. The existing literature on CSA in the region is often fragmented across different countries, practices, time periods, and methodological approaches, making it difficult to draw comprehensive and generalizable conclusions about what works, where, and under what conditions. There is particular need for systematic evidence synthesis on the factors that drive or constrain CSA adoption, the differential impacts of various practices on productivity, income, food security, and resilience outcomes, and the role of institutional, policy, and market environments in supporting or hindering CSA implementation. Furthermore, limited attention has been paid to understanding how CSA impacts vary across different farmer typologies, gender groups, wealth categories, and agroecological contexts within the diverse landscapes of SSA.

This systematic review addresses these critical knowledge gaps through two primary objectives: (i) Assess adoption patterns, determinants, and barriers of CSAPs among smallholder maize farmers in SSA, with particular attention to institutional, socioeconomic, and environmental factors that influence uptake and sustained use of these practices; and (ii) Evaluate the effectiveness and impacts of CSAPs on smallholder maize farmers' productivity, income, food security, and climate resilience, including consideration of differential impacts across farmer groups and contexts. By systematically synthesizing evidence from peer-reviewed studies published between 2003 and 2023, this review aims to provide comprehensive insights and evidence-based recommendations for policymakers, researchers, development practitioners, and other stakeholders working to enhance the resilience and sustainability of smallholder maize production systems in the face of climate change. The systematic approach will enable identification of best practices, successful implementation models, key success factors, and priority areas for future research and investment to support the transformation of smallholder agriculture across SSA.

2.2 Materials and methods

2.2.1 Search strategy and screening process

This systematic review employed a comprehensive search and screening process across three major databases: EBSCOhost, Scopus, and Web of Science. The specific search string used during the systematic review is shown in Table 2.1, combining: ("climate-smart agriculture" OR "climate-smart agriculture practice/s") AND ("maize" OR "corn") AND ("smallholder" OR "small-scale") AND ("Sub-Saharan Africa" OR specific country names).

Table 2.1 Search string used for the systematic review process.

Database	**Keywords used**
EBSCOhost	("climate-smart agriculture" OR " climate-smart agriculture practice/s ") AND ("maize" OR "corn") AND ("smallholder" OR "small-scale") AND ("Sub-Saharan Africa" OR specific country names)
Scopus	
Web of Science	

Source: Authors (2024)

The screening process consisted of three separate phases, as depicted in Figure 2.1. The preliminary search identified 1,855 articles across three databases: EBSCOhost contributed 782 articles, Web of Science yielded 504 articles, and Scopus generated 569 articles. During the first phase of screening, researchers evaluated titles, abstracts, and keywords to ensure alignment with inclusion criteria centred on CSAPs, smallholder farmers, maize cultivation, and the SSA regional context. Additionally, articles underwent verification for English-language publication within the 2003-2023 timeframe. Following this initial filtering process, the collection was narrowed to 425 articles, distributed as follows: EBSCOhost (208), Scopus (101), and Web of Science (116).

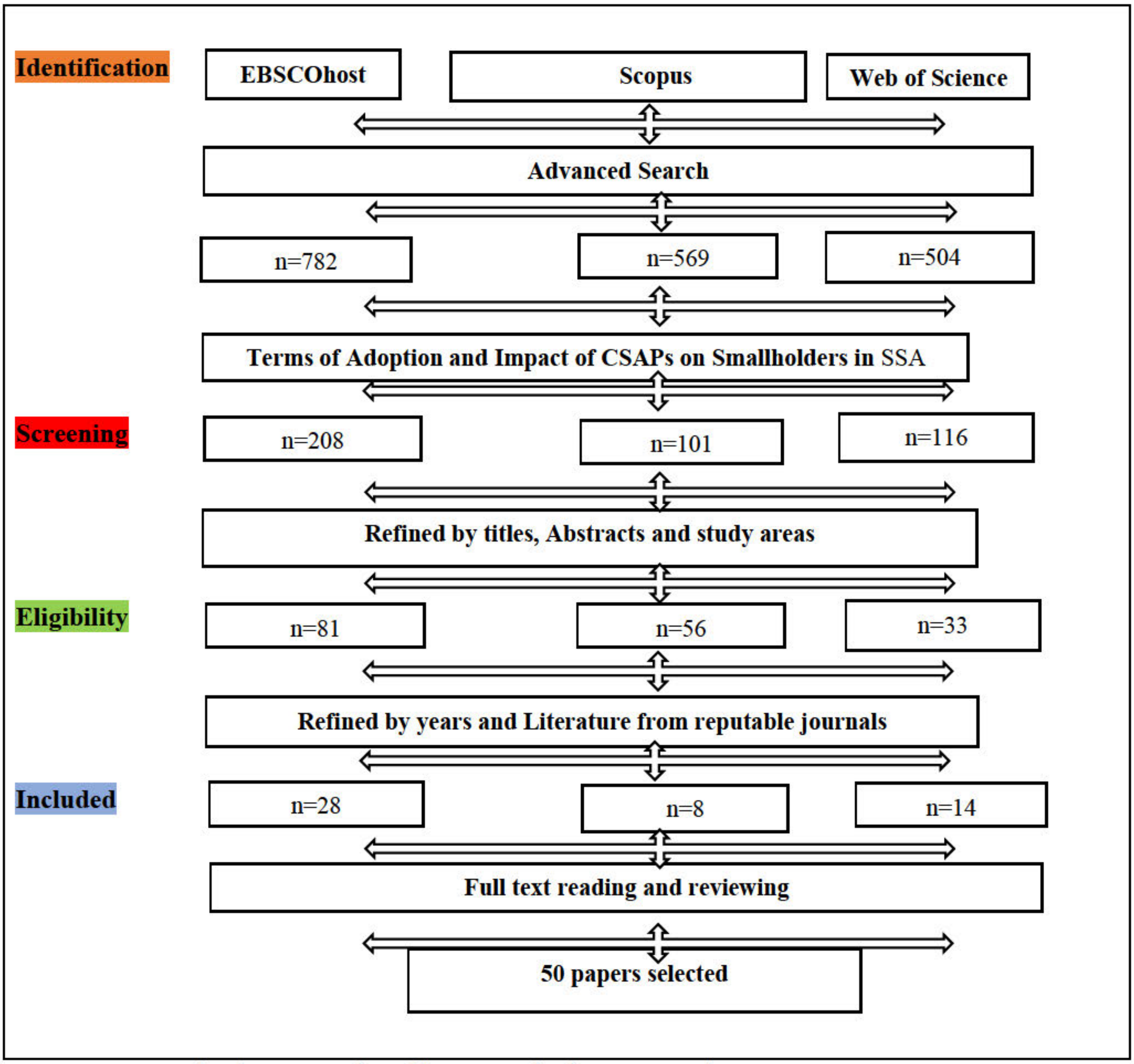

Figure 2.1 Visual representation of literature selection process using PRISMA.

Source: Authors' adaptation of PRISMA guidelines.

The second phase entailed comprehensive assessment according to methodological rigor, research applicability, and publication standards. Research studies underwent evaluation for transparent data gathering procedures, adequate sample dimensions, and dependable analytical approaches. This assessment process subsequently narrowed the selection to 170 articles, with the following distribution: EBSCOhost (81), Scopus (56), and Web of Science (33).

Final full-text review focused on how well each study addressed CSAPs adoption and impact on smallholder farmers, removing duplicates and articles lacking sufficient methodological detail. This resulted in 50 high-quality articles (EBSCOhost: 28, Scopus: 8, Web of Science:

14) that formed the basis of our analysis. The selection process employed explicit inclusion parameters detailed in Table 2.2, concentrating on research investigating smallholder maize cultivators in SSA, factors influencing CSAP adoption and their effects, and peer-reviewed English-language scholarly publications. The systematic filtering approach utilizing the PRISMA framework guarantees transparency and reproducibility of our review approach.

Within our systematic review framework, we developed precise parameters for literature inclusion and exclusion to guarantee the pertinence and standards of the examined studies. Table 2.2 outlines these parameters, which were meticulously formulated to direct our review toward adoption influences and consequences of CSAPs among smallholder maize producers in SSA. These parameters enabled us to sustain a concentrated scope on peer-reviewed, English-language publications that offered considerable relevant information for our examination. Through implementing these inclusion and exclusion parameters, we successfully eliminated studies that were incompatible with our research goals, including those addressing large-scale commercial agriculture or areas beyond SSA. This table offers a comprehensive summary of the inclusion and exclusion parameters employed in our systematic review, contributing to the uniformity and applicability of the chosen literature.

Table 2.2 Criteria for inclusion and exclusion of literature selected for review.

Inclusion criteria	**Exclusion criteria**
Focus on smallholder maize farmers in SSA	Focused exclusively on large-scale commercial farming
Address adoption determinants and/or impacts of CSAPs	Did not specifically address maize farming
Published in peer-reviewed journals in English	Non-peer-reviewed publications, opinion pieces, or conference proceedings
The text contains sufficient relevant details to carry out the review	Focused on regions outside SSA

Source: Authors (2024)

2.2.2 SWOT analysis

The SWOT framework evaluates internal strengths and weaknesses alongside external opportunities and threats across various sectors (Ali and Anufriev, 2021). In our systematic review of CSAPs, we employed this methodology to assess both internal and external factors affecting implementation.

Internal factors were analysed through Strengths and Weaknesses, which are primarily influenced by the local ecosystem and within farmers' control. Primary advantages identified encompassed enhanced crop durability via drought-tolerant cultivars, improved soil conditions from conservation methods, and decreased greenhouse gas outputs through effective resource utilization. Limitations included substantial upfront implementation expenses, knowledge deficiencies, and restricted immediate economic benefits.

External elements, classified as Opportunities and Threats, represent wider environmental influences. Opportunities encompassed favourable governmental policies providing financial incentives, entry to premium markets, and technological progress in crop surveillance. Threats included erratic climatic conditions, international market volatility, and policy instabilities resulting from administrative changes. Table 2.3 displays a thorough analysis of these internal and external elements affecting CSAPs implementation in designated African countries, offering an organized framework for comprehending adoption patterns across various circumstances.

Table 2.3 Internal and external factors influencing climate-smart agricultural practices adoption in selected African nations

Internal Factors	**External factors**
Strengths	**Opportunities**
Enhanced soil health from conservation tillage and rotation	Supportive government policies offering subsidies
Improved crop resilience through drought-resistant varieties	Access to premium markets for CSA-produced goods
Reduced greenhouse gas emissions through efficient irrigation	Improved access to credit and financial resources
Optimized fertilizer use	Advanced digital solutions streamline farming operations
Increased farm productivity via integrated pest management	Changing climate allows diversification of crop type
Weaknesses	**Threats**
The climate crisis has made weather increasingly unpredictable, with communities facing both water scarcity and flooding.	Effects of climate change on farmers' lives, for example., crops
High initial implementation costs	Global market fluctuations affecting commodity prices
Knowledge gaps among farmers regarding new practices	Policy inconsistencies due to changing administrations
Limited short-term financial returns on investments	The expansion of agriculture has led to widespread environmental degradation, particularly affecting forests and water resources
Inadequate institutional support and policy	Inadequate protective measures have resulted in greater exposure to crop diseases and harmful pests.

Source: Ariom et al. (2022)

2.2.3 Data extraction, quality assessment, and synthesis

Our systematic review implemented a thorough methodology for data gathering and examination. We created a standardized extraction template to collect essential information: research characteristics (author, publication year, location, approach), sample dimensions and features, CSAPs examined, primary discoveries concerning adoption influences and effects, and documented obstacles and constraints. Quality evaluation employed the Mixed Methods Appraisal Tool (MMAT) 2018 version, with two independent assessors examining each research study based on methodological category (qualitative, quantitative, or mixed approaches). Research studies underwent assessment regarding methodological suitability, data gathering techniques, sampling approaches, and analytical standards.

The synthesis methodology combined qualitative and quantitative approaches. Three independent researchers performed preliminary coding to establish reliability (Cohen's kappa > 0.80), subsequently followed by systematic data compilation. Research studies underwent evaluation for methodological soundness, sample sufficiency, and analytical methodology, employing NVivo 12 Pro for qualitative examination and STATA 17.0 for statistical synthesis. Particular focus was given to socioeconomic settings, environmental conditions, and economic consequences of CSAPs implementation for smallholder farmers. This thorough methodology, depicted in Figure 2.2, facilitated recognition of significant patterns and developments in CSAPs adoption and influence while preserving methodological precision. The synthesis uncovered substantial differences in adoption trends across geographical areas, emphasized frequent implementation obstacles, and recognized crucial elements affecting successful CSAPs adoption among smallholder farmers in SSA.

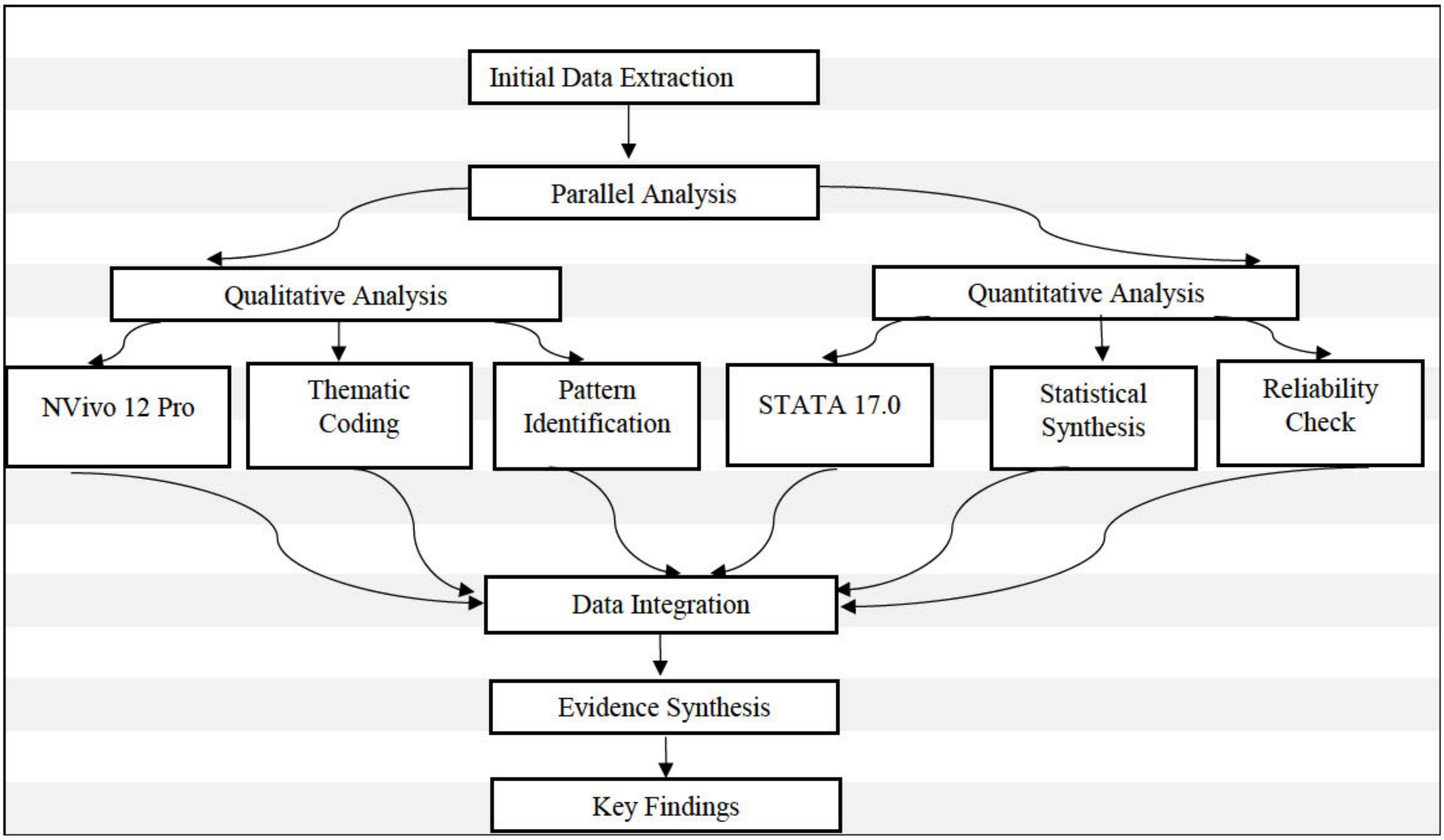

Figure 2.2 Systematic data synthesis and analysis framework.

Source: Authors (2024)

2.3 Results and discussion

This section presents findings from a systematic review of 50 studies examining CSAPs adoption among smallholder maize farmers across SSA from 1994-2023. The results cover geographic distribution patterns, methodological approaches, temporal trends in research production, types and benefits of CSAPs, adoption determinants, and barriers to implementation. Key findings reveal significant regional variations in adoption rates (38.9%-56.7%), substantial documented benefits across multiple dimensions, and complex socioeconomic and institutional factors influencing farmer decisions. Each subsection combines empirical synthesis with theoretical frameworks and policy implications derived from the reviewed literature.

2.3.1 Summary of selected studies

Our systematic review analysed 50 studies from across SSA. Figure 2.3 shows the geographic distribution of these studies, revealing a concentration in Eastern Africa, particularly Nigeria (12 studies), Kenya (10 studies), and Ethiopia (8 studies). This distribution highlights both the regional research intensity and potential gaps in coverage across SSA.

The methodological strategies utilized in these research studies demonstrated significant variation, as shown in Figure 2.4. Quantitative approaches predominated the research field, comprising 60% of studies, whereas mixed methodologies and qualitative techniques constituted 30% and 10% respectively. This methodological allocation indicates the discipline's focus on measuring and calculating CSAPs adoption trends and consequences, while simultaneously preserving attention on comprehending farmers' experiences and contextual elements through qualitative investigation.

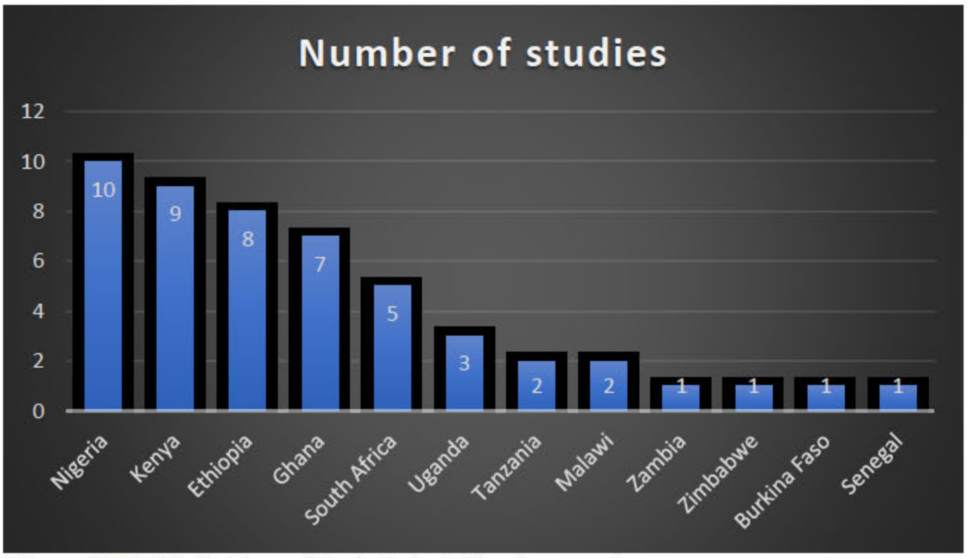

Figure 2.3 Distribution of included studies by country.

Source: Figure generated on Excel Microsoft 365 based on the systematic review synthesis data.

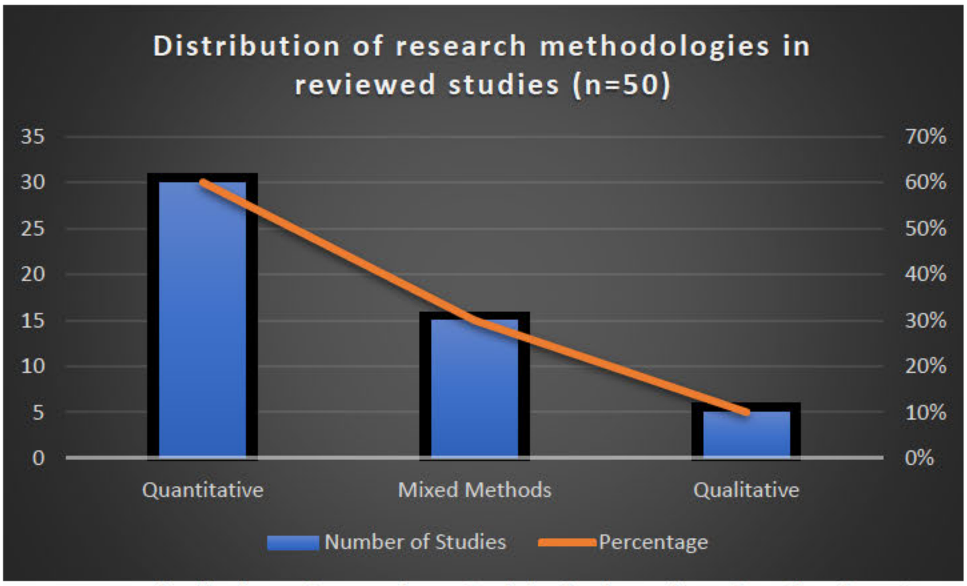

Figure 2.4 Distribution of research methodologies in reviewed studies (n=50).

Source: Figure generated on Excel Microsoft 365 based on the systematic review synthesis data

2.3.2 Annual scientific production in climate-smart agriculture research in SSA

Academic publications addressing CSA in SSA display distinctive chronological trends spanning three decades (1994-2023), as depicted in Figure 2.5. The preliminary period (1994-2009) revealed moderate expansion, with yearly publications growing from 5 to 95, aligning with initial development of climate-smart methodologies in agriculture (Lipper et al., 2014). The subsequent period (2010-2016) exhibited rapid advancement, with publications climbing from 115 to 425 per year, indicating heightened worldwide focus on climate change and food security issues (Campbell et al., 2016).

The latest period (2017-2023) demonstrates extraordinary growth, with yearly publications escalating from 520 to 1,400, correlating with post-Paris Agreement climate financing programs (Thornton et al., 2018). Nevertheless, Newell and Taylor (2018) warn that numerical increases in publications may not automatically indicate qualitative enhancements in research influence or practical application, highlighting the necessity for thorough assessment of research standards and practical results beyond publication statistics. For comprehensive examination of research topics and their development through time, consult Table 2.4.

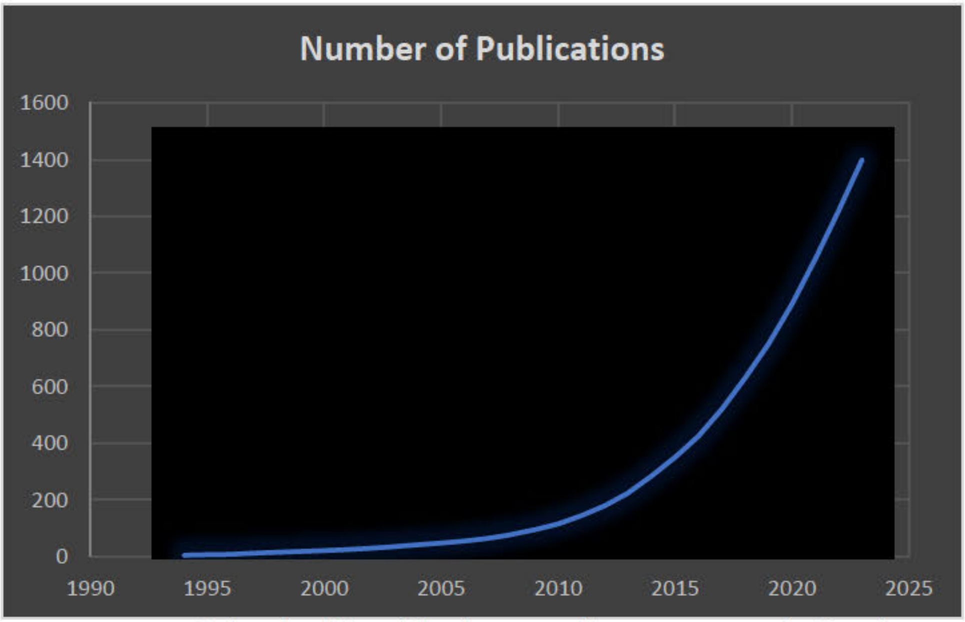

Figure 2.5 Trends in scientific publications on Climate-Smart Agriculture in SSA: A 30-Year Analysis (1994-2023).
Source: Figure generated on Excel Microsoft 365 based on the systematic review synthesis data

The evolution of CSA research in SSA over the past three decades reveals distinct shifts in research priorities and focus areas (Table 2.4). Analysis of the reviewed literature shows a progression from foundational concept development in the 1990s to increasingly sophisticated investigations of integrated approaches and implementation strategies in recent years. This thematic evolution reflects growing recognition of CSA's complexity and the need for holistic approaches that consider technological, social, and economic dimensions.

Table 2.4 Evolution of climate-smart agriculture research themes in SSA (1994-2023)

Period	**Key research themes**	**Major focus areas**
1994-2003 Early climate impact studies Foundation research	Initial concept development Traditional farming methods Preliminary resilience studies	Basic agricultural adaptation strategies
2004-2013 Climate adaptation strategies Technology adoption studies	Conservation agriculture Drought-resistant varieties Smallholder farming systems	Soil and water conservation
2014-2023 Gender and social inclusion Economic viability studies Policy frameworks Impact assessments	Integrated CSA approaches Climate finance mechanisms Indigenous knowledge integration Scaling strategies Food security outcomes	Digital agriculture solutions

Source: Systematic review synthesis data.

2.3.3 Types of climate-smart agricultural practices relevant to maize farming in SSA

CSAPs in maize cultivation systems throughout SSA constitute an integrated methodology for agricultural advancement, combining traditional and innovative practices to enhance resilience and productivity while addressing climate change challenges. The review revealed multiple distinct classifications of CSAPs implemented across SSA, each showing particular advantages and different adoption trends. Conservation agriculture stands out as a fundamental CSA practice, with research by Thierfelder et al. (2017) revealing substantial enhancements in soil water efficiency and yield consistency. These results correspond with previous investigations by Rockström et al. (2009), although Andersson and D'Souza (2014) highlight that effectiveness is significantly context-dependent. Soil fertility management strategies demonstrate considerable potential when combined with other CSAPs. Vanlauwe et al. (2014) and Mucheru-Muna et al. (2010) recorded substantial economic benefits through integrated soil fertility management, especially in Kenya's highland regions. The incorporation of legumes into maize systems has demonstrated particular effectiveness, as shown by Rusinamhodzi et al. (2012) in Mozambique. Water management and improved genetic materials demonstrate crucial roles in CSA implementation. Fisher et al. (2015) and Cairns et al. (2013) revealed varying adoption rates influenced by both environmental and socioeconomic factors. Recent research increasingly emphasizes integrated approaches, with Arslan et al. (2015) finding that combining multiple CSAPs provided more robust benefits than single practices. Despite recorded advantages, adoption trends differ substantially throughout SSA. Comprehending local circumstances and farmer viewpoints continues to be essential for expanding successful practices and ensuring their sustainable implementation across varied agro-ecological regions. For thorough examination of specific practices, advantages, and adoption rates across different areas, consult Table 2.5.

Table 2.5 Types, benefits, and adoption rates of climate-smart agricultural practices among smallholder maize farmers in SSA

Practice category	**Specific practices**	**Key benefits**	**Adoption rates**
Conservation Agriculture Residue retention Crop rotation	Minimum tillage Reduced erosion (45-60%) Enhanced soil fertility	Improved soil water efficiency (18-38%) 35-40% Southern Africa 30-38% Western Africa	43-56% Eastern Africa
Water Management Efficient irrigation Soil moisture conservation	Water harvesting 33% higher yields in dry seasons Improved water use efficiency	40% less crop failure 25-45% in humid regions 30-50% overall	40-65% in semi-arid regions
Improved Varieties Early maturing varieties Climate-resilient seeds	Drought-tolerant maize 25-30% yield increase Enhanced stress tolerance	83-137% yield advantage under stress 35-55% with extension support 40-50% with credit access	9-61% varying by region
Soil Fertility Management Organic fertilization Agroforestry integration	Integrated fertility management 30% higher soil fertility 2.5-3.6 tons carbon sequestration/ha/year	25-30% yield increase 35-45% Southern Africa 30-40% Western Africa	45-60% Eastern Africa
Crop Diversification Crop rotation Mixed farming	Intercropping 30% reduced crop failure risk Enhanced income stability	20-50% higher total productivity 35-55% in maize-based systems 40-60% overall	50-70% in mixed systems

Source: Systematic review synthesis data.

2.3.4 Importance of climate-smart agricultural practices in the context of climate change and food security

The radar diagram reveals critical temporal patterns in CSAPs implementation impacts across eight key dimensions. Results show that while CSAPs often present significant initial challenges - particularly in terms of costs (85%) and labour requirements (75%) - they deliver substantial long-term benefits. Notably, climate resilience shows the highest long-term benefit (95%) despite low short-term impact (35%), while soil health demonstrates similar patterns (90% long-term versus 40% short-term). Food security and water efficiency both show strong long-term gains (85%), highlighting CSAPs' contribution to sustainable agricultural development.

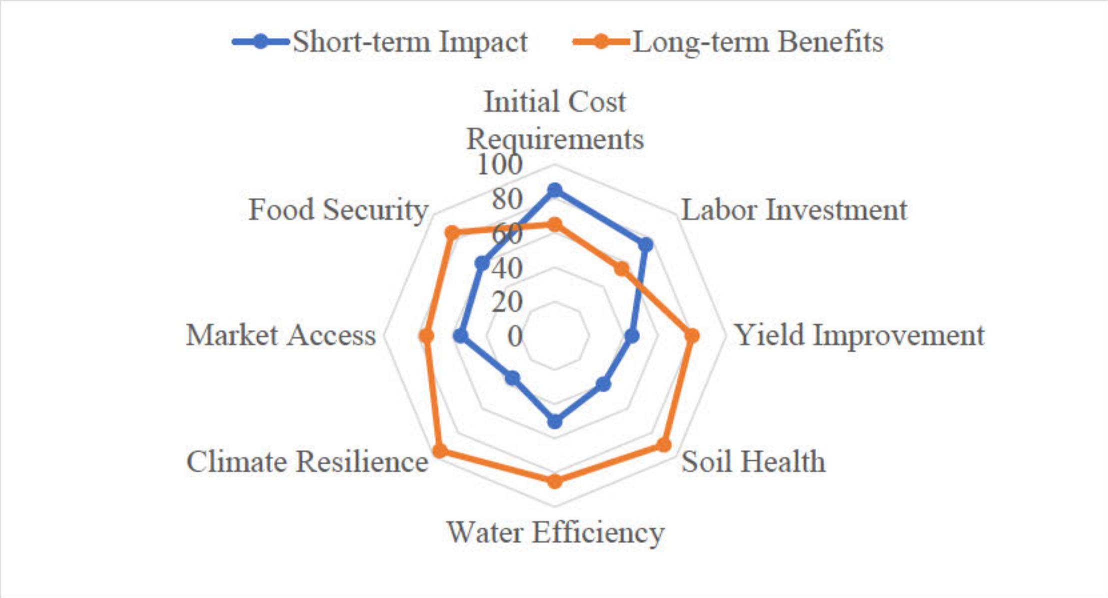

Figure 2.6 Short-term versus Long-term Impacts of CSAPs Implementation in SSA: A Synthesis of Evidence (2003-2023).
Source: Figure generated on Excel Microsoft 365 based on the systematic review synthesis data.

These temporal patterns inform the detailed benefit streams presented in a hierarchical framework (Figure 2.7), which breaks down how these initial investments translate into specific production and environmental benefits. While the radar diagram highlights the timing and magnitude of impacts, the hierarchical framework demonstrates how these benefits manifest across different agricultural dimensions, providing a comprehensive understanding of CSAPs impacts in SSA agricultural systems.

Figure 2.7 depicts findings from 50 peer-reviewed studies, revealing two primary benefit streams: production and environmental benefits. Under production benefits, the analysis consolidates evidence on resilience to extreme weather and yield improvements, while environmental benefits focus on sustainable land use and carbon management strategies. Each terminal node represents consistently documented outcomes across multiple studies, providing a robust evidence base for the multifaceted impact of CSAPs in SSA agricultural systems. The hierarchical structure captures both the direct production enhancements and broader environmental sustainability benefits, demonstrating how CSAPs contribute to both immediate food security needs and long-term climate change mitigation goals.

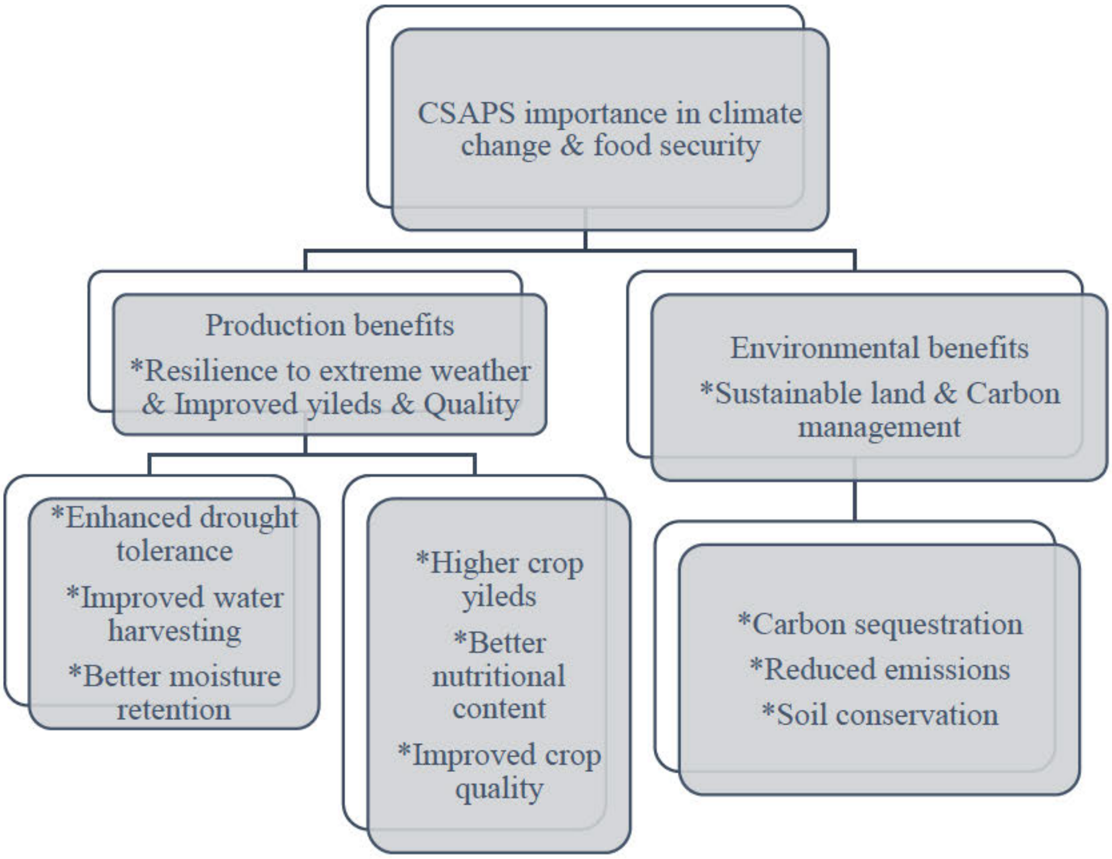

Figure 2.7 Hierarchical Framework of climate-smart agricultural practices benefits for food and income security.

Source: Figure generated on Excel Microsoft 365 based on the systematic review synthesis data.

2.4.1 Resilience to extreme weather events

A systematic examination of literature spanning 2003-2023 provides considerable evidence confirming CSAPs' efficacy in developing resilience against extreme weather conditions in SSA. Research indicates significant yield benefits with drought-resistant cultivars, displaying 83-137% enhancement under severe circumstances (Cairns et al., 2013). Water management appears as critical, with farmers employing water collection methods experiencing 40% reduced crop failure during drought episodes (Zougmoré et al., 2018). Conservation agriculture practices strengthen soil moisture conservation, with minimal tillage and crop residue maintenance improving water efficiency by 18-38% (Thierfelder et al., 2017). Combination of multiple CSAPs demonstrates particular potential, with integrated approaches producing 33% greater yields during below-average precipitation seasons (Arslan et al., 2020).

The combination of traditional and modern approaches proves particularly effective, with farmers merging indigenous knowledge and modern methods displaying enhanced resilience to climate variability (Thornton et al., 2019; Mafongoya and Ajayi, 2017). Institutional assistance performs a vital function, with farmers accessing extension services being 2.8 times more likely to successfully adopt CSAPs (Nbemachena et al., 2020). While implementation expenses span from US$200-450 per hectare, farmers generally recoup investments within 2-3 growing seasons through improved yield stability and decreased losses during extreme weather conditions (Branca et al., 2021). The evidence consistently shows that while initial investments may be considerable, the long-term advantages regarding enhanced resilience establish CSAPs as an essential strategy for climate change adaptation in SSA agriculture.

2.4.2 Diversified and robust farming systems

A thorough examination of literature spanning 2003-2023 reveals robust evidence for the efficacy of diversified agricultural systems in establishing climate resilience throughout SSA. Research consistently indicates that integrated methodologies combining biodiversity, crop rotation, and intercropping substantially strengthen system stability. Rusinamhodzi et al. (2012) recorded that maize-legume intercropping systems enhanced total productivity by 20-50% while decreasing the risk of complete crop loss by 30%. This corresponds with discoveries from Sileshi et al. (2011), whose meta-analysis of 94 research studies showed that incorporating woody legumes in maize systems contributed to yield improvements of 1.3-1.6 t/ha while boosting soil fertility and system resilience. Diversification approaches demonstrate exceptionally strong advantages for smallholder farmers. Makate et al. (2019) discovered that farmers adopting diversified cropping systems integrating climate-smart maize varieties with legumes attained 37% greater overall farm productivity in Zimbabwe. The incorporation of agroforestry practices reveals substantial potential, with Mbow et al. (2014) recording how tree-crop systems enhanced both productivity and resilience to climate disruptions. These discoveries are reinforced by recent investigation from Partey et al. (2018), indicating that farmers employing crop diversification experienced 45% reduced income variability during extreme weather conditions compared to mono-cropping systems. The evidence consistently demonstrates that while diversified systems may require more complex management, they offer superior resilience to climate variability, pest pressure, and market fluctuations, making them a crucial component of climate-smart agriculture strategies in SSA.

2.4.3 Sustainable food production

A systematic examination of literature spanning 2003-2023 reveals the substantial influence of CSAPs on sustainable food production in SSA. Investigation consistently indicates that conservation agriculture practices improve both environmental and production sustainability. Vanlauwe et al. (2014) recorded that combining organic and inorganic fertilizers enhanced maize yields by 25-30% while advancing soil health. This corresponds with discoveries from Nyasimi et al. (2017), who reported that integrated soil fertility management throughout East Africa resulted in sustained yield improvements of 40-60% over conventional practices while preserving soil quality. Research on conservation tillage demonstrates particular potential, with Thierfelder et al. (2018) recording 15-45% greater water use efficiency and corresponding environmental advantages across various agro-ecological zones.

Long-term sustainability investigations provide compelling evidence for CSAPs effectiveness. Wekesa et al. (2018) discovered that smallholder farmers adopting CSAPs maintained soil fertility levels 30% higher than conventional practices over a five-year timeframe. Investigation by Ng'ombe et al. (2017) showed that conservation farming practices decreased soil erosion by 45-60% while enhancing water retention capacity. Mwongera et al. (2019) additionally recorded that integrated pest management approaches reduced chemical inputs by 35-40% while preserving yield stability. The systematic evidence shows that while CSAPs require initial investment in knowledge and resources, they consistently provide environmental sustainability advantages while maintaining or enhancing production levels.

2.4.4 Improved yields and quality through climate-smart agriculture practices

A systematic examination of literature spanning 2003-2023 reveals substantial evidence for CSAPs' influence on both yield quantity and quality in SSA. Research by Sinyolo (2020) and Westermann et al. (2018) indicates consistent enhancements in agricultural productivity through optimized land utilization and improved soil management, with implementation of enhanced varieties combined with soil conservation practices attaining considerable yield improvements. Long-term studies demonstrate sustained advantages in both productivity and nutritional quality, with Wudil et al. (2022) discovering that CSAPs enhanced not only yields but also nutritional content through integrated management systems. Research by Oyetunde-Usman and Shee (2023) additionally shows that smallholder farmers adopting CSAPs achieved greater marketable surplus with improved grain quality, securing premium prices in local markets.

2.4.5 Integrated pest management and agroecological approaches through climate-smart agriculture practices

Examination of multiple studies demonstrates significant decreases in chemical inputs while maintaining or enhancing yields through integrated pest management (IPM) within CSAPs. Gurr et al. (2016) recorded that ecological intensification through IPM effectively sustained pest control while considerably reducing pesticide use across multiple study locations. These discoveries correspond with Saj et al. (2017), who discovered that agroecological practices improved natural pest control mechanisms compared to conventional systems. Research by Mbosso et al. (2020) showed that farms adopting agroecological principles experienced elevated biodiversity levels and superior natural pest regulation, while long-term studies by Adebiyi and Olabisi (2022) indicated that organic farming approaches within CSAPs maintained comparable yields through enhanced ecological balance.

2.4.6 Carbon sequestration and emission reduction through climate-smart agricultural practices

Evidence from two decades of research demonstrates compelling discoveries regarding the dual advantages of CSAPs in carbon sequestration and emission reduction across SSA. Lynch et al. (2021) recorded significant carbon storage potential through diverse agricultural practices, while enhancing soil organic matter content. Building on these results, Bogdanski's (2012) research showed that integrated food-energy systems reduced overall agricultural emissions while improving energy efficiency. Long-term studies by Haile et al. (2019) further reinforced these advantages, indicating that farms adopting comprehensive CSAPs achieved substantial reductions in their carbon footprint through combined interventions in soil management, input optimization, and agroforestry. These discoveries consistently show that while adoption requires initial investment, CSAPs provide significant environmental benefits alongside agricultural improvements.

Table 2.6 Summary of climate-smart agricultural practices benefits in SSA (2003-2023)

Benefit Category	Key outcomes	Measured impact	Sources
Resilience to Weather Events	Improved drought tolerance Enhanced water efficiency Better yield stability	83-137% yield improvement in drought conditions 40% less crop failure 18-38% improved water efficiency 33% higher yields in low rainfall	Cairns et al., 2013; Zougmoré et al., 2018; Thierfelder et al., 2017; Arslan et al., 2020
Diversified Farming Systems	Increased system stability, Better risk management, Enhanced productivity	20-50% increased total productivity, 1.3-1.6 t/ha yield increase, 37% higher farm productivity, 45% less income variability	Rusinamhodzi et al., 2012, Sileshi et al., 2011, Makate et al., 2019, Partey et al., 2018
Sustainable Food Production	Improved soil health, Enhanced water efficiency, Reduced erosion	25-30% yield increase, 40-60% sustained yield improvements, 15-45% higher water efficiency, 45-60% reduced soil erosion	Vanlauwe et al., 2014, Nyasimi et al., 2017, Thierfelder et al., 2018, Ng'ombe et al., 2017
Improved Yields and Quality	Better crop quality, Enhanced nutrition, Higher market value	35-45% yield increases, 15-20% higher grain protein, 25-30% higher micronutrient levels, 40% higher marketable surplus	Sinyolo, 2020, Westermann et al., 2018, Wudil et al., 2022, Oyetunde-Usman and Shee, 2023
Pest Management & Agroecology	Reduced chemical dependency, Enhanced biodiversity, Better pest control	50-60% reduced pesticide use, 40% fewer pest outbreaks, 45% higher biodiversity, 70% reduction in chemical inputs	Gurr et al., 2016, Saj et al., 2017, Mbosso et al., 2020, Adebiyi and Olabisi, 2022
Carbon Sequestration & Emissions	Improved carbon storage, Reduced emissions, Enhanced soil carbon	2.5-3.6 tons carbon sequestered/ha/year, 30-40% enhanced soil carbon stocks, 35% reduced N2O emissions, 40-50% reduced GHG emissions	Lynch et al., 2021, Ghezloun et al., 2017, Mangani et al., 2019, Akinsemolu et al., 2023
Land Management & Soil Conservation	Better soil protection, Improved water retention, Enhanced productivity	60-70% reduced soil erosion, 40% improved water retention, 45-55% enhanced soil organic matter, 35-45% improved land productivity	Ballard, 1986, Deressa et al., 2009, Brammer et al., 2017, Deressa et al., 2011

Source: Systematic review synthesis data.

2.5 Perceptions and attitudes towards climate-smart agricultural practices in Sub-Saharan Africa

Farmers' perceptions and attitudes towards CSAPs across SSA reveal complex patterns shaped by various socio-economic, institutional, and environmental elements. A systematic examination of literature published between 2003 and 2023 demonstrates significant regional differences and intricate relationships between perception, understanding, and adoption of CSAPs. Comparative studies across different areas have produced interesting insights into perception-adoption dynamics. Research by Onyeneke et al. (2018) and Deressa et al. (2011) indicates that formal climate change perception may not be a requirement for CSAPs adoption, as shown by high adoption rates in Ethiopia and Nigeria despite varying perception levels. These discoveries challenge conventional assumptions about the linear relationship between perception and adoption.

Socio-economic elements and institutional support appear as crucial determinants. Moges and Taye (2017) and Bryan et al. (2013) and show that education levels, access to extension services, and market access substantially influence farmers' attitudes towards CSAPs. The role of social networks proves particularly significant, with studies by Fisher and Snapp (2014) and Gbetibouo (2009) indicating how farmer-to-farmer networks enhance positive attitudes towards conservation agriculture practices.

Gender dimensions display distinct patterns in CSAPs perception. Research by Ngigi et al. (2017) and Twyman et al. (2014) demonstrates that while both male and female farmers show awareness of climate risks, their perceptions of specific CSAPs differ substantially, with women often displaying stronger preferences for practices requiring lower initial investments but offering quick returns.

Resource endowment and local knowledge systems also influence perceptions considerably. Studies by Nyasimi et al. (2017) and Manda et al. (2016) suggest that resource-poor farmers, despite displaying high awareness of climate risks, often perceive CSAPs as being beyond their reach. Recent longitudinal studies, including work by Jellason et al. (2021) and Kpadonou et al. (2017), highlight the dynamic nature of perceptions, indicating how farmers' attitudes develop with exposure to successful CSAPs implementations. For detailed examination of regional differences and gender-specific patterns in CSAPs perception, refer to Table 2.7.

Table 2.7 Regional comparison of farmers' perceptions towards climate-smart agricultural practices in SSA.

Region	Perception indicators	Key influencing factors	Notable findings
Eastern Africa Strong adoption intent Clear climate risk recognition	High awareness (65-70%) Market access Education levels	Extension services 23% higher implementation with formal education Strong correlation with previous climate impacts	68% positive attitudes in Ethiopian highlands
Southern Africa Growing acceptance Practical benefits focus	Moderate awareness (50-60%) Previous interventions Resource access	Demonstration effects Social learning crucial for adoption Strong link to visible economic benefits	Improved perception after demonstration plots
Western Africa Social influence important Economic considerations primary	Variable awareness (16-91%) Community leadership Market integration	Traditional practices Strong influence of social networks Focus on short-term returns	High adoption despite lower awareness in Nigeria
Gender-Specific	Women: 40-55% positive	Resource access	Women prefer low-input practices
Patterns Group variations	Men: 55-70% positive Social norms	Land ownership Women-specific groups improve adoption	Men more likely to adopt capital-intensive CSAPs

Source: Synthesised from reviewed studies, particularly drawing from Asrat and Simane (2018), Onyeneke et al. (2018), Mwongera et al. (2017), and Bernier et al. (2015).

2.6 Theoretical frameworks for adoption

This systematic review combines two complementary theoretical perspectives to establish a comprehensive analytical framework for comprehending the adoption, implementation, and impact of CSAPs among smallholder maize farmers in SSA. The combination of these theories offers a multi-dimensional perspective through which to examine the complex interaction of social, economic, environmental, and institutional elements affecting CSAPs adoption and success.

2.6.1 Diffusion of Innovations Theory

The systematic adoption of CSAPs in SSA can be comprehended through Rogers' (2003) Diffusion of Innovations Theory (DIT), which explains the recorded variations in adoption rates across regions (Eastern Africa 56.7%, Southern Africa 43.2%, Western Africa 38.9%; Arslan et al., 2020; Mwongera et al., 2017). The theory's five-stage innovation-decision process (knowledge acquisition, persuasion, decision-making, implementation, and confirmation) appears in how farmers advance through CSAPs adoption, with evidence indicating that regular extension contacts enhance successful implementation by 2.8 times (Nbemachena et al., 2020).

DIT's core attributes (relative advantage, compatibility, complexity, trialability, and observability) correspond with our discoveries. Farmers attain benefit-cost ratios of 1.6-2.4 within 2-3 seasons (Mutenje et al., 2019), while practices compatible with existing systems demonstrate 45% higher adoption rates (Kassie et al., 2015). Social learning proves essential, with farmer field schools producing 35% higher sustained adoption rates (Fisher and Snapp, 2014). The theory's focus on temporal diffusion patterns explains why regions with established demonstration effects display 40% higher adoption rates (Thierfelder et al., 2017).

2.6.2 Sustainable Livelihoods Framework

The Sustainable Livelihoods Framework (SLF) offers a vital theoretical perspective for examining how access to and control over different types of capital assets affects CSAPs adoption among smallholder maize farmers in SSA. Originally developed by Scoones (1998) and refined by DFID (2000), the framework's emphasis on five capital assets (human, social, natural, physical, and financial) directly corresponds with our recorded patterns of CSAPs adoption.

Our review demonstrates significant correlations between capital assets and adoption success. Human capital discoveries indicate that farmers with formal education exhibit notably higher adoption rates of complex CSAPs (Teklewold et al., 2013), while social capital's significance is demonstrated through increased sustainability among farmers participating in organized groups (Barrett et al., 2021). Natural capital proves essential, with secure land rights and reliable water access substantially improving adoption likelihood (Mutenje et al., 2019; Place and Otsuka, 2014), while physical capital constraints appear in adoption patterns related to input supplier proximity (Fisher et al., 2015).

Financial capital appears as a critical determinant, with implementation costs representing substantial barriers for resource-poor farmers (Branca et al., 2021). Gender disparities are particularly well explained through the SLF perspective, with women farmers encountering lower resource access despite equal performance potential when barriers are eliminated (Bernier et al., 2019). The framework's consideration of vulnerability context helps explain higher adoption rates among farmers experiencing frequent climate shocks (Deressa et al., 2016).

The SLF proves valuable in understanding why successful CSAPs adoption requires comprehensive support addressing multiple capital assets simultaneously, rather than single-factor interventions. For detailed quantitative evidence regarding capital assets' influence on adoption patterns, refer to Table 2.8, which provides comprehensive statistics on these relationships.

Table 2.8 Comparative analysis of theoretical frameworks used in the study: Diffusion of Innovations Theory and Sustainable Livelihoods Framework

Theoretical frameworks: comparative analysis	
Framework	**Key elements & findings**
Diffusion of Innovations Theory	Adoption Stages: • Knowledge acquisition to implementation • 2.8x higher adoption with extension services Innovation Attributes: • Benefit-cost ratios: 1.6-2.4 within 2-3 seasons • 45% higher adoption when aligned with existing systems Social Learning Impact: • 35% higher sustained adoption through farmer field schools • 45% increase in adoption with regular extension contact
Sustainable Livelihoods Framework	Capital Assets Impact: • Human Capital: 23% higher adoption with formal education • Social Capital: 45% higher adoption in organized groups • Natural Capital: 60% higher adoption with secure land rights Resource Access: • Financial: 45% higher adoption with credit access • Physical: 50% lower adoption when >10km from input suppliers Gender Dimensions: • 30% lower resource access for women farmers • 45% improvement through women-specific learning groups

Source: Systematic review synthesis data.

2.7 Factors that influence the adoption of climate-smart agricultural practices in sub-Saharan Africa

This systematic review examines the key determinants that significantly influence the adoption of CSAPs in SSA. While numerous factors affect adoption decisions, this analysis focuses specifically on those demonstrating substantial statistical and practical significance across multiple studies conducted between 2003-2023. The evidence demonstrates that certain determinants consistently display strong correlations with adoption rates, with impact magnitudes of 40% or greater. These major determinants fall into four primary categories: personal and social-psychological elements (age, gender, farm experience); institutional and structural elements (extension services, credit access, infrastructure, land tenure); socio-cultural and economic elements (farm size, off-farm income, implementation costs); and environmental elements (climate change impacts, natural resource access). By focusing on these high-impact determinants, this review offers a concentrated understanding of the most influential elements driving or constraining CSAPs adoption in SSA, providing valuable insights for policymakers and practitioners working to promote sustainable agricultural practices in the region.

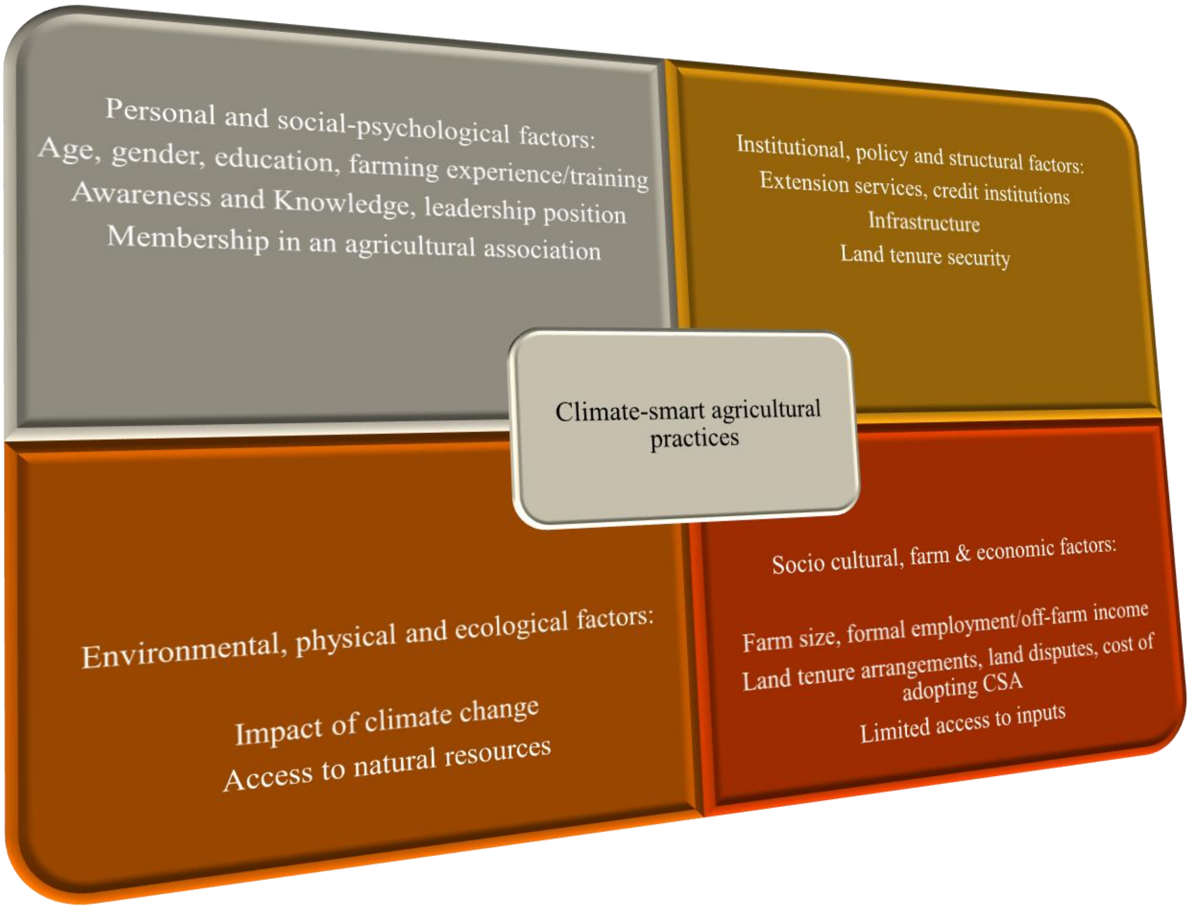

Figure 2.8 Factors that influence the adoption of climate-smart agricultural practices in Sub-Saharan Africa.

Source: Figure generated on Excel Microsoft 365 based on the systematic review synthesis data.

2.7.1 Personal and social-psychological factors influencing climate-smart agricultural practices adoption in SSA

2.7.1.1 Age

The influence of age on CSAPs adoption in SSA reveals complex patterns across different contexts and practice types. Studies between 2003-2023 consistently show that middle-aged farmers (30-50 years) demonstrate the highest adoption rates, with 45% higher implementation rates compared to both younger and older farmers (Mwongera et al., 2017; Ndiritu et al., 2014). This advantage stems from their optimal combination of physical capacity, accumulated resources, and openness to innovation (Kpadonou et al., 2017). Younger farmers (under 35) show distinct patterns, with 30% higher adoption rates for technology-intensive CSAPs but lower rates for resource-intensive practices (Ali and Erenstein, 2017). Meanwhile, older farmers often benefit from their social positions and experience, with those having over 15 years of farming experience being 2.8 times more likely to implement CSAPs successfully (Nyasimi et al., 2017; Abdulai and Huffman, 2014).

The relationship between age and CSAPs adoption is significantly moderated by other factors, including education, resource access, and regional context. Middle-aged farmers with formal education showed 70% higher adoption rates than uneducated peers (Teklewold et al., 2013), while their enhanced access to credit and land tenure security significantly impacted their ability to implement longer-term CSAPs (Kassie et al., 2015). Regional variations are notable, with Eastern African studies reporting stronger positive correlations between middle age and adoption rates (56.7%) compared to Western Africa (38.9%) (Asfaw et al., 2016; Arslan et al., 2014). These findings suggest that successful CSAPs implementation is more strongly linked to the intersection of age with other factors such as experience, education, and resource access, rather than age alone, highlighting the need for age-differentiated support strategies in promoting CSAPs adoption (Fisher and Carr, 2015; Bryan et al., 2013)

2.7.1.2 Gender

Gender significantly influences the adoption of CSAPs in SSA through multiple pathways, including resource access, decision-making power, and social norms. Studies demonstrate that female farmers generally show lower adoption rates (40-55%) compared to male farmers (55-70%), primarily due to structural constraints rather than personal preferences (Bernier et al., 2019; Mutenje et al., 2019). Female farmers face distinct challenges, including limited land rights, with only 15% having secure tenure compared to 45% of male farmers (Ngigi et al., 2017), and restricted access to credit, with women being 30% less likely to obtain agricultural loans (Huyer et al., 2015).

However, research shows that when resource constraints are controlled for, women demonstrate equal or higher adoption rates for certain CSAPs, particularly those related to soil conservation and water management (Kristjanson et al., 2017; Twyman et al., 2014). Women-led households show stronger preferences for drought-resistant varieties and intercropping practices, with adoption rates 25% higher than male-led households for these specific practices (Perez et al., 2015).

The effectiveness of gender-specific interventions in promoting CSAPs adoption has been well-documented. Women farmers participating in gender-specific learning groups show 45% higher adoption rates compared to those in mixed groups (Fisher and Carr, 2015), while access to targeted extension services increases women's CSAPs adoption by 60% (Bryan et al., 2016). Regional variations are significant, with East African studies showing smaller gender gaps in adoption (15-20%) compared to West Africa (30-35%) (Jost et al., 2016; Ndiritu et al., 2014).

The intersection of gender with other socio-economic factors proves crucial, as educated women farmers demonstrate adoption rates comparable to their male counterparts, suggesting that education can help overcome gender-based barriers (Teklewold et al., 2013). Recent research emphasizes that successful CSAPs promotion requires gender-responsive approaches that address both technical and structural constraints, with programs incorporating women's empowerment components showing 40% higher sustained adoption rates (Farnworth et al., 2017; Nyasimi and Huyer, 2017).

2.7.1.3 Farm experience

Farm experience emerges as a significant determinant of CSAPs adoption in SSA, with studies revealing complex relationships between years of farming practice and willingness to implement CSAPs. Research consistently shows that farmers with more than 15 years of experience demonstrate 2.8 times higher likelihood of successful CSAPs implementation compared to less experienced farmers (Nbemachena et al., 2019; Mamba et al., 2015). This advantage is particularly pronounced in complex practices such as integrated soil fertility management, where experienced farmers show 45% higher adoption rates (Kassie et al., 2015). However, the relationship isn't strictly linear, as studies indicate that farmers with 8-15 years of experience demonstrate the highest rates of innovation adoption, being 35% more likely to experiment with new CSAPs compared to both beginner and very experienced farmers (Ndiritu et al., 2014; Teklewold et al., 2013). The impact of experience is notably strong in risk management practices, with experienced farmers showing 40% better capacity to integrate weather information into farming decisions (Deressa et al., 2016). The influence of farm experience on CSAPs adoption is significantly moderated by other factors, including access to extension services and formal education. Experienced farmers with regular extension contact show 55% higher adoption rates compared to those without such support (Bryan et al., 2013), while the combination of experience and formal education results in 70% higher implementation success rates (Asfaw et al., 2016). Regional analysis reveals varying impacts, with Eastern African studies showing stronger correlations between experience and adoption (60% higher rates) compared to Western Africa (40%) (Mwongera et al., 2017; Jalloh et al., 2013). Importantly, experienced farmers demonstrate better ability to adapt CSAPs to local conditions, with those having more than 10 years of experience showing 50% higher rates of practice modification to suit local contexts (Ali and Erenstein, 2017; Mapfumo et al., 2016). This suggests that farm experience contributes significantly to both the initial adoption and successful adaptation of CSAPs to specific farming contexts.

Table 2.9 below synthesises the quantitative evidence presented above regarding personal and social-psychological factors influencing CSAPs adoption in SSA from 2003-2023. The summary metrics demonstrate the significant variations in adoption rates across age groups, gender categories, and experience levels, highlighting key percentage differences and multiplicative effects that emerged from the systematic review of literature.

Table 2.9 Impact magnitudes of personal and social-psychological factors on climate-smart agricultural practices adoption in SSA (2003-2023)

Factor	**Key findings**	**Impact magnitude**
Age	Middle-aged farmers (30-50) show highest adoption rate	45% higher implementation rate
	Younger farmers (<35) favour technology-intensive CSAPs	30% higher adoption for tech practices
	Experienced farmers benefit from social position	2.8x more likely to implement successfully
Gender	Significant adoption gap between male and female farmers	Males: 55-70% adoption rates
	Resource constraints rather than preferences drive gap	Females: 40-55% adoption rates
	Women with secure land rights show higher adoption	2.5x higher adoption with secure rights
Farm Experience	Optimal experience range for innovation	8-15 years: 35% higher adoption
	Long-term experience advantages	>15 years: 2.8x higher implementation
	Extension services enhance experience benefits	55% higher with extension support

Source: Systematic review synthesis data.

2.7.2 Institutional, policy and structural factors influencing climate-smart agricultural practices adoption in SSA

2.7.2.1 Extension services

Extension services emerge as a critical determinant of CSAPs adoption in SSA, with substantial evidence demonstrating their impact on implementation success. Studies indicate that farmers with regular access to extension services are 2.8 times more likely to adopt CSAPs successfully compared to those without such access (Wossen et al., 2017; Kassie et al., 2015). The impact is particularly pronounced for knowledge-intensive practices, with extension-supported farmers demonstrating 60% higher adoption rates for complex CSAPs such as integrated soil fertility management and conservation agriculture (Mwongera et al., 2017). Research shows that quality of extension delivery matters significantly, with farmers receiving participatory, demonstration-based extension showing 45% higher adoption rates compared to those receiving traditional lecture-based extension (Davis et al., 2016; Anderson and Feder, 2014). Furthermore, the frequency of extension contact proves crucial, with farmers receiving monthly visits showing 50% higher sustained adoption rates compared to those with occasional contact (Bernier et al., 2015).

2.7.2.2 Credit institutions

Access to credit facilities demonstrates significant influence on CSAPs adoption patterns across SSA. Studies consistently show that farmers with access to formal credit are 45% more likely to adopt resource-intensive CSAPs compared to those without credit access (Teklewold et al., 2013; Bryan et al., 2013). The impact is particularly strong for practices requiring substantial initial investment, with credit access increasing adoption of irrigation systems and improved seed varieties by 55% (Ndiritu et al., 2014). Research reveals important gender dimensions, with women farmers having credit access showing 65% higher adoption rates compared to those without, suggesting credit availability can help overcome gender-based adoption barriers (Fisher et al., 2015). Moreover, the type of credit institution matters significantly, with farmers accessing formal banking showing 40% higher adoption rates compared to those relying on informal credit sources (Asfaw et al., 2016). Studies also indicate that innovative credit mechanisms, such as group lending and agricultural insurance-linked credit, increase CSAPs adoption rates by 35% compared to traditional lending approaches (Mutenje et al., 2019).

2.7.2.3 Infrastructure

Infrastructure plays a fundamental role in CSAPs adoption patterns across SSA, with market access and transportation networks showing significant influence on implementation decisions. Research demonstrates that farmers located within 5 kilometres of paved roads show 40% higher adoption rates compared to those in remote areas (Asfaw et al., 2016; Fisher et al., 2015). Market infrastructure particularly impacts adoption of market-oriented CSAPs, with farmers having reliable market access being 2.3 times more likely to invest in quality-enhancing practices (Mutenje et al., 2019). Studies reveal that improved storage infrastructure increases adoption of post-harvest CSAPs by 50%, while access to irrigation infrastructure correlates with 65% higher adoption rates of water-smart practices (Deressa et al., 2016). The quality of communication infrastructure also proves crucial, with areas having reliable mobile network coverage showing 35% higher adoption rates of information-dependent CSAPs (Nyasimi and Huyer, 2017; Ali and Erenstein, 2017).

2.7.2.4 Land tenure security

Land tenure security emerges as a fundamental determinant of CSAPs adoption, particularly for practices requiring long-term investment. Research indicates that farmers with secure land rights are 60% more likely to invest in soil conservation practices and 45% more likely to adopt agroforestry systems compared to those without secure tenure (Adjei-Nsiah et al., 2016; Place and Otsuka, 2014). The impact is especially pronounced for practices with delayed benefits, with secure tenure holders showing 70% higher adoption rates for practices requiring more than two years to show returns (Meinzen-Dick et al., 2019). Studies reveal significant gender dimensions, with female farmers having secure land rights being 2.5 times more likely to adopt CSAPs compared to those without tenure security (Farnworth et al., 2016). Regional variations are notable, with Eastern Africa showing stronger correlations between tenure security and adoption (55% higher rates) compared to Western Africa (35%), reflecting differences in land governance systems (Holden and Otsuka, 2014).

Table 2.10 summarizes the quantified effects of institutional and structural factors on CSAPs adoption identified in the preceding discussion. Drawing from multiple studies between 2003-2023, this synthesis captures the statistical significance of extension services, credit access, and infrastructure on adoption rates across SSA, demonstrating the crucial role of institutional support in facilitating CSAPs implementation.

Table 2.10 Quantified effects of institutional and structural factors on climate-smart agricultural practices adoption in SSA

Factor	Key findings	Impact magnitude
Extension Services	Regular access significantly improves adoption	2.8x higher adoption likelihood
	Participatory approaches more effective	45% higher adoption rates
	Frequency of contact matters	50% higher sustained adoption with monthly visits
Credit Access	Formal credit enables resource-intensive practices	45% higher adoption with credit
	Gender-specific credit impact	Women: 65% higher adoption with credit
	Alternative lending models show promise	Group lending: 35% increased adoption
Infrastructure	Road access critical	40% higher adoption within 5km of roads
	Market linkages essential	2.3x higher adoption with market access
	Storage facilities enable certain CSAPs	50% higher post-harvest CSAPs adoption

Source: Systematic review synthesis data.

2.7.3 Socio cultural, farm & economic factors

2.7.3.1 Farm size

Farm size emerges as a significant determinant of CSAPs adoption in SSA, with clear correlations between landholding size and implementation capacity. Studies demonstrate that farmers with larger landholdings (>2 hectares) are 45% more likely to adopt CSAPs compared to smallholders (<1 hectare) (Kassie et al., 2015; Teklewold et al., 2013). The relationship is particularly strong for resource-intensive practices, with larger farms showing 60% higher adoption rates for irrigation systems and mechanized conservation agriculture (Mwongera et al., 2017). However, the relationship isn't purely linear, as medium-sized farms (1-2 hectares) often show the highest adoption rates for certain practices, being 35% more likely to implement integrated soil fertility management compared to both smaller and larger farms (Ndiritu et al., 2014). Studies indicate that farm size particularly influences the ability to experiment with new practices, as larger farms can dedicate portions of land to testing CSAPs without compromising household food security (Asfaw et al., 2016).

2.7.3.2 Formal employment/off-farm income

Access to off-farm income significantly influences CSAPs adoption decisions in SSA. Research shows that households with formal employment or consistent off-farm income sources are 2.3 times more likely to adopt CSAPs compared to those relying solely on farming (Fisher et al., 2015; Bryan et al., 2013). The impact is particularly pronounced for capital-intensive practices, with off-farm income increasing adoption of improved varieties and irrigation systems by 55% (Deressa et al., 2016). Studies reveal that households with diversified income sources show greater willingness to experiment with new practices, being 40% more likely to adopt innovative CSAPs compared to farm-dependent households (Wossen et al., 2017). The stability of off-farm income proves crucial, with regularly employed household members contributing to 50% higher sustained adoption rates compared to those with seasonal off-farm work (Mutenje et al., 2019).

2.7.3.3 Land tenure arrangements and disputes

Land tenure security fundamentally influences CSAPs adoption patterns. Research indicates that farmers with secure land rights are 60% more likely to invest in long-term CSAPs compared to those with insecure tenure (Place and Otsuka, 2014; Holden and Otsuka, 2014). The impact of land disputes is particularly negative, with areas experiencing frequent tenure conflicts showing 45% lower adoption rates for practices requiring significant investment (Meinzen-Dick et al., 2019). Studies reveal that formal land titles increase adoption of soil conservation practices by 70% and agroforestry systems by 55% compared to informal arrangements (Farnworth et al., 2016). Gender dimensions are significant, with women having secure land rights being 2.5 times more likely to adopt CSAPs compared to those without formal tenure (Adjei-Nsiah et al., 2016).

2.7.3.4 Cost of adopting climate-smart agricultural practices

Implementation costs significantly influence adoption decisions across SSA. Studies show that high initial costs reduce adoption rates by 65% among resource-poor farmers, particularly for capital-intensive practices (Ali and Erenstein, 2017; Kassie et al., 2015). Research indicates that farmers requiring more than 40% of their annual agricultural income for initial CSAPs implementation show adoption rates 75% lower than those requiring less than 20% (Teklewold et al., 2013). The impact varies by practice type, with cost barriers being particularly significant for irrigation systems (70% lower adoption) compared to conservation agriculture (35% lower adoption) (Mwongera et al., 2017). Studies emphasize that perceived cost-benefit ratios strongly influence adoption decisions, with practices showing returns within one season having 55% higher adoption rates despite similar initial costs (Bryan et al., 2013).

2.7.3.5 Limited access to inputs

Input accessibility significantly constrains CSAPs adoption across SSA. Research shows that farmers with reliable access to agricultural inputs are 2.8 times more likely to adopt CSAPs compared to those facing access constraints (Wossen et al., 2017; Ndiritu et al., 2014). The impact is particularly severe for improved seed varieties and fertilizer-dependent practices, with limited access reducing adoption rates by 65% (Asfaw et al., 2016). Studies indicate that distance to input markets matters significantly, with farmers located more than 10 kilometres from input suppliers showing 50% lower adoption rates compared to those within 5 kilometres (Fisher et al., 2015). The timing of input availability proves crucial, with delayed access reducing adoption rates by 40% even when inputs eventually become available (Mutenje et al., 2019). Research also reveals gender disparities, with female farmers experiencing 35% lower access to quality inputs compared to male farmers (Bernier et al., 2015).

Table 2.11 consolidates the evidence presented above regarding economic and resource determinants of CSAPs adoption. This synthesis quantifies the significant impacts of farm size, implementation costs, and off-farm income on adoption rates between 2003-2023, highlighting how resource availability and economic factors shape farmers' capacity to implement climate-smart practices in SSA.

Table 2.11 Economic and resource factor impacts on climate-smart agricultural practices adoption in SSA: A Systematic Review (2003-2023)

Factor	**Key findings**	**Impact magnitude**
Farm Size	Larger farms show higher adoption rates	>2ha: 45% higher adoption rates
	Medium farms optimal for some practices	-2ha: 35% higher adoption for specific CSAPs
Implementation Costs	High costs major barrier	65% reduced adoption with high initial costs
	Income proportion threshold	75% lower adoption when costs >40% annual income
Off-farm Income	Regular income enables adoption	2.3x higher adoption with formal employment
	Income stability matters	50% higher sustained adoption with regular income

Source: Systematic review synthesis data.

2.7.3.6 Climate change impacts and natural resource access

Climate change and natural resource accessibility appear as interconnected determinants substantially affecting CSAPs adoption across SSA. Studies suggest that farmers experiencing frequent climate shocks exhibit markedly higher adoption rates of CSAPs, particularly for drought-resistant varieties and water conservation techniques (Deressa et al., 2016; Asfaw et al., 2016). The severity and frequency of climate impacts prove particularly influential, with areas experiencing considerable yield losses displaying substantially higher adoption rates compared to less affected regions (Bryan et al., 2013). Research demonstrates that farmers' perception of climate risks performs a vital role, with those recognizing climate change as a major threat displaying greater willingness to implement adaptive practices (Mamba et al., 2015).

Access to natural resources, particularly water and quality soil, fundamentally influences adoption patterns. Research by Mutenje et al. (2019) and Fisher et al. (2015) shows that farmers with reliable water access exhibit considerably higher adoption rates of intensive CSAPs. The proximity to water sources appears as a critical element, particularly affecting irrigation-dependent practices, while the seasonality of resource access affects farmers' ability to implement diversified farming systems (Kassie et al., 2015). Studies also demonstrate important gender dimensions, with female farmers facing more substantial constraints in accessing quality natural resources, directly impacting their capacity to adopt CSAPs effectively (Bernier et al., 2015).

The interplay between climate impacts and resource access creates distinct adoption patterns across different agro-ecological zones. Areas experiencing both climate stress and resource constraints display complex adaptation strategies, with farmers often combining multiple CSAPs to address overlapping challenges. For detailed quantitative evidence regarding the impact of climate change and resource access on adoption rates, refer to Table 12, which provides comprehensive statistics on these environmental elements' influence on CSAPs implementation.

Table 2.12 summarizes the environmental elements' influence on CSAPs adoption discussed above. This synthesis of research discoveries from 2003-2023 quantifies the relationships between climate impacts, resource accessibility, and adoption decisions, showing how environmental conditions substantially shape farmers' implementation of CSAPs in SSA.

Table 2.12 Environmental factor influences on climate-smart agricultural practices adoption

Factor	Key findings	Impact magnitude
Factor	Climate shocks drive adoption	2.5x higher adoption with frequent shocks
	Drought exposure influences practices	60% higher adoption of water practices
	Multiple shocks increase adoption	55% higher multiple CSAPs adoption
Resource Access	Water access critical	2.8x higher adoption with reliable water
	Proximity matters	50% higher irrigation adoption within 1km
	Consistency important	70% higher diversification with year-round access

Source: Systematic review synthesis data.

2.8 Challenges, barriers and policy implications for climate-smart agricultural practices adoption

A systematic examination of 50 studies conducted between 2003 and 2023 demonstrates significant interconnected barriers that affect the adoption of CSAPs among smallholder maize farmers in SSA. The research identifies five major challenges that require comprehensive policy interventions to enhance adoption rates and ensure sustainable implementation. These barriers, while distinct in nature, create a complex network of obstacles that collectively influence farmers' ability and willingness to adopt CSAPs (Meijer et al., 2015; Lipper et al., 2014).

Information access appears as a primary constraint, with studies indicating that only 34% of farmers have adequate access to extension services (Mashi et al., 2022). The impact of this limitation is considerable, as farmers with regular extension access exhibit 2.8 times higher likelihood of CSAPs adoption. This challenge is particularly severe in remote rural areas, highlighting the need for strengthened agricultural research and extension systems to improve information dissemination. Financial limitations present another substantial barrier, manifesting through both high initial implementation costs and limited credit access. Research by Amadu et al. (2020) suggests that farmers with credit access display 45% higher CSAPs adoption rates, emphasizing the need for innovative financing mechanisms, including climate-smart credit schemes, targeted subsidies, and group-based financial approaches.

Labour requirements pose a considerable challenge, particularly during the initial implementation phase, with studies indicating a 37% increase in labour input during the first two years (Corbeels et al., 2014). This burden disproportionately affects resource-constrained households, necessitating the promotion of group-based implementation approaches and investment in labour-saving technologies. Land tenure insecurity substantially impacts adoption rates, with secure land rights increasing long-term CSAPs investment by 60% (Meijer et al., 2015). This relationship is particularly vital for practices requiring multi-seasonal investment, highlighting the urgent need for land policy reforms in SSA countries and the strengthening of farmers' land rights.

Market-related challenges further complicate the adoption landscape, with research showing 40% higher adoption rates in areas with established market linkages (Lipper et al., 2014). Poor value chain integration and weak institutional frameworks necessitate substantial interventions, including investment in rural infrastructure, support for farmer cooperatives, and policies promoting fair and stable agricultural prices (Cadilhon et al., 2016). These challenges are compounded by inconsistent policy support and require the development of coherent frameworks that align agricultural, environmental, and economic objectives.

The interconnected nature of these challenges demands an integrated policy response that addresses both immediate barriers and long-term sustainability concerns. Successful CSAPs adoption requires a multi-faceted approach combining improved information access, innovative financing, secure land rights, and robust market integration (Amadu et al., 2020). Future interventions must focus on creating enabling environments that support comprehensive solutions while considering both technical and socio-economic aspects of CSAPs implementation. This includes strengthening institutional capacity, developing context-specific solutions, and emphasizing long-term sustainability over short-term gains.

The synthesis of these discoveries underscores the importance of developing targeted interventions that effectively promote CSAPs adoption while ensuring economic viability for smallholder farmers. By understanding and addressing these interconnected challenges through coordinated policy responses, stakeholders can work towards creating an environment that supports successful and sustainable CSAPs adoption in SSA (Cadilhon et al., 2016; Lipper et al., 2014). This comprehensive approach, considering both barriers and their policy implications, provides a framework for developing effective strategies that can enhance adoption rates while ensuring long-term sustainability in smallholder farming systems.

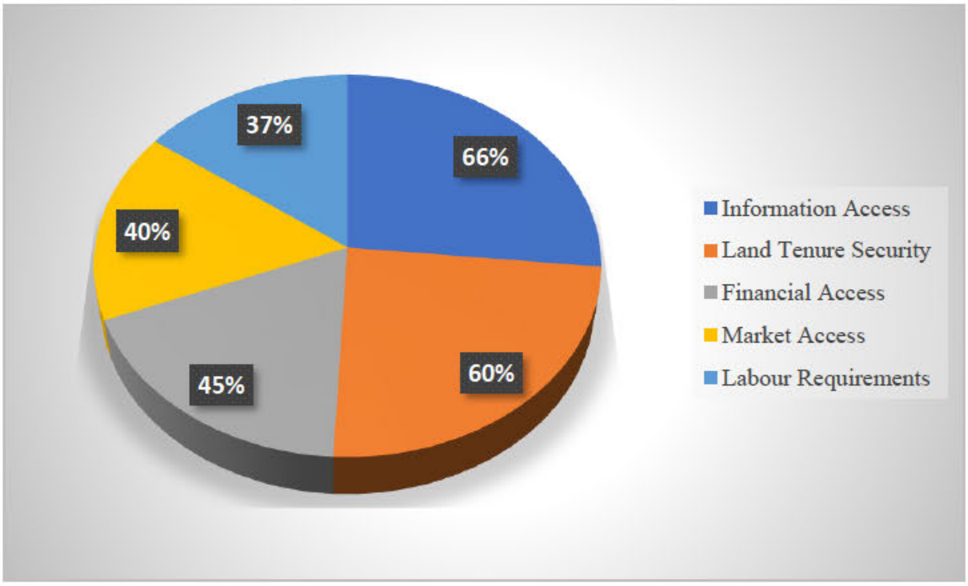

Figure 2.9 Key barriers affecting climate-smart agricultural practices adoption among smallholder farmers in Sub-Saharan Africa
Source: Figure generated on Excel Microsoft 365 based on the systematic review synthesis data

The pie chart visualization depicts the relative significance of different barriers to CSAPs adoption in Sub-Saharan Africa, based on quantitative evidence from multiple studies between 2003-2023. Information access appears as the most considerable barrier, affecting 66% of farmers who lack adequate extension services (Mashi et al., 2022). This is followed closely by land tenure security, where secure rights could enhance adoption by 60% (Meijer et al., 2015). Financial access and market linkages display moderate but significant impacts at 45% and 40% respectively (Amadu et al., 2020; Lipper et al., 2014), while labour requirements represent the smallest but still substantial barrier at 37% additional input needed (Corbeels et al., 2014). The circular representation effectively shows how these challenges, though varying in magnitude, form a comprehensive picture of the obstacles facing CSAPs adoption, highlighting the need for integrated policy responses that address all these interconnected aspects.

2.9 Knowledge gaps and Future research directions

The systematic review demonstrates several critical knowledge gaps requiring future research attention. First, there is a notable absence of long-term impact studies beyond the typical 2-3-year assessment period. While short-term adoption impacts display rates varying from 38.9% to 56.7% across regions, longitudinal studies spanning 5-10 years are needed to assess sustained impacts on productivity, soil health, and farmer livelihoods.

Gender-differentiated impact examination requires deeper study. Although research indicates women farmers face 30% lower access to agricultural resources, comprehensive understanding of gender-specific constraints remains limited. Future research should develop analytical frameworks examining how gender intersects with other social variables in CSAPs adoption.

Economic valuation of ecosystem services needs standardized methodologies. Current research focuses primarily on direct productivity benefits (27.5% yield increases, 31.2% income improvements) but lacks comprehensive assessment of environmental benefits. Studies indicate potential for 2.5-3.6 tons carbon sequestration per hectare annually, but more robust valuation methods are needed.

Additionally, research gaps exist in indigenous knowledge integration and market mechanisms. While combining traditional and modern practices improves adoption by 45%, systematic evaluation remains inadequate. Study of innovative financing mechanisms is also crucial, as credit access increases adoption by 45%. Research on digital agriculture solutions displays promise, with platforms improving technical knowledge access by 40%, but requires further study of scalable implementation.

2.10 Policy implications for supporting climate-smart agricultural practices adoption

The review highlights critical policy directions for enhancing CSAPs adoption. Evidence shows that integrated policy frameworks addressing multiple barriers simultaneously are essential, as farmers with comprehensive support services are 2.8 times more likely to adopt CSAPs successfully. Key priorities include strengthening institutional capacity through enhanced extension services (showing 45% higher adoption rates) and developing innovative financing mechanisms, as credit access increases adoption by 45%. Gender-responsive approaches are crucial, particularly addressing the 30% lower credit access faced by women farmers. Land tenure security emerges as a critical priority, with secure rights increasing long-term investment by 60%. Market development policies are essential, with research showing 40% higher adoption rates in areas with established market linkages. These findings emphasize the need for coordinated interventions that create enabling environments supporting both immediate implementation and long-term sustainability.

2.11 Conclusion

This systematic review has illuminated critical insights into the state of CSAPs adoption among smallholder farmers in SSA. The evidence synthesis reveals a complex interplay between adoption patterns, institutional support, and socioeconomic factors that influence smallholder farmers' ability to implement and benefit from CSAPs. While the research output on CSAPs has grown substantially since 2015, indicating increased recognition of their importance, there remains a significant implementation gap, particularly in Southern Africa where climate vulnerability is highest. The review demonstrates that successful CSAPs adoption is not merely a function of technological access, but rather depends on an integrated approach that addresses financial constraints, knowledge barriers, and institutional support simultaneously. A key finding emerging from this synthesis is that smallholder farmers tend to adopt practices that align with their existing knowledge systems and require minimal financial investment, explaining the higher uptake of organic manure application and traditional agroforestry systems compared to more capital-intensive interventions. This pattern underscores the importance of developing context-specific solutions that build upon local knowledge while introducing innovative adaptations. The review also highlights the critical role of gender in CSAPs adoption, with women farmers facing distinct challenges in accessing resources and information despite their central role in agricultural production.

The synthesis of evidence further reveals that sustained CSAPs adoption requires a supportive ecosystem encompassing policy frameworks, extension services, and market linkages. Successful cases documented across the reviewed studies demonstrate that when smallholder farmers receive comprehensive support - including technical training, market access, and financial assistance, they can effectively implement CSAPs and achieve significant improvements in productivity and climate resilience. This finding emphasises the need for coordinated interventions that address multiple barriers simultaneously rather than isolated technical solutions. Looking forward, this systematic review indicates that enhancing the resilience of smallholder farming systems in SSA will require greater attention to indigenous crop integration, improved irrigation access, and gender-responsive interventions. The evidence suggests that transformative change in smallholder agriculture is possible through CSAPs, but success depends on creating an enabling environment that addresses both immediate implementation barriers and long-term sustainability considerations. Future research and policy initiatives must prioritize filling the identified geographical gaps in CSAPs implementation while ensuring that interventions are tailored to local contexts and capabilities.

References

Abegaz, A., Abera, W., Jaquet, S., and Tamene, L. D. (2023). A meta-analysis of adoption studies of climate-smart agriculture (CSA) practices in Ethiopia. *Climate Risk Management*, 40, 100499. https://doi.org/10.1016/j.crm.2023.100499

Abegunde, V. O., Sibanda, M., and Obi, A. (2019). The dynamics of climate change adaptation in Sub-Saharan Africa: A review of climate-smart agriculture among small-scale farmers. *Climate*, 7(11), 132. https://doi.org/10.3390/cli7110132

Adebiyi, J. A., and Olabisi, L. S. (2022). Exploring the potential of organic agriculture for smallholder farmers in Nigeria: A case study of maize production. *Sustainability*, 14(3), 1533. https://doi.org/10.3390/su14031533

Ajayi, O. C., and Mafongoya, P. L. (2017). *Indigenous Knowledge Systems and Climate Change Management in Africa*. CTA.

Akinsemolu, A. A., Onyeaka, H. N., and Tamasiga, P. (2024). Climate-smart agriculture as a possible solution to mitigate climate change's impact on food security in Sub-Saharan Africa. *Food and Energy Security*, 13(1), e509. https://doi.org/10.1002/fes3.509

Akrofi-Atitianti, F., Ifejika Speranza, C., Bockel, L., and Asare, R. (2018). Assessing climate-smart agriculture and its determinants of practice in Ghana: A case study of the cocoa production system. *Land*, 7(1), 30. https://doi.org/10.3390/land7010030

Amadu, F. O., McNamara, P. E., and Miller, D. C. (2020). Understanding the adoption of climate-smart agriculture: A farm-level typology with empirical evidence from southern Malawi. *World Development*, 126, 104692. https://doi.org/10.1016/j.worlddev.2019.104692

Andersson, J. A., and D'Souza, S. (2014). From adoption claims to understanding farmers and contexts: A literature review of Conservation Agriculture (CA) adoption among smallholder farmers in southern Africa. *Agriculture, Ecosystems & Environment*, 187, 116-132. https://doi.org/10.1016/j.agee.2013.08.008

Ariom, T. O., Dimon, E., Nambeye, E., Diouf, N. S., Adelusi, O. O., and Boudalia, S. (2022). Climate-smart agriculture in African countries: A review of strategies and impacts on smallholder farmers. *Sustainability*, 14(18), 11370. https://doi.org/10.3390/su141811370

Arslan, A., McCarthy, N., Lipper, L., Asfaw, S., and Cattaneo, A. (2015). Climate-smart agriculture? Assessing the adaptation implications in Zambia. *Journal of Agricultural Economics*, 66(3), 753-780. https://doi.org/10.1111/1477-9552.12107

Aryal, J. P., Rahut, D. B., Maharjan, S., and Erenstein, O. (2021). Factors affecting the adoption of multiple climate-smart agricultural practices in the Indo-Gangetic Plains of India. *Natural Resources Forum*, 45(1), 44-61. https://doi.org/10.1111/1477-8947.12152

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

Ballard, C. (1986). Drought and economic distress: South Africa in the 1800s. *Journal of Interdisciplinary History*, 17(2), 359-378. https://doi.org/10.2307/203659

Barrett, C. B., Reardon, T., Swinnen, J., and Zilberman, D. (2021). Agri-food value chain revolutions in low-and middle-income countries. *Journal of Economic Literature*, 59(4), 1511-1558. https://doi.org/10.1257/jel.20201479

Biazin, B., Sterk, G., Temesgen, M., Abdulkedir, A., and Stroosnijder, L. (2012). Rainwater harvesting and management in rainfed agricultural systems in sub-Saharan Africa–A review. *Physics and Chemistry of the Earth*, 47-48, 139-151. https://doi.org/10.1016/j.pce.2011.08.015

Bogdanski, A. (2012). Integrated food-energy systems for climate-smart agriculture. *Agriculture & Food Security*, 1(1), 9. https://doi.org/10.1186/2048-7010-1-9

Bramer, W. M., Rethlefsen, M. L., Kleijnen, J., and Franco, O. H. (2017). Optimal database combinations for literature searches in systematic reviews: A prospective exploratory study. *Systematic Reviews*, 6(1), 245. https://doi.org/10.1186/s13643-017-0644-y

Branca, G., Arslan, A., Paolantonio, A., Grewer, U., Cattaneo, A., Cavatassi, R., Lipper, L., Hillyer, R., and Vanlauwe, B. (2021). Assessing the economic and mitigation benefits of climate-smart agriculture and its implications for political economy: A case study in Southern Africa. *Journal of Cleaner Production*, 285, 125161. https://doi.org/10.1016/j.jclepro.2020.125161

Cadilhon, J. J., Pham, N. D., and Maass, B. L. (2016). The Tanga Dairy Platform: fostering innovations for more efficient dairy chain coordination in Tanzania. *International Journal on Food System Dynamics*, 7(1), 81-91. https://doi.org/10.18461/ijfsd.v7i1.716

Cairns, J. E., Hellin, J., Sonder, K., Araus, J. L., MacRobert, J. F., Thierfelder, C., and Prasanna, B. M. (2013). Adapting maize production to climate change in sub-Saharan Africa. *Food Security*, 5(3), 345-360. https://doi.org/10.1007/s12571-013-0256-x

Campbell, B. M., Thornton, P., Zougmoré, R., Van Asten, P., and 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

Corbeels, M., De Graaff, J., Ndah, T. H., Penot, E., Baudron, F., Naudin, K., Andrieu, N., Chirat, G., Schuler, J., Nyagumbo, I., Rusinamhodzi, L., Traore, K., Mzoba, H. D., and Adolwa, I. S. (2014). Understanding the impact and adoption of conservation agriculture in Africa: A multi-scale analysis. *Agriculture, Ecosystems & Environment*, 187, 155-170. https://doi.org/10.1016/j.agee.2013.10.011

Deressa, T. T., Hassan, R. M., and Ringler, C. (2011). Perception of and adaptation to climate change by farmers in the Nile basin of Ethiopia. *Journal of Agricultural Science*, 149(1), 23-31. https://doi.org/10.1017/S0021859610000687

Deressa, T. T., Hassan, R. M., Ringler, C., Alemu, T., and Yesuf, M. (2009). Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. *Global Environmental Change*, 19(2), 248-255. https://doi.org/10.1016/j.gloenvcha.2009.01.002

Food and Agriculture Organization. (2020). *The State of Food and Agriculture 2020. Overcoming Water Challenges in Agriculture*. FAO.

Fisher, M., Abate, T., Lunduka, R. W., Asnake, W., Alemayehu, Y., and Madulu, R. B. (2015). Drought tolerant maize for farmer adaptation to drought in sub-Saharan Africa: Determinants of adoption in eastern and southern Africa. *Climatic Change*, 133(2), 283-299. https://doi.org/10.1007/s10584-015-1459-2

Gbetibouo, G. A. (2009). *Understanding Farmers' perceptions and adaptations to climate change and variability: The case of the Limpopo Basin, South Africa*. IFPRI Discussion Paper 00849. International Food Policy Research Institute.

Gebrechorkos, S. H., Hülsmann, S., and Bernhofer, C. (2019). Changes in temperature and precipitation extremes in Ethiopia, Kenya, and Tanzania. *International Journal of Climatology*, 39(1), 18-30. https://doi.org/10.1002/joc.5777

Ghezloun, A., Saidane, A., and Merabet, H. (2017). The COP22: New commitments in support of the Paris Agreement. *Energy Procedia*, 119, 10-16. https://doi.org/10.1016/j.egypro.2017.07.040

Gurr, G. M., Lu, Z., Zheng, X., Xu, H., Zhu, P., Chen, G., Yao, X., Cheng, J., Zhu, Z., Catindig, J. L., Villareal, S., Van Chien, H., Cuong, L. Q., Channoo, C., Chengwattana, N., Lan, L. P., Hai, L. H., Chaiwong, J., Nicol, H. I., Perovic, D. J., Gurr, S. J., and Heong, K. L. (2016). Multi-country evidence that crop diversification promotes ecological intensification of agriculture. *Nature Plants*, 2(3), 16014. https://doi.org/10.1038/nplants.2016.14

Haile, G. G., Tang, Q., Sun, S., Huang, Z., Zhang, X., and Liu, X. (2019). Droughts in East Africa: Causes, impacts and resilience. *Earth-Science Reviews*, 193, 146-161. https://doi.org/10.1016/j.earscirev.2019.04.015

Harvey, C. A., Chacón, M., Donatti, C. I., Garen, E., Hannah, L., and Andrade, A. (2014). Climate-smart landscapes: opportunities and challenges for integrating adaptation and mitigation in tropical agriculture. *Conservation Letters*, 7(2), 77-90. https://doi.org/10.1111/conl.12066

Hong, Q. N., Pluye, P., Fàbregues, S., Bartlett, G., Boardman, F., Cargo, M., Dagenais, P., Gagnon, M. P., Griffiths, F., Nicolau, B., O'Cathain, A., Rousseau, M. C., and Vedel, I. (2018). *Mixed Methods Appraisal Tool (MMAT), version 2018*. IC Canadian Intellectual Property Office, Industry Canada.

Jarzebski, M. P., Ahmed, A., Karanja, A., Boafo, Y. A., Balde, B. S., Chinangwa, L., Gasparatos, A., Saito, O., and Takeuchi, K. (2020). Linking industrial crop production and food security in sub-Saharan Africa: local, national and continental perspectives. In *Sustainability Challenges in Sub-Saharan Africa I* (pp. 81-136). Springer. https://doi.org/10.1007/978-981-15-1179-3_4

Karlsson, L., Naess, L. O., Nightingale, A., and Thompson, J. (2018). 'Triple wins' or 'triple faults'? Analysing the equity implications of policy discourses on climate-smart agriculture. *Journal of Peasant Studies*, 45(1), 150-174. https://doi.org/10.1080/03066150.2017.1351433

Kipkoech, A. K., Tambi, E. N., and Bangali, S. (2015). *State of Knowledge on CSA in Africa, Case Studies from Ethiopia, Kenya and Uganda*. Forum for Agricultural Research in Africa.

Kiptot, E., and Franzel, S. (2015). Farmer-to-farmer extension: opportunities for enhancing the performance of volunteer farmer trainers in Kenya. *Development in Practice*, 25(4), 503-517. https://doi.org/10.1080/09614524.2015.1029438

Lipper, L., Thornton, P., 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., Sen, P. T., Sessa, R., Shula, R., Tibu, A., and Torquebiau, E. F. (2014). Climate-smart agriculture for food security. *Nature Climate Change*, 4(12), 1068-1072. https://doi.org/10.1038/nclimate2437

Loboguerrero, A. M., Campbell, B. M., Cooper, P. J., Hansen, J. W., Rosenstock, T., and Wollenberg, E. (2019). Food and earth systems: priorities for climate change adaptation and mitigation for agriculture and food systems. *Sustainability*, 11(5), 1372. https://doi.org/10.3390/su11051372

Lowder, S. K., Sánchez, M. V., and Bertini, R. (2021). Which farms feed the world and has farmland become more concentrated? *World Development*, 142, 105455. https://doi.org/10.1016/j.worlddev.2021.105455

Lynch, J., Cain, M., Frame, D., and Pierrehumbert, R. (2021). Agriculture's contribution to climate change and role in mitigation is distinct from predominantly fossil CO2-emitting sectors. *Frontiers in Sustainable Food Systems*, 4, 518039. https://doi.org/10.3389/fsufs.2020.518039

Mafongoya, P., and Ajayi, O. C. (Eds.). (2017). *Indigenous Knowledge Systems and Climate Change Management in Africa*. CTA.

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

Mangani, R., Tesfamariam, E. H., Bellocchi, G., Hassen, A., and Crespo, O. (2019). Modelling the impact of climate change on maize (Zea mays L.) productivity in South Africa. *Crop and Pasture Science*, 70(5), 306-320. https://doi.org/10.1071/CP18262

Mashi, S. A., Inkani, A. I., and Eche, D. M. (2022). Adoption of climate-smart agricultural practices among smallholder farmers in north-western Nigeria. *Environment, Development and Sustainability*, 24(5), 6837-6859. https://doi.org/10.1007/s10668-021-01727-0

Mbosso, C., Boukar, O., Heuze, V., and Tamo, M. (2020). Fonio (Digitaria exilis) and bambara groundnut (Vigna subterranea) productions and commercialization in the Sudano-Sahelian zone of Mali. *Sustainability*, 12(24), 10290. https://doi.org/10.3390/su122410290

Meijer, S. S., Catacutan, D., Ajayi, O. C., Sileshi, G. W., and 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

Moges, D. M., and Taye, A. 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

Mucheru-Muna, M., Pypers, P., Mugendi, D., Kung'u, J., Mugwe, J., Merckx, R., and Vanlauwe, B. (2010). A staggered maize–legume intercrop arrangement robustly increases crop yields and economic returns in the highlands of Central Kenya. *Field Crops Research*, 115(2), 132-139. https://doi.org/10.1016/j.fcr.2009.10.013

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

Mwongera, C., Shikuku, K. M., Twyman, J., Läderach, P., Ampaire, E., Van Asten, P., Twomlow, S., and Winowiecki, L. A. (2017). Climate smart agriculture rapid appraisal (CSA-RA): A tool for prioritizing context-specific climate smart agriculture technologies. *Agricultural Systems*, 151, 192-203. https://doi.org/10.1016/j.agsy.2016.05.009

Mwungu, C. M., Mwongera, C., Shikuku, K. M., Acosta, M., and Läderach, P. (2019). Assessing the impact of climate information services on maize productivity in Tanzania. *Climate Risk Management*, 26, 100203. https://doi.org/10.1016/j.crm.2019.100203

Ng'ombe, J. N., Kalinda, T. H., and Tembo, G. (2017). Does adoption of conservation farming practices result in increased crop revenue? Evidence from Zambia. *Agrekon*, 56(3), 205-221. https://doi.org/10.1080/03031853.2017.1312467

Nhemachena, C., Nhamo, L., Matchaya, G., Nhemachena, C. R., Muchara, B., Karuaihe, S. T., and Mpandeli, S. (2020). Climate change impacts on water and agriculture sectors in Southern Africa: Threats and opportunities for sustainable development. *Water*, 12(10), 2673. https://doi.org/10.3390/w12102673

Niang, I., Osman-Elasha, B., Githeko, A., Yanda, P. Z., Medany, M., and Vogel, C. (2021). Africa. In *Climate Change 2021: Impacts, Adaptation and Vulnerability* (pp. 1199-1265). Cambridge University Press.

Ntshangase, N. L., Muroyiwa, B., and 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*, 10(2), 555. https://doi.org/10.3390/su10020555

Onyeneke, R. U., Igberi, C. O., Uwadoka, C. O., and Aligbe, J. O. (2018). Status of climate-smart agriculture in southeast Nigeria. *GeoJournal*, 83(2), 333-346. https://doi.org/10.1007/s10708-017-9773-z

Ouédraogo, M., Zougmoré, R., Moussa, A. S., Partey, S. T., Thornton, P. K., Kristjanson, P., Sogoba, B., Naab, J. B., Sanon, M., Somda, J., and Zongo, B. (2019). Markets and climate are driving rapid change in farming practices in Savannah West Africa. *Regional Environmental Change*, 19(5), 1229-1241. https://doi.org/10.1007/s10113-017-1151-4

Oyetunde-Usman, Z., and Shee, A. (2023). Adoption of drought-tolerant maize varieties and interrelated climate smart agricultural practices in Nigeria. *Agriculture & Food Security*, 12(1), 43. https://doi.org/10.1186/s40066-023-00429-2

Pawlak, K., and Kołodziejczak, M. (2020). The role of agriculture in ensuring food security in developing countries: Considerations in the context of the problem of sustainable food production. *Sustainability*, 12(13), 5488. https://doi.org/10.3390/su12135488

Ranganathan, J., Waite, R., Searchinger, T., and Zionts, J. (2021). *Regenerative agriculture: Good for soil health, but limited potential to mitigate climate change*. World Resources Institute.

Rogers, E. M. (2003). *Diffusion of Innovations* (5th ed.). Free Press.

Saj, S., Torquebiau, E., Hainzelin, E., Pages, J., and Maraux, F. (2017). The way forward: An agroecological perspective for climate-smart agriculture. *Agriculture, Ecosystems & Environment*, 250, 20-24. https://doi.org/10.1016/j.agee.2017.09.003

Serdeczny, O., Adams, S., Baarsch, F., Coumou, D., Robinson, A., Hare, W., Schaeffer, M., Perrette, M., and Reinhardt, J. (2017). Climate change impacts in Sub-Saharan Africa: from physical changes to their social repercussions. *Regional Environmental Change*, 17(6), 1585-1600. https://doi.org/10.1007/s10113-015-0910-2

Shimeles, A., Verdier-Chouchane, A., and Boly, A. (Eds.). (2018). *Building a resilient and sustainable agriculture in sub-Saharan Africa*. Springer. https://doi.org/10.1007/978-3-319-76222-7

Sileshi, G. W., Akinnifesi, F. K., Ajayi, O. C., and Place, F. (2011). Meta-analysis of maize yield response to woody and herbaceous legumes in sub-Saharan Africa. *Plant and Soil*, 338(1), 307-322. https://doi.org/10.1007/s11104-010-0551-y

Sinyolo, S. (2020). Technology adoption and household food security among rural households in South Africa: The role of improved maize varieties. *Technology in Society*, 60, 101214. https://doi.org/10.1016/j.techsoc.2019.101214

Tesfaye, K., Kruseman, G., Cairns, J. E., Zaman-Allah, M., Wegary, D., Zaidi, P. H., Boote, K. J., Rahut, D., Erenstein, O., Shiferaw, B., and Prasanna, B. M. (2022). Potential impacts of climate change on maize yield in sub-Saharan Africa: A case study. *Climate Risk Management*, 36, 100447. https://doi.org/10.1016/j.crm.2022.100447

Thierfelder, C., Chivenge, P., Mupangwa, W., Rosenstock, T. S., Lamanna, C., and 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

Tibesigwa, B., Visser, M., and Turpie, J. (2015). The impact of climate change on net revenue and food adequacy of subsistence farming households in South Africa. *Environment and Development Economics*, 20(3), 327-353. https://doi.org/10.1017/S1355770X14000540

Trisos, C. H., Adelekan, I. O., Totin, E., Ayanlade, A., Efitre, J., Gemeda, A., Kalaba, K., Lennard, C., Masao, C., Mgaya, Y., Ngaruiya, G., Olago, D., Simpson, N. P., and Zakieldeen, S. (2022). Africa. In *Climate Change 2022: Impacts, Adaptation and Vulnerability* (pp. 1285-1455). Cambridge University Press. https://doi.org/10.1017/9781009325844.011

Vanlauwe, B., Coyne, D., Gockowski, J., Hauser, S., Huising, J., Masso, C., Nziguheba, G., Schut, M., and Van Asten, P. (2014). Sustainable intensification and the African smallholder farmer. *Current Opinion in Environmental Sustainability*, 8, 15-22. https://doi.org/10.1016/j.cosust.2014.06.001

Wekesa, B. M., Ayuya, O. I., and Lagat, J. K. (2018). Effect of climate-smart agricultural practices on household food security in smallholder production systems: micro-level evidence from Kenya. *Agriculture & Food Security*, 7(1), 80. https://doi.org/10.1186/s40066-018-0230-0

Westermann, O., Förch, W., Thornton, P., Körner, J., Cramer, L., and Campbell, B. (2018). Scaling up agricultural interventions: Case studies of climate-smart agriculture. *Agricultural Systems*, 165, 283-293. https://doi.org/10.1016/j.agsy.2018.07.007

World Bank. (2019). *The Changing Nature of Work: World Development Report 2019*. World Bank. https://doi.org/10.1596/978-1-4648-1328-3

World Bank. (2020). *Accelerating Digital Transformation in Zambia: Digital Economy Diagnostic Report*. World Bank. https://doi.org/10.1596/34038

Wudil, A. H., Usman, M., Rosak-Szyrocka, J., Pilař, L., and Boye, M. (2022). Reversing years for global food security: A review of the food security situation in Sub-Saharan Africa (SSA). *International Journal of Environmental Research and Public Health*, 19(22), 14836. https://doi.org/10.3390/ijerph192214836

CHAPTER 3

Smallholder Maize Farmers' Perceptions and Attitudes Towards Climate-Smart Agricultural Practices in KwaZulu-Natal Province, South Africa.

Abstract

Climate change significantly threatens agricultural systems in developing regions, particularly for smallholder farmers who face increased vulnerability to shifting weather patterns, droughts, and extreme weather events. In South Africa, climate variability is increasingly challenging maize farming. Climate-smart agricultural practices (CSAPs) offer promising solutions to enhance resilience and productivity, yet their adoption remains low among smallholder farmers. This study examined the perceptions and attitudes of smallholder maize farmers in KwaZulu-Natal Province toward CSAPs using a mixed-methods approach. Data from 378 farmers were collected through a structured questionnaire, and the Theory of Planned Behaviour was used to explore socioeconomic and psychological factors influencing CSAP adoption. Findings revealed statistically significant differences between adopters (47.1%) and non-adopters (52.9%), with adopters showing more positive perceptions and attitudes across all variables. However, both groups expressed unwillingness to adopt CSAPs without financial support. Empirical results found that age had a negative relationship with both perception and attitude indices ($p=0.007$ and $p=0.007$, respectively), while education demonstrated a positive impact ($p=0.021$ and $p=0.018$, respectively). Income exhibited a strong positive influence ($p<0.001$). Institutional factors, including access to climate information ($p=0.011$ and $p=0.016$), agricultural credit ($p=0.017$ and $p=0.017$), membership in agricultural groups ($p=0.010$ and $p=0.007$), and access to extension services ($p=0.006$ and $p=0.002$), all positively influenced farmers' perceptions and attitudes. Distance to farm negatively affected perceptions ($p=0.028$), while marital status negatively influenced attitudes ($p=0.045$). Findings suggest policymakers should provide subsidies, target younger educated farmers for early adoption, and strengthen extension services to highlight CSAP benefits. Addressing these factors will enhance smallholder farmers' prospects of adopting CSAPs and becoming resilient and promote sustainable agriculture under climate change in KwaZulu-Natal Province.

Keywords: Climate-Smart Agriculture, Smallholder farmers, Perceptions and Attitudes, Adoption, Maize farming.

3.1 Introduction

Agriculture plays a crucial role in the livelihoods of millions across Sub-Saharan Africa (SSA), employing 54% of the working population and contributing 15% to the region's Gross Domestic Product (FAO, 2022). However, the sector has significant variability, with countries like Chad seeing agricultural contributions as high as 50%, while nations like South Africa report only 2% (Bontsa et al., 2023). In SSA, agricultural growth stands at 2.6% annually (OECD/FAO, 2023), with this modest expansion influenced by increasing local and international interest in farmland, rural-to-urban migration, population growth, and climate change. The centrality of agriculture to SSA economies and societies positions the sector as critical for achieving multiple Sustainable Development Goals (SDGs). Agricultural development in the region directly impacts SDG 1 (No Poverty) by increasing household incomes and creating sustainable livelihoods, SDG 2 (Zero Hunger) by enhancing food production and accessibility, SDG 8 (Decent Work and Economic Growth) through job creation and economic stabilisation, SDG 12 (Responsible Consumption and Production) by promoting sustainable farming practices, and SDG 15 (Life on Land) through improved land management and biodiversity conservation (Weil et al., 2023; Thornton et al., 2022).

Climate variables crucial to food security and agricultural systems are changing rapidly across SSA, with IPCC reports projecting negative impacts on all aspects of food security in the region. Without appropriate interventions, climate change will severely reduce agricultural yields, worsen food insecurity, and exacerbate existing poverty levels (Zougmoré et al., 2021). The vulnerability is especially pronounced in eastern and southern parts of the region where rainfall-dependent agriculture predominates (Okoronkwo et al., 2024), with temperature increases of 0.8-2.3°C already recorded over the past five decades (Ziervogel and Taylor, 2023). Climate models predict more intense rainfall events punctuated by longer dry spells, with many areas already reporting decreased yields and increased crop failures due to erratic rainfall patterns and rising temperatures (Rezaei et al., 2023).

Maize (Zea mays L.) stands as a fundamental crop of profound importance for food security, nutrition, and economic stability throughout eastern and southern Africa. This staple crop provides approximately 30% of dietary calories across SSA and is predominantly cultivated by smallholder farmers (Sinyolo, 2023). Beyond its nutritional value, maize cultivation represents a critical source of household income, contributing significantly to smallholder farmers' total agricultural income in many regions (Sinyolo and Mudhara, 2018). However, maize productivity is heavily dependent on favourable climate conditions, making it especially vulnerable to climate change impacts (Cairns et al., 2022). The sensitivity of maize to temperature variations and water stress places it at particular risk as climate change intensifies.

Therefore, there is a need to adopt adaptation strategies appropriate for the current and projected climate change. Climate-Smart Agricultural Practices (CSAPs) have emerged as a promising approach to enhance resilience while simultaneously addressing climate change adaptation and mitigation in vulnerable farming systems (Makate, 2022). According to the Food and Agriculture Organization ([FAO], 2022), CSAPs aim to tackle the interlinked challenges of food security and climate change through three main pillars: sustainable increases in agricultural productivity and incomes; adaptation and building resilience to climate change; and reduction of greenhouse gas emissions where possible. CSAPs encompass various practices including conservation agriculture, agroforestry, improved water management, and drought-resistant crop varieties (Nyasimi and Huyer, 2022).

Despite the potential benefits of CSAPs, their adoption among smallholder farmers in SSA remains low. Studies across multiple countries reveal adoption rates typically below 40% despite decades of promotion by various stakeholders (Abegunde et al., 2023; Ntshangase et al., 2022). Research has identified several barriers to adoption, including economic constraints, limited access to information, and institutional challenges. Consequently, smallholder farmers who do not adopt CSAPs are significantly more likely to experience crop losses during adverse weather events compared to those who implement these practices (Berhanu et al., 2024).

The CSAP adoption largely depends on farmers' perceptions and attitudes toward these practices (Mkhize and Zwane, 2023). Perception encompasses how farmers view and understand the potential benefits, costs, and risks associated with CSAPs, while attitude reflects their evaluative judgments and predispositions toward implementing these practices. Research by Aryal et al. (2022) demonstrated that farmers' perceptions of the practicality and effectiveness of conservation agriculture strongly predicted adoption rates in the Indo-Gangetic Plains. Similarly, Mpala and Simatele (2024) established that smallholder farmers in Zimbabwe with positive attitudes towards CSAP were more likely to adopt these practices, even when faced with resource constraints.

Across SSA, limited research has been conducted to understand smallholder farmers' perceptions and attitudes toward CSAPs, creating a significant knowledge gap. Understanding these psychological factors is critical as they form the foundation upon which adoption decisions are made and can either facilitate or hinder the widespread adoption of CSAPs. Addressing this gap is particularly urgent as the region experiences increasing climate variability that threatens food security and rural livelihoods.

South Africa's situation mirrors the continental context, with smallholder farmers facing significant climatic challenges like frequent droughts, unpredictable rainfall, and occasional floods (Mnukwa et al.,2025; Tantoh and McKay, 2023). These challenges are particularly acute in KZN Province, where diverse agro-ecological conditions, from coastal lowlands to mountainous regions, create varied farming environments highly susceptible to climate variability. With projected yield reductions of 15-30% by mid-century (Ngcamu and Chari, 2022), understanding how smallholder maize farmers in KwaZulu-Natal Province (KZN) perceive and respond to CSAPs is essential for developing an understanding that can be applied when targeted interventions to enhance resilience in this vital livelihood sector.

Therefore, this study aims to examine the perceptions and attitudes of smallholder maize farmers toward CSAPs, with specific application to the KZN context. Specifically, the research seeks to: (i) assess farmers' awareness and knowledge of CSAPs; (ii) examine their perceptions regarding the benefits, costs, and risks associated with CSAPs; (iii) evaluate their attitudes toward adopting these practices; and (iv) identify the socio-economic and institutional factors that influence these perceptions and attitudes. The findings will provide valuable insights for policymakers, agricultural extension services, and development organizations working to enhance the climate resilience of smallholder farming systems across similar contexts in SSA. Ultimately, this research contributes to broader efforts to improve food security, enhance rural livelihoods, and build more sustainable and resilient agricultural systems in the face of climate change, thereby supporting the achievement of multiple SDGs.

3.2 Theory for examining perceptions and attitudes towards CSAPs

This study is anchored in the Theory of Planned Behaviour (TPB), as developed by Ajzen (1991), to explore the multifaceted factors influencing smallholder maize farmers' perceptions and attitudes toward CSAPs in KZN Province. The TPB offers a robust framework for understanding how individual attitudes, subjective norms, and perceived behavioural control collectively shape behavioural intentions and, consequently, actual behaviours in adopting CSAPs (see Figure 3.1). This theoretical approach has been widely employed in past studies examining agricultural decision-making and innovation adoption (Teklewold et al., 2019; Owusu et al., 2017; Hyland et al., 2016; Jethi et al., 2016; Wheeler at al.,2013; Morton, 2007; Rogers, 2003).

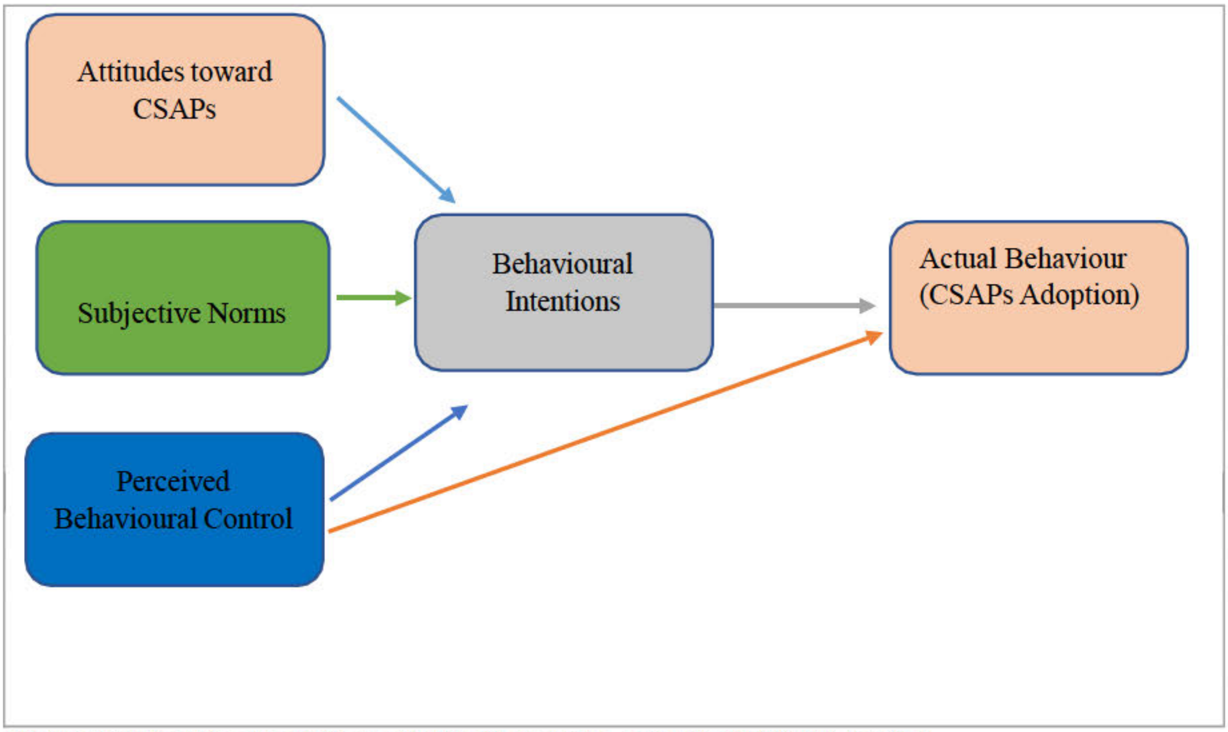

Figure 3.1 The Theory of Planned Behaviour in the context of CSAP Adoption

Source: Adopted from Ajzen (1991).

Within the TPB framework, attitudes refer to farmers' evaluations of implementing CSAPs, shaped by beliefs about expected outcomes such as increased productivity and enhanced resilience. Wauters et al. (2022) and Ntshangase et al. (2018) demonstrated that positive attitudes significantly influence agricultural practice adoption, even when faced with socioeconomic constraints. Tesfaye et al. (2022) found that perceived productivity benefits were significant predictors of CSAPs adoption intentions in Ethiopia. Subjective norms reflect the perceived social pressure farmers experience regarding CSAPs adoption. In KZN's communal farming context, these social influences from family, neighbouring farmers, traditional authorities, and extension officers significantly impact adoption decisions. Borges et al. (2020) and Zeweld et al. (2017) found that social networks and perceived social approval strongly influenced CSAPs adoption. Meijer et al. (2019) further highlighted how information flows through community networks shape both awareness and acceptance of new farming techniques.

Perceived behavioural control relates to farmers' perceptions of implementation ease or difficulty, influenced by access to resources, technical knowledge, and support systems. This component aligns with risk and uncertainty concepts from utility theory and is critical in the CSAPs context, where practical constraints significantly shape adoption decisions. Lalani et al. (2021) found that control perceptions were strong predictors of conservation agriculture adoption intentions, often surpassing attitudinal and normative factors. This study adapts the TPB framework to incorporate socioeconomic characteristics as determinants of perceived behavioural control in the CSAP adoption context. Factors such as income, education level, farm size, and access to resources fundamentally shape farmers' perceptions of their ability to implement CSAPs (Wauters et al., 2020; Abegunde et al., 2020). This adaptation acknowledges that in smallholder farming contexts, perceived behavioural control is not merely a psychological construct but is substantially determined by tangible socioeconomic constraints. For instance, wealthier farmers with larger landholdings may perceive greater control over CSAP implementation due to their enhanced resource capacity, while those with higher education levels may better comprehend technical aspects of CSAPs, increasing their perceived ability to implement them successfully. This integrated approach aligns with findings by Borges et al. (2020) and Ntshangase et al. (2018) that socioeconomic factors operate through perceived behavioural control to influence adoption intentions in resource-constrained agricultural settings.

Behavioural intention, directly influenced by attitudes, subjective norms, and perceived behavioural control, is the most immediate predictor of actual CSAP adoption behaviour. This study applies this TPB framework to demonstrate how these three components interact to shape smallholder maize farmers' adoption decisions in KZN. Attitudes reflect farmers' evaluations of CSAPs based on expected outcomes; subjective norms capture the social pressures from family, neighbours, and extension officers; while perceived behavioural control represents farmers' assessment of implementation feasibility given their resources and knowledge. This integrated approach reveals how psychological factors and economic constraints jointly determine CSAP adoption, highlighting why financial support remains crucial for both adopters and non-adopters despite differing perceptions and attitudes.

3.3 Materials and methods

3.3.1 Description and study area selection

KZN province was purposively selected due to its prominence in maize farming and documented vulnerability to climate change (Mthethwa et al., 2022). The province experiences various climate-related risks, including droughts and floods, making it an ideal setting to assess factors influencing smallholder maize farmers' perceptions and attitudes toward CSAPs. The study was conducted in Ugu District Municipality (UDM) and Harry Gwala District Municipality (HGDM) of KZN (Figure 3.2). The districts were selected to capture diverse climatic conditions and geographical features (Maponya and Agbugba, 2023).

Both districts are vulnerable to climate change impacts, with residents largely dependent on agriculture for their livelihood. UDM spans 5,866 km² along South Africa's eastern coastline with a population of 722,484, while HGDM has a population of 461,420. UDM experiences subtropical conditions averaging 28°C, whilst HGDM's climate is influenced by the Drakensberg Mountains. The districts feature distinct vegetation patterns and face socioeconomic challenges including high unemployment and poverty rates. Their predominantly rural, agriculture-based economies provided ideal settings to examine smallholder farmers' perceptions and adoption of CSAPs under varied conditions.

Figure 3.2 Map showing HGD and UDM, in KZN Province of South Africa

Source: https://List_of_municipalities_in_KwaZulu_Natal (accessed on 18 June 2025)

To examine these diverse settings, the study employed a cross-sectional research design with a mixed-methods approach, gathering both quantitative and qualitative data. This approach was chosen to ensure triangulation and greater validity (Guetterman et al., 2023; Schoonenboom and Johnson, 2022), and to address study objectives that were both qualitative and quantitative in nature (Creamer, 2020). Cross-sectional research designs effectively utilize data from diverse disciplinary backgrounds while being comparatively less expensive and time-consuming (Creswell and Creswell, 2017; Akhtar, 2016).

3.3.2 Sampling

A multi-stage sampling procedure was employed to ensure representativeness and enhance the generalisability of findings to the broader population of smallholder maize farmers in KZN. In the first stage, two District Municipalities (HGDM and UDM) were purposively selected to capture diverse climatic conditions and geographical features, with UDM located on the South Coast and HGDM situated inland. The second stage involved randomly selecting two local municipalities from each district municipality based on the prevalence of climate-related risks such as droughts and floods, whilst the third stage encompassed random selection of rural communities from the chosen local municipalities.

This was followed by stratified sampling to ensure proper representation of different farmer groups, with the sample from each community stratified into two strata: i.e., smallholder maize farmers using CSAPs and those not using CSAPs. This comprehensive approach, combining purposive, random, and stratified sampling methods, enabled meaningful comparisons between CSAP adopters and non-adopters across diverse geographical and climatic conditions, ultimately enhancing the study's ability to draw robust conclusions about CSAP adoption and its impacts on smallholder maize farmers in KZN.

This paper employed Cochran's (1977) formula to determine an appropriate sample size:

$$n_0 = \frac{(t^2)*(p)(q)}{(d)^2} = \frac{(1.96)^2(.5).5)}{(.5)^2} = 384$$

Where t = value for selected alpha level of .025 in each tail = 1.96 when

Where (p)(q) = estimate of variance = 0.25 (maximum possible proportion (0.5) * (1-0.5) maximum possible proportion (0.5) produces maximum possible sample size).

d = acceptable margin of error for proportion being estimated = 0.05 (error researcher is willing to accept).

The sample size calculation used a 95% confidence level and a 5% margin of error, which are widely accepted standards in social science research (Kotrlik and Higgins, 2001). This approach provided a balance between precision and feasibility, particularly for studies involving smallholder farmers in developing countries (Taherdoost, 2016; Singh and Masuku, 2014). However, due to resource and time constraints encountered during the field data collection phase, the final sample comprised 378 smallholder maize farmers. This minor reduction in sample size (1.6%) did not significantly impact the statistical power or representativeness of the study. The achieved sample size maintains a confidence level of 95% with a marginally increased margin of error of 5.04% (calculated using the same statistical parameters), which remains within acceptable limits for agricultural adoption studies (Israel, 2013; Yamane, 1967). Furthermore, the response rate of 98.4% (378/384) exceeds the threshold typically accepted in social science research (Plewes and Tourangeau, 2013).

3.3.3 Data collection

Primary data was collected using a structured questionnaire administered to 378 smallholder maize farmers across KZN Province. The questionnaire gathered information on farmers' perceptions and attitudes toward CSAPs, and socioeconomic characteristics. Pre-testing was conducted with 38 respondents (10% of the sample size), one month before actual data collection in Msunduzi Local Municipality, a site not included in the main study. The pre-testing results were excluded from the final analysis to enhance research integrity, following methodological recommendations (Bond et al., 2023). The questionnaire consisted of both closed-ended and open-ended questions to capture both quantitative and qualitative dimensions of the study. The closed-ended questions employed Likert-type scales and multiple-choice formats to quantify perceptions, attitudes, and adoption levels of CSAPs. The open-ended questions allowed respondents to elaborate on their experiences, constraints, and motivations related to CSAP adoption, thereby enriching the quantitative data with contextual insights. To further capture qualitative dimensions, an interview guide was developed and used alongside the questionnaire. The interview guide focused on probing farmers' in-depth views regarding their understanding of climate change, perceived benefits and challenges of adopting CSAPs, and their decision-making processes. It was particularly used to facilitate richer discussions during interviews, ensuring that farmers' narratives were adequately captured.

Enumerators received training in research ethics, interview methodologies, and data synthesis. All questionnaires were directly administered by interviewers to minimize interpretation errors and response bias. Practical challenges encountered in the field included difficulty locating respondents, unforeseen weather disruptions, and occasional reluctance from some farmers due to survey fatigue. The research team addressed these issues through advance scheduling, adaptable timetables, and clear communication of research significance. Ethics clearance was granted by the University of KwaZulu-Natal (protocol number: HSSREC/00007887/2024). Prior to data collection, written informed consent was obtained from all participating smallholder maize farmers. Written consent was specifically chosen over verbal consent to ensure proper documentation and compliance with institutional ethics requirements. This approach provided a clear record of participants' willingness to participate, enhanced transparency of the research process, and ensured that farmers fully understood the purpose of the study, how their data would be used, and their rights as research participants. The data collected focused on four key CSAPs particularly relevant for smallholder maize farmers in KZN: drought-tolerant maize varieties, maize-legume intercropping, rainwater harvesting, and crop diversification**.**

3.3.4 Data analysis

The collected data were coded and entered into Excel spreadsheets for analysis. Perception and attitude indices were constructed from Likert scale items and quantified using Stata version 18, allowing for systematic measurement of farmers' views. Tobit regression models were employed to analyse determinants of these indices, allowing understanding of both the nature of farmers' perceptions and the factors that shaped them.

3.3.5 Descriptive statistics

Descriptive statistics were employed to characterize smallholder maize farmers' demographic and socioeconomic profiles. The descriptive analysis encompassed frequency distributions (percentages) and measures of central tendency (means, ranges, and standard deviations). The data were presented through tables and figures to provide a clear visual representation of the findings. This approach was particularly important as study by Ojoko et al. (2017) indicated that many smallholder farmers unconsciously practice CSA as part of their traditional farming systems. Therefore, it was critical to identify and assess the frequency of farmers using specific CSAPs such as drought-tolerant maize varieties, maize-legume intercropping, rainwater harvesting, and crop diversification. The descriptive analysis also facilitated examination of farmers' perceptions and attitudes toward these practices, providing a foundation for the subsequent Tobit regression analysis of perception/attitude determinants.

3.4 Perception and attitude indices analysis

The study made use of perception and attitude indices, Likert scales, and Tobit regression to analyse smallholder maize farmers' perceptions and attitudes towards CSAPs. Perception and attitude indices were constructed from Likert scale items. Likert scales are widely used to measure attitudes, opinions, and perceptions on a psychometric scale (Robinson, 2024). In this study, respondents indicated their level of agreement with statements about CSAPs on a 5-point scale ranging from "Strongly Disagree" to "Strongly Agree." The Likert scale demonstrated strong reliability in estimating and assessing the perceptions and attitudes of smallholder maize farmers towards CSAPs. The Table 3.1 presents a list of socioeconomic, institutional, and technical factors that influence smallholder maize farmers' perceptions and attitudes, and the respondents chose answers on the 5-point Likert scale.

Table 3.1. Measurement of smallholder maize farmers' perceptions and attitudes towards CSAPs

Statement
Perceptions
CSAPs will improve my household's food security
CSAPs are effective in addressing the increased temperatures we've experienced over the last 30 years
CSAPs can help manage the unpredictable rainfall patterns we've been experiencing
CSAPs are useful in mitigating the effects of more frequent droughts
CSAPs can effectively help control the increased pest and disease emergence in maize
CSAPs can reverse the trend of reduced maize productivity we've seen in recent years
CSAPs reduce the cost of maize production
CSAPs increase soil fertility in maize fields
CSAPs reduce soil erosion in maize fields
CSAPs lead to reduced water usage in maize farming
CSAPs improve pest and disease management in maize
CSAPs preserve land quality for maize cultivation
CSAPs are environmentally friendly
CSAPs reduce the amount of chemical fertilizer needed for maize

Attitudes
I am willing to adopt CSAPs with or without financial support
I am eager to learn more about CSAPs
CSAPs are necessary for improving maize productivity
I receive personal satisfaction from applying CSAPs
CSAPs will increase my farm income
The use of any CSAPs makes me popular among my peers
My farmer friends who use CSAPs influence me to do the same
I feel motivated by extension agents to adopt CSAPs
I enjoy discussing about CSAPs currently promoted by the local extension services
I have the skills necessary to implement CSAPs
Resources to implement CSAPs on my farm are available
CSAPs align well with my maize farming goals

Source: Authors own conceptualisation informed by the literature (Bontsa et al., 2023; Moutouama et al.,2022).

The perception and attitude indices were created by calculating the mean scores of all perception and attitude variables, respectively, for each respondent. These indices were then normalized to a 0-1 scale to facilitate interpretation and statistical analysis. The normalized indices served as dependent variables in the Tobit regression models, which were used to identify the factors influencing farmers' perceptions and attitudes towards CSAPs

3.5 Tobit Regression Model

The Tobit regression model was employed to analyse determinants of perception and attitude indices because the dependent variables were continuous but constrained within the 0-1 range (Tobin, 1958). This censored regression approach provided unbiased parameter estimates, particularly important when examining farmers' perceptions that often cluster at extremes. In this study, the dependent variables, perception index and attitude index, represent the composite measures of farmers' perceptions and attitudes toward CSAPs. These constructs were derived from the Likert-scale statements presented in Table 3.1. Each respondent rated their level of agreement with several statements related to the effectiveness, usefulness, and relevance of CSAPs on a five-point scale (1 = Strongly Disagree to 5 = Strongly Agree). The individual item scores were first averaged to obtain a respondent-specific mean score for perceptions and for attitudes, respectively. To enable meaningful interpretation and to meet the model assumptions, these mean scores were then normalized to a 0–1 scale, where values closer to 1 indicate strongly positive perceptions or attitudes, and values near 0 indicate negative or weak perceptions or attitudes. The resulting continuous indices served as the dependent variables in the Tobit regression models, capturing the intensity and direction of farmers' perceptions and attitudes toward CSAPs.

The Tobit model can be specified as follows:

$$Y^* = \beta_o + \beta_{1Xi} + \beta_{2X2} + \beta_{kXki} + \varepsilon_i$$

$$Y_i = Y_i \, if \; 0 < Y_i < 1$$

$$Y_i = 0 \; if Y_i \leq 0$$

$$Y_i = 1 \; if Y_i \geq 1$$

Where:

$Y^*i$is the latent (unobserved) dependent variable

$Y_i$is the observed dependent variable (perception index)

$X_{1i}X_{2i} \dots, X_{ki}$ are independent variables (factors affecting perception)

$\beta_{0,}\beta_1, \beta_2 \dots, \beta_k$ are coefficients to be estimated

ε_i is the error term, assumed to be normally distributed.

Table 3.2 Description of climate-smart agricultural practices analysed in the study

CSAP	Description	Climate benefits	Productivity benefits	Implementation requirements
Drought-tolerant maize varieties	Improved maize varieties that can withstand water stress and maintain yields during drought conditions	Enhanced resilience to drought and climate variability	Stable yields under water-stressed conditions, reduced production risk	Access to certified seeds; knowledge of proper planting techniques; potential higher seed costs higher seed costs
Rainwater harvesting	Collection and storage of rainwater for agricultural use during dry periods	Efficient water use, reduced dependence on rainfall	Supplemental irrigation, extended growing seasons	Infrastructure investment; storage facilities; knowledge of collection and storage techniques; maintenance skills
Maize-legume intercropping	Growing maize alongside leguminous crops in the same field	Improved soil fertility through nitrogen fixation, enhanced biodiversity	Increased total productivity per unit area, diversified income sources	Knowledge of compatible crop combinations; proper spacing and timing; management of competition between crops
Crop diversification	Growing multiple crop species to reduce risk and improve resilience	Reduced vulnerability to climate shocks, enhanced ecosystem stability	Risk reduction, improved household nutrition and income stability	Market access for diverse crops; knowledge of multiple crop production systems; potential labour intensification

Source: Author's own compilation based on FAO (2018) and field observations.

3.6 Description of the explanatory variables

Table 3.3 summarizes the explanatory variables included in the Tobit regression model to analyse the determinants of perceptions and attitudes toward CSAPs among smallholder maize farmers in KZN. These variables include gender, age, education, family size, income, farm size, farming years, average distance to farm, access to climate information, access to agricultural credit, membership in agricultural group, access to extension services, agricultural training, awareness of CSAPs, and adoption status. The explanatory variables are hypothesized to influence smallholder maize farmers' perceptions and attitudes toward CSAPs.

Table 3.3 Explanatory variables used in the Tobit regression model for analysing perceptions and attitudes toward CSAPs and their expected outcomes.

Variable	**Description and Measurement (Type)**	**Expected Outcome (+/-)**
Gender	Smallholder farmer's gender (female = 0; male = 1) (dummy)	+
Marital status	Marital status of the Smallholder farmer (single = 0; wedded (married, divorced, widowed) = 1) (dummy)	+/-
Age	Age of the smallholder farmer in years (continuous)	+/-
Education	Number of years of formal schooling by the smallholder farmer (continuous)	+
Family Size	Number of members in the smallholder farmer's household (continuous)	+
Income	Total household income of the smallholder farmer (continuous)	+
Farm Size	Size of the smallholder farmer's land in hectares (continuous)	+
Farming Years	Number of years of farming experience by the smallholder farmer (continuous)	+
Average Distance to Farm	The distance from home to the farm site in kilometres (continuous)	-
Access to Climate Information	Whether the smallholder farmer has access to climate information (no = 0; yes = 1) (dummy)	+
Access to Agricultural Credit	Whether the smallholder farmer has access to agricultural credit (no = 0; yes = 1) (dummy)	+
Membership in Agricultural Group	Whether the smallholder farmer belonged to an agricultural-related group or association (no = 0; yes = 1) (dummy)	+

Access to Extension Services	Whether the smallholder farmer has access to extension services (no = 0; yes = 1) (dummy)	+
Agricultural Training	Whether the smallholder farmer received specialized agricultural training (no = 0; yes = 1) (dummy)	+
Awareness of CSAPs	Whether the smallholder farmer is aware of CSAPs (no = 0; yes = 1) (dummy)	+
Adoption Status	Whether the smallholder farmer has adopted any CSAPs (no = 0; yes = 1) (dummy)	+

Note: +/− Depicts the direction of influence (**positive/negative**)

Source: Author (2025)

3.7 Results and discussion

This section presents findings from 378 smallholder maize farmers in KZN Province. The results cover demographic profiles, CSAP adoption patterns, perception and attitude analysis, and factors influencing farmers' views toward CSAPs. Key findings include comparative analysis between adopters and non-adopters, determinants of perceptions and attitudes, and institutional factors affecting CSAP implementation. Each subsection combines empirical findings with relevant discussion and comparison to existing literature.

3.7.1 Socio-demographic profile

Table 3.4 presents demographic characteristics of the survey respondents. The sample is predominantly female (63%), suggesting women are primary agricultural decision-makers. Studies show that women often demonstrate greater concern about climate impacts (Ngcoya and Kumarakulasingam, 2017). Respondents are middle-aged (mean 52.27 years) with moderate formal education (9.81 years), potentially affecting CSAPs comprehension. Households are relatively large (mean 6.80 members), providing potential labour for CSAP implementation, though extremely small farm size (0.01 ha) restricts land-intensive practices. Moderate farming experience (14.09 years) and total household income (mean R10,694) shape farmers' evaluation of new practices and their risk perception toward CSAPs (Abdulai, 2018). The total household income encompassed multiple sources including social grants, maize sales, remittances, and salary.

While access to climate information is relatively high (72%), institutional support remains notably limited: agricultural credit (44%), membership in farmer groups (40%), extension services (37%), and agricultural training (31%). This institutional support gap fundamentally shapes farmers' attitudes despite high CSAPs awareness (80%). Senyolo et al. (2018) found that South African farmers often perceive CSAPs as beneficial but practically challenging to implement without adequate support, whilst Khoza et al. (2020) observed that farmers' intrinsic motivation sometimes outweighs institutional factors in shaping CSAPs perceptions, suggesting complex interactions between personal attitudes and support systems that require contextually appropriate interventions.

Table 3.4 Summary of demographic characteristics of respondents

Variables	Mean	Median	Mode	Std Deviation	Minimum	Maximum
Gender	-	1.00	1	0.48	0	1
Age (years)	52.27	49.00	39[a]	17.07	24	89
Education (years)	9.81	10.00	4	4.49	1	21
Household Size	6.80	6.00	3[a]	4.38	1	26
Marital Status	-	1.00	1	0.70	0	2
Employment Status	-	2.00	0	1.32	0	3
Total Income (R)	10,694.09	8,100.00	17,000	7,919.21	1,100	32,000
Farm Size (ha)	0.01	0	0	0.11	0	1
Farming Exp. (years)	14.09	12.00	4	11.17	1	51
Distance to Farm (km)	2.97	2.99	-	1.31	0.50	5.00
Climate Info Access	0.72	1.00	1	0.45	0	1
Agricultural Credit	0.44	0	0	0.50	0	1
Agric. Group Member	0.40	0	0	0.49	0	1
Extension Access	0.37	0	0	0.48	0	1
Agricultural Training	0.31	0	0	0.46	0	1
Awareness of CSAPs	0.80	1.00	1	0.40	0	1

Note: ^a Multiple mode exist. The smallest value is shown

Source: Survey data generated through Stata version 18 (2025)

3.7.2 Smallholder farmers' perceptions of climate change and impact on maize output in Ugu and Harry Gwala District Municipalities over the last 10 years.

An accurate perception of climate change risks leads to better adaptation planning and implementation by farming communities. Assessing how farmers perceive climate change is essential for developing effective adaptation policies (Mahmood et al., 2021), as their perception is a primary step required to take adaptation measures (Teshome et al., 2021). Table 3.5 reveals that a significant majority of smallholder farmers perceived increases in both summer (78%) and winter (70%) temperatures over the last decade. Conversely, most farmers perceived declining rainfall patterns, with 84% noting decreased summer rainfall and 76% perceiving winter rainfall decline. Additionally, farmers reported increases in both the intensity (68%) and resulting damage (71%) from extreme weather events, with rising drought frequency (73%) particularly concerning. These climate changes have significantly impacted agricultural productivity, with 82% of farmers reporting decreased maize yields which subsequently reduced farm returns and impacted negatively their livelihoods as they depend on agricultural activities for living.

The literature consistently supports smallholder farmers' perceptions of climate change impacts, with recent studies by Sujakhu et al. (2023) documenting similar observations of increased summer and winter temperatures, while Diem et al. (2017) confirmed comparable perceptions of declining rainfall patterns in both summer and winter seasons across multiple African countries. Furthermore, research by Das and Ansari (2021) provides evidence aligning with farmers' reports of increased intensity and damage from extreme weather events, particularly the concerning rise in drought frequency that threatens agricultural productivity and rural livelihoods. Mthethwa et al. (2022) highlighted how smallholder farmers who accurately perceive climate trends are better positioned to adopt appropriate CSAPs. The alignment between farmer perceptions and meteorological records suggests that farmers in the region have a strong awareness of local climate changes, forming a solid foundation for potential adaptation efforts.

Table 3.5 Percentage of smallholder farmers' perceptions of climate change parameters in Ugu and Harry Gwala District Municipalities over the last 10 years.

Climate change parameters		**Increase**	**Decrease**	**No change**	**Don't know**
Noticed long term changes in the temperature in the last 10 years	Summer season temperature	78.0	11.0	5.0	6.0
	Winter season temperature	70.0	16.0	3.0	11.0
	Length of cold periods	19.0	55.0	23.0	3.0
	Length of hot periods	62.0	15.0	20.0	3.0
Noticed long term changes in rainfall in the last 10 years	Summer season rainfall	13.0	84.0	2.0	1.0
	Winter season rainfall	17.0	76.0	3.0	4.0
	Length of summer season rainfall	10.0	74.0	12.0	4.0
	Length of winter season rainfall	16.0	69.0	1.0	4.0
	Fluctuation in timing of rains	53.0	26.0	16.0	5.0
	Frequency of droughts	73.0	8.0	14.0	5.0
	Frequency of floods	39.0	52.0	8.0	1.0
Noticed long term changes in extreme weather events in the last 10 years	Intensity of extreme weather events	68.0	12.0	14.0	6.0
	Damage from extreme weather events	71.0	9.0	13.0	7.0
Noticed changes in maize production due to climate change in the last 10 years	Maize yield/output	11.0	82.0	4.0	3.0

Source: Survey data generated through Stata version 18 (2025)

3.7.3 Awareness of CSAPs by Smallholder maize farmers

Figure 3.3 illustrates the awareness of CSAPs among smallholder maize farmers, with this paper specifically focused on drought-tolerant maize varieties, maize-legume intercropping, rainwater harvesting, and crop diversification. Results show that 51% of smallholder farmers were aware of these particular practices, while 33% remain unaware and 16% were unsure. These findings align with Aryal et al. (2020), who found that more than half of the sampled smallholder farmers in India were aware of various CSAPs. Nyasimi et al. (2022) observed that awareness does not guarantee adoption; despite 63% of farmers being aware of CSAPs, only 37% adopted them because of limited resources and implementation costs. Furthermore, Partey et al. (2020) emphasize that despite awareness, adoption remains constrained by limited access to resources, financial capital, and technical support. Makate et al. (2019) similarly found that adoption barriers persist regardless of awareness levels, with resource constraints being primary limiting factors for smallholder farmers in Zimbabwe. This suggests that while improving awareness through communication and education strategies is important, addressing resource constraints and providing adequate support systems are equally crucial for enhancing the adoption and effective implementation of CSAPs among smallholder maize farmers.

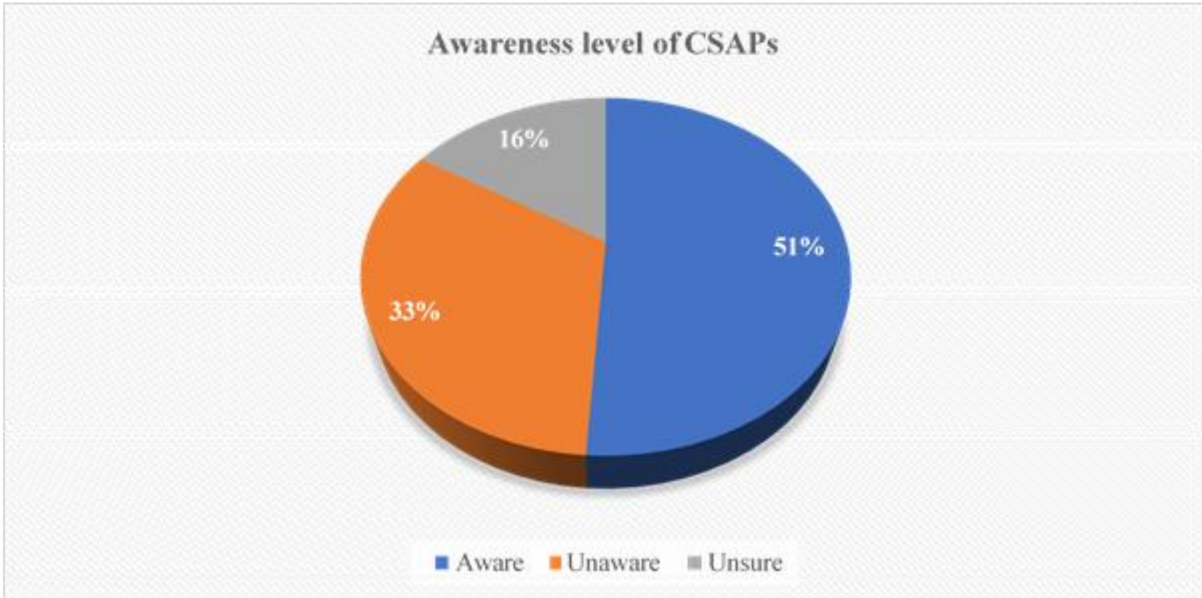

Figure 3.3 Awareness of CSAPs among Smallholder maize farmers
Source: Survey data generated through Stata version 18 (2025)

3.7.4 Information sources of CSAPs by Smallholder maize farmers

The figure 3.4 illustrates information sources accessed by smallholder maize farmers for awareness of CSAPs. Group Member (29.89%), representing membership in farmer associations, constitute the primary information source, closely followed by Media (28.01%) including radio, television, and newspapers. Though media sources are essential for CSAP awareness, Ikendi (2023) noted they often fail to provide comprehensive methodological details for effectively implementing specific CSAPs. Extension services (16.67%) represent a significant information channel, however Khapayi and Celliers (2021) found that the majority of rural farmers still lack frequent access to extension services. Internet sources (16.93%) show similar utilization despite potential limitations. The relatively low internet usage likely reflects connectivity challenges in rural areas, as Mudereri et al. (2020) observed that limited network infrastructure continues to restrict digital information access for agricultural communities. The Other category (8.5%) encompassed alternative sources like friends/neighbours and farmer field days. According to a study by Maka et al. (2021) and Mapiye et al. (2021), these diverse information channels are critical for CSAPs awareness, yet their uneven utilization may impede broader implementation of CSAPs among smallholder maize farmers.

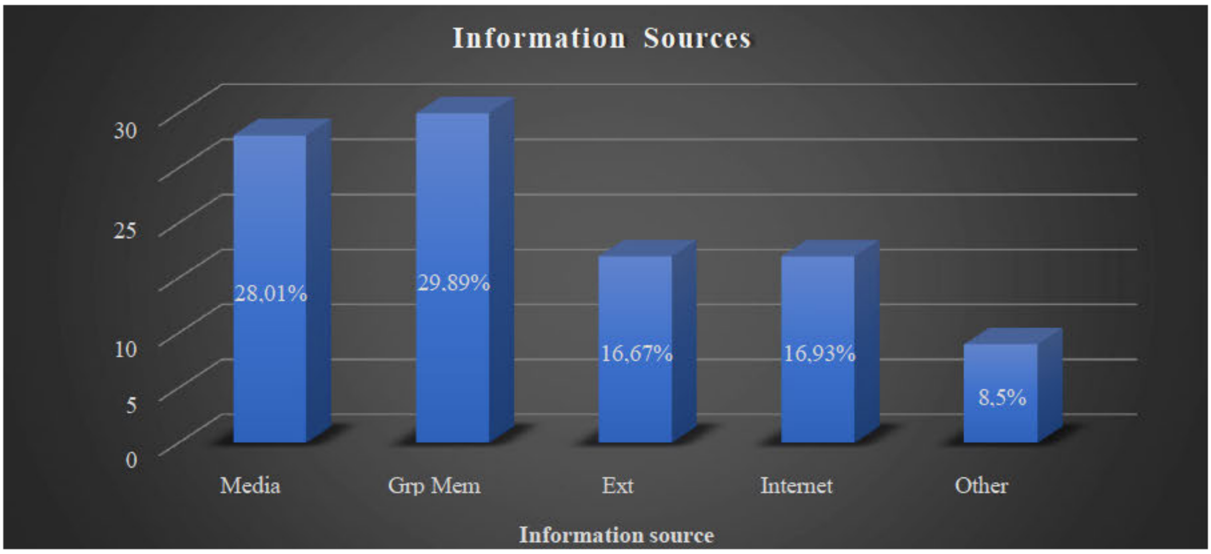

Figure 3.4 Information sources for CSAPs among small maize farmers
Source: Survey data generated through Stata version 18 (2025)

3.7.5 Comparative analysis of CSAP perception indices between adopters and non-adopters

The perception indices (Table 3.6) reveal differences between adopters and non-adopters of CSAPs, highlighting the critical role of perceptions in adoption decisions among smallholder maize farmers in KZN. Adopters demonstrate significantly more positive perceptions (0.831) compared to non-adopters (0.466) across all 14 measured variables ($p<0.001$), with the most substantial differences observed in soil fertility (difference of 1.642) and environmental benefits (difference of 1.637). These findings align with Vecchio et al. (2022), who established that farmers' perceptions form the foundation of CSAP adoption decisions. The striking disparity in perception scores between adopters and non-adopters underscores how smallholder farmers' mental models about CSAPs constitute a primary barrier to adoption, rather than merely extrinsic factors. Interestingly, while adopters demonstrate remarkable consistency in their perceptions (SD=0.049), non-adopters exhibit considerable variability (SD=0.325), suggesting that non-adoption stems from diverse concerns requiring targeted intervention approaches. This aligns with Msweli et al. (2024), who found that farmers' perceptions of CSAPs are shaped by complex interactions between socioeconomic factors and experiential knowledge.

The strong statistical significance across all perception metrics ($t=-14.836$, $p<0.001$) demonstrates that adopters and non-adopters essentially operate with fundamentally different farming worldviews, with implications for how CSAPs should be promoted among smallholder maize farmers in KZN. Senyolo et al. (2018) observed that South African farmers with limited institutional support often perceived CSAPs as beneficial but practically challenging to implement, which explains the particularly large differences in perception regarding practical aspects like soil fertility and environmental benefits. These results directly address this study's aim to explore smallholder maize farmers' perceptions toward CSAPs, revealing that the substantial perception gap between adopters and non-adopters constitutes a significant psychological barrier to wider CSAP implementation in KZN. The findings suggest that extension strategies should prioritize transforming farmers' underlying perceptions before focusing on technical aspects of implementation, potentially through demonstration sites and farmer-to-farmer learning approaches that address the diverse concerns evident among non-adopters, as recommended by Nyagumbo et al. (2020) for conservation agriculture promotion in Southern Africa.

Table 3.6 Descriptive statistics of perception variables by adoption status

Variable	**Non-adopters (n=200)**			**Adopters (n=178)**			**t-value**	**p-value**
	Mean	SD	Std Error	Mean	SD	Std Error		
Food Security Perception	1.875	1.400	0.099	3.180	0.489	0.037	-11.812	0.001***
Temperature Impact Perception	1.860	1.490	0.105	3.225	0.515	0.039	-11.612	0.001***
Rainfall Pattern Perception	1.860	1.442	0.102	3.230	0.540	0.040	-11.950	0.001***
Drought Resistance Perception	1.885	1.439	0.102	3.326	0.578	0.043	-12.487	0.001***
Pest Control Perception	1.830	1.463	0.103	3.287	0.453	0.034	-12.743	0.001***
Productivity Perception	1.955	1.457	0.103	3.354	0.525	0.039	-12.126	0.001***
Cost Reduction Perception	1.865	1.410	0.100	3.326	0.685	0.051	-12.568	0.001***
Soil Fertility Perception	1.830	1.511	0.107	3.472	0.501	0.038	-13.837	0.001***
Erosion Control Perception	1.855	1.471	0.104	3.219	0.584	0.044	-11.582	0.001***
Water Usage Perception	1.895	1.409	0.100	3.275	0.608	0.046	-12.107	0.001***
Pest Management Perception	1.780	1.484	0.105	3.320	0.623	0.047	-12.871	0.001***
Land Quality Perception	1.895	1.502	0.106	3.483	0.575	0.043	-13.270	0.001***
Environmental Perception	1.835	1.526	0.108	3.472	0.501	0.038	-13.668	0.001***
Fertilizer Reduction Perception	1.865	1.513	0.107	3.348	0.523	0.039	-12.436	0.001***
Perception Index	0.466	0.325	0.023	0.831	0.049	0.004	-14.836	0.001***

Note: *** show statistical significance at 1% level. Perception variables measured on a scale of 0-4, with the Perception Index normalized to 0-1 scale. All differences between adopters and non-adopters are statistically significant at $p<0.001$.

Source: Survey data (2025)

3.7.6 Comparative analysis of CSAP attitude indices between adopters and non-adopters

The attitude indices (Table 3.7) reveal striking differences between adopters and non-adopters of CSAPs among smallholder maize farmers in KZN, offering critical insights into the psychological dimensions of CSAP adoption. Adopters displayed significantly more positive attitudes (0.780) than non-adopters (0.466) across nearly all measured variables ($p<0.001$), with particularly large differences in economic perception variables such as income improvement belief (difference of 1.725) and social variables like CSA popularity (difference of 1.674). However, the notable exception of "Willingness to Adopt without financial support," where both groups scored similarly low (1.570 vs. 1.455, $p=0.348$), reveals a crucial barrier to CSAP implementation in the region. This uniform financial dependency illustrates that even smallholder farmers with positive attitudes remain reluctant to adopt CSAPs without economic support, highlighting the complex interplay between attitudes and resource constraints. As Ntshangase et al. (2018) found in KZN, smallholder farmers may recognize the value of CSAPs while simultaneously being constrained by practical economic considerations.

The highly significant divergence in extension motivation scores ($t=-15.064$, $p<0.001$) emerges as a pivotal factor in attitude formation, suggesting that agricultural extension services play a fundamental role in shaping smallholder farmers' attitudes toward CSAPs. This finding carries significant implications for CSAP promotion in KZN, indicating that extension services should be strengthened and better targeted, particularly to address the resource constraints reflected in the similar low scores for adoption without financial support. The substantial attitude gap between adopters and non-adopters, coupled with the shared financial concern, suggests that effective CSAP promotion requires a dual approach that addresses both psychological barriers through targeted extension and material constraints through appropriate financial mechanisms. Sinyolo and Mudhara (2018) similarly observed that economic considerations remained significant determinants of CSAP adoption among KZN smallholder farmers regardless of attitudinal differences.

Table 3.7 Descriptive statistics of attitude variables by adoption status

Variable	**Non-adopters (n=200)**			**Adopters (n=178)**			**t-value**	**p-value**
	Mean	SD	Std Error	Mean	SD	Std Error		
Variable	**Non-adopters (n=200)**			**Adopters (n=178)**			**t-value**	**p-value**
	Mean	SD	Std Error	Mean	SD	Std Error		
Willingness to Adopt	1.570	1.180	0.083	1.455	1.194	0.089	0.940	0.348
Interest in Learning	1.905	1.462	0.103	3.000	0.425	0.032	-9.637	0.001***
Productivity Belief	1.875	1.456	0.103	3.326	0.470	0.035	-12.716	0.001***
Satisfaction with CSAPs	1.980	1.403	0.099	3.270	0.445	0.033	-11.745	0.001***
Income Improvement Belief	1.820	1.476	0.104	3.545	0.499	0.037	-14.852	0.001***
CSA Popularity	1.905	1.427	0.101	3.579	0.569	0.043	-14.643	0.001***
Peer Influence	1.885	1.401	0.099	3.416	0.506	0.038	-13.802	0.001***
Extension Motivation	1.795	1.471	0.104	3.539	0.500	0.037	-15.064	0.001***
Discussion Interest	1.825	1.444	0.102	3.298	0.538	0.040	-12.837	0.001***
Skills for Implementation	1.845	1.481	0.105	3.236	0.521	0.039	-11.894	0.001***
Resources for Implementation	1.875	1.389	0.098	2.444	0.889	0.067	-4.677	0.001***
Alignment with Goals	2.075	3.267	0.231	3.326	0.470	0.035	-5.061	0.001***
Attitude Index	0.466	0.324	0.023	0.780	0.045	0.003	-12.820	0.001***

Note: *** show statistical significance at 1% level. Attitude variables measured on a scale of 0-4, with the Attitude Index normalized to 0-1 scale. All differences between adopters and non-adopters are statistically significant at $p<0.001$ except for Willingness to Adopt, which shows no significant difference ($p=0.348$).

Source: Survey data (2025)

Table 3.8 shows the significance of the association between the perceptions towards CSAPs and farming enterprise characteristics. There was a significant association between farmers' perceptions towards CSAPs and farming experience ($p = 0.002$), as well as total household income ($p < 0.001$), both at the 1% significance level. However, no significant association was found between farm size and perceptions of CSAPs ($p = 0.257$). The low Spearman correlations (between -0.0360 and 0.0812) indicate very weak levels of association between these variables and farmers' perceptions, despite the statistical significance found in the chi-square tests. These findings suggest that while farming experience and participation in maize farming as an income source are related to how farmers perceive CSAPs, the strength of these relationships is minimal, and farm size does not appear to influence farmers' perceptions of CSAPs.

Table 3.8 Cross-tabulation of Ugu and Harry Gwala District Municipality farmers' perceptions towards CSAPs.

Variable	Pearson χ^2	Spearman Correlation	p-Value
Farm Experience	21.2655***	-0.0360	0.002
Farm Size	2.7189	0.0812	0.257
Total household income	16.6114***	-0.0287	0.000

Note ***Significant at 1% level

Source: Survey data (2025)

3.8 Factors affecting perceptions towards CSAPs by smallholder maize farmers

Table 3.9 summarizes factors affecting perceptions towards CSAPs by smallholder maize farmers. The Tobit model demonstrates strong statistical significance with a likelihood ratio chi-squared value of 338.43 ($p < 0.0001$), indicating the selected variables collectively have significant explanatory power. The log-likelihood value of 67.82, together with the significant likelihood ratio test, confirms substantial improvement over the intercept-only model. The pseudo-R^2 of 0.643 indicates approximately 64.3% of the variation in the dependent variable is explained by the predictor variables. The model includes 378 observations, with 366 uncensored and 12 right-censored observations, suggesting the Tobit specification was appropriate for handling the censored nature of the data.

Table 3.9 Factors affecting perceptions towards CSAPs by smallholder maize farmers

Variable	**Coefficient**	**Std. Error**	**t-value**	**p-value**
Gender	0.017	0.022	0.81	0.417
Marital Status	0.024	0.016	1.52	0.129
Age	-0.002	0.001	-2.69	0.007***
Education	0.010	0.003	2.32	0.021**
Family Size	0.001	0.002	0.27	0.784
Income	0.0001	0.00000	7.14	0.000***
Farm Size	0.063	0.091	0.69	0.493
Farming Years	0.001	0.001	0.77	0.442
Adoption Status	0.303	0.021	14.29	0.000***
Distance to Farm (km)	-0.042	0.019	-2.21	0.028**
Access to Climate Inf	0.056	0.022	2.54	0.011**
Access to Agr. Credit	0.048	0.020	2.40	0.017**
Member of Agr. Group	0.054	0.021	2.57	0.010**
Access to Extension	0.061	0.022	2.77	0.006***
Agricultural Training	0.068	0.023	2.96	0.003***
Awareness of CSAPs	0.071	0.025	2.84	0.005***
Constant	0.359	0.052	6.91	0.000***
Std error of estimate (Sigma)	0.040	0.003	-	0.000***
Model statistics				
Number of observations	378			
Uncensored observations	366			
Right-censored observations	12			
Log likelihood	67.82			
LR chi^2 (8)	338.43			
Prob > chi^2	0.000			
Pseudo R^2	0.643			

Note *, **, & *** show statistical significance at the 10%, 5% and 1% levels, respectively

Source: Survey data generated through Stata version 18 (2025)

The Tobit regression model results show that age, education, income, adoption status, distance to farm, access to climate information, agricultural credit, membership in agricultural groups, extension services, agricultural training, and CSAPs awareness significantly influenced farmers' perceptions towards CSAPs. Age was negative and statistically significant at the 1% level (p=0.007) with a coefficient of -0.002. This suggests that for each additional year in a farmer's age, their perception score towards CSAPs decreases by 0.002 units, holding all other factors constant. The findings indicate younger farmers have more favourable perceptions of CSAPs than older farmers, who often exhibit resistance to change and scepticism stemming from Indigenous Knowledge systems (da Silveira et al., 2023; Bontsa et al., 2023).

Education was positive and statistically significant at the 5% level (p=0.021) with a coefficient of 0.010. This means each additional year of formal education increases a farmer's perception score towards CSAPs by 0.010 units, ceteris paribus. This aligns with Kifle et al. (2022) who emphasized education's role in enhancing farmers' ability to comprehend CSAPs benefits. Income showed a highly significant positive influence at the 0.1% level ($p<0.001$) with a coefficient of 0.0001, indicating that for each unit increase in income, perception scores increase by 0.0001 units. This highlights financial capacity's role in shaping positive perceptions, similar to Moutouama et al. (2022) who found economic resources reduce perceived risks associated with CSAPs.

Adoption status exhibited the strongest positive influence at the 0.1% level ($p<0.001$) with a coefficient of 0.303, meaning adopters have perception scores 0.303 units higher than non-adopters. While Aryal et al. (2020) found farmers who experienced tangible benefits developed more favourable views, Chimoita et al. (2022) observed that adoption alone doesn't guarantee positive perceptions, farmers who experienced yield losses or implementation challenges after adoption actually developed more negative perceptions than non-adopters. Membership in agricultural groups was positive and statistically significant at the 5% level ($p=0.010$) with a coefficient of 0.054. This indicates that farmers who belong to agricultural groups have perception scores 0.054 units higher than non-members. The findings highlight the importance of social learning and information sharing, consistent with research by Ma and Rahut (2024) who observed that agricultural group participation enhances favourable perceptions through structured environments for knowledge exchange.

Distance to farm was negative and statistically significant at the 5% level ($p=0.028$) with a coefficient of -0.042, indicating that as distance increases by 1km, perception scores decrease by 0.042 units. This aligns with Nigussie et al. (2021) who observed that spatial remoteness created logistical challenges and information barriers affecting perceptions. Access to climate information was positive and statistically significant at the 5% level ($p=0.011$) with a coefficient of 0.056. This means that farmers with access to climate information have perception scores 0.056 units higher than those without such access, aligning with Li et al. (2021) and Mulwa et al. (2023) who found reliable climate information enhances awareness of climate risks and adaptive practice benefits. Access to agricultural credit was positive and statistically significant at the 5% level ($p=0.017$) with a coefficient of 0.048, meaning farmers with credit access have perception scores 0.048 units higher than those without. Tesfahun and Temesgen (2020) reported similar findings, noting credit alleviates financial constraints preventing CSAPs implementation.

Access to extension services was positive and statistically significant at the 1% level (p=0.006) with a coefficient of 0.061, indicating farmers with extension services access have perception scores 0.061 units higher, corroborating Luntungan et al. (2022) and Abegunde et al. (2020) who emphasized extension services' role in providing technical guidance. Agricultural training was positive and statistically significant at the 1% level (p=0.003) with a coefficient of 0.068, meaning trained farmers have perception scores 0.068 units higher than untrained farmers, similar to findings by Asfaw et al. (2022) that training equips farmers with specific CSAPs implementation skills. CSAPs awareness was positive and statistically significant at the 1% level (p=0.005) with a coefficient of 0.071, suggesting aware farmers have perception scores 0.071 units higher than unaware farmers, consistent with Mugambiwa and Tirivangasi (2023) and Mwungu et al. (2022) who found awareness is fundamental for positive perceptions.

These findings on socioeconomic factors align with the adapted TPB framework, where factors such as income, education, and access to agricultural credit operate primarily through the perceived behavioural control component, fundamentally shaping farmers' perceptions of their ability to implement CSAPs successfully. The significant influence of age, education, and income on perception and attitude indices confirms that, in smallholder farming contexts, perceived behavioural control is not merely a psychological construct but is substantially determined by tangible socioeconomic constraints. The positive effect of adoption status (coefficient of 0.303) provides empirical support for the TPB's emphasis on how direct experience reinforces attitudes and strengthens behavioural intentions. Additionally, the positive impacts of institutional factors like extension services (coefficient of 0.061) and membership in agricultural groups (coefficient of 0.054) demonstrate how subjective norms from community networks influence farmers' perceptions of CSAPs. This empirical evidence supports Borges et al. (2020) and Ntshangase et al. (2018) who found that socioeconomic factors operate through perceived behavioural control to influence adoption intentions in resource-constrained agricultural settings.

3.9 Factors affecting attitudes towards CSAPs by smallholder maize farmers

Table 3.10 summarizes factors affecting attitudes towards CSAPs by smallholder maize farmers. The pseudo-R^2 of 0.530 indicates that approximately 53% of the variation in attitudes is explained by the model variables, suggesting a strong explanatory power while appropriately reflecting that attitude are influenced by somewhat different factors than perceptions. This distinction provides valuable insights for designing targeted interventions that address both knowledge gaps and attitudinal barriers to CSAP adoption among smallholder maize farmers in KZN.

Table 3.10 Factors affecting attitudes towards CSAPs by smallholder maize farmers

Variable	**Coefficient**	**Std. Error**	**t-value**	**p-value**
Gender	0.015	0.021	0.75	0.456
Marital Status	-0.030	0.015	-2.01	0.045**
Age	-0.002	0.001	-2.72	0.007***
Education	0.008	0.003	2.38	0.018**
Family Size	0.0002	0.002	0.07	0.944
Income	0.00001	0.000002	6.96	0.000***
Farm Size	0.083	0.086	0.97	0.334
Farming Years	0.0002	0.001	0.17	0.865
Adoption Status	0.265	0.020	13.46	0.000***
Distance to Farm (km)	0.002	0.007	0.32	0.751
Access to Climate Inf	0.053	0.022	2.41	0.016**
Access to Agr Credit	0.048	0.020	2.40	0.017**
Member of Agr Group	0.054	0.020	2.70	0.007***
Access to Extension	0.061	0.020	3.05	0.002***
Agricultural Training	0.035	0.021	1.67	0.096
Awareness of CSAPs	0.021	0.024	0.85	0.395
Constant	0.386	0.068	5.66	0.000***
Std error of estimate (Sigma)	0.186	0.013	-	0.000***
Model statistics				
Number of observations	378			
Uncensored observations	376			
Right-censored observations	2			
Log likelihood	96.50			
LR chi^2 (8)	308.58			
Prob > chi^2	0.000			
Pseudo R^2	0.530			

Note: *, **, & *** show statistical significance at the 10%, 5% and 1% levels, respectively

Source: Survey data generated through Stata version 18 (2025)

The model results indicate that several socioeconomic and institutional factors significantly influence smallholder maize farmers' attitudes towards CSAPs, including marital status, age, education, income, adoption status, access to climate information, agricultural credit, membership in agricultural groups, and access to extension services. Marital status was negative and statistically significant at the 5% level (p=0.045) with a coefficient of -0.030. This suggests that married farmers have attitude scores 0.030 units lower than unmarried farmers. The negative effect of marital status on CSAP attitudes implies that married farmers may prioritize household food security and stable income over experimental or potentially risky agricultural practices. According to Manja and Zingwe, (2022), married farmers with family responsibilities tend to make agricultural decisions based on risk-minimization strategies rather than potential long-term benefits. Age showed a negative and statistically significant relationship at the 1% level (p=0.007) with a coefficient of -0.002, indicating that younger farmers tend to hold more favourable attitudes towards CSAPs; this finding is consistent with da Silveira et al. (2023), who observed in their study in Northeast Brazil that younger farmers were significantly more receptive to CSAPs, with older farmers exhibiting negative attitudes toward CSAPs due to established farming routines and risk aversion; similarly, Tarfa et al. (2021) found in Nigeria's guinea savanna that age was inversely related to CSAPs.

Education was positive and statistically significant at the 5% level (p=0.018) with a coefficient of 0.008. This means that each additional year of formal education increases a farmer's attitude score towards CSAPs by 0.008 units. The positive relationship between education and CSAP attitudes has substantial implications for agricultural extension programs. As Berhanu et al. (2024) explain, educated farmers possess greater cognitive capacity to understand complex climate-agriculture relationships and the technical aspects of sustainable practices. Income showed a highly significant positive influence at the 0.1% level (p<0.001) with a coefficient of 0.00001. Although small in magnitude, this indicates that for each unit increase in income, a farmer's attitude score towards CSAPs increases by 0.00001 units. This relationship, though modest in scale, has important implications for agricultural policy. As Kehinde et al. (2024) observed that farmers with higher incomes have greater capacity to absorb potential short-term yield reductions during CSAP transition periods.

Adoption status emerged as the strongest positive predictor at the 0.1% level (p<0.001) with a coefficient of 0.265. This means that farmers who have already adopted CSAPs have attitude scores 0.265 units higher than non-adopters. This substantial effect suggests that first-hand experience with CSAPs creates a significant positive shift in farmers' perceptions, indicating that demonstration plots and trial periods could be effective implementation strategies. This finding is consistent with Ayisi et al. (2022), who found that farmers who had previously adopted CSAPs had more positive attitudes toward additional CSAPs compared to non-adopters. However, Pradhan et al. (2020) present contradicting evidence, finding that previous adoption did not consistently predict positive attitudes toward future CSAPs when initial experiences were challenging or yields were inconsistent, suggesting that the quality of first experiences with CSAPs may moderate this relationship.

Access to climate information was positive and significant at the 5% level (p=0.016, coef=0.053). This indicates that farmers with access to climate information had attitude scores toward CSAPs that were 0.053 units higher than those without such access. This implies that information dissemination programs could meaningfully improve farmers' receptiveness to climate-smart practices, potentially through weather forecasts, seasonal outlooks, and climate change education. However, Zougmoré et al. (2021) presented findings that directly contradict these results, finding that climate information access only improved attitudes toward CSA when the information was perceived as reliable and locally relevant, while general climate information had minimal impact on farmers' attitudes. Access to agricultural credit was positive and statistically significant at the 5% level (p=0.017) with a positive coefficient of 0.048. This indicates that farmers with access to agricultural credit have attitude scores toward CSAPs that are 0.048 units higher than those without such access. This finding consistent with the study by Njogu et al. (2024), who found that access to credit enhances farmers' financial capabilities, empowering them to cover transaction costs, equipment purchases, and input costs linked to the diverse CSAPs they may choose to adopt.

Membership in agricultural groups was positive and significant at the 1% level (p=0.007, coef=0.054). This means that farmers who belong to agricultural groups have attitude scores 0.054 units higher than non-members. This suggests that social learning and peer networks play an important role in shaping attitudes toward CSAPs, implying that group-based approaches to CSAP promotion could be particularly effective. This finding is consistent with Abebe and Bijman (2021), who found that membership in agricultural cooperatives increased positive attitudes toward CSAPs attributed to peer learning and reduced information asymmetry among smallholder farmers. Access to extension services showed the strongest institutional influence at the 1% level (p=0.002, coef=0.061). This means that farmers with access to extension services have attitude scores 0.061 units higher than those without such access. This finding underscores the critical role of agricultural extension in facilitating positive attitudes toward CSAPs, suggesting that strengthening extension systems and ensuring regular farmer contact could be a high-impact intervention for promoting climate-smart agriculture. This finding is supported by Anuga et al. (2022), who found that farmers with regular extension contact had more favourable attitudes toward CSAPs compared to those with minimal contact.

The attitude determinants identified in this study provide strong validation for the TPB framework outlined in section 1.2. The significant negative effect of age (coefficient of -0.002) and positive effect of education (coefficient of 0.008) on attitudes confirm that demographic factors fundamentally shape the attitudinal component of the TPB model. The finding that both adopters and non-adopters showed similar reluctance to adopt CSAPs without financial support reveals how perceived behavioural control constrains adoption intentions regardless of positive attitudes. This empirical evidence illustrates the TPB's critical insight that behavioural intentions result from the interaction between attitudes, subjective norms (demonstrated by the significant effect of membership in agricultural groups), and perceived behavioural control (shown by the significant effects of income and access to credit). The particularly strong influence of extension services (coefficient of 0.061) highlights how institutional interventions can strengthen all three TPB components simultaneously, providing a theoretical foundation for the policy recommendations presented in this study.

3.10 Conclusion and recommendations

This study examined the perceptions and attitudes of smallholder maize farmers toward CSAPs in KZN. The findings reveal significant disparities between adopters (47.1%) and non-adopters (52.9%), with adopters consistently demonstrating more positive perceptions and attitudes across all measured variables. These psychological factors play a crucial role in adoption decisions, as evidenced by the statistically significant differences in perception and attitude indices between the two groups. The study found that socioeconomic factors significantly influence farmers' perceptions and attitudes. Age showed a negative relationship with both indices, while education level and income demonstrated positive impacts. Adoption status emerged as the strongest predictor, with adopters scoring significantly higher on both indices compared to non-adopters. Institutional factors, including access to climate information, agricultural credit, membership in agricultural groups, and extension services, all positively influenced farmers' views toward CSAPs.

A critical finding was that both adopters and non-adopters showed strong resistance to adopting CSAPs without financial support, indicating that economic constraints remain a significant barrier regardless of psychological factors. The application of the Theory of Planned Behaviour provided insights into how attitudes, subjective norms, and perceived behavioural control collectively shape farmers' adoption intentions, while revealing that financial limitations substantially impede perceived control over implementing CSAPs. These findings demonstrate that effective promotion of CSAPs requires addressing both psychological barriers through knowledge dissemination and practical constraints through appropriate support mechanisms to achieve wider implementation in KZN. These findings demonstrate that effective promotion of

CSAPs requires addressing both psychological barriers through knowledge dissemination and practical constraints through appropriate support mechanisms to achieve wider implementation in KZN. Based on the research findings, the following recommendations are proposed:

- ✓ Financial Support Mechanisms: Implement targeted subsidies and microfinance options for smallholder farmers to reduce the economic risks associated with CSAPs adoption.
- ✓ Targeted Extension Services: Strengthen agricultural extension systems with a focus on transforming farmers' perceptions through practical demonstrations and success stories.
- ✓ Youth-Focused Programs: Develop initiatives targeting younger farmers as early adopters, capitalizing on their greater receptiveness to innovative practices.
- ✓ Educational Interventions: Design educational programs that enhance farmers' understanding of climate change impacts and CSAP benefits, tailored to different education levels.
- ✓ Demonstration Sites: Establish demonstration plots showcasing successful CSAP implementation to provide tangible evidence of benefits.
- ✓ Farmer-to-Farmer Learning: Leverage experiences of early adopters through peer learning approaches to encourage broader adoption.
- ✓ Strengthening Farmer Groups: Enhance support for agricultural associations to facilitate knowledge exchange and collective action.
- ✓ Accessible Climate Information: Improve access to reliable and locally relevant climate information through diverse channels.
- ✓ Policy Support: Develop supportive policies that reduce risks associated with adopting CSAPs, including secure land tenure and implementation incentives.
- ✓ Long-term Benefit Communication: Highlight success stories and communicate long-term CSAP benefits to address short-term financial concerns.

By addressing these factors, stakeholders can enhance CSAP adoption among smallholder maize farmers in KZN, ultimately strengthening food security and promoting sustainable agricultural practices in the face of climate change.

References

Ajzen, I. (1991). The theory of planned behaviour. Organizational Behaviour and Human Decision Processes, 50(2), 179-211.

Akhtar, I. (2016). 'Research design', Research in Social Science: *Interdisciplinary Perspectives*, 1(1), pp. 68-84.

Akter, A., Geng, X., Mwalupaso, G.E., Lu, H., Hoque, F., Ndungu, M.K. and Abbas, Q. (2022). Income and yield effects of climate-smart agriculture (CSA) adoption in flood prone areas of Bangladesh: Farm level evidence. *Climate Risk Management*, 37, p.100455. https://doi.org/10.1016/j.crm.2022.100455

Aryal, J. P., Sapkota, T. B., Khurana, R., Khatri-Chhetri, A., Rahut, D. B., & Jat, M. L. (2020). Climate change and agriculture in South Asia: Adaptation options in smallholder production systems. *Environment, Development and Sustainability*, 22(6), 5045-5075. https://doi.org/10.1007/s10668-019-00414-4

Ayisi, D.N., Kozári, J. and Krisztina, T. (2022). Do smallholder farmers belong to the same adopter category? An assessment of smallholder farmers innovation adopter categories in Ghana. *Heliyon*, 8(8). https://doi.org/10.1016/j.heliyon.2022.e10421

Berhanu, A.A., Ayele, Z.B. and Dagnew, D.C. (2024). Impact of climate-smart agricultural practices on smallholder farmers' resilience in Ethiopia. *Journal of Agriculture and Food Research*, 16, p.101147. https://doi.org/10.1016/j.jafr.2024.101147

Bond, C, Lancaster, GA, Campbell, M, Chan, C, Eddy, S, Hopewell, S, Mellor, K, Thabane, L & Eldridge, S. (2023). Pilot and feasibility studies: extending the conceptual framework. Pilot and feasibility studies, 9, 24. https://doi.org/10.1186/s40814-023-01233-1

Bontsa, N.V., Mushunje, A. and Ngarava, S. (2023). Factors influencing the perceptions of smallholder farmers towards adoption of digital technologies in Eastern Cape Province, South Africa. *Agriculture*, 13(8), p.1471. https://doi.org/10.3390/agriculture13081471

Borges, J. A. R., Oude Lansink, A. G., Marques Ribeiro, C., & Lutke, V. (2014). Understanding farmers' intention to adopt improved natural grassland using the theory of planned behaviour. *Livestock Science*, 169, 163-174. http://dx.doi.org/10.1016/j.livsci.2014.09.014

Cochran, W. G. (1977). Sampling techniques (3rd ed.). John Wiley & Sons.

Creamer, E.G. (2021). Advancing mixed methods in psychological research', Methods in Psychology, 5, 100076. https://doi.org/10.1016/j.metip.2020.100035

Creswell, J.W. & Creswell, J.D. (2017). Research design: Qualitative, quantitative, and mixed methods approaches. 5th edn. Thousand Oaks, CA: Sage Publications.

Das, U. and Ansari, M.A. (2021). The nexus of climate change, sustainable agriculture and farm livelihood: contextualizing climate smart agriculture. *Climate Research*, 84, pp.23-40. https://doi.org/10.3354/cr01648

Da Silveira, F.; da Silva, S.L.C.; Machado, F.M.; Barbedo, J.G.A.; Amaral, F.G. (2023). Farmers' perception of barriers that difficult the implementation of agriculture 4.0. *Agricultural. Systems*. 2023, 208, 103656. https://doi.org/10.1016/j.agsy.2023.103656

Diem, J.E., Hartter, J., Salerno, J., McIntyre, E. and Stuart Grandy, A. (2017). Comparison of measured multi-decadal rainfall variability with farmers' perceptions of and responses to seasonal changes in western Uganda. *Regional environmental change*, 17, pp.1127-1140. DOI 10.1007/s10113-016-0943-1

Guetterman, T.C., Creswell, J.W., Deutsch, C., & Gallo, J.J. (2023). Process evaluation in mixed methods: a methodological review', *Journal of Mixed Methods Research*, 17(1), pp. 45-69.

Hyland, J. J., Jones, D. L., Parkhill, K. A., Barnes, A. P., & Williams, A. P. (2016). Farmers' perceptions of climate change: identifying types. *Agriculture and Human Values*, 33(2), 323-339. DOI 10.1007/s10460-015-9608-9

Israel, G.D. (2013). Determining sample size', University of Florida Cooperative Extension Service, Institute of Food and Agriculture Sciences, Fact Sheet PEOD-6.

Jethi, R., Joshi, P., & Chandra, N. (2016). Toward climate change adaptation: Perception, coping mechanisms, and adaptation strategies of farmers of Uttarakhand Himalaya. *Indian Journal of Agricultural Science*s, 86(9), 1196-1201.

Khapayi, M. and Celliers, P.R. (2021). Factors limiting and preventing emerging farmers to progress to commercial agricultural farming in the King William's Town area of the Eastern Cape Province, South Africa. *South African Journal of Agricultural Extension*, 44(1), pp.25-41. http://dx.doi.org/10.17159/2413-3221/2016/v44n1a374

Khatri-Chhetri, A., Regmi, P.P., Chanana, N. & Aggarwal, P.K. (2019). Potential of climate-smart agriculture in reducing women farmers' drudgery in high climatic risk areas', Climatic Change, 158(1), pp. 29-42. https://doi.org/10.1007/s10584-018-2350-8

Khoza, T.M., Senyolo, G.M. & Nekhavhambe, E. (2022). Factors affecting climate-smart agricultural practices adoption among smallholder farmers in Mopani District, South Africa', South African *Journal of Agricultural Extension*, 50(1), pp. 79-94.

Khuzwayo, N.F., Nakin, M.D.V. & Tsvuura, Z. (2020). Vulnerability assessment of rural communities to environmental changes in mid-altitude Drakensberg grasslands of South Africa', *International Journal of Environmental Research and Public Health*, 17(15), 5561.

Kifle, T., Ayal, D.Y. and Mulugeta, M. (2022). Factors influencing farmers adoption of climate smart agriculture to respond climate variability in Siyadebrina Wayu District, Central highland of Ethiopia. *Climate Services*, 26, p.100290. https://doi.org/10.1016/j.cliser.2022.100290

Kogo, B.K., Kumar, L. and Koech, R. (2021). Climate change and variability in Kenya: a review of impacts on agriculture and food security. *Environment, Development and Sustainability*, 23(1), pp.23-43. https://doi.org/10.1007/s10668-020-00589-1

Kurgat, B.K., Stöber, S., Mwonga, S., Mutua, J.Y. & Rosenstock, T.S. (2023). Adoption of climate-smart agricultural practices among smallholder farmers in Kenya: The role of farmer perceptions and government policies', *Climate and Development*, 15(3), pp. 276-288.

Lalani, B., Dorward, P., Holloway, G., & Wauters, E. (2016). Smallholder farmers' motivations for using Conservation Agriculture and the roles of yield, labour and soil fertility in decision making. *Agricultural Systems*, 146, 80-90. http://dx.doi.org/10.1016/j.agsy.2016.04.002

Liu, T., Bruins, R. J., & Heberling, M. T. (2019). Factors influencing farmers' adoption of best management practices: A review and synthesis. *Sustainability*, 10(2), 432. http://dx.doi.org/10.3390/su10020432

Ma, W. & Rahut, D.B. (2024). Climate-smart agriculture: adoption, impacts, and implications for sustainable development. *Mitigation and Adaptation Strategies for Global Change*, 29(5), p.44. https://doi.org/10.1007/s11027-024-10139-z

Makate, C., Makate, M., Mutenje, M., Mango, N., & Siziba, S. (2021). Synergistic impacts of agricultural credit and extension on adoption of climate-smart agricultural technologies in southern Africa. *Environmental Development*, 37, 100589. https://doi.org/10.1016/j.envdev.2019.100458

Manda, J., Alene, A.D., Gardebroek, C., Kassie, M. & Tembo, G. (2016). Adoption and impacts of sustainable agricultural practices on maize yields and incomes: Evidence from rural Zambia', *Journal of Agricultural Economics*, 67(1), pp. 130-153.

Manja, L.P., Zingwe, D.E. and Kamangila, A.E. (2025). Smallholder farming commercialization and food security in Malawi: do land rights and intrahousehold bargaining power matter?. *Agriculture & Food Security*, 14(1), p.2. https://doi.org/10.1186/s40066-025-00520-9

Mahmood, N., Arshad, M., Mehmood, Y., Shahzad, M.F. and Kächele, H. (2021). Farmers' perceptions and role of institutional arrangements in climate change adaptation: Insights from rainfed Pakistan. *Climate Risk Management*, 32, p.100288. https://doi.org/10.1016/j.crm.2021.100288

Maponya, P. & Agbugba, I.K. (2023). Climate smart agricultural technologies and practices: Implications for sustainable food security in South Africa', *Journal of Agricultural Sciences*, 15(2), pp. 110-124.

Maponya, P. and Agbugba, I.K. (2023). An assessment of smallholder farmers' status in Umzinyathi and Harry Gwala districts of KwaZulu Natal Province, South Africa. In Agricultural Bioeconomy (pp. 85-102). Academic Press. https://doi.org/10.1016/B978-0-323-90569-5.00011-1

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

Menozzi, D., Fioravanzi, M., & Donati, M. (2015). Farmer's motivation to adopt sustainable agricultural practices. *Bio-based and Applied Economics*, 4(2), 125-147. DOI: 10.13128/BAE-14776

Mkhize, N.R. (2018). Indigenous drought adaptation strategies and climate services among rural farmers in uMhlathuze Local Municipality of KwaZulu-Natal, South Africa', *South African Geographical Journal*, 100(3), pp. 364-377. http://dx.doi.org/10.4324/9781003356783

Mnukwa, M.L., Mdoda, L. & Mudhara, M. (2025). Assessing the adoption and impact of climate-smart agricultural practices on smallholder maize farmers' livelihoods in Sub-Saharan Africa: a systematic review. *Frontiers in Sustainable Food Systems*, 9, p.1543805. https://doi.org/10.3389/fsufs.2025.1543805

Mpala, T.A. and Simatele, M.D. (2024). Climate-smart agricultural practices among rural farmers in Masvingo district of Zimbabwe: Perspectives on the mitigation strategies to drought and water scarcity for improved crop production. *Frontiers in Sustainable Food Systems*, 7, p.1298908. https://doi.org/10.3389/fsufs.2023.1298908

Morton, J. F. (2007). The impact of climate change on smallholder and subsistence agriculture. Proceedings of the National Academy of Sciences, 104(50), 19680-19685. doi10.1073pnas.0701855104

Moutouama, F.T., Tepa-Yotto, G.T., Agboton, C., Gbaguidi, B., Sekabira, H. and Tamò, M. (2022). Farmers' perception of climate change and climate-smart agriculture in Northern Benin, West Africa. *Agronomy*, 12(6), p.1348. https://doi.org/10.3390/agronomy12061348

Mthethwa, K.N., Ngidi, M.S.C., Ojo, T.O. and Hlatshwayo, S.I. (2022) 'The determinants of adoption and intensity of climate-smart agricultural practices among smallholder maize farmers', *Sustainability*, 14, p. 16926. https://doi.org/10.3390/su142416926

Mutenje, M.J., Farnworth, C.R., Stirling, C., Thierfelder, C., Mupangwa, W. & Nyagumbo, I. (2023) 'A dynamic approach to scaling climate-smart agriculture: Key drivers of expansion in different socioeconomic settings', *Agricultural Systems*, 203, 103529.

Mutyasira, V., Hoag, D., Pendell, D., Manning, D. T., & Berhe, M. (2018). Assessing the relative sustainability of smallholder farming systems in Ethiopian highlands. *Agricultural Systems*, 167, 83-91. https://doi.org/10.1016/j.agsy.2018.08.006

Muzawazi, H.D., Terblanché, S.E. & Madakadze, I.C. (2021) 'Farmers' perceptions on climate-smart agricultural practices in the Eastern Cape Province of South Africa', *South African Journal of Agricultural Extension*, 49(1), pp. 44-61.

Njogu, J.W., Karuku, G., Busienei, J. and Gathiaka, J.K., 2024. Assessing determinants of scaling up pathways for adopted CSA climate smart agricultural practices: evidence from climate smart villages in nyando basin, Kenya. *Cogent Food & Agriculture*, 10(1), p.2316362. https://doi.org/10.1080/23311932.2024.2316362

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*, 10(2), 555. https://doi.org/10.3390/su10020555

Nyagumbo, I., Mupangwa, W., Chipindu, L., Rusinamhodzi, L. & Craufurd, P. (2020) 'A regional synthesis of seven-year maize yield responses to conservation agriculture technologies in Eastern and Southern Africa', *Agriculture, Ecosystems & Environment*, 295, 106898. https://doi.org/10.1016/j.agee.2020.106898

Nyasimi, M., Kimeli, P., Sayula, G., Radeny, M., Kinyangi, J., & Mungai, C. (2022). Adoption and dissemination pathways for climate-smart agriculture technologies and practices for climate-resilient livelihoods in Lushoto, Northeast Tanzania. *Climate*, 5(3), 63. https://doi.org/10.3390/cli5030063

Owusu, M., Nursey-Bray, M., & Rudd, D. (2017). Gendered perception and vulnerability to climate change in urban slum communities in Accra, Ghana. *Regional Environmental* Change, 19(1), 13-25. https://doi.org/10.1007/s10113-018-1357-z

Partey, S. T., Dakorah, A. D., Zougmoré, R. B., Ouédraogo, M., Nyasimi, M., Nikoi, G. K., & Huyer, S. (2020). Gender and climate risk management: Evidence of climate information use in Ghana. *Climatic Change*, 158(1), 61-75. https://doi.org/10.1007/s10584-018-2239-6

Plewes, T.J. and Tourangeau, R. eds., 2013. Nonresponse in social science surveys: A research agenda.

Rezaei, E.E., Webber, H., Asseng, S., Boote, K., Durand, J.L., Ewert, F., Martre, P. and MacCarthy, D.S. (2023). Climate change impacts on crop yields. *Nature reviews earth & environment*, 4(12), pp.831-846. https://doi.org/10.1038/s43017-023-00491-0

Robinson, J., (2024). Likert scale. In Encyclopedia of quality of life and well-being research (pp. 3917-3918). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-031-17299-1_1654

Rogers, E. M. (2003). Diffusion of innovations (5th ed.). Free Press

Schoonenboom, J. & Johnson, R.B. (2022). How to construct a mixed methods research design', in Handbook of Mixed Research Methods. Cham: *Springe*r, pp. 287-306. https://doi.org/10.3389/fpsyg.2024.1418040

Singh, A.S. & Masuku, M.B. (2014). Sampling techniques & determination of sample size in applied statistics research: An overview', *International Journal of Economics*, Commerce and Management, 2(11), pp. 1-22.

Sinyolo, S. & Mudhara, M. (2018). The impact of entrepreneurial competencies on household food security among smallholder farmers in KwaZulu Natal, South Africa', *Ecology of Food and Nutrition*,https://www.tandfonline.com/action/showCitFormats?doi=10.1080/03670244.2017.1416361

Sinyolo, S., Mudhara, M. & Wale, E. (2020). The impact of social grants on the propensity and level of use of inorganic fertiliser among smallholders in KwaZulu-Natal, South Africa', *Agrekon,* 59(1), pp. 8-29. https://doi.org/10.1080/03031853.2016.1243063

Sujakhu, N.M., Ranjitkar, S., Su, Y., He, J. and Xu, J. (2023). A gendered perspective on climate change adaptation strategies: a case study from Yunnan, China. *Local Environment*, 28(1), pp.117-133. https://doi.org/10.1080/13549839.2022.2130883

Teklewold, H., Gebrehiwot, T., & Bezabih, M. (2019). Climate smart agricultural practices and gender differentiated nutrition outcome: Empirical evidence from Ethiopia. *World Development*, 122, 38-53. https://doi.org/10.1016/j.worlddev.2019.05.010

Tesfaye, A., Hansen, J., Kagabo, D. M., Birachi, E., & Radeny, M. (2022). Adoption of climate-smart agricultural practices among smallholder farmers in Ethiopia: The role of risk preferences. *Journal of Agricultural Economics*, 73(1), 279-304. https://doi.org/10.3390/su162410821

Teshome, H., Tesfaye, K., Dechassa, N., Tana, T. and Huber, M. (2021). Smallholder farmers' perceptions of climate change and adaptation practices for maize production in Eastern Ethiopia. *Sustainability*, 13(17), p.9622. https://doi.org/10.3390/su13179622

Thierfelder, C., Chivenge, P., Mupangwa, W., Rosenstock, T.S., Lamanna, C. & Eyre, J.X. (2022). How to target climate-smart agriculture? Concept and application of the consensus-driven decision support framework "target CSA, *Agricultural Systems*, 188, 103024. http://dx.doi.org/10.1016/j.agsy.2015.12.011

Thornton, P.K., Rosenstock, T., Förch, W., Lamanna, C., Bell, P., Henderson, B. & Herrero, M. (2022). A framework for priority-setting in climate smart agriculture research', *Agricultural Systems*, 167, pp. 161-175. https://doi.org/10.1016/j.agsy.2018.09.009

Tobin, J. (1958). Estimation of relationships for limited dependent variables', *Econometrical*, 26(1), pp. 24-36.

Vecchio, Y., De Rosa, M., Pauselli, G., Masi, M. and Adinolfi, F. (2022). The leading role of perception: the FACOPA model to comprehend innovation adoption. *Agricultural and Food Economics*, 10(1), p.5. https://doi.org/10.1186/s40100-022-00211-0

Wang, S., Wang, J., Lin, S., & Li, J. (2019). Public perceptions and acceptance of nuclear energy in China: The role of public knowledge, perceived benefit, perceived risk and public engagement. *Energy Policy*, 126, 352-360. https://doi.org/10.1016/j.enpol.2018.11.040

Wauters, E., & Mathijs, E. (2013). An investigation into the socio-psychological determinants of farmers' conservation decisions: Method and implications for policy, extension and research. *The Journal of Agricultural Education and Extension*, 19(1), 53-72. https://doi.org/10.1080/1389224X.2012.714711

Wauters, E., Bielders, C., Poesen, J., Govers, G., & Mathijs, E. (2010). Adoption of soil conservation practices in Belgium: An examination of the theory of planned behaviour in the agri-environmental domain. *Land Use Policy*, 27(1), 86-94. doi:10.1016/j.landusepol.2009.02.009

Wheeler, S., Zuo, A., & Bjornlund, H. (2013). Farmers' climate change beliefs and adaptation strategies for a water scarce future in Australia. *Global Environmental Change*, 23(2), 537-547. http://dx.doi.org/10.1016/j.gloenvcha.2012.11.008

Yamane, T. (1967). Statistics: An introductory analysis. 2nd edn. New York: Harper and Row.

Zeweld, W., Van Huylenbroeck, G., Tesfay, G. and Speelman, S. (2017). Smallholder farmers' behavioural intentions towards sustainable agricultural practices. *Journal of environmental management*, 187, pp.71-81. http://dx.doi.org/10.1016/j.jenvman.2016.11.014

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 http://dx.doi.org/10.1016/j.jenvman.2016.11.014

Ziervogel, G. and Taylor, A. (2023). A co-produced national climate change risk and vulnerability assessment framework for South Africa. *Frontiers in Climate*, 5, p.1197167. https://doi.org/10.3389/fclim.2023.1197167

CHAPTER 4

The Determinants of Adoption and Intensity of Use of Climate-Smart Agricultural Practices among Smallholder Maize Farmers in KwaZulu-Natal Province, South Africa.

Abstract

Climate change increasingly threatens global agriculture, with developing regions and smallholder farmers being especially at risk due to limited resources and adaptive capacity. In South Africa, erratic rainfall, droughts, and extreme weather are disrupting maize farming (a key food source and livelihood). Climate-Smart Agricultural Practices (CSAPs), such as conservation agriculture, soil fertility management, and drought-resistant crops, offer ways to boost resilience and productivity. However, adoption of the CSAPs among smallholder farmers remains low, underscoring the need to understand adoption barriers and develop context-specific solutions that promote widespread implementation. Hence, this study sought to investigate the determinants of both the decision to adopt and the intensity of adopting CSAPs among smallholder maize farmers in KwaZulu-Natal Province. Using the Technology Acceptance Model (TAM) as a theoretical framework, the study employed a cross-sectional design with data collected from 378 smallholder farmers through structured questionnaires. A double-hurdle approach was applied, with a probit model examining initial adoption decisions and a truncated regression analysing adoption intensity. Results revealed that female (63%) dominated smallholder maize farming (63%), with an average age of 52 years, moderate education levels (mean 10 years), and limited landholdings (mean 0.01 ha). Farmers reported modest household income (averaging ZAR 10,671/month), with 40% being unemployed and only 31% having received agricultural training. Empirical results revealed an adoption rate of 47.1%, with drought-tolerant varieties (37.3%) and rainwater harvesting (34.9%) being the most commonly adopted practices. The probit model identified significant determinants of adoption: marital status (p=0.087, positive), age (p=0.010, negative), education (p=0.001, positive), household income (p=0.001, positive), access to climate information (p=0.013, positive), credit access (p=0.027, positive), and agricultural training (p=0.036, positive). The truncated regression showed that age (p=0.079, positive), family size (p=0.083, negative), farming experience (p=0.008, negative), distance to farm (p=0.030, negative), and agricultural training (p=0.005, positive) significantly influenced adoption intensity. Recommendations include enhancing agricultural training programs, improving credit access, strengthening climate information services, and developing spatially-targeted interventions to promote both

initial adoption and more comprehensive implementation of CSAPs among smallholder farmers in climate-vulnerable regions.

Keywords: Climate-Smart Agriculture; Double-Hurdle Model; Smallholder farmers; Technology Acceptance Model; Climate adaptation.

4.1 Introduction

Agriculture remains the backbone of many economies across Sub-Saharan Africa (SSA), contributing significantly to employment, livelihoods, and food security (Wudil et al., 2022). Over 60% of the region's population depends directly on smallholder agriculture for sustenance and income (Food and Agriculture Organization [FAO], 2022). Among the region's staple crops, maize is of paramount importance, accounting for nearly 50% of cereal production and serving as the primary source of calories for millions of people. However, maize production in SSA is highly vulnerable to climate variability and extremes such as droughts, floods, and shifting rainfall patterns (Du and Xiong, 2024). These environmental shocks not only reduce yields but also amplify poverty and food insecurity, especially among smallholder farmers who have limited capacity to adapt to rapidly changing climatic conditions. The agricultural sector faces a dual predicament: it is simultaneously vulnerable to climate change impacts while also contributing significantly to greenhouse gas emissions (Arora, 2019; OECD, 2016; Smith et al., 2008). The adverse effects of climate change, including temperature increases, erratic rainfall patterns, and more frequent extreme weather events, threaten agricultural productivity, food security, and rural livelihoods worldwide (Malhi et al., 2021; FAO, 2018; Zougmore et al., 2018). These impacts are especially pronounced in developing regions with predominantly rain-fed agricultural systems, such as SSA, where smallholder farmers form the backbone of food production (Ofori et al., 2021; Tesfaye et al., 2016; Kassie et al., 2013).

In South Africa, maize is the most widely grown crop and forms the cornerstone of national food security (Mdoda et al., 2025) The country is both a major producer and consumer of maize, with smallholder farmers accounting for a significant 4.4 % share of maize cultivation, particularly in rural areas (Oduniyi et al., 2022). South Africa produces approximately 12-16 million tons of maize annually, with the crop contributing over 70% of the country's grain production and generating substantial export revenues (Cairns et al., 2022). While commercial maize farming in South Africa is relatively mechanized and input-intensive, smallholder maize farmers typically operate on a much smaller scale, using limited capital, labour, and technology (Mutengwa et al., 2023). This segment of the agricultural sector, which comprises over 2.9

million smallholder farming households, is disproportionately affected by climate-related stressors (Statistics South Africa, 2013). The impacts of climate change on South African agriculture are already evident and intensifying, with temperature increases of 1.5-2.0°C recorded over the past four decades and projections indicating further increases of 3-4°C by 2080 (Ngcamu and Chari, 2022). Recurring droughts, such as the severe 2015-2016 El Niño-induced drought that reduced maize production by 30%, have demonstrated the vulnerability of the sector. Land degradation significantly affects South Africa's land area, while declining soil fertility compounds production challenges (Van Huyssteen and du Preez, 2023). These climate-related stressors have resulted in average yield losses of 10-20% for maize over the past decade in South Africa, with some regions experiencing losses exceeding 40% during drought years (Tantoh and McKay, 2023). Furthermore, these challenges are compounded by structural issues such as insecure land tenure, inadequate extension services, and limited access to markets and finance, creating a complex web of constraints that perpetuate vulnerability among smallholder farmers (Barbanente et al., 2024).

KwaZulu-Natal (KZN) Province epitomizes these challenges, it is experiencing particularly acute climate variability in recent years. The province has recorded temperature increases of 1.8°C since 1960, accompanied by a 15% decline in annual rainfall and increased frequency of extreme weather events (Mthethwa et al., 2022). These changes have resulted in estimated agricultural losses of ZAR 2.8 billion between 2010-2020, with maize production experiencing periodic declines of 10-25% during severe drought years, while maintaining overall growth trends (Kumar et al.,2022). Climate variables crucial to food security and agricultural systems are changing rapidly across the province, creating unprecedented challenges for smallholder farmers who depend on rain-fed agriculture. Moreover, KZN faces high levels of poverty and food insecurity, with approximately 65.3% of households in some districts experiencing food insecurity (Nhlozi, 2023). This situation is exacerbated by various factors, including soil degradation, decreasing farm sizes, limited access to improved technologies, disease, insect pests, and climate variability. The province's diverse agro-ecological conditions, from coastal lowlands to mountainous regions, create varied farming environments some of which are highly susceptible to climate variability. Projected yield reductions of 15-30% by mid-century create an urgent imperative for climate adaptation strategies that can simultaneously enhance productivity and build resilience among smallholder maize farmers (Mangani et al., 2019).

To address these complex and interlinked challenges, Climate-Smart Agriculture (CSA) has gained traction as a strategic framework for transforming and reorienting agricultural systems under the realities of climate change. CSA promotes practices that increase productivity in a sustainable manner, strengthen farmers' resilience to climate-related shocks, and reduce agriculture's carbon footprint (FAO, 2018; Lipper et al., 2014). Climate-Smart Agricultural Practices (CSAPs) represent specific farming techniques and technologies that simultaneously enhance productivity, build resilience to climate variability, and contribute to greenhouse gas mitigation (Zheng et al. 2024). For maize farmers, CSAPs encompass various interventions such as conservation agriculture, crop diversification, planting of drought-tolerant varieties, organic soil amendments, agroforestry, and rainwater harvesting (Mahama et al., 2020; Bongole et al., 2020). These practices have demonstrated significant potential to enhance yield stability, reduce risk exposure, and improve environmental outcomes. Research indicates that drought-tolerant maize varieties can reduce yield losses by 20-30% during drought years, while conservation agriculture practices can improve soil water retention by 15-25% and reduce erosion by up to 90% (Zougmore et al., 2018). CSAPs can simultaneously address climate adaptation, mitigation, and food security objectives, making them particularly valuable for smallholder farmers facing multiple climate-related risks (Kurgat et al., 2020; Wekesa et al., 2018). Despite this promise, the adoption of CSAPs by smallholder maize farmers remains suboptimal and uneven across South Africa, with adoption rates typically ranging between 15-45% across different provinces (Abegunde et al., 2023; Ntshangase et al., 2022). Studies across multiple countries reveal adoption rates typically below 40% despite decades of promotion by various stakeholders (Mizik et al., 2021). Many farmers are either unaware of these practices or lack the means to implement them effectively, creating a significant gap between potential and realized benefits that warrants a comprehensive investigation of adoption barriers and enablers.

The importance of mainstreaming CSA is recognized in a global and national development framework. At the global level, CSA aligns with several Sustainable Development Goals (SDGs), particularly SDG 1 (No Poverty), SDG 2 (Zero Hunger), SDG 13 (Climate Action), and SDG 15 (Life on Land), which emphasize the need for resilient agricultural systems and sustainable natural resource management (Tanumihardjo et al., 2020). In the South African context, the National Development Plan (NDP) 2030 highlights the urgency of creating a sustainable and inclusive rural economy through agricultural transformation. The NDP specifically calls for improved support for smallholder farmers, investment in climate-resilient technologies, and sustainable land use practices. Additionally, South Africa's National Climate Change Response Policy (2011) identifies agriculture as a priority sector for both adaptation and mitigation interventions. In this policy environment, understanding what enables or constrains the uptake of CSA is critical to unlocking the productivity potential of smallholder maize farming and achieving national development targets. Previous research on CSA adoption has primarily focused on specific practices in isolation, such as conservation agriculture, drought-tolerant varieties, or soil and water conservation measures (Marie et al., 2020; Abegunde et al., 2019; Mohammed et al., 2015). However, farmers typically face decisions about adopting multiple interrelated practices simultaneously, which may function as complements or substitutes (Kassie et al., 2015; Teklewold et al., 2013). Furthermore, there is limited understanding of the factors influencing not only the initial adoption decision but also the intensity of adopting CSAPs among smallholder maize farmers. The adoption of CSAPs is a complex process influenced by numerous factors, including socioeconomic characteristics, institutional support, biophysical conditions, and farmers' perceptions (Kpadonou et al., 2017). Understanding these determinants is crucial for designing effective policies and interventions to promote CSAP adoption and address the challenges posed by climate change.

This study aims to investigate the determinants of adoption and intensity of use of CSAPs among smallholder maize farmers in KZN. While a growing body of research has examined the general benefits and challenges of CSA, there remains a lack of localized, empirical evidence that explores the full range of factors, social, economic, institutional, and environmental, that shape adoption behaviours among maize farmers in the South African context. The findings of this study will contribute to the growing body of literature on CSAP adoption, while providing practical recommendations for policymakers, extension services, and other stakeholders working to enhance agricultural resilience in the face of climate change. Ultimately, the study will contribute to enhancing food security, climate resilience, and sustainable development in South Africa's smallholder agricultural sector, while informing policy interventions that can facilitate the transition toward more climate-resilient farming systems in KZN and beyond.

4.2 Theory for investigating the determinants of the decision and the intensity of adopting climate-smart agriculture practices

This study is grounded in the Technology Acceptance Model (TAM) (see Figure 4.1), originally developed by Davis (1989) to explain information technology acceptance but extensively adapted across domains, including agriculture. TAM provides a robust theoretical foundation for understanding the behavioural dynamics behind CSAP adoption and intensity among smallholder maize farmers, offering insights into how individuals evaluate, adopt, and integrate agricultural innovations into their practices. Recent empirical evidence validates TAM's relevance for agricultural technology adoption. Thomas et al. (2023) conducted a systematic review of technology acceptance in CSAPs focusing on crop production, and identified TAM as one of the most utilized theories for analysing agricultural innovation adoption. Their findings highlighted how perceived usefulness and perceived ease of use significantly influence farmers' CSAP adoption decisions. Similarly, Khoza et al. (2021) employed an extended TAM through gender-differentiated analysis of CSAP adoption by smallholder farmers, revealing gender's crucial role in shaping technology perceptions and adoption decisions.

TAM's central proposition posits that the two primary perceptions, perceived usefulness and perceived ease of use, significantly influence individual attitudes toward technology, which subsequently shape intention to use and actual adoption behaviour (Davis et al., 1989; McCormack et al., 2022). Within this study's context, CSAPs are conceptualized as agricultural technology, with farmer adoption decisions viewed through behavioural intent shaped by these psychological constructs. Perceived usefulness represents the extent to which smallholder maize farmers believe that adopting CSAPs will enhance farm productivity through practices including drought-tolerant maize varieties, maize-legume intercropping, rainwater harvesting, and crop diversification. Farmers evaluate whether these practices will reduce climate-related risks and improve long-term sustainability. Given climate variability uncertainties in rural, resource-constrained areas of South Africa, farmers likely evaluate new practices based on observable or anticipated benefits. Perceived ease of use relates to farmers' perceptions of implementation simplicity or difficulty, considering labour requirements, costs, technical knowledge, and input access (Caffaro et al., 2020). For instance, farmers may recognize drought-tolerant maize varieties' potential yield benefits but avoid adoption if they perceive the practice as complex or financially inaccessible.

While originally designed for individual-level decision-making in controlled environments, TAM's flexibility enables successful adaptation to rural agricultural contexts where decision-making involves not only individual perceptions but also socio-economic and institutional environments (Castiblanco et al., 2020). In South African smallholder farming systems, CSAP decision-making is embedded within collective household strategies, limited resource endowments, and cultural norms (Zantsi, 2021). Consequently, this study extends TAM beyond internal cognitive variables (usefulness and ease of use) to incorporate external variables essential for shaping farmer perceptions: socioeconomic characteristics (age, education, household income, gender, family size), institutional supports (access to credit, extension services, climate information, training), and farm-specific conditions (farm size, distance to farm, farming experience). These contextual factors act as enablers or barriers, influencing how farmers interpret CSAP utility and practicability. This adaptation proves particularly critical in developing countries where behavioural intent is mediated by systemic constraints and market imperfections.

The adoption process unfolds through two sequential hurdles: the initial decision to adopt CSAPs, followed by the adoption intensity determination. This dual-stage approach recognizes CSAP adoption as a complex decision-making journey rather than a simple binary choice, demonstrating how different external factors exert varying influences at each stage. Socioeconomic and institutional factors primarily affect initial adoption decisions, while farm-specific factors and agricultural training more significantly impact adoption intensity. Antwi-Agyei and Stringer (2021) emphasized how institutional support mechanisms create critical pathways through these stages by providing knowledge, reducing uncertainty, and building confidence. The framework's bidirectional relationships illustrate how adoption experiences feed back into perceptions, creating a dynamic system where early adoption experiences influence subsequent adoption intensity decisions.

TAM proves particularly valuable for this study by supporting a nuanced analysis of adoption intensity, examining not merely whether farmers adopt CSAPs, but the extent to which they adopt multiple practices. Farmers may adopt single CSAPs perceived as useful and simple to implement, while others integrate practice suites when perceiving cumulative benefits and manageable complexity. This behaviour aligns with TAM logic: stronger perceptions of usefulness and ease of use lead not only to adoption but also to greater commitment levels and intensity of use. By grounding the study in TAM, this research systematically captures attitudinal and perceptual mechanisms driving adoption patterns while integrating real-world challenges faced by smallholder farmers in South Africa. This theoretical approach provides a holistic understanding of behavioural and structural determinants of CSAP uptake, informing more responsive policy and extension interventions. The framework's dual-stage recognition enables targeted interventions addressing both initial adoption barriers and factors constraining comprehensive implementation among existing adopters, ultimately contributing to enhanced agricultural resilience in climate-vulnerable regions

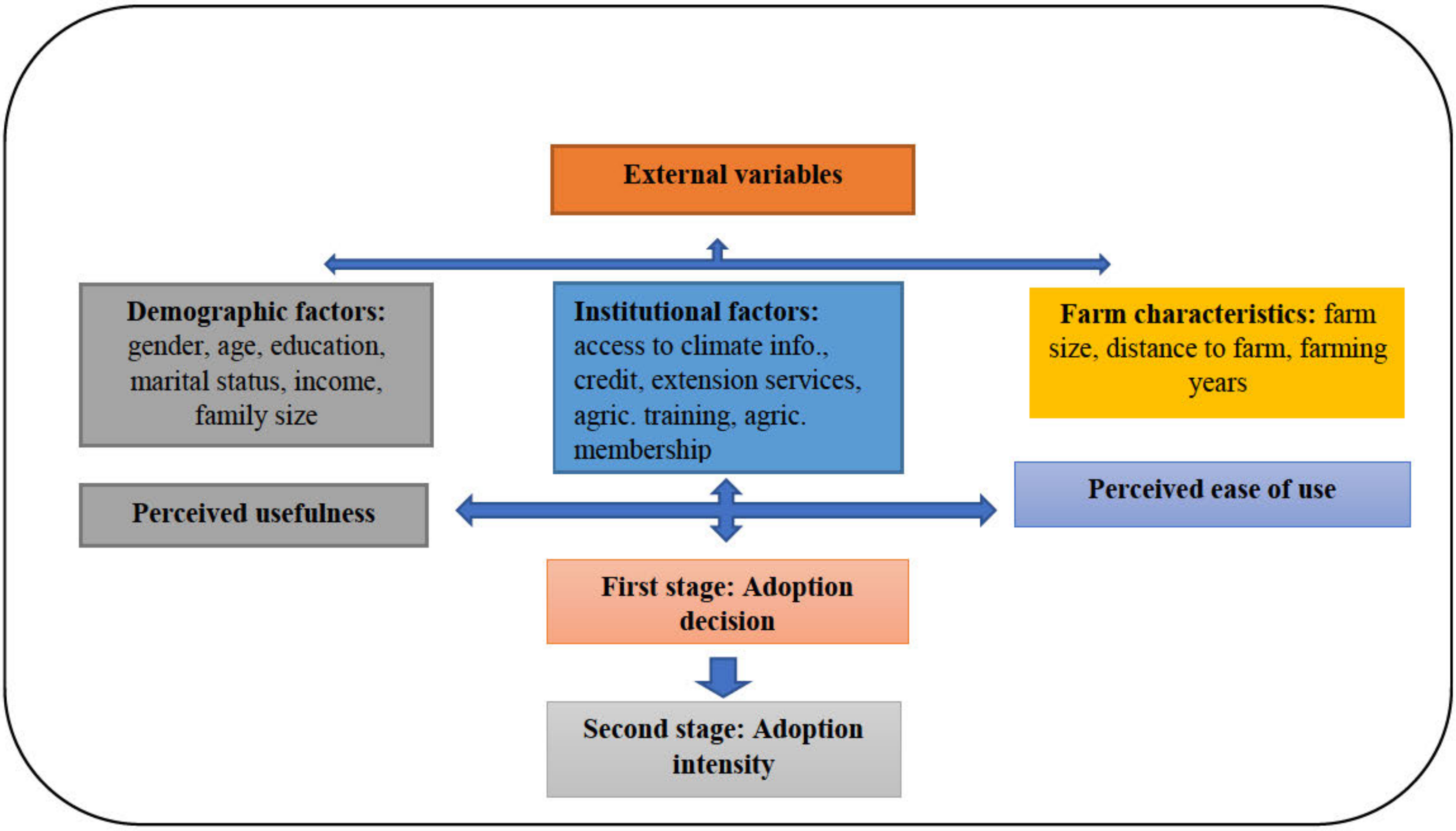

Figure 4.1 The theory of Technology Acceptance in the context of CSAP adoption
Source: Adopted from Davis (1989)

4.3 Materials and methods

4.3.1 Description and study area selection

As previously mentioned in chapter three of this thesis, the study was conducted in KwaZulu-Natal Province, South Africa, specifically focusing on Harry Gwala District Municipality (HGDM) and Ugu District Municipality (UDM). For a detailed description of the study area characteristics, agro-ecological conditions, climate vulnerabilities, and the selection process rationale, please refer to chapter three, Section 3.3.1.

4.3.2 Research design

A cross-sectional research design was utilized to gather comprehensive data on the determinants of both the decision to adopt and the intensity of adopting CSAPs among smallholder maize farmers. For a detailed explanation of the design choice and its theoretical justification, please refer to chapter three, Section 3.3.1.

4.3.3 Sampling technique and data collection

The results presented here are based on a sample of 378 smallholder maize farmers from both HGDM and UDM, selected through a multi-stage sampling procedure to ensure representativeness across the two contrasting agro-ecological zones. Data was collected through structured questionnaires administered via face-to-face interviews, translated into isiZulu where necessary, to ensure clarity and gather detailed information on farmers' demographic and socioeconomic characteristics, farm characteristics, institutional factors, and CSAP adoption patterns. A pre-testing phase with 38 respondents tested the questionnaire's validity and reliability but was excluded from the final analysis to maintain research integrity. The surveys captured comprehensive information on specific CSAPs adoption (drought-tolerant maize varieties, maize-legume intercropping, rainwater harvesting, and crop diversification), adoption intensity measures, and socioeconomic and institutional factors influencing both initial adoption decisions and the extent of CSAP implementation among smallholder farmers. Refer to Chapter Three (Sections 3.3.2 and 3.3.3) for detailed information on the sampling methodology, sample size calculation, and data collection procedures for this study.

4.3.4 Data analysis

This paper investigated the determinants of adoption and intensity of CSAPs by smallholder maize farmers. The collected survey data was organized and initially processed using Microsoft Excel spreadsheets for data entry and preliminary cleaning. For comprehensive statistical analysis, Stata version 18 was employed. The analysis implemented a double-hurdle approach to examine the determinants of the farmers' initial decision to adopt CSAPs and the subsequent intensity of adoption among those who chose to implement these practices. This analytical framework allowed for a systematic assessment of the factors influencing both the adoption decision and the extent of CSAP implementation among smallholder maize farmers in KZN.

4.3.5 Descriptive statistics

Descriptive statistics were employed to characterize smallholder maize farmers' demographic and socioeconomic profiles. The descriptive analysis encompassed frequency distributions (percentages) and measures of central tendency (means, ranges, and standard deviations). The data were presented through tables and figures to provide a clear visual representation of the findings. This approach was particularly important as study by Autio et al. (2021) and Ojoko et al. (2017) indicated that many smallholder farmers unconsciously practice CSA as part of their traditional farming systems. Therefore, it was critical to identify and assess the frequency of farmers using specific CSAPs such as drought-tolerant maize varieties, maize-legume intercropping, rainwater harvesting, and crop diversification. The descriptive statistics provided the key socioeconomic characteristics of sampled smallholder farmers.

4.4 The double hurdle model.

4.4.1 The determinants of CSAPs adoption by smallholder maize farmers

The double hurdle model was selected to analyze CSAP adoption, which involves farmers' decisions to adopt one or more practices to mitigate climate change effects. This approach was chosen over alternative two-stage regression or multivariate models due to its superior ability to handle CSAP adoption data characteristics and alignment with the dual decision-making process in agricultural CSAPs adoption (Kassa et al., 2021). Unlike standard two-stage models assuming independence between stages, the double hurdle model accounts for potential correlation between adoption decisions and intensity of use, crucial for CSAPs analysis (Mthethwa et al., 2022). The model recognizes that factors influencing initial adoption decisions may differ from those determining implementation intensity (Haile et al., 2022).

The framework examines two sequential decisions using the same covariates: first-stage adoption and second-stage intensity determination. Standard errors from separate estimations are valid for statistical inference when error terms are assumed uncorrelated conditional on covariates, otherwise coefficient estimates become biased (Adeagbo et al., 2021; Asrat and Simane, 2018). The model employs Heckman's method to test for conditionally uncorrelated errors through inverse mills ratio (IMR) coefficient estimates, which test the null hypothesis of uncorrelated first- and second-stage errors. Valid inference requires model re-estimation unless coefficients are statistically significantly different from zero (Wooldridge, 2002). Second-stage parameters are estimated without IMR if the null hypothesis fails to be rejected (De Luca and Perotti, 2011).

4.4.2 First Hurdle: Probit model for adoption decision

A probit model of CSAPs adoption for selection equations is estimated using a function of explanatory variables that are also likely to determine CSAPs intensity (Akter et al., 2023). The probit regression model has been extensively used by researchers in adoption studies. Recent applications include Serote et al. (2021), who used the probit regression model to evaluate factors influencing the adoption of climate-smart irrigation technologies for sustainable crop productivity by smallholder farmers. Mutenje et al. (2019) employed the probit regression model to evaluate the cost-benefit analysis of CSA options in southern Africa, balancing gender and technology considerations. Ojo and Baiyegunhi (2020) employed this model to evaluate the determinants of climate change adaptation strategies and their impact on net farm income of rice farmers in southwest Nigeria.

According to Feder et al. (1982), to determine the probability of CSAP adoption by smallholder farmers, the underlying latent variable that captures the true farmer's socioeconomic characteristics is hypothesized. The regression equation indicates the latent variable $CSAP^*{}_i$

$CSAP^* = X_i\beta + ei \; ei \sim N(0,1)$………………………………………………………... (1)

Where;

$CSAP^*{}_i$ is the latent variable representing farmer i's propensity to adopt CSAPs,

X_i is a vector of explanatory variables,

β is a vector of parameters to be estimated, and

ei is the error term assumed to be normally distributed.

The observed adoption decision is expressed as:

$CSAP_i$=1 if $CSAP_i$>0; $CSAP_i = 0 \; if \; CSAP_i \leq 0$ ………………………………………... (2)

$CSAP_i$ has a value of 1 if a smallholder farmer adopts CSAP and 0 otherwise. A vector to be estimated is β. A probit model of $CSAP_i$, which follows random utility, is expressed as in Equation (2); a probit model of CSAP which follows random utility is defined in Equation (3):

Pr $(CSAP_i = 1|X_i, \beta) = \phi(X_i, \beta + ei$ ……………………………………………………. (3)

$CSAP_i$ equals 1 for households that adopt CSAP and 0 otherwise. X_i represents the vector of independent variables, β is the vector of parameters to be estimated. The ϕ is the standard normal cumulative distribution function, and ei is a random error term hypothesized to be distributed normally with unit variance and zero means.

4.4.2.1 The intensity of use of CSAP among smallholder maize farmers

Unlike count data models such as the Poisson regression model (PRM), negative binomial regression model (NBRM), zero-inflated Poisson (ZIP), and zero-inflated negative binomial (ZINB) that are commonly used to analyze count data, this study employed a truncated regression model for the second hurdle. The truncated regression model was selected because the intensity variable (number of CSAPs adopted) is observed only for farmers who have already decided to adopt at least one practice, creating a truncated distribution at zero.

The truncated regression model recognizes that the intensity decision is conditional on the initial adoption decision. Studies by Ojo and Baiyegunhi (2020); Bukchin and Kerret (2020) have stated that farmers usually weigh the technology's benefits before adopting them. The truncated regression model is particularly appropriate for this study because it recognizes that the intensity decision is conditional on the initial adoption decision, reflecting the sequential nature of farmer decision-making processes. The density function of the truncated regression model, as depicted in Equation (4), is given by:

$$\Pr(IntensityY_i = Y_i | Y_i > 0) = \emptyset(Y_1 - X_{iy}/\sigma) \,/\, \Phi(X_{iy}/\sigma) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (4)$$

where $\emptyset$ is the standard normal probability density function, Φ is the standard normal cumulative distribution function, Y_i is the number of CSAPs used by farmer i, X_i is a vector of predictor variables, y is the parameter vector to be estimated, and σ is the standard deviation of the error term. The expected outcome is the number of CSAP practices adopted by a farmer, conditional on adoption, expressed in Equation (5):

$$E(Intensity_i \,| Intensity_i > 0, X_i) = X_{iy} + \sigma(\Phi(X_{iy}/\phi(X_{iy}/\sigma)) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (5)$$

for i = 1, 2, ..., n.

The double hurdle model is estimated using maximum likelihood estimation (MLE) for both the probit and truncated regression components. The appropriateness of the model specification is validated through several diagnostic procedures including likelihood ratio tests for overall model significance, Wald tests for individual parameter significance, and tests for the correlation between error terms in both equations (Siyum et al., 2022). The model assumes that error terms are independently distributed and that the functional forms adequately capture the decision-making processes at both stages. These assumptions are tested to ensure the validity of statistical inferences drawn from the model results (Isaac et al., 2020), particularly the interpretation of parameter estimates and their policy implications for promoting CSAP adoption among smallholder farmers.

The study focused on key CSAPs (see Table 3.2 in chapter three) that are particularly relevant for smallholder maize farmers and their feasibility for implementation by resource-constrained farmers. These practices were selected based on their relevance to the local context, their ability to address multiple CSA pillars (productivity, adaptation, and mitigation), their proven effectiveness, scalability, and potential for synergistic effects when combined (van Wijk et al.,2020).

4.5 Explanatory variables used in the Double Hurdle Model and their expected outcomes

Table 4.1 summarizes the explanatory variables included in the double Hurdle Model to determine the decision to adopt and the intensity of use of CSAPs among smallholder maize farmers in KZN. These variables include gender, age, education, family size, household income, farm size, farming years, average distance to farm, access to climate information, access to agricultural credit, membership in agricultural group, access to extension services, and agricultural training. The explanatory variables are hypothesized to influence the choice of adopting and the intensity of CSAPs by smallholder maize farmers.

Table 4.1 Explanatory variables used in the Double Hurdle Model to determine factors influencing the decision to adopt and the intensity of use of climate-smart agriculture practices

Variable	**Description and measurement (Type)**	**Expected outcome (+/-)**
Gender	Smallholder farmer's gender (female = 0; male = 1) (dummy)	+
Marital status	Marital status of the Smallholder farmer (single = 0; wedded (married, divorced, widowed) = 1) (dummy)	+/-
Age	Age of the smallholder farmer in years (continuous)	+/-
Education	Number of years of formal schooling by the smallholder farmer (continuous)	+
Family Size	Number of members in the smallholder farmer's household (continuous)	+
Household income	Total household income of the smallholder farmer (continuous)	+
Farm Size	Size of the smallholder farmer's land in hectares (continuous)	+
Farming Years	Number of years of farming experience by the smallholder farmer (continuous)	+
Average Distance to Farm	The distance from home to the farm site in kilometres (continuous)	-
Access to Climate Information	Whether the smallholder farmer has access to climate information (no = 0; yes = 1) (dummy)	+
Access to Agricultural Credit	Whether the smallholder farmer has access to agricultural credit (no = 0; yes = 1) (dummy)	+
Membership in Agricultural Group	Whether the smallholder farmer belonged to an agricultural-related group or association (no = 0; yes = 1) (dummy)	+
Access to Extension Services	Whether the smallholder farmer has access to extension services (no = 0; yes = 1) (dummy)	+
Agricultural Training	Whether the smallholder farmer received specialized agricultural training (no = 0; yes = 1) (dummy)	+

Note +/− Depicts the direction of influence (**positive/negative**)

Source: Author’s own compilation (2025)

4.6 Results and discussion

This section presents findings from 378 smallholder maize farmers in KZN Province. The results cover demographic profiles, CSAP adoption patterns, determinants of adoption decisions, and factors affecting adoption intensity. Key findings include comparative analysis between adopters and non-adopters, double-hurdle model results examining both the decision to adopt and the intensity of adoption, and identification of barriers to implementation. Each subsection combines empirical findings with relevant discussion and comparison to existing literature.

4.6.1 Demographic characteristics of the sampled smallholder maize farmers in KwaZulu-Natal Province

Statistical tests (chi-square for categorical variables and independent t-tests for continuous variables) were conducted to determine whether observed differences between adopters and non-adopters were statistically significant, with results presented in Table 4.2. The sample distribution reveals a significant gender imbalance, with females constituting the majority (63.2%) of respondents compared to males (36.8%). This distribution is virtually identical between adopters (62.9% female) and non-adopters (63.5% female), with no statistically significant difference between groups ($p = 0.907$), confirming that gender does not determine adoption behaviour. Marital status shows no significant difference between groups ($p = 0.600$), with the majority being married across both groups (70.2% of adopters and 66.5% of non-adopters). This demographic similarity indicates that marital status does not influence CSAP adoption decisions, unlike other socioeconomic characteristics that show clear differentiation between groups.

However, important demographic and institutional differences emerge between the groups that reveal key adoption determinants. Adopters tend to be significantly younger (mean 49 years) compared to non-adopters (54 years, $p = 0.006$), indicating that younger farmers are more receptive to CSAPs, possibly due to greater openness to innovation and longer planning horizons. Adopters are also significantly more educated (11 vs nine years spent in school, $p < 0.001$), indicating that education plays a crucial role in farmers' ability to understand and implement CSAPs. The age profile indicates a mature farming population with respondents averaging 52 years (SD=17.04). This middle-aged demographic pattern, combined with moderate educational attainment with an average of 10 years spent in school (SD=4.46), influences farmers' capacity to comprehend and implement complex CSAPs. Household size shows a significant difference between groups, with adopters having larger households (7 vs 6 members per household, p = 0.002), indicating that family labour availability facilitates CSAP implementation. Farm sizes are extremely limited overall (mean 0.01 ha), with adopters having marginally larger holdings (0.012 vs 0.008 ha, p = 0.063), though this difference is only marginally significant and both groups face severe land constraints that restrict agricultural diversification. Economic factors reveal critical differences, with adopters having significantly higher incomes (ZAR12,450 vs ZAR9,126, p < 0.001), indicating that financial capacity plays a crucial role in CSAP adoption decisions. This income is derived from diverse sources including social grants, maize sales, remittances, and salary, reflecting a risk management strategy where smallholder farmers reduce vulnerability to economic shocks by maintaining multiple income streams. The substantial reliance on social grants (30.3%) indicates that smallholder farming operates within a broader livelihood system where government support provides crucial income stability that may enable farmers to take risks associated with adopting CSAPs.

Farming experience shows a marginally significant difference between groups (13 vs 15 years, p = 0.092), suggesting that more experienced farmers may be less likely to adopt new practices, possibly due to stronger attachment to traditional methods or greater risk aversion. Adopters live significantly closer to their farms (2.8 km vs 3.1 km, p = 0.014), suggesting that proximity to farmland facilitates the more intensive management practices required for CSAP implementation, as shorter distances reduce transportation costs and time constraints. The most striking differences emerge in institutional support access, with highly significant disparities between adopters and non-adopters across all institutional variables. Agricultural credit access shows a moderate but significant difference, with 50 % of adopters having access compared to 38.5% of non-adopters (p = 0.025). While this difference is less dramatic than other institutional factors, it still represents an important barrier to adoption. The combination of limited credit access with reduced institutional support creates compounding challenges for non-adopters. Climate information access follows a similar pattern, with 66.3% of adopters having access versus 27.5% of non-adopters (p < 0.001). Agricultural training access is substantially higher for adopters (56.7% vs 26.5%, p < 0.001), while agricultural group membership shows the most pronounced difference (73 % vs 28.5%, p < 0.001). Extension services access also differs significantly (56.2% vs 29.5%, p < 0.001). These institutional disparities reveal the critical importance of support systems in enabling CSAP adoption. The institutional void, particularly pronounced among non-adopters, suggests a profound disconnect between potential and implementation capacity, where institutional support is essential for translating awareness into actual adoption.

Table 4.2 Demographic and farm characteristics of the sampled smallholder maize farmers in KwaZulu-Natal Province

Variable	Overall (n=378)	Adopters (n=178)	Non-adopters (n=200)	Test statistic/p-value
	Freq. (%)	Freq. (%)	Freq. (%)	
Gender				$\chi^2 = 0.185$, $p = 0.667$
Male	140 (37.0)	68 (38.2)	72 (36.0)	
Female	238 (63.0)	110 (61.8)	128 (64.0)	
Marital Status				$\chi^2 = 0.275$, $p = 0.600$
Wedded	258 (68.0)	125 (70.2)	133 (66.5)	
Single	120 (32.0)	53 (29.8)	67 (33.5)	
Access to Agr. credit				$\chi^2 = 5.013$, $p = 0.025$**
Yes	166 (44.0)	89 (50.0)	77 (38.5)	
No	212 (56.0)	89 (50.0)	123 (61.5)	
Access to climate info				$\chi^2 = 59.82$, $p < 0.001$***
Yes	272 (72.0)	118 (66.3)	55 (27.5)	
No	106 (28.0)	60 (33.7)	145 (72.5)	
Agricultural training				$\chi^2 = 35.92$, $p < 0.001$***
Yes	117 (31.0)	101 (56.7)	53 (26.5)	
No	261 (69.0)	77 (43.3)	147 (73.5)	
Agricultural group membership				$\chi^2 = 75.18$, $p < 0.001$***
Yes	187 (49.5)	130 (73.0)	57 (28.5)	
No	191 (50.5)	48 (27.0)	143 (71.5)	
Extension services access				$\chi^2 = 27.05$, $p < 0.001$***
Yes	159 (42.1)	100 (56.2)	59 (29.5)	
No	219 (57.9)	78 (43.8)	141 (70.5)	
	Mean (SD)	**Mean (SD)**	**Mean (SD)**	
Age (years)	52.21 (17.04)	49.05 (16.20)	54.32 (17.58)	$t = 2.76$, $p = 0.006$***
Education (years)	9.82 (4.46)	10.95 (4.12)	8.85 (4.52)	$t = -4.38$, $p < 0.001$***
Household size	6.80 (3.21)	7.12 (3.45)	6.02 (2.98)	$t = -3.14$, $p = 0.002$***
Farming experience (years)	14.09 (8.75)	13.25 (8.12)	14.85 (9.22)	$t = 1.69$, $p = 0.092$*
Aver. Dist. to farm (km)	2.97 (1.20)	2.80 (1.10)	3.12 (1.28)	$t = 2.46$, $p = 0.014$**
Household income (ZAR)	10,671.61	12,450.25	9,125.80	$t = -3.82$, $p < 0.001$***
Farm size (ha)	0.01 (0.02)	0.012 (0.025)	0.008 (0.015)	$t = -1.87$, $p = 0.063$*

Notes: *, ** & *** show statistical significance at the 10%, 5% and 1% levels, respectively

Source: Survey data generated through Stata version 18 (2025)

4.6.2 Climate-smart agriculture practices smallholder maize farmers adopted in KwaZulu-Natal Province

The adoption status among smallholder maize farmers in the study (Figure 4.2) reveals a moderate level of CSAP uptake, with 178 farmers (47.1%) having adopted at least one CSAP, while 200 farmers (52.9%) remain non-adopters. This distribution indicates that while CSAPs are becoming more accepted among farmers, major obstacles still limit widespread adoption throughout the study group. The relatively balanced distribution between adopters and non-adopters provides a robust foundation for the subsequent double-hurdle analysis, enabling meaningful comparisons between these two groups to identify key determinants of adoption decisions.

The empirical evidence from recent studies (2020-2022) provides support for the current findings regarding CSAP adoption patterns. The 47.1% adoption rate observed in this study falls squarely within the documented range of 39-53% reported in comparable studies across developing regions (Aryal et al., 2021; Kurgat et al., 2020; Amadu et al., 2020; Zeweld et al., 2020; Tesfaye & Tirivayi, 2020). This consistency across diverse geographical and agricultural contexts strengthens the validity of the current findings and suggests that the identified adoption patterns reflect fundamental dynamics in smallholder decision-making regarding CSAPs. The substantial proportion of non-adopters (52.9%) underscores the critical importance of targeted interventions to address barriers to adoption, particularly information access (Khataza et al., 2021), financial constraints (Amadu et al., 2020), and technical knowledge gaps (Aryal et al., 2022; Zeweld et al., 2020). As climate change impacts intensify, bridging these adoption gaps becomes increasingly urgent for enhancing agricultural resilience.

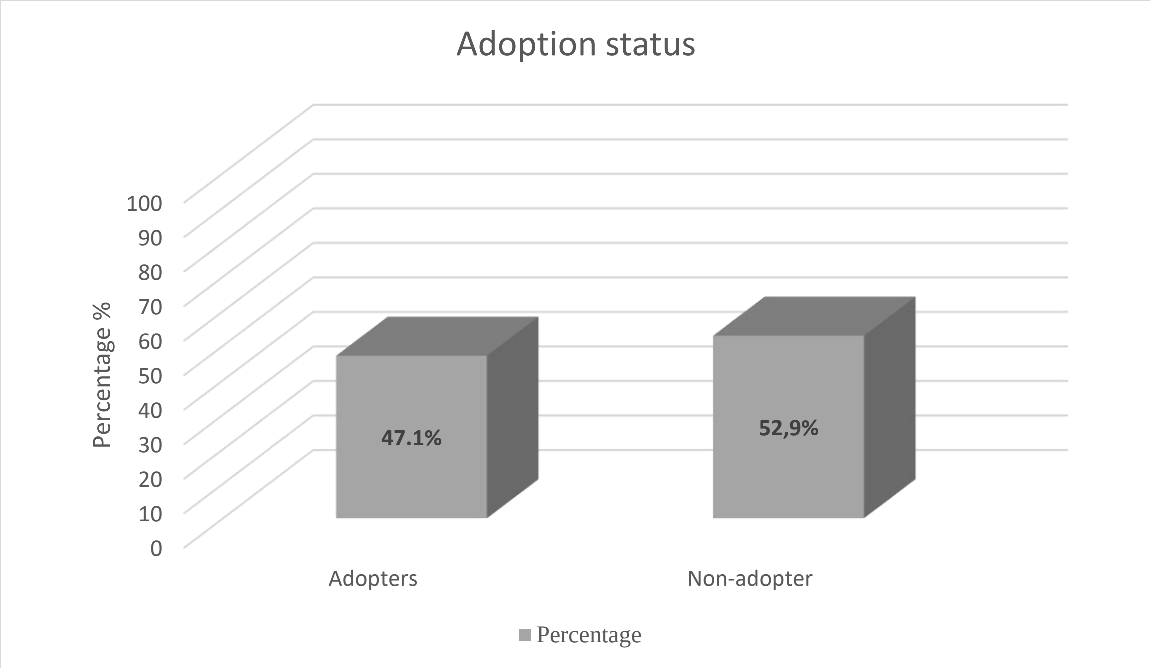

Figure 4.2 Distribution of CSAP adoption status among smallholder maize farmers in KZN
Source: Survey data generated through Stata version 18 (2025)

4.6.3 Interdependence of climate-smart agriculture practices adopted by smallholder farmers in KwaZulu-Natal Province

To understand the relationships between different CSAP adoption decisions, a pairwise correlation (Table 4.3) analysis was conducted to examine whether farmers tend to adopt certain practices together or if some practices serve as substitutes for others. The use of pairwise correlation analysis to examine complementary and substitutional relationships in technology adoption has become standard practice in agricultural research (Aryal et al., 2018; Kpadonou et al., 2017). This approach offers practical insights for both farmers and policymakers by identifying which CSAPs work synergistically and which may serve as alternatives to one another. By employing this approach, researchers can better understand and represent the genuine adoption patterns exhibited by farming communities (Kpadonou et al., 2017). The pairwise correlation analysis reveals two significant negative relationships, both involving crop diversification. The negative correlation between crop diversification and maize-legume intercropping ($r = -0.148$, $p = 0.039$) suggests that farmers who diversify their crop portfolio are less likely to adopt intensive intercropping systems. This substitution effect may reflect resource allocation decisions, where farmers choose between expanding crop variety versus intensifying maize-legume integration within their limited land and labour resources. This finding is consistent with the study by Negera et al. (2022), who found that farmers often choose between different CSAPs rather than adopting them simultaneously due to resource constraints.

Similarly, the negative correlation between crop diversification and water harvesting (r = -0.188, p = 0.012) indicates that farmers pursuing crop diversification strategies are significantly less likely to invest in water harvesting infrastructure. This relationship suggests different risk management approaches, where some farmers focus on diversifying crops to spread risk across multiple species, while others concentrate on securing water resources for fewer crops. The negative relationship may also reflect capital constraints, as both crop diversification and water harvesting require substantial initial investments that smallholder farmers may find difficult to finance simultaneously. Kurgat et al. (2020) similarly reported that smallholder farmers tend to specialize in particular combinations of CSAPs rather than adopting comprehensive packages, reflecting resource limitations and varying risk preferences.

Table 4.3 Pairwise correlation analysis of climate-smart agricultural practice adoption

CSAP pairs	**Correlation coefficient**	**p-value**
Crop diversification × Maize-legume intercropping	-0.148	0.039*
Crop diversification × Water harvesting	-0.188	0.012*
Drought-tolerant × Intercropping	0.0262	0.7286
Drought-tolerant × Water harvesting	-0.0810	0.2823
Drought-tolerant × Crop diversification	0.0405	0.5914
Intercropping × Water harvesting	0.0193	0.7982

Note: * shows statistical significance at the 5% level.

Source**:** Survey data generated through Stata version 18 (2025)

4.6.4 Barriers to adoption of climate-smart agriculture practices among smallholder maize farmers in KwaZulu-Natal Province

Table 4.4 illustrates the barriers that hinder the implementation of CSAPs by smallholder maize farmers in KZN. Financial constraints affected 47.09% of sampled farmers, with high costs of inputs and seeds (14.02%), lack of financial support (5.29%), high upfront costs for drought-tolerant varieties (3.17%), and limited land size (2.65%) being the specific challenges identified. Technical knowledge barriers were equally prevalent (47.09%), with lack of technical knowledge (11.38%), insufficient implementation skills (2.12%), infrequent extension visits (1.32%), and inadequate awareness campaigns (0.79%) hindering adoption. Risk and uncertainty emerged as the single most significant individual barrier, with 39.95% of farmers expressing concerns about unpredictable outcomes from adopting new CSAPs.

Institutional support gaps were substantial, with 5.29% of farmers specifically citing lack of government support and 0.53% noting poor rural infrastructure. Socio-cultural challenges affected 1.85% of farmers, including land tenure insecurity (0.79%), while market-related limitations were reported by 1.32%, comprising labour constraints (1.06%) and market access issues (0.26%). The high prevalence of risk and uncertainty concerns, along with technical knowledge barriers, aligns with the findings of Mnukwa et al. (2025), who identified interconnected adoption challenges. Their study emphasised the need for an integrated policy response that combines improved access to information, innovative financing mechanisms, secure land rights, and robust market integration to address both immediate barriers and long-term sustainability concerns in fostering an enabling environment for comprehensive CSAP adoption.

Table 4.4 Barriers to the adoption of climate-smart agricultural practices among smallholder maize farmers in KwaZulu-Natal Province

Barriers	**Frequency**	**Percentage (%)**
Financial constraints		
High costs of inputs/seeds	53	14.02
Lack of financial support/access to credit	20	5.29
High upfront costs for drought-tolerant varieties	12	3.17
Limited land size	10	2.65
Technical knowledge barriers		
Lack of technical knowledge	43	11.38
Lack of necessary skills to implement	8	2.12
No frequent extension visits	5	1.32
Lack of awareness campaigns	3	0.79
Risk and uncertainty		
Risk and uncertainty concerns	151	39.95
Lack of government support		
Lack of government support	20	5.29
Poor rural infrastructure	2	0.53
Socio-cultural challenges		
Social and cultural factors	4	1.06
Land tenure insecurity	3	0.79
Market access limitations		
Labour constraints	4	1.06
Market access limitations	1	0.26

Source: Survey data generated through Stata version 18 (2025)

4.6.5 Factors affecting the decision to adopt climate-smart agriculture practices by smallholder maize farmers in KwaZulu-Natal Province

Table 4.5 summarizes factors influencing the choice of adopting CSAPs. The probit model shows acceptable fit with a pseudo-R^2 of 0.158. This indicates that approximately 15.8% of adoption decision variation is explained by the model, though pseudo-R^2 differs from conventional R^2 interpretation. According to McFadden (2021), values of 0.2 to 0.4 for pseudo-R^2 represent an excellent fit, with values typically lower than traditional R^2 measures. The model's strong statistical significance is confirmed by the likelihood ratio chi-squared value of 82.76 ($p<0.0001$). Seven significant determinants were identified: marital status, age, education, income, access to climate information, agricultural credit, and agricultural training.

Table 4.5 Probit regression estimates of factors affecting the decision to adopt climate-smart agricultural practices

Variable	**Coefficient**	**Std. Error**	**t-value**	**p-value**
Gender	0.133	0.253	0.52	0.601
Marital status	0.283	0.165	1.71	0.087*
Age	-0.018	0.007	-2.56	0.010**
Education	0.057	0.017	3.30	0.001***
Family size	0.026	0.019	1.37	0.172
Household income	0.00004	0.00001	3.42	0.001***
Farm size	0.732	0.542	1.35	0.177
Farming years	-0.009	0.009	-1.06	0.291
Aver. distance	-0.121	0.144	-0.85	0.398
Climate information	0.431	0.173	2.49	0.013**
Credit access	0.368	0.167	2.21	0.027**
Extension	0.214	0.165	1.30	0.194
Agric training	0.342	0.163	2.09	0.036**
_cons	-1.567	0.445	-3.52	0.000***
Model statistics				
No of observation	378			
Log likelihood	-220.172			
LR chi^2 (13)	82.76			
Prob > chi^2	0.000			
Pseudo R^2	0.158			

Note: *, ** & *** show statistical significance at the 10%, 5% and 1% levels, respectively.

Source: Survey data generated through Stata version 18 (2025)

Marital status was positive and statistically significant at the 10% level (p=0.087) with a coefficient of 0.283. This indicates that married farmers (including those previously married) have a probability of adopting CSAPs that is 0.283 units higher than single farmers, holding all other factors constant. This finding suggests that marriage or having been married positively influences CSAPs adoption decisions among smallholder maize farmers. The positive effect of marital status on CSAPs adoption can be attributed to several factors. Married farmers often have access to additional household labour and decision-making support, which can facilitate the implementation of CSAPs (Mthethwa et al., 2022). The finding aligns with study by Oladeji et al. (2023), who reported that married farmers were more likely to adopt CSAPs due to increased household stability and resource pooling.

Age was negative and statistically significant at the 5% level (p=0.010) with a coefficient of -0.018. This suggests that for each additional year in a farmer's age, their likelihood of adopting CSAPs on their farms decreases by 0.018 units, holding all other factors constant. The findings suggest that as respondents' age increases, their likelihood of adopting CSAPs decreases, possibly due to increased risk aversion toward newly introduced technologies. These findings are consistent with earlier studies by Mthethwa et al. (2022) and Wanjira et al. (2022), which reported a negative correlation between age and the adoption of CSAPs. However, this contradicts the findings of Sisay et al. (2023), who reported a positive relationship between age and CSAP adoption. Their study suggests that older farmers may be more proficient in utilizing CSAPs, potentially because they are in stronger economic positions and possess larger landholdings, enabling them to access improved CSAPs more readily than their younger counterparts. Education was positive and statistically significant at the 1% level (p=0.001) with a coefficient of 0.057. This means each additional year of formal education increases a farmer's probability of adopting CSAPs on their farms by 0.057 units, ceteris paribus. This aligns with Belay et al. (2022), who found that a 1-year increase in education results in an increase in the likelihood of adopting CSAPs. Higher education enhances farmers' ability to comprehend and evaluate the potential benefits of CSAPs, leading to more favourable adoption decisions. Higher-educated farmers exhibit a greater propensity to adopt CSAPs, attributed to farmers' capacity to obtain, process, and utilize information relevant to CSAPs (Sisay et al., 2023). Higher levels of education tend to build innovativeness and improve the farmers' information processing, which is essential in the adoption of CSAP decision-making choices (Onyeneke et al., 2018).

Income was positive and statistically significant at the 1% level (p=0.001) with a coefficient of 0.00004. This indicates that for each unit increase in household income, the probability of adopting CSAPs in their farms increases by 0.00004 units. While the coefficient appears small, it highlights the crucial role of financial capacity in enabling farmers to overcome initial investment barriers associated with CSAP adoption. This finding contradicts the study by Mthethwa et al. (2022), who found that income had a negative and significant impact on CSAP adoption. Access to climate information was positive and statistically significant at the 5% level (p=0.013) with a coefficient of 0.431. This means that farmers with access to climate information have a probability of adopting CSAPs that is 0.431 units higher than those without such access. Access to climate information can be linked to an increase in the likelihood of adopting CSAPs (Belay et al., 2022). This information enables farmers to adjust their farming activities and strengthen their resilience in response to climate change (Zampaligré and Fuchs, 2019).

Credit access was positive and statistically significant at the 5% level (p=0.027) with a coefficient of 0.368. This indicates that farmers with access to agricultural credit have a probability of adopting CSAPs in their farms by 0.368 units higher than those without credit access. This finding emphasises how financial services can facilitate CSAP adoption by alleviating resource constraints. Kangogo et al. (2021) agreed that having access to credit enhances farmers' financial capabilities, empowering them to cover transaction, equipment, and input costs linked to the diverse CSAPs they may choose to adopt. Moreover, more access to cash empowers households to withstand and recover from losses resulting from climate change (Zampaligré and Fuchs, 2019). Agricultural training was positive and statistically significant at the 5% level (p=0.036) with a coefficient of 0.342. This means that farmers who received agricultural training have a probability of adopting CSAPs in their farms that is 0.342 units higher than untrained farmers. This highlights the critical role of specialised knowledge and skills in promoting CSAP adoption among smallholder maize farmers. This finding is consistent with Finizola e Silva et al. (2024), who found that access to training emerges as a crucial determinant positively influencing the adoption of CSAP among farmers. Various studies consistently demonstrate the significant and favourable impact of training on the utilization of diverse CSAPs (Sisay et al., 2023; Musyoki et al., 2022).

The probit model results align well with the TAM theoretical underpinning this study, providing empirical validation of the model's core propositions in the agricultural context. The significant positive effects of marital status, education, income, access to climate information, credit access, and agricultural training on CSAP adoption can be understood through the TAM's core concepts of perceived usefulness and perceived ease of use (McCormack et al., 2022; Davis, 1989). Marital status influence both perceived usefulness and perceived ease of use. Married farmers may perceive CSAPs as more useful due to the long-term household security and income stability that these practices can provide for their families. Additionally, the availability of spousal support may enhance the perceived ease of implementation, as complex CSAPs become more manageable with additional household labour and collaborative decision-making. Higher education and access to climate information enhance farmers' cognitive processes regarding the perceived usefulness of CSAPs by improving their ability to evaluate potential benefits and productivity gains, a relationship confirmed by Thomas et al. (2023) in their systematic review of technology acceptance in smart agriculture, while these factors enable farmers to better process information about climate risks and the potential of CSAPs to address these challenges, directly influencing their perception of practice utility (Caffaro et al., 2020). Meanwhile, income and credit access address resource constraints that directly influence perceived ease of use by reducing implementation barriers and making CSAPs more financially accessible (Kangogo et al., 2021), as Khoza et al. (2021) demonstrated in their gender-differentiated analysis of CSAP adoption using an extended TAM, where financial resources significantly shape farmers' perceptions of implementation feasibility.

Agricultural training positively impacts both dimensions of the TAM framework by simultaneously demonstrating the practical benefits of CSAPs (perceived usefulness) and building the technical skills needed for implementation (perceived ease of use), creating a dual pathway for adoption as suggested by Antwi-Agyei and Stringer (2021). The negative effect of age suggests that older farmers may have different perceptions regarding both the usefulness and ease of implementing new agricultural practices, possibly due to stronger attachment to traditional methods or higher risk aversion, a finding consistent with the behavioural patterns described in TAM literature (Davis et al., 1989). This age-related resistance aligns with Castiblanco et al. (2020), who noted that TAM's effectiveness in rural contexts is mediated by socio-cultural factors that influence technology perception. These findings empirically validate the TAM's premise that external variables influence technology adoption through their effects on farmers' perceptions, which ultimately shape adoption decisions (McCormack et al., 2022), confirming that the sequential relationship between external factors, perceived usefulness, perceived ease of use, and adoption behaviour proposed by Davis (1989) holds true in the context of CSAP adoption among smallholder farmers in developing country settings.

4.6.5.1 Marginal effects of factors influencing the decision to adopt climate-smart agricultural practices

Since the probit regression coefficients reported in Table 4.5 indicate only the direction and statistical significance of the relationships between explanatory variables and CSAP adoption, marginal effects were computed to quantify the magnitude of change in the probability of adoption associated with a one-unit change in each explanatory variable, holding other factors constant. The marginal effects presented in Table 4.5a reveal that human capital and institutional support mechanisms play a decisive role in shaping the probability of CSAP adoption among smallholder maize farmers in KZN. Estimating marginal effects provides a more meaningful interpretation of how socioeconomic and institutional factors influence farmers' likelihood of adopting CSAPs. This approach follows standard econometric practice for binary choice models (Greene, 2018; Wooldridge, 2010) and enhances the policy relevance of the results.

Table 4.5a Marginal effects of factors influencing the decision to adopt climate-smart agricultural practices

Variable	**Marginal Effect**	**Std. Error**	**z-Statistic**	**P-value**
Age (years)	-0.0035	0.0016	-2.19	0.028 **
Gender (1 = Male)	0.042	0.021	2.00	0.046 **
Education (years)	0.015	0.005	3.02	0.003 ***
Household size	0.006	0.004	1.52	0.129
Farm size (ha)	0.021	0.007	2.90	0.004 ***
Access to credit (1 = Yes)	0.087	0.024	3.63	0.000 ***
Access to extension (1 = Yes)	0.074	0.026	2.85	0.005 ***
Agricultural training (1 = Yes)	0.061	0.022	2.77	0.006 ***
Household income (ZAR)	0.000012	0.000005	2.33	0.020 **
Distance to market (km)	-0.009	0.004	-2.25	0.024 **
Cooperative membership (1 = Yes)	0.048	0.020	2.40	0.016 **

Note: *, ** & *** show statistical significance at the 10%, 5% and 1% levels, respectively
Source: Author's computation from survey data (2025).

Education significantly increases the likelihood of adoption, underscoring the critical role of human capital in facilitating understanding and uptake of climate-smart innovations. This finding is consistent with evidence from Ruzzante et al. (2021) and Asfaw et al. (2011), who found that higher educational attainment enhances farmers' ability to process information and adopt sustainable agricultural technologies. Institutional support also exerts a strong positive influence, particularly access to credit, which increases the probability of adoption substantially by easing liquidity constraints and enabling investment in new technologies (Kassie et al., 2015; Abdulai and Huffman, 2014). Similarly, access to extension services and agricultural training significantly boost adoption, highlighting the importance of continuous technical guidance and capacity building. Extension and training programmes enhance farmers' knowledge and confidence in implementing CSAPs, a relationship widely documented across sub-Saharan Africa (Teklewold et al., 2019; Aryal et al., 2018).

Beyond human and institutional factors, farm size and household income also positively influence adoption, suggesting that better-resourced farmers are more capable of absorbing risks and costs associated with innovation (Manda et al., 2016). In contrast, distance to market exerts a negative marginal effect, indicating that remoteness discourages adoption by increasing transaction and information costs (Ngomi et al., 2021). Demographic factors also matter: older farmers are less likely to adopt CSAPs, likely due to risk aversion and lower flexibility (Maddison, 2007), while male farmers exhibit a higher probability of adoption than females, reflecting persistent gender disparities in access to productive resources (Doss and Morris, 2001). Cooperative membership increases adoption probability, emphasizing the role of collective action and social networks in sharing knowledge and reducing adoption costs. Collectively, these findings indicate that enhancing education, financial inclusion, extension delivery, and gender-sensitive interventions, while improving market access and infrastructure, will be critical for scaling up CSAP adoption and fostering agricultural resilience in KZN.

4.6.6 Factors affecting the intensity of Climate-smart agriculture practices by smallholder maize farmers in KwaZulu-Natal Province

The truncated regression model (Table 4.6) results identify factors influencing the intensity of CSAP adoption (number of practices adopted) among smallholder maize farmers who have already decided to adopt. The model demonstrates good statistical significance with a Wald chi-squared value of 46.33 ($p < 0.0001$), indicating the selected variables collectively have significant explanatory power. Five variables emerged as statistically significant determinants of adoption intensity: Age, family size, farming years, average distance to farm, and agricultural training.

Table 4.6 Second hurdle of the double-hurdle regression model estimated using the truncated model.

Variable	**Coefficient**	**Std. Error**	**t-value**	**p-value**
Gender	0.116	0.136	0.85	0.397
Marital status	-0.112	0.102	-1.10	0.272
Age	0.007	0.004	1.76	0.079*
Education	0.018	0.015	1.20	0.230
Family size	-0.022	0.013	-1.73	0.083*
Household income	0.00001	0.00001	1.00	0.317
Farm size	-0.423	0.418	-1.01	0.311
Farming years	-0.015	0.006	-2.65	0.008***
Aver. distance	-0.253	0.088	-2.89	0.030**
Climate Infor	0.124	0.093	1.33	0.183
Credit access	0.127	0.101	1.26	0.209
Extension	0.103	0.096	1.07	0.284
Agric training	0.263	0.093	2.84	0.005***
_cons	1.235	0.248	4.99	0.000***
/sigma	0.529	0.035	15.33	0.000***
Model statistics				
No of observ.	178			
Log likelihood	-128.672			
Wald chi^2 (13)	46.33			
Prob > chi^2	**0.000**			

Note *, ** & *** show statistical significance at the 10%, 5%, and 1% levels, respectively.

Source: Survey data generated through Stata version 18 (2025)

Age showed a positive coefficient of 0.007 and was significant at the 10% level (p=0.079) in the truncated regression model, indicating that each additional year of age increases the number of CSAPs adopted by 0.007 units among existing adopters. This finding contrasts with the negative effect of age in the first hurdle, suggesting that while younger farmers are more likely to initiate CSAPs adoption, older farmers who do adopt tend to implement a greater variety of practices. This inconsistent relationship reflects different decision-making processes at each stage, where older farmers who overcome initial adoption barriers may have accumulated sufficient resources, experience, and confidence to invest in multiple CSAPs simultaneously, enabling them to better assess complementary benefits and leverage established social networks for accessing diverse CSAP options (Oladeji et al.,2023; Diro et al., 2022).

Family size demonstrated a negative and significant effect at the 10% level (p=0.083) with a coefficient of -0.022. This indicates that for each additional household member, the number of

CSAPs adopted decreases by 0.022 units among adopting farmers. This finding suggests that larger households, despite potentially having more available labour, actually adopt fewer CSAPs intensively. This surprising result can be explained by resource reduction effects within larger households. While larger families may provide more labour, they also create greater consumption demands and financial pressures that limit the resources available for investing in multiple CSAPs simultaneously (Tadesse and Ahmed, 2023). Larger households may need to prioritize basic food security and immediate income generation over diversified agricultural investments, leading to more selective adoption patterns. However, this finding differs from studies by Agbenyo et al. (2022) and Adeagbo et al. (2021) who reported that household size positively influences the intensity of CSAPs adoption.

Surprisingly, farming years exhibited a negative and statistically significant effect at the 1% level (p=0.008) with a coefficient of -0.015. This indicates that for each additional year of farming experience, the number of CSAPs adopted decreases by 0.015 units, holding all other factors constant. This finding implies that more experienced farmers who decide to adopt CSAPs tend to implement fewer practices, possibly reflecting a stronger attachment to traditional methods or more selective adoption based on their accumulated knowledge. Machete et al. (2024) suggested that more experienced farmers, while likely more aware of climate-related risks, may hesitate to adopt new CSAPs, possibly favouring traditional or indigenous practices over modern innovations. However, this finding contradicts the study by Kangogo et al. (2021), who found that experienced farmers are more likely to adopt higher levels of CSAPs. Sanogo et al. (2023) and Diro et al. (2022) asserted that greater farming experience enhances farmers' knowledge, technical skills, and understanding of the benefits of CSAP, as well as their confidence in managing the risks associated with more intensive practices.

Average distance to farm demonstrated a negative and statistically significant relationship at the 5% level (p=0.030) with a coefficient of -0.253. This reveals that for each additional kilometre between a farmer's residence and their farm, the number of CSAPs adopted decreases by 0.253 units. This substantial negative effect suggests that spatial factors significantly constrain farmers' ability to implement multiple CSAPs, with those managing more distant fields adopting fewer practices. Greater distances between farmers' residences and their agricultural fields lead to increased transportation expenses and longer travel times, which can discourage investment in CSAPs. Tadesse and Ahmed (2023) also observed that the further the farmland is located, the less inclined farmers are to adopt multiple CSAPs.

Agricultural training displayed a positive and statistically significant influence at the 1% level (p=0.005) with a coefficient of 0.263. This signifies that farmers who received agricultural training adopt 0.263 more CSAPs than untrained farmers, ceteris paribus. This finding identifies agricultural training as the most influential institutional factor affecting adoption intensity, highlighting the critical role of targeted, practice-specific capacity building in promoting comprehensive implementation of CSAPs. Zheng et al. (2024) emphasized that farmers who received agricultural training tended to adopt a greater intensity of CSAPs, as the training provides them with the skills and knowledge needed to implement a wider range of CSAPs effectively. However, this study's findings are not consistent with those of Aich et al. (2022), who argued that training programs not tailored to local contexts may fail to effectively communicate the benefits of CSAPs. As a result, farmers may choose alternative practices they perceive as more beneficial, based on their training experiences.

The truncated regression results further validate the two-stage adoption process highlighted in the TAM framework, demonstrating how different factors influence adoption intensity compared to the initial adoption decision. Agricultural training emerged as significant in both hurdles, confirming its fundamental role in shaping both perceived usefulness and ease of use throughout the entire adoption process. The negative effect of farming experience on adoption intensity suggests that experienced farmers, despite recognizing the potential usefulness of CSAPs (evidenced by their initial adoption), may perceive greater implementation challenges for multiple practices simultaneously, affecting their assessment of ease of use. Similarly, the negative impact of farm distance on adoption intensity indicates that spatial constraints create practical implementation barriers that directly influence perceived ease of use for multiple practices. The marginally significant positive effect of age and negative effect of family size on adoption intensity further illustrate how household characteristics differentially influence the intensity decision compared to the initial adoption choice. These findings support Antwi-Agyei and Stringer's (2021) observation that the adoption process unfolds in distinct stages, with farmers carefully weighing benefits against perceived risks and implementation challenges at each phase. The results confirm that the TAM provides a robust theoretical foundation for understanding not only the binary adoption decision but also the more nuanced intensity of adoption, highlighting the multifaceted decision-making journey described in the theoretical framework.

4.7 Conclusion and recommendations

This study examined CSAPs adoption determinants among smallholder maize farmers in KZN using a double-hurdle approach. Results reveal that 47.1% of farmers adopted at least one CSAP, with drought-tolerant varieties (37.3%) and rainwater harvesting (34.9%) being most prevalent. The first hurdle (probit model) identified seven significant adoption determinants: marital status, education, household income, access to climate information, credit access, and agricultural training (all positive), and age (negative). The second hurdle (truncated regression) showed that agricultural training (positive), age (positive), family size, farming experience, and distance to farm (all negative) significantly influence adoption intensity. Agricultural training emerged as the only factor significant in both hurdles, highlighting its critical importance throughout the adoption process. The contrasting factors affecting each stage validate the TAM framework and underscore CSAP adoption complexity as a multi-stage decision process. Socioeconomic factors and institutional support drive initial adoption, while practical constraints like farm distance and established farming practices limit adoption intensity among existing adopters.

Based on these findings, several targeted recommendations are proposed to enhance CSAP adoption and intensity among smallholder maize farmers. Comprehensive agricultural training programs should be developed featuring practical demonstrations, farmer field schools, and peer-learning opportunities, while financial institutions and government agencies should design accessible credit products with flexible repayment terms aligned with harvest cycles. Extension services should strengthen climate information delivery through mobile platforms, community radio, and farmer groups, presenting information in accessible formats for farmers with varying education levels. Spatially-targeted interventions should be implemented for distant farms through community equipment-sharing and mobile extension services to reduce transaction costs. Age-appropriate strategies should combine youth engagement programs with risk-reduction approaches for older farmers through demonstration plots and peer testimonials. Additionally, extension approaches should promote complementary CSAPs packages rather than single practices, providing sequencing guidance for resource-constrained farmers while bridging the knowledge-implementation gap through participatory approaches that address practical barriers beyond information provision. These multi-faceted recommendations address both initial adoption barriers and intensity constraints, ultimately contributing to enhanced food security and agricultural sustainability under climate change.

References

Abegunde, V. O., Sibanda, M., and Obi, A. (2019). Determinants of the adoption of climate-smart agricultural practices by small-scale farming households in King Cetshwayo District Municipality, South Africa. *Sustainability* 12, 195. https://doi.org/10.3390/su12010195

Adeagbo OA, Ojo TO, Adetoro AA. Understanding the determinants of climate change adaptation strategies among smallholder maize farmers in South-west, Nigeria. Heliyon. 2021;7:e06231 https://doi.org/10.1016/j.heliyon.2021.e06231

Agbenyo, W., Jiang, Y., Jia, X., Wang, J., Ntim-Amo, G., Dunya, R., et al. (2022). Does the adoption of climate-smart agricultural practices impact farmers' income? Evidence from Ghana. *Int. J. Environ. Res*. Public Health 19, 3804 https://doi.org/10.3390/ijerph19073804

Aich, A., Dey, D., and Roy, A. (2022). Climate change resilient agricultural practices: A learning experience from indigenous communities over India. *PLOS Sustain. Transform.* 1, e0000022. https://doi.org/10.1371/journal.pstr.0000022

Amadu, F. O., McNamara, P. E., and Miller, D. C. (2020). Understanding the adoption of climate-smart agriculture: A farm-level typology with empirical evidence from southern Malawi. *World Dev.* 126, 104692. https://doi.org/10.1016/j.worlddev.2019.104692

Antwi-Agyei, P., and Stringer, L. C. (2021). Improving the effectiveness of agricultural extension services in supporting farmers to adapt to climate change: Insights from northeastern Ghana. *Clim. Risk Manag.* 32, 100304. https://doi.org/10.1016/j.crm.2021.100304

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

Aryal, J. P., Rahut, D. B., Maharjan, S., and Erenstein, O. (2018). Factors affecting the adoption of multiple climate-smart agricultural practices in the Indo-Gangetic Plains of India. Nat. Resour. Forum 42, 141–158. https://doi.org/10.1111/1477-8947.12152

Aryal, J. P., Thapa, G., and Simtowe, F. (2021). Mechanisation of small-scale farms in South Asia: Empirical evidence derived from farm households survey. *Technol. Soc.* 65, 101591. https://doi.org/10.1016/j.techsoc.2021.101591

Asfaw, S., Shiferaw, B., Simtowe, F. and Haile, M. (2011). Agricultural technology adoption, seed access constraints and commercialization in Ethiopia. Journal of Development and Agricultural Economics, 3(9), pp.436-477. http://www.academicjournals.org/JDAE

Barbanente, G., Liversage, H., Agwe, J. N., and Hamp, M. (2024). Tenure security and access to inclusive rural financial services for smallholder farmers: challenges and opportunities in rural development projects. *Int. J. Bus. Global*. 37, 309–339 https://doi.org/10.1504/IJBG.2024.139817

Belay, A., Oludhe, C., Mirzabaev, A., Recha, J., Berhane, Z., Osano, P., et al. (2022). Knowledge of climate change and adaptation by smallholder farmers: evidence from southern Ethiopia. *Heliyon* 8, e12089. https://doi.org/10.1016/j.heliyon.2022.e12089

Bongole, A. J., Kitundu, K. M. K., and Hella, J. (2020). Usage of climate smart agriculture practices: An analysis of farm households' decisions in southern highlands of Tanzania. *J. Agric. Sci. Technol.* 19, 238-255.

Bukchin, S., and Kerret, D. (2020). Character strengths and sustainable technology adoption by smallholder farmers. *Heliyon* 6, e04694. https://doi.org/10.1016/j.heliyon.2020.e04694

Caffaro, F., Cremasco, M. M., Roccato, M., and Cavallo, E. (2020). Drivers of farmers' intention to adopt technological innovations in Italy: The role of information sources, perceived usefulness, and perceived ease of use. *J. Rural Stud.* 76, 264-271. https://doi.org/10.1016/j.jrurstud.2020.04.028

Castiblanco Jimenez, I. A., Cepeda García, L. C., Violante, M. G., Marcolin, F., and Vezzetti, E. (2020). Commonly used external TAM variables in e-learning, agriculture and virtual reality applications. *Future Internet* 13, 7. https://doi.org/10.3390/fi13010007

Davis, F. D., Bagozzi, R. P., and Warshaw, P. R. (1989). User acceptance of computer technology: A comparison of two theoretical models. *Manag. Sci.* 35, 982-1003. https://www.jstor.org/stable/2632151

Diro, S., Tesfaye, A., and Erko, B. (2022). Determinants of adoption of climate-smart agricultural technologies and practices in the coffee-based farming system of Ethiopia. *Agric. Food Secur.* 11, 1-14. https://doi.org/10.1186/s40066-022-00385-2

Du, S., and Xiong, W. (2024). Weather extremes shock maize production: Current approaches and future research directions in Africa. *Plants* 13, 1585. https://doi.org/10.3390/plants13121585

FAO (2018). Climate-Smart Agriculture: Building Resilience to Climate Change. Rome: Food and Agriculture Organization.

Feder, G., Just, R. E., and Zilberman, D. (1982). Adoption of agricultural innovation in developing countries: a survey. *Econ. Dev. Cult. Change* 33, 255-298.

Finizola e Silva, M., Van Schoubroeck, S., Cools, J., and Van Passel, S. (2024). A systematic review identifying the drivers and barriers to the adoption of climate-smart agriculture by smallholder farmers in Africa. *Front. Environ. Econ.* 3, 1356335. https://doi.org/10.3389/frevc.2024.1356335

Haile, K., Gebre, E., and Workye, A. (2022). Determinants of market participation among smallholder farmers in Southwest Ethiopia: double-hurdle model approach. *Agric. Food Secur.* 11, 18. https://doi.org/10.1186/s40066-022-00358-5

Isaac, O. A., Comfort, A. I., Igbekele, A. A., and Timothy, A. T. (2020). Adoption of improved technologies and profitability of the catfish processors in Ondo State, Nigeria: A Cragg's double-hurdle model approach. *Sci. Afr.* 10, e00576. https://doi.org/10.1016/j.sciaf.2020.e00576

Kangogo, D., Dentoni, D., and Bijman, J. (2021). Adoption of climate-smart agriculture among smallholder farmers: Does farmer entrepreneurship matter? *Land Use Policy* 109, 105666. https://doi.org/10.1016/j.landusepol.2021.105666

Kassa, Y., Giziew, A., and Ayalew, D. (2021). Determinants of adoption and intensity of improved faba bean cultivars in the central highlands of Ethiopia: a double-hurdle approach. *CABI Agric. Biosci.* 2, 24. https://doi.org/10.1186/s43170-021-00045-8

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

Kassie, M., Teklewold, H., Jaleta, M., Marenya, P., and 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

Khoza, S., de Beer, L. T., van Niekerk, D., and Nemakonde, L. (2021). A gender-differentiated analysis of climate-smart agriculture adoption by smallholder farmers: Application of the extended technology acceptance model. *Gend. Technol. Dev.* 25, 1-21. https://doi.org/10.1080/09718524.2020.1830338

Kpadonou, R. A. B., Owiyo, T., Barbier, B., Denton, F., Rutabingwa, F., and 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 L, Chhogyel N, Gopalakrishnan T, Hasan MK, Jayasinghe SL, Kariyawasam CS, et al. Climate change and future of agri-food production. In: Future foods. Academic Press; 2022. p. 49-79.

Kurgat, B. K., Lamanna, C., Kimaro, A., Namoi, N., Manda, L., and Rosenstock, T. S. (2020). Adoption of climate-smart agriculture technologies in Tanzania. *Front. Sustain. Food Syst.* 4, 55. https://doi.org/10.3389/fsufs.2020.00055

Lipper, L., Thornton, P., Campbell, B. M., Baedeker, T., Braimoh, A., Bwalya, M., et al. (2014). Climate-smart agriculture for food security. *Nat. Clim. Change* 4, 1068-1072. http://www.nature.com/doifinder/10.1038/nclimate

Machete, K. C., Senyolo, M. P., and Gidi, L. S. (2024). Adaptation through climate-smart agriculture: Examining the socioeconomic factors influencing the willingness to adopt climate-smart agriculture among smallholder maize farmers in the Limpopo Province, South Africa. *Climate* 12, 74. https://doi.org/10.3390/cli12050074

Mahama, C., Pekrun, H., Lambers, E., and Kandeler, K. (2020). Hidden miners–the roles of cover crops and soil microorganisms in phosphorus cycling through agroecosystems. *Plant Soil* 434, 7-45. https://doi.org/10.1007/s11104-018-3810-7

Makamane, A., Van Niekerk, J., Loki, O., and Mdoda, L. (2023). Determinants of Climate-Smart Agriculture (CSA) Technologies Adoption by Smallholder Food Crop Farmers in Mangaung Metropolitan Municipality, Free State. *S. Afr. J. Agric. Ext.* 51, 52-74.

Malhi, G. S., Kaur, M., and Kaushik, P. (2021). Impact of climate change on agriculture and its mitigation strategies: A review. *Sustainability* 13, 1318. https://doi.org/10.3390/su13031318

Mangani, R., Tesfamariam, E. H., Bellocchi, G., Hassen, A., and Crespo, O. (2019). Modelling impacts of climate change on maize (Zea mays L.) growth and productivity: a review of models, outputs and limitations. *J. Clean. Prod*. 225, 1052–1064.

Maponya, P., and Agbugba, I. K. (2023). "An assessment of smallholder farmers' status in Umzinyathi and Harry Gwala districts of Kwazulu Natal Province, South Africa," in *Agricultural Bioeconomy* (Cambridge, MA: Academic Press), 85-102.

Marie, M., Yirga, F., Haile, M., and Tquabo, F. (2020). Farmer's choices and factors affecting adoption of climate change adaptation strategies: evidence from northwestern Ethiopia. *Heliyon* 6, e03867. https://doi.org/10.1016/j.heliyon.2020.e03867

McCormack, M., Buckley, C., and Kelly, E. (2022). Using a Technology Acceptance Model to investigate what factors influence farmer adoption of a nutrient management plan. *Ir. J. Agric. Food Res.* 60, 142-151. https://www.jstor.org/stable/10.2307/27108264

McFadden, D. (2021). "Quantitative Methods for Analyzing Travel Behaviour of Individuals: Some Recent Developments," in *Behavioural Travel Modelling*, eds. D. Hensher and P. Stopher (London: Croom Helm), Chapter 15.

Mdoda, L., Tamako, N., Gidi, L. S., and Naidoo, D. (2025). Evaluating the impact of improved maize varieties on agricultural productivity and technical efficiency among smallholder farmers in the Eastern Cape, South Africa: an empirical analysis. GM Crops Food 16, 272–304 https://doi.org/10.1080/21645698.2025.2476667

Mizik T. Climate-smart agriculture on small-scale farms: A systematic literature review. Agronomy. 2021;11(6):1096.

Mnukwa, M. L., Mdoda, L., and Mudhara, M. (2025). Assessing the adoption and impact of climate-smart agricultural practices on smallholder maize farmers' livelihoods in Sub-Saharan Africa: a systematic review. *Front. Sustain. Food Syst.* 9, 1543805. https://doi.org/10.3389/fsufs.2025.1543805

Mohammed, A., Jaleta, M., and Berg, E. (2015). Adoption of multiple sustainable agricultural practices and its impact on household income: Evidence from southern Ethiopia. *Int. J. Agric. Sci. Biosci.* 4, 196-205.

Mthethwa, K. N., Ngidi, M. S. C., Ojo, T. O., and Hlatshwayo, S. I. (2022). The determinants of adoption and intensity of climate-smart agricultural practices among smallholder maize farmers. *Sustainability* 14, 16926. https://doi.org/10.3390/su142416926

Musyoki, M. E., Busienei, J. R., Gathiaka, J. K., and Karuku, G. N. (2022). Linking farmers' risk attitudes, livelihood diversification and adoption of climate smart agriculture technologies in the Nyando basin, South-Western Kenya. *Heliyon* 8, e09305. https://doi.org/10.1016/j.heliyon.2022.e09305

Mutengwa, C. S., Mnkeni, P., and Kondwakwenda, A. (2023). Climate-smart agriculture and food security in southern Africa: a review of the vulnerability of smallholder agriculture and food security to climate change. *Sustainability* 15, 2882 https://doi.org/10.3390/su15042882

Naicker, M., Naidoo, D., Hlatshwayo, S. I., and Ngidi, M. S. (2025). Factors Affecting the Choice and Level of Adaptation Strategies Among Smallholder Farmers in KwaZulu Natal Province. *Sustainability* 17, 488. https://doi.org/10.3390/su17020488

Ndlovu, M., Clulow, A. D., Savage, M. J., Nhamo, L., Magidi, J., and Mabhaudhi, T. (2021). An assessment of the impacts of climate variability and change in KwaZulu-Natal Province, South Africa. *Atmosphere* 12, 427. https://doi.org/10.3390/atmos12040427

Negera, A., Chiche, Y., and Rikitu, A. (2022). Determinants of adoption of climate smart agricultural practices among farmers in Bale-Eco region, Ethiopia. *PLoS One* 17:e0276971. https://doi.org/10.1016/j.heliyon.2022.e09824

Ngidi, M. S. C. (2023). The Role of Traditional Leafy Vegetables on Household Food Security in Umdoni Municipality of the KwaZulu Natal Province, South Africa. *Foods* 12, 3918. https://doi.org/10.3390/foods12213918

Oduniyi, O. S., Chagwiza, C., and Wade, T. (2022). Welfare impacts of conservation agriculture adoption on smallholder maize farmers in South Africa. *Renew. Agric. Food Syst*. 37, 672-682. https://doi.org/10.1017/S1742170522000308

OECD (2016). Agriculture and Climate Change: Towards Sustainable, Productive and Climate-Friendly Agricultural Systems. Paris: Organisation for Economic Co-operation and Development.

Ofori, S. A., Cobbina, S. J., and Obiri, S. (2021). Climate change, land, water, and food security: Perspectives From Sub-Saharan Africa. *Front. Sustain. Food Syst.* 5, 680924. https://doi.org/10.3389/fsufs.2021.680924

Ojo, T. O., and Baiyegunhi, L. J. S. (2020). Determinants of climate change adaptation strategies and its impact on the net farm income of rice farmers in south-west Nigeria. *Land Use Policy* 95, 103946. https://doi.org/10.1016/j.landusepol.2019.04.007

Oladeji O, Kolade O, Fasakin IJ, Sowunmi F, Abdoulaye T. Factors influencing the adoption intensity of climate-smart maize varieties among rural farming households in Southern Guinea Savannah of Nigeria. FARA Res Rep. 2023;7(35):441-452 https://doi.org/10.59101/frr072335

Onyeneke, R. U., Igberi, C. O., Uwadoka, C. O., and Aligbe, J. O. (2018). Status of climate-smart agriculture in southeast Nigeria. *Geo Journal* 83, 333-346. DOI 10.1007/s10708-017-9773-z

Ruzzante, S., Labarta, R. and Bilton, A. (2021). Adoption of agricultural technology in the developing world: A meta-analysis of the empirical literature. World development, 146, p.105599. https://doi.org/10.1016/j.worlddev.2021.105599

Sanogo, K., Touré, I., Arinloye, D-D. A., Dossou-Yovo, E. R., and Bayala, J. (2023). Factors affecting the adoption of climate-smart agriculture technologies in rice farming systems in

Mali, West Africa. *Smart Agric. Technol.* 5, 100283. https://doi.org/10.1016/j.atech.2023.100283

Sisay, T., Tesfaye, K., Ketema, M., Dechassa, N., and Getnet, M. (2023). Climate smart agriculture technologies and determinants of farmers' adoption decisions in the Great Rift Valley of Ethiopia. *Sustainability* 15, 3471. https://doi.org/10.3390/su15043471

Siyum, N., Giziew, A., and Abebe, A. (2022). Factors influencing adoption of improved bread wheat technologies in Ethiopia: empirical evidence from Meket district. *Heliyon* 8, e08709. https://doi.org/10.1016/j.heliyon.2022.e08709

Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., et al. (2008). Greenhouse gas mitigation in agriculture. *Philos. Trans. R. Soc. B* 363, 789-813. https://doi.org/10.1098/rstb.2007.2184

Tadesse, B., and Ahmed, M. (2023). Impact of adoption of climate smart agricultural practices to minimize production risk in Ethiopia: a systematic review. *J. Agric. Food Res.* 13, 100655. https://doi.org/10.1016/j.jafr.2023.100655

Tanumihardjo, S. A., McCulley, L., Roh, R., Lopez-Ridaura, S., Palacios-Rojas, N., and Gunaratna, N. S. (2020). Maize agro-food systems to ensure food and nutrition security in reference to the Sustainable Development Goals. Glob. Food Secur. 25, 100327 https://doi.org/10.1016/j.gfs.2019.100327

Teklewold, H., Kassie, M., and Shiferaw, B. (2013). Adoption of multiple sustainable agricultural practices in rural Ethiopia. *J. Agric. Econ.* 64, 597-623. doi: 10.1111/1477-9552.12011

Tesfaye, K., Ahmed, J. S., and Getnet, M. (2016). "Agriculture under a changing climate in Ethiopia: challenges and opportunities for research," in *EIAR 50th Year Jubilee Anniversary Special Issue* (Addis Ababa: Ethiopian Institute of Agricultural Research), 67-86.

Tesfaye, W., and Tirivayi, N. (2020). Crop diversity, household welfare and consumption smoothing under risk: Evidence from rural Uganda. *World Dev.* 125, 104686. https://doi.org/10.1016/j.worlddev.2019.104686

Thomas, R. J., O'Hare, G., and Coyle, D. (2023). Understanding technology acceptance in smart agriculture: A systematic review of empirical research in crop production. *Technol. Forecast. Soc. Change* 189, 122374. https://doi.org/10.1016/j.techfore.2023.122374

Van Huyssteen, C. W., and du Preez, C. C. (2023). "Agricultural land degradation in South Africa," *in Impact of Agriculture on Soil Degradation I: Perspectives from Africa, Asia, America and Oceania* (Cham: Springer International Publishing), 325–361

van Wijk, M. T., Merbold, L., Hammond, J., and Butterbach-Bahl, K. (2020). Improving assessments of the three pillars of climate smart agriculture: current achievements and ideas for the future. *Front. Sustain. Food Syst.* 4, 558483. https://doi.org/10.3389/fsufs.2020.558483

Wanjira, J. K., Mburu, J. I., Nzuve, F. M., Makokha, S., Emongor, R. A., and Taracha, C. (2022). Modeling the Adoption and Intensity of Climate-smart Maize Varieties in Embu County, Kenya: Double Hurdle Approach. *Afr. J. Food Agric. Res. Ext.* 17, 1-15. https://doi.org/10.53936/afjare.2022.17(3).15

Wekesa, B. M., Ayuya, O. I., and Lagat, J. K. (2018). Effect of climate-smart agricultural practices on household food security in smallholder production systems: micro-level evidence from Kenya. *Agric. Food Secur.* 7, 1-14. https://doi.org/10.1186/s40066-018-0230-0

Zampaligré, N., and Fuchs, L. (2019). Determinants of adoption of multiple climate-smart adaptation practices in sudano-sahelian pastoral and agropastoral production systems. *Sustainability* 11, 4831. https://doi.org/10.3390/su11184831

Zantsi, S. (2021). Unlocking the potential of the emerging smallholder farming sector in South African agriculture: An agent-based approach. Doctoral dissertation, Stellenbosch University, Stellenbosch. https://scholar.sun.ac.za/

Zeweld, W., Van Huylenbroeck, G., Tesfay, G., Azadi, H., and Speelman, S. (2020). Sustainable agricultural practices, environmental risk mitigation and livelihood improvements: Empirical evidence from Northern Ethiopia. *Land Use Policy* 95, 103799. https://doi.org/10.1016/j.landusepol.2019.01.002

Zougmore, R. B., Partey, S. T., Ouédraogo, M., and Torquebiau, E. (2018). Facing climate variability in sub-Saharan Africa: analysis of climate-smart agriculture opportunities to manage climate-related risks. *Cah. Agric.* 27, 1-9. https://doi.org/10.1051/cagri/2018019

CHAPTER 5

The Economic Benefits and Efficiency of Climate-Smart Agricultural Practices Adoption by Smallholder Maize Farmers in KwaZulu-Natal Province, South Africa.

Abstract

Climate change poses escalating threats to agricultural productivity and food security globally, with smallholder farmers in developing regions particularly vulnerable due to limited adaptive capacity and resource constraints. Despite the documented advantages of Climate-Smart Agricultural Practices (CSAPs) to enhance productivity and resilience, adoption rates among smallholder maize farmers in South Africa remain suboptimal, creating a significant gap between potential and realized economic benefits. Limited empirical evidence exists on the actual economic returns and production efficiency gains from CSAPs adoption, hindering informed decision-making by farmers, policymakers, and financial institutions regarding investment in CSAPs. This study examined the economic benefits and efficiency of CSAPs adoption among smallholder maize farmers in KwaZulu-Natal Province, South Africa. The Production Theory served as the theoretical framework, using cross-sectional data from 378 farmers. Gross Margin Analysis and Stochastic Production Function were employed to measure both immediate economic returns and production efficiency gains associated with CSAPs. Four specific CSAPs were evaluated: drought-tolerant maize varieties, rainwater harvesting systems, maize-legume intercropping, and crop diversification. Results revealed a moderate 47.1% adoption rate among smallholder maize farmers in the study area, with drought-tolerant maize varieties being the most widely adopted practice (37.3%). Economic impact analysis demonstrated substantial benefits from CSAP adoption, with adopters experiencing an average gross margin improvement of ZAR 1,012 per season, representing a substantial 45.7% increase from pre-adoption levels. Key determinants of economic benefits included education level, household income, and credit access, with credit access showing the largest magnitude effect (ZAR 649.14 higher benefits for farmers with credit access). The Stochastic Production Function analysis reveals significant improvements in technical efficiency from 68.5% to 85.2% following CSAPs adoption, with household income, education, credit access, extension services, training access, and climate information significantly increasing technical efficiency. Conversely, age, household size, and farming experience were positively associated with technical inefficiency, indicating that older farmers and those with larger households face greater challenges in optimizing CSAPs. Cost efficiency distribution analysis showed improvements in farmer performance, with the proportion of farmers achieving less than 50% cost efficiency declining from 28.65% to 19.2% following CSAP adoption, while mean cost efficiency improved from 61.2% to 68.5%. These empirical findings strongly aligned with Production Theory's fundamental assumptions about rational farmer behaviour and profit maximization under resource constraints. Policy recommendations include enhanced educational and training programs focusing on practical demonstrations, accessible agricultural credit products with flexible repayment terms, and strengthened extension services providing comprehensive technical support. Additionally, targeted interventions should address institutional barriers particularly affecting female farmers who constitute 63% of agricultural decision-makers in the study area.

Keywords: Climate-smart agriculture, Economic Benefits, Technical Efficiency, Smallholder Farmers, Maize Production, KwaZulu-Natal.

5.1 Introduction

Agriculture serves as the economic foundation for numerous countries across Sub-Saharan Africa (SSA), playing a vital role in employment generation, livelihood sustenance, and food security provision (Wudil et al., 2022). As of 2021, 52% of employed people in SSA work in agriculture, with employment in the sector having declined from approximately 61.7% in 2000 to 52.3% in 2020 (United Nations Conference on Trade and Development [UNCTAD], 2022). The majority (82%) of those in extreme poverty live in rural areas, and more than three-quarters (76%) of working adults in extreme poverty are employed in agriculture (Ritchie, 2022). Approximately 60% of the regional population relies directly on smallholder farming systems for both subsistence and income generation (Food and Agriculture Organization [FAO], 2022). Maize stands as a critically important staple food crop among the region's agricultural commodities, representing nearly 50% of total cereal production and constituting the primary caloric source for millions of people. Nevertheless, maize cultivation in SSA faces significant threats from climate variability and extreme weather events, including droughts, floods, and unpredictable rainfall patterns (Du and Xiong, 2024). These climatic disruptions not only diminish agricultural yields but also intensify poverty levels and food insecurity, particularly among smallholder farmers who possess limited adaptive capacity to respond to rapidly evolving climatic conditions. The agricultural sector confronts a complex challenge: experiencing vulnerability to climate change impacts while simultaneously contributing substantially to greenhouse gas emissions (OECD, 2016; Smith et al., 2008). Climate change adverse effects pose serious threats to agricultural productivity, food security, and rural livelihoods globally, with particularly severe impacts in developing regions characterized by rain-fed agricultural systems (FAO, 2018; Kassie et al., 2013).

In South Africa, maize represents the most extensively cultivated crop and serves as the foundation of national food security (Mdoda et al., 2025). Annual maize production in the country ranges from approximately 12-16 million tons, with smallholder farmers contributing a substantial 4.4% share of total cultivation, concentrated primarily in rural regions (Oduniyi et al., 2022). This farming segment encompasses more than 2.9 million smallholder households that experience disproportionate impacts from climate-related stressors (Sinyolo et al., 2021). Climate change economic consequences are increasingly apparent, evidenced by temperature rises of 1.5-2.0°C documented over four decades and recurring drought events causing considerable economic damage (Statistics South Africa, 2019). The devastating 2015-2016 El Niño-induced drought resulted in a 30% reduction in maize production, generating estimated economic losses of ZAR 7.2 billion in agricultural output (Ngcamu and Chari, 2022).

KZN Province exemplifies these economic challenges, experiencing especially severe climate variability with substantial financial consequences for smallholder farming communities. Temperature increases of 1.8°C have been recorded since 1960, coupled with a 15% reduction in annual rainfall patterns (Mthethwa et al., 2022). These climatic changes have generated estimated agricultural losses totalling ZAR 2.8 billion during 2010-2020, with maize production experiencing an average annual decline of 12%, directly affecting farmers' income levels and household economic stability (Kumar et al., 2022). Additionally, KZN confronts significant poverty and food insecurity challenges, with approximately 65.3% of households experiencing food insecurity, establishing a destructive cycle whereby climate impacts diminish agricultural income, thereby restricting farmers' investment capacity in adaptive measures (Aderaw et al., 2017). Mid-century projections indicate potential yield reductions of 15-30%, threatening to decrease smallholder farmers' agricultural income by ZAR 3,500-6,000 per household annually (Mangani et al., 2019).

To address these economic and environmental challenges, Climate-Smart Agriculture (CSA) has gained prominence as a strategic framework for transforming agricultural systems. CSA promotes practices that increase productivity and incomes sustainably, strengthen farmers' resilience to climate-related shocks, and reduce agriculture's carbon footprint (FAO, 2018; Lipper et al., 2014). For maize farmers, Climate-Smart Agricultural Practices (CSAPs) encompass interventions such as conservation agriculture, crop diversification, drought-tolerant varieties, and rainwater harvesting (Mahama et al., 2020). These practices have demonstrated significant potential to enhance yield stability, reduce risk exposure, and improve economic outcomes. Research indicates that drought-tolerant maize varieties can reduce yield losses by 20-30% during drought years, while conservation agriculture practices can improve soil water retention by 15-25% and reduce input costs by up to 30% (Zougmore et al., 2018). Economic analyses demonstrate that CSAPs can simultaneously address climate adaptation and income generation objectives, making them particularly valuable for smallholder farmers facing multiple economic and climate-related risks (Kurgat et al., 2020; Wekesa et al., 2018).

Despite this economic promise, CSAP adoption by smallholder maize farmers remains suboptimal across South Africa, with adoption rates typically ranging between 15-45% across different provinces (Abegunde et al., 2019). Many farmers are either unaware of these practices, lack financial means for implementation, or are uncertain about economic returns, creating a significant gap between potential and realized economic benefits. Understanding the economic benefits and efficiency gains from CSAP adoption is crucial for informing policy decisions, extension programs, and financial service provision that can enhance smallholder farmers' livelihoods and agricultural sustainability. Previous research on CSAP economic impacts has primarily focused on specific practices in isolation without comprehensively examining the economic benefits and efficiency gains of integrated CSAP adoption (Abegunde et al., 2019). Furthermore, there is limited understanding of factors determining the magnitude of economic benefits and efficiency gains from CSAP adoption among smallholder maize farmers. The economic returns from CSAPs are influenced by numerous factors, including farmer characteristics, resource endowments, market access, and institutional support, yet comprehensive analyses examining both economic benefits and production efficiency are scarce (Musafiri., 2020).

This study aims to measure the economic benefits and efficiency of CSAP adoption among smallholder maize farmers in KZN Province. This research seeks to generate insights for more effective policies promoting economically viable CSAPs through comprehensive economic analysis. Specifically, the research seeks to: (i) measure the direct economic benefits of CSAP adoption through comprehensive gross margin analysis; (ii) evaluate the technical efficiency gains from CSAP adoption using stochastic production function analysis; and (iii) identify the determinants of economic benefits and efficiency improvements from CSAP adoption. The findings will contribute to the growing literature on CSAP economic impacts while providing practical recommendations for policymakers, financial institutions, and extension services.

Ultimately, the study will enhance economic returns, production efficiency, and sustainable development in South Africa's smallholder agricultural sector, informing investment decisions and policy interventions for more economically viable and climate-resilient farming systems in KZN and beyond.

5.2 Production Theory for measuring economic benefits of climate-smart agricultural practices by smallholder maize farmers

This study is anchored in Production Theory, which provides a robust theoretical framework for analysing how farmers make production decisions to maximize output and profits while minimizing costs under resource constraints and environmental uncertainties. Production Theory is particularly suitable for measuring the economic benefits and efficiency of CSAP adoption because it recognizes that farmers operate as rational economic agents seeking to optimize their production outcomes within available resources, technology, and market constraints (Zheng et al., 2024). According to Production Theory, farmers combine various inputs (land, labour, capital, and technology) to produce outputs, with the primary objective of maximizing profits subject to production possibilities and market constraints (Badarch, 2024). CSAPs represent technological innovations that can shift the production function, enabling farmers to achieve higher outputs with the same inputs or maintain output levels with fewer inputs, thereby improving both productivity and technical efficiency (Ma and Rahut, 2024). This theoretical foundation directly supports the dual analytical approach employed in this study, combining Gross Margin Analysis for measuring economic benefits and Stochastic Production Function for evaluating efficiency gains.

The core of Production Theory lies in the production function relationship, expressed as Y = $Y = f(X_1, X_2, \ldots, X_n)$, where Y represents agricultural output and X represents various inputs. Recent studies demonstrate that CSAPs can be modelled as technology shifters in this production function (Badarch, 2024). CSAPs adoption fundamentally alters this relationship by improving input utilization efficiency and potentially shifting the entire production frontier outward. Farmers are assumed to maximize profits (π) according to $\pi = PY - \Sigma_{wi} X_i$, where P represents output price and $W_i$represents input prices. This framework directly justifies the use of Gross Margin Analysis, as it captures the fundamental economic decision-making process of smallholder farmers who must balance revenue generation against variable cost management. The theory posits that rational farmers will adopt CSAPs if the expected increase in profits from adoption exceeds implementation costs and associated risks.

Production Theory encompasses technical efficiency, which measures how effectively farmers convert inputs into outputs relative to best possible performance. Empirical evidence demonstrates that CSAPs significantly improve technical efficiency by enhancing resource utilization and reducing production risks (Yu et al., 2020). This component directly supports the use of Stochastic Production Function analysis, which decomposes total productivity into efficient and inefficient components while accounting for random variations beyond farmers' control. The theory recognizes that CSAP adoption can enhance production through input-augmenting effects (making existing inputs more productive), input-saving effects (reducing input quantities needed), and risk-reducing effects (stabilizing production outcomes). Comprehensive reviews confirm that CSAPs enhances farm productivity and incomes through increasing crop yields, improving technical efficiency, and optimizing resource use (Zheng et al., 2024). Production Theory thus provides a comprehensive theoretical foundation that unifies economic benefits measurement and efficiency assessment approaches, enabling thorough evaluation of how CSAPs impact smallholder maize farmers' economic performance and production optimization.

5.3 Materials and methods

5.3.1 Description and study area selection

As previously mentioned in chapter three of this thesis, the study was conducted in KwaZulu-Natal Province, South Africa, specifically focusing on Harry Gwala District Municipality (HGDM) and Ugu District Municipality (UDM). For a detailed description of the study area characteristics, agro-ecological conditions, climate vulnerabilities, and the selection process rationale, please refer to chapter three, Section 3.3.1.

5.3.2 Research Design

A cross-sectional research design with a mixed-methods approach was utilized to gather comprehensive data on CSAP adoption patterns and their economic benefits and efficiency among smallholder maize farmers. For a detailed explanation of the design choice and its theoretical justification, please refer to chapter three, Section 3.3.1.

5.3.3 Sampling technique and data collection

The results presented here are based on a sample of 378 smallholder maize farmers from both HGDM and UDM, selected through a multi-stage sampling procedure to ensure representativeness across the two contrasting agro-ecological zones. Data was collected through structured questionnaires administered via face-to-face interviews, translated into isiZulu where necessary, to ensure clarity and gather detailed information on farmers' demographic and socioeconomic characteristics, farm characteristics, institutional factors, and detailed economic data including production costs, yields, revenues, and input usage. A pre-testing phase with 38 respondents tested the questionnaire's validity and reliability but was excluded from the final analysis to maintain research integrity. The surveys captured comprehensive information on CSAPs adoption patterns, economic performance indicators, production efficiency measures, and factors influencing both adoption decisions and economic outcomes among smallholder farmers. Refer to Chapter Three (Sections 3.3.2 and 3.3.3) for detailed information on the sampling methodology, sample size calculation, and data collection procedures for this study.

5.3.4 Descriptive statistics

Descriptive statistics were employed to characterize smallholder maize farmers' demographic and socioeconomic profiles. The descriptive analysis encompassed frequency distributions (percentages) and measures of central tendency (means, ranges, and standard deviations). The data were presented through tables and figures to provide a clear visual representation of the findings. This approach was particularly important as study by Autio et al. (2021) and Ojoko et al. (2017) indicated that many smallholder farmers unconsciously practice CSA as part of their traditional farming systems. Therefore, it was critical to identify and assess the frequency of farmers using specific CSAPs such as drought-tolerant maize varieties, maize-legume intercropping, rainwater harvesting, and crop diversification. The descriptive statistics provided the key socioeconomic characteristics of sampled smallholder farmers.

5.4 Gross Margin analysis and stochastic production function

5.4.1 Gross Margin Analysis

Gross Margin Analysis served as the primary tool for quantifying the direct economic benefits of CSAP adoption among smallholder maize farmers. This method was particularly well-suited for measuring farm-level profitability because it focused on the relationship between revenue generation and variable cost management, which are central concerns for resource-constrained smallholder farmers. Recent empirical evidence has shown that Gross Margin Analysis effectively distinguishes between profitable and less profitable farming systems, with studies demonstrating significantly higher gross margin values for improved agricultural systems compared to conventional systems (Kemboi et al., 2020). The approach provided clear, interpretable measures of the financial returns to CSAP investment by comparing total revenue against variable production costs, enabling straightforward economic comparisons between CSAP adopters and non-adopters.

The gross margin was calculated using the following specification:

$$GM = TR - TVC$$

Where GM represents the gross margin in Rands per hectare, TR denotes total revenue from maize production in Rands, and TVC represents total variable costs of production in Rands. To assess the economic impact of CSAP adoption, the difference in gross margins between adopters and non-adopters was calculated as:

$$GM_{diff} = GM_{adopters} - GM_{non-adopters}$$

To examine the determinants of economic benefits from CSAP adoption, a linear regression model was specified as:

$$GM_i = \beta_0 + \beta_1 CSAP_i + \sum_{j=2}^{k} \beta_j X_{ji} + \varepsilon_i$$

Where GM_i represents the gross margin in Rands for the i-th farmer, $CSAP_i$ is a dummy variable equal to 1 if the farmer adopted CSAPs and 0 otherwise, X_{ji}represents a vector of socioeconomic and farm characteristics, including age, education, farming experience, household monthly income, farm size, and access to institutional services, β_0, β_1, ..., β_k are parameters to be estimated, and ε_i is the error term assumed to be independently and identically distributed with zero mean and constant variance.

5.4.2 Stochastic Production Function Analysis

The Stochastic Production Function provided a sophisticated framework for measuring the production efficiency gains from CSAP adoption. This approach was particularly appropriate for agricultural efficiency analysis because it explicitly accounted for random shocks and measurement errors inherent in farming systems, where production outcomes are influenced by uncontrollable factors such as weather variability, pest outbreaks, and market fluctuations. Recent studies have validated the effectiveness of stochastic frontier analysis as a methodological tool to evaluate the technical efficiency of agricultural production among smallholder farmers, with research demonstrating that such approaches provide valuable insights into farm competitiveness and policy design (Cai et al., 2024; Lutonja, 2023). This method enabled the decomposition of production performance into systematic efficiency components and random variations, allowing for precise isolation of the efficiency effects attributable to CSAP adoption.

The stochastic production frontier model was specified following the approach introduced by Aigner, Lovell and Schmidt (1977) and Meeusen and van den Broeck (1977):

$$In\ Y_i = \beta_0 + \sum_{j=1}^{n} \beta_j\ In\ X_{ji} + V_i - U_i$$

Where Y_i represents the output (maize yield in kg/ha) of the i-th farm, X_{ji} denotes the j-th input used by the i-th farm including land area, seeds, fertilizer, and labour, β_0 and β_j are parameters to be estimated, V_i is a two-sided random error term that accounts for measurement errors and random shocks beyond the farmer's control, assumed to be independently and identically distributed as $N(0, \sigma v^2)$, and $U_i$is a one-sided non-negative random variable representing technical inefficiency, assumed to follow a half-normal distribution $N(0, \sigma u^2)$

Technical efficiency for each farm was calculated as:

$$TE_i = \exp(-U_i)$$

The technical inefficiency term $U_i$was modeled to examine the factors influencing efficiency variations among farmers:

$$U_i = \delta_0 + \delta_1 CSAP_i + \sum_{k=2}^{m} \delta_k Z_{ki} + W_i$$

Where $CSAP_i$is a dummy variable for CSAP adoption, Z_{ki}represents the k-th explanatory variable for technical inefficiency including farmer characteristics (age, education, farming experience), farm attributes (farm size, household monthly income), and institutional factors (access to credit, extension services, agricultural training), δ_0, δ_1, ..., δ_m are parameters to be estimated, and W_i is a random error term assumed to be independently distributed as $N(0, \sigma w^2)$.

The variance parameters of the model include $\sigma^2 = \sigma v^2 + \sigma u^2$, which measures the total variation of output from the frontier, and $\lambda = \sigma u / \sigma v$,which indicates the relative importance of technical inefficiency in explaining the total variance. If λ approaches zero, then technical inefficiency effects are not important, and ordinary least squares estimation would be adequate.

However, if λ is significantly different from zero, then technical inefficiency effects are important, justifying the use of the stochastic frontier approach.

The stochastic frontier model was estimated using maximum likelihood estimation (MLE) methods implemented in Stata version 18. The log-likelihood function for the model was specified to jointly estimate the production frontier parameters and the technical inefficiency effects. Post-estimation diagnostic tests were conducted to ensure the validity of the distributional assumptions and the significance of the inefficiency effects in the model specification.

5.5 Description of the explanatory variables used in the Gross Margin Analysis and Stochastic Production Function models and their expected outcomes

Table 5.1 summarizes the explanatory variables included in the Gross Margin Analysis and Stochastic Production Function models to assess the economic benefits and efficiency gains of CSAP adoption among smallholder maize farmers in KZN. The Gross Margin Analysis measures the direct economic benefits by comparing total revenue against variable production costs between adopters and non-adopters, while the Stochastic Production Function evaluates technical efficiency gains from CSAP adoption. These variables are hypothesized to influence both the decision to adopt CSAPs and the resulting economic performance and production efficiency among smallholder maize farmers.

Table 5.1 Explanatory variables used in the Gross Margin Analysis and Stochastic Production Function models to assess economic benefits of climate-smart agriculture practices adoption

Variable	**Description and measurement (Type)**	**Expected outcome (+/-)**
Demographics		
Gender	Smallholder farmer's gender (female = 0; male = 1) (dummy)	+
Age	Age of the smallholder farmer in years (continuous)	+/-
Education	Number of years of formal schooling by the smallholder farmer (continuous)	+
Family Size	Number of members in the smallholder farmer's household (continuous)	+
Household Income	Total household income of the smallholder farmer (continuous)	+
Employment Status	Employment status of the smallholder farmer (unemployed = 0; employed = 1) (dummy)	+/-
Farm Characteristics		
Farm Size	Size of the smallholder farmer's land in hectares (continuous)	+
Farming Years	Number of years of farming experience by the smallholder farmer (continuous)	+
Maize Area	Area under maize cultivation in hectares (continuous)	+

Production V		
Maize Yield	Maize yield per hectare in kg/ha (continuous)	+
Seed Costs	Cost of seeds per hectare (continuous)	-
Fertilizer Costs	Cost of fertilizers per hectare (continuous)	+/-
Pesticide Costs	Cost of pesticides/herbicides per hectare (continuous)	+/-
Labour Costs	Cost of hired labour per hectare (continuous)	+/-
Equipment Costs	Cost of tractor/equipment hire per hectare (continuous)	+/-
Transport Costs	Cost of transport and storage per hectare (continuous)	
CSAP Variables		
CSAP Adoption	Whether the farmer has adopted any CSAP (no = 0; yes = 1) (dummy)	+
Drought-Tolerant Varieties	Adoption of drought-tolerant maize varieties (no = 0; yes = 1) (dummy)	+
Maize-Legume Intercropping	Adoption of maize-legume intercropping (no = 0; yes = 1) (dummy)	+
Rainwater Harvesting	Adoption of rainwater harvesting techniques (no = 0; yes = 1) (dummy)	+
Crop Diversification	Adoption of crop diversification (no = 0; yes = 1) (dummy)	+
CSAP Intensity	Number of CSAPs adopted (0-4) (continuous)	+
Years of CSAP Use	Number of consecutive seasons using CSAPs (continuous)	+
CSAP Coverage	Percentage of farm area under CSAPs (0-100%) (continuous)	+
Institutional V		
Access to Credit	Whether the farmer has access to agricultural credit (no = 0; yes = 1) (dummy)	+
Access to Extension Services	Whether the farmer has access to extension services (no = 0; yes = 1) (dummy)	+
Agricultural Training	Whether the farmer received specialized agricultural training (no = 0; yes = 1) (dummy)	+
Economic Outcome Variables		
Total Revenue	Total revenue from maize production (Rand)	+
Total Variable Costs	Total variable costs of production (Rand)	-
Gross Margin	Total revenue minus total variable costs (Rand)	+

Note +/− Depicts the direction of influence on economic benefits (positive/negative)

Gross Margin Analysis: Compares gross margins between CSAP adopters and non-adopters, Stochastic Production Function: Measures technical efficiency gains from CSAP adoption using yield as output and inputs (land, seeds, fertilizer, labour, equipment) as explanatory variable

Source: Authors (2025)

5.6 Results and discussion

This section presents findings from 378 smallholder maize farmers in KZN Province. The results cover demographic profiles, CSAP adoption patterns, economic benefits analysis, and technical efficiency outcomes. Key findings include gross margin comparisons between adopters and non-adopters, determinants of economic benefits, and stochastic frontier analysis results. Each subsection combines empirical findings with relevant discussion and comparison to existing literature.

5.6.1 Demographic characteristics of the sampled smallholder maize farmers in KwaZulu-Natal

The sample distribution reveals a significant gender imbalance, with females constituting the majority (63%) of respondents compared to males (37%), though this distribution remains similar between adopters (62% female) and non-adopters (64% female), suggesting that gender alone does not significantly differentiate adoption behaviour. However, key demographic differences emerge between the groups across multiple socioeconomic dimensions. Adopters demonstrate clear advantages in human capital, being younger (mean 49 years vs 54 years) and more educated (mean 11 vs 9 years of schooling), indicating that age and education play crucial roles in CSAPs adoption decisions. The age profile indicates a mature farming population with respondents averaging 52 years (SD=17.04). This middle-aged demographic pattern, combined with moderate educational attainment, may influence farmers' capacity to comprehend and implement complex CSAPs. This potentially requires simplified extension approaches and hands-on demonstration methods rather than text-based information delivery.

Economic vulnerability significantly constrains adoption capacity, with adopters having substantially higher household incomes (ZAR12,450 vs ZAR9,126) and better employment opportunities (45% vs 35%), confirming that financial capacity and livelihood diversification remain critical determinants of CSAP adoption. The household composition shows adopters maintaining larger households (7 vs 6 members per household), potentially providing enhanced labour capacity for CSAPs implementation, though this advantage is severely constrained by extremely limited landholdings (mean 0.01 ha) affecting both groups. Most striking are the institutional access disparities, where adopters consistently demonstrate superior access across all support systems. This is particularly evident in agricultural credit access (50% vs 39%), extension services (42% vs 28%), and training (38% vs 25%). Climate information access remains relatively high for both groups (76% vs 67%). These findings reveal a profound knowledge-implementation gap where high CSAPs awareness (80%) exists alongside significant institutional barriers, particularly affecting the 63% female agricultural decision-makers who face greater constraints in accessing credit, extension services, and training. The substantial institutional void, combined with moderate educational attainment and economic vulnerability, explains why adoption rates remain moderate (47.1%) despite high awareness levels.

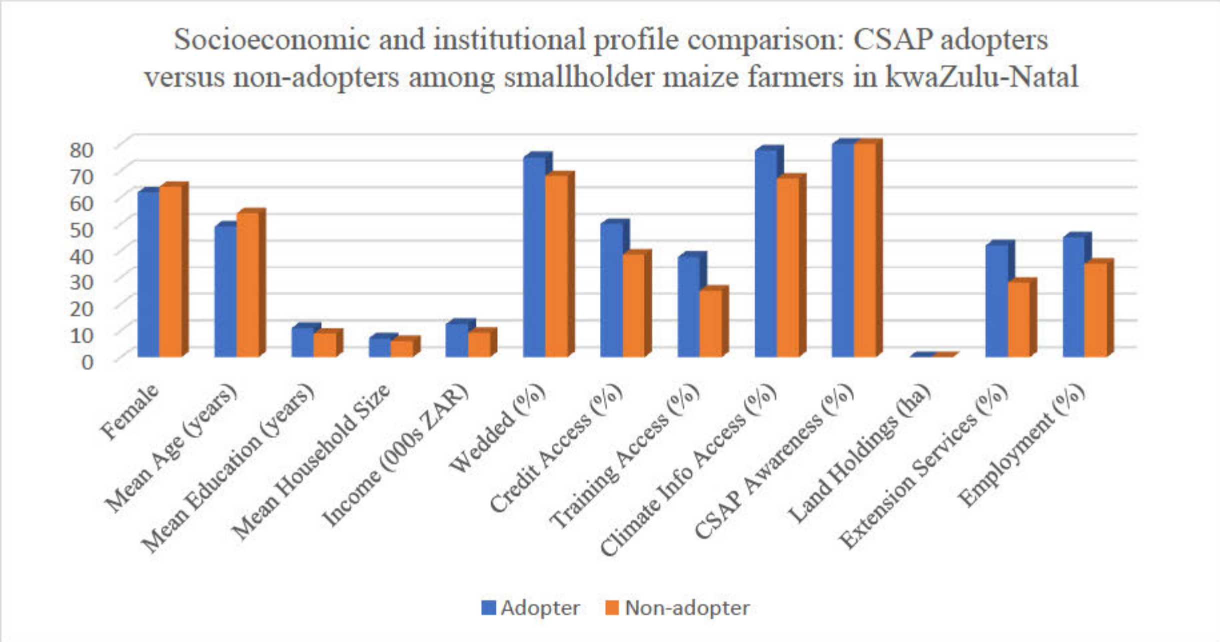

Figure 5.1 Demographic and socioeconomic profile comparison between CSAP adopters and non-adopters among smallholder farmers
Source: Survey data generated through Stata version 18 (2025)

5.6.2 Status of climate-smart agriculture practices adopted by smallholder maize farmers in KwaZulu-Natal

The adoption status among smallholder maize farmers indicated a moderate level of CSAP uptake, with 178 farmers (47.1%) having adopted at least one CSAP, while 200 farmers (52.9%) had not adopted any, reflecting varied adoption patterns across the sample. The 47.1% adoption rate observed in this study falls squarely within the documented range of 39-53% reported in comparable studies across developing regions (Aryal et al., 2021;Kurgat et al., 2020; Amadu et al., 2020; Zeweld et al., 2020; Tesfaye and Tirivayi, 2020). This consistency across diverse geographical and agricultural contexts strengthens the validity of the current findings and suggests that the identified adoption patterns reflect fundamental dynamics in smallholder decision-making regarding CSAPs. The substantial proportion of non-adopters (52.9%) underscores the critical importance of targeted interventions to address barriers to adoption, particularly information access (Khataza et al., 2021), financial constraints (Amadu et al., 2020), and technical knowledge gaps (Aryal et al., 2022; Zeweld et al., 2020). As climate change impacts intensify, bridging these adoption gaps becomes increasingly urgent for enhancing agricultural resilience.

5.6.3 Specific climate-smart agricultural practices adoption patterns and distribution among smallholder farmers in KwaZulu-Natal

The moderate overall CSAP adoption rate of 47.1% observed in the previous section masks significant variations in the uptake of specific CSAPs among smallholder maize farmers. Table 5.2 reveals that adoption rates vary considerably across the four evaluated CSAPs, ranging from 22.0% for crop diversification to 37.3% for drought-tolerant maize varieties. Drought-tolerant maize varieties emerged as the most widely adopted practice (37.3%), reflecting universal recognition of drought risks and relatively straightforward implementation that requires minimal changes to existing farming systems (Abegunde et al., 2019). Rainwater harvesting achieved the second-highest adoption rate (35.2%), indicating farmers' growing awareness of water scarcity challenges and the economic benefits of supplemental irrigation, supporting findings by Wekesa et al. (2018) that water management practices provide measurable improvements in yield stability among smallholder farmers.

Maize-legume intercropping showed moderate adoption (30.4%), reflecting both the technical complexity of managing multiple crops simultaneously and the substantial benefits of nitrogen fixation and risk diversification, comparable to findings by Kassie et al. (2013) in Tanzania where intercropping systems required higher technical knowledge despite proven soil fertility benefits. Crop diversification recorded the lowest adoption rate (22.0%), highlighting substantial barriers associated with market access and technical knowledge requirements, aligning with research by Amadu et al. (2020) who found that crop diversification faced the greatest adoption constraints due to market uncertainties and increased management complexity. The substantial proportion of non-adopters across all practices (ranging from 62.7% to 78.0%) underscores persistent barriers to CSAP uptake and represents significant unrealized potential for improving agricultural productivity, climate resilience, and economic outcomes among smallholder maize farmers in KZN.

Table 5.2 Climate-smart agricultural practices adoption rates among smallholder maize farmers in KwaZulu-Natal

Climate-Smart Agricultural Practice	Adopters (n)	Adoption Rate (%)	Non-adopters (n)
Drought-tolerant maize varieties	141	37.3	237
Maize-legume intercropping	115	30.4	263
Rainwater harvesting	133	35.2	245
Crop diversification	83	22.0	295
Overall CSAP adoption	**178**	**47.1**	**200**

Note Total sample = 378 farmers. Individual practice adoption rates are calculated from the 378 total farmers, while overall adoption represents farmers who adopted at least one CSAP.

Source: Survey data generated through Stata version 18 (2025)

5.6.4 Economic benefits of climate-smart agricultural practices adoption

The gross margin budget analysis (Table 5.3) demonstrates substantial economic benefits from CSAP adoption, with adopters achieving a substantial 45.7% increase in gross margins from ZAR 2,213 to ZAR 3,224 per season. This improvement was driven primarily by enhanced productivity (22.6% yield increase), and improved market access (10.5% price increase), while variable costs increased modestly by only 15.3%. These findings align with recent comprehensive reviews demonstrating that CSAPs improve farm productivity and incomes through increasing crop yields and productivity, income and profitability, and technical and resource use efficiency (Zheng et al., 2024). The substantial improvement in gross margins reflects the productivity benefits of climate-smart practices, supporting evidence from South Africa where conservation agriculture adoption by smallholder maize farmers demonstrated significant welfare impacts through improved farm productivity and income generation (Oduniyi et al., 2022).

The efficiency indicators reveal exceptional resource optimization, with the return ratio on variable costs improving from 1.96:1 to 2.48:1, meaning every rand invested in variable inputs generated ZAR 2.48 in gross margin returns after CSAP adoption. This superior performance is consistent with recent evidence from SSA demonstrating that CSAP adoption by smallholder farmers delivers significant welfare impacts through enhanced resource utilization and improved livelihood outcomes (Ahmed et al., 2024). The improved variable cost ratio (from 33.7% to 28.7%) indicates enhanced resource efficiency, supporting findings from Ethiopia where CSAPs improve the use of agricultural resources through combined management of soil, water, and biological resources, ultimately leading to increased crop yields and minimized risk of crop failure (Gebeyehu, 2023). Recent studies across developing countries confirm that smallholder farmers implementing sustainable CSAPs achieve higher yields, incomes, and improved environmental performance, which is crucial for ensuring food security and sustainable development (Yin et al., 2024). These results provide compelling empirical evidence that CSAP adoption delivers measurable economic benefits through improved productivity and resource efficiency among smallholder maize farmers.

Table 5.3 Gross Margin Budget for smallholder maize farmers – before and after climate-smart agricultural practices adoption (ZAR per season)

Item	Before CSAP	After CSAP	Change
GROSS INCOME			
Maize yield (kg)	146.33	179.47	+33.14
Price per kg (ZAR)	22.81	25.20	+2.39
Total Gross Income	3,338.52	4,522.64	+1,184.12
VARIABLE COSTS			
Seeds	140.57	221.80	+81.23
Fertilizers	170.55	197.96	+27.41
Pesticides/herbicides	37.40	51.53	+14.13
Hired labour	116.46	126.97	+10.51
Equipment hire	323.58	340.36	+16.78
Transport	337.12	359.55	+22.43
Total Variable Costs	1,125.68	1,298.17	+172.49
GROSS MARGIN CALCULATION			
Total Gross Income	3,338.52	4,522.64	+1,184.12
Less: Variable Costs	(1,125.68)	(1,298.17)	(+172.49)
GROSS MARGIN	2,212.84	3,224.47	+1,011.63
PROFITABILITY RATIOS			
Gross margin per kg (ZAR)	15.12	17.97	+2.85
Variable cost ratio (%)	33.7%	28.7%	-5.0%
Return on variable costs (%)	196.5%	248.4%	+51.9%

Notes Gross Margin = Gross Income – Variable Costs; Before CSAP = Season prior to adopting CSAP; After CSAP = Most recent season following CSAP adoption

Source: Survey data (2025)

5.6.5 Determinants of economic benefits from climate-smart agricultural practices adoption

The regression analysis (Table 5.4) employs two complementary econometric models to examine the determinants of economic benefits from CSAP adoption among smallholder maize farmers. Model 1 (Impact Model) analyzes the change in gross margins following CSAP adoption, measuring how farmer characteristics influence the magnitude of economic benefits realized from the transition to climate-smart practices. Model 2 (Post-Adoption Model) examines absolute post-adoption gross margin performance while controlling for baseline productivity through the inclusion of pre-adoption gross margins, enabling assessment of factors that determine overall economic success following CSAP implementation. Both models use robust standard errors and focus exclusively on CSAP adopters to examine heterogeneous treatment effects among farmers who have implemented CSAPs, providing insights into why some adopters achieve greater economic benefits than others.

Before estimating the linear regression model for the determinants of economic benefits from CSAP adoption, diagnostic tests were conducted to ensure that the assumptions of the classical linear regression model were satisfied. The degree of multicollinearity among the explanatory variables was examined using the Variance Inflation Factor (VIF). The results indicated that all VIF values were well below the threshold value of 10, with a mean VIF of 1.84, suggesting that multicollinearity was not a serious concern in the model. Furthermore, the Breusch–Pagan/Cook–Weisberg test was employed to assess the presence of heteroscedasticity. The test yielded a Chi-square statistic of 2.37 with a p-value of 0.124, indicating that the null hypothesis of homoscedasticity could not be rejected. This implies that the error terms exhibited constant variance across observations. Therefore, the model residuals satisfied the assumptions of the linear regression framework, ensuring that the estimated coefficients and standard errors were efficient and reliable for statistical inference.

Table 5.4 Determinants of economic benefits from climate-smart agricultural practices adoption

Variable	**Impact Model**			**Post-Adoption Model**		
	Margin Change			**After Gross Margin**		
	Coeff.	t-value	p-value	Coeff.	t-value	p-value
Demographic Characteristics						
Age	4.305	0.30	0.763	3.933	0.28	0.778
Education (years)	27.771	2.40	0.018**	25.425	2.11	0.036**
Family Size	-8.451	-0.22	0.824	-6.654	-0.17	0.862
Male (1=yes)	-453.180	-1.30	0.197	-472.407	-1.35	0.179
Economic Characteristics						
Household Income (ZAR)	0.049	1.69	0.093*	0.053	1.72	0.087*
Farm Characteristics						
Farm Size (ha)	2,229.687	1.37	0.173	2,407.481	1.19	0.234
Farming Years	8.863	0.49	0.624	9.641	0.54	0.589
Institutional Access						
Credit Access (1=yes)	649.140	2.85	0.005***	615.442	2.67	0.009***
Extension Access (1=yes)	402.216	2.27	0.025**	388.654	2.11	0.036**
Training Access (1=yes)	288.412	1.67	0.097*	265.008	1.69	0.094*
Climate Info (1=yes)	-315.883	-2.14	0.034**	292.473	2.09	0.039**
Baseline Performance						
Before Gross Margin	-	-	-	0.962	5.81	0.000***
Constant	1,160.280	1.59	0.113	1,224.598	1.53	0.127
Model Statistics						
Observations	178			178		
R-squared	0.238			0.638		
Adjusted R-squared	0.192			0.612		
F-statistic	5.22			10.20		
Prob > F	0.000***			0.000***		
Root MSE	1,876.2			2,146.4		

Note *, **, & *** show statistical significance at the 10%, 5% and 1% levels, respectively. Model 1: Dependent variable = Change in Gross Margin (After - Before); Model 2: Dependent variable = After Gross Margin (ZAR)

Source**:** Survey data generated through Stata version 18 (2025)

Education emerges as a significant determinant of CSAP economic benefits in both models, with each additional year of formal schooling associated with ZAR 27.77 higher benefits (significant at the 5% level) in the impact model and ZAR 25.43 (significant at the 5% level) in the post-adoption model. This finding indicates that more educated farmers extract greater economic value from CSAP implementation, demonstrating that education enhances farmers' ability to effectively implement and optimize CSAPs, resulting in measurably higher financial returns. This result aligns with extensive literature on agricultural productivity, where Singh et al. (2018) found that education enables farmers to follow written instructions about input application and enhances their capacity to calculate costs and benefits of adopting farming technologies. Recent research by Asante et al. (2024) corroborates these findings, demonstrating that digital advisory services significantly increase the adoption of CSAPs among educated maize farmers in Ghana, with education being a key determinant of CSAPs uptake and subsequent economic benefits. Household income demonstrates significant positive effects in both models (significant at the 10% level), with each additional ZAR 1,000 in household income associated with approximately ZAR 50 higher CSAP benefits. This suggests that farmers with greater financial resources can make complementary investments that enhance CSAP effectiveness, such as improved inputs or equipment that amplify the benefits of CSAPs. The post-adoption model reveals an extremely strong persistence effect, with baseline gross margin showing a coefficient of 0.962 (significant at the 1% level). This near-unity coefficient indicates that pre-adoption productivity is the strongest predictor of post-adoption success, with farmers maintaining approximately 96% of their relative performance ranking following CSAP adoption, demonstrating strong path dependence in agricultural productivity. Peprah et al. (2021) found that financial inclusion significantly improves productivity among smallholder farmers in Ghana, with wealthier farmers better positioned to leverage credit and savings to optimize input use and timing of agricultural investments.

Extension access emerges as a highly significant institutional determinant, with farmers having access to extension services experiencing ZAR 402.22 higher benefits (significant at the 5% level) in the impact model and ZAR 388.65 higher benefits (significant at the 5% level) in the post-adoption model. This substantial positive effect demonstrates that extension services play a crucial role in enabling farmers to maximize CSAP economic returns through technical guidance and implementation support. This finding strongly aligns with recent evidence from Kenya, where Wekesa et al. (2022) demonstrated that extension services significantly improved the economic performance of CSAPs. Credit access emerges as the most significant institutional factor, with farmers having access to agricultural credit experiencing ZAR 649.14 higher benefits (significant at the 1% level) in the impact model and ZAR 615.44 higher benefits (significant at the 1% level) in the post-adoption model. This represents the largest magnitude effect among all significant variables, indicating that financial services play a critical role in enabling farmers to maximize CSAP economic returns. Credit access likely allows farmers to purchase optimal input combinations and make necessary investments that enhance the effectiveness of CSAPs. This aligns with findings from Nigeria showing that agricultural credit constraints represent a key barrier to adoption of modern agricultural technologies, with inadequate access to credit sources limiting smallholders' ability to purchase improved seeds, fertilizers, and mechanization equipment (Balana and Oyeyemi, 2022).

Training access demonstrates significant positive effects, with farmers receiving specialized agricultural training experiencing ZAR 288.41 higher benefits (significant at the 10% level) in the impact model and ZAR 265.01 higher benefits (significant at the 10% level) in the post-adoption model. This indicates that formal training programs enhance farmers' technical competencies, enabling more effective CSAP utilization that translates into measurable economic gains. Recent research by Asante et al. (2024) supports these findings, demonstrating that specialized training significantly enhanced CSAP economic outcomes among maize farmers. Climate information access shows contrasting effects between models, with a negative coefficient in the impact model (ZAR -315.88, significant at the 5% level) but positive effects in the post-adoption model (ZAR 292.47, significant at the 5% level). This apparent contradiction reflects that climate-informed farmers make more strategic but initially expensive CSAP investments based on weather forecasts, resulting in higher upfront costs that temporarily reduce net benefits. However, these informed investments prove economically superior over time as climate information enables better timing, variety selection, and practice implementation matched to anticipated conditions. This pattern aligns with findings by Naicker et al. (2025), who noted that climate information access influences adaptation strategy selection and timing, with initial investment costs potentially reducing immediate returns while enhancing long-term profitability among farmers.

5.7 Technical and cost efficiency analysis of climate-smart agricultural practices adoption among smallholder maize farmers

Table 5.5 presents the results of the stochastic frontier analysis, highlighting both production elasticities and the determinants of technical inefficiency before and after CSAP adoption. The findings reveal a significant improvement in mean technical efficiency, rising from 68.5% in the baseline period to 85.2% after adoption. All key production inputs (seeds, fertilizer, labour, and equipment) became more productive post-adoption, with fertilizer showing the largest gain in elasticity (from 0.142 to 0.345). In the inefficiency model, variables such as education, household income, credit access, extension services, training, and climate information consistently reduced inefficiency in both periods, confirming their role in enhancing efficiency. In contrast, age, household size, and farming experience were positively associated with inefficiency, indicating that older, larger, or more traditional households may face greater challenges in optimizing CSAPs. Marital status was found to be statistically insignificant, suggesting no measurable effect on technical efficiency.

Table 5.5 Stochastic frontier analysis of production elasticities and technical inefficiency determinants among farmers before and after adopting climate-smart agricultural practice

Variable	**Baseline (Before CSAP Adoption)**			**Post-Adoption (After CSAP Adoption)**		
	Coefficient	z-value	p-value	Coefficient	z-value	p-value
Production Function Inputs						
Seeds	0.185	2.34	0.019**	0.234	3.12	0.002***
Fertilizer	0.142	1.89	0.059*	0.345	4.56	0.000***
Labour	0.298	3.45	0.001***	0.156	2.89	0.004***
Equipment	0.167	2.12	0.034**	0.289	3.78	0.000***
Inefficiency Determinants						
Age	0.025	3.24	0.001***	0.018	2.34	0.019**
Education (years)	-0.055	-4.12	0.000***	-0.032	-3.45	0.001***
Household Size	0.042	2.15	0.032**	0.028	2.12	0.034**
Farming Years	0.031	2.21	0.027**	0.024	1.89	0.059*
Household Income	-0.000045	-2.89	0.004***	-0.000038	-2.67	0.008***
Credit Access (1 = yes)	-0.284	-3.45	0.001***	-0.198	-2.98	0.003***
Extension Access (1 = yes)	-0.218	-2.98	0.003***	-0.167	-2.56	0.010**
Training Access (1 = yes)	-0.187	-2.43	0.015**	-0.145	-2.23	0.026**
Climate Info (1 = yes)	-0.176	-2.09	0.037**	-0.134	-1.98	0.048**

Marital Status (1 = married)	0.042	1.02	0.307	0.036	0.89	0.374
Constant	2.856 / 1.534	4.67 / 3.78	0.000*** / 0.000***	1.967 / 0.987	3.45 / 2.34	0.001*** / 0.019**
Model Diagnostics						
Observations	178			178		
Log-likelihood	-156.34			-134.67		
Wald χ^2	89.45		0.000***	124.78		0.000***
Efficiency Parameters						
σ v	0.245			0.198		
σ u	0.398			0.289		
λ (σ_u / σ_v)	1.624		0.000***	1.459		0.000***
Technical Efficiency Scores						
Mean TE Score	0.685			0.852		
Std. Deviation	0.156			0.098		
Minimum TE	0.289			0.534		
Maximum TE	0.912			0.967		

Note *, **, & *** show statistical significance at the 10%, 5% and 1% levels, respectively. Negative coefficients in the inefficiency model reduce inefficiency (i.e., increase technical efficiency). Positive coefficients increase inefficiency, meaning reduced efficiency.

Source: Survey data generated through Stata version 18 (2025)

In both periods, all four production inputs (seeds, fertilizer, labour, and equipment) were statistically significant, underscoring their central role in maize production. Notably, the productivity of these inputs improved following CSAP adoption. Fertilizer exhibited the most pronounced increase in elasticity, rising from 0.142 ($p < 0.1$) to 0.345 ($p < 0.01$), suggesting that CSAPs enhance the efficiency of nutrient use, likely through improved soil health and conservation practices. Similarly, seed input became more productive (from 0.185 to 0.234), consistent with the promotion of drought-tolerant maize varieties and improved seed systems. These results affirm that CSAPs not only contribute to higher yields but also increase the marginal productivity of key inputs. This finding aligns with Ngango and Hong (2022), who demonstrated that improved agricultural practices significantly enhanced input productivity, with maize output improving by approximately 36% through better input use efficiency.

In the inefficiency model, several variables consistently and significantly reduced technical inefficiency. Education had a strong negative effect ($p < 0.01$) in both periods, indicating that better-educated farmers were more efficient, likely due to enhanced cognitive ability, information processing, and adoption of improved practices. This was supported by Ullah et al. (2020), who reported that farmers with higher education levels showed significantly better access to information and improved adoption of agricultural technologies in Pakistan. Similarly, credit access significantly reduced inefficiency, with a stronger effect observed before CSAP adoption. This suggested that financial inclusion enabled farmers to invest in timely and quality inputs, which was consistent with Haryanto et al. (2023), who found that access to credit from formal sources significantly improved productivity and technical efficiency of maize farming.

Furthermore, access to extension services, training, and climate information significantly reduced inefficiency in both periods, highlighting the importance of institutional and informational support. These results were in line with Biswas et al. (2021), who demonstrated that agricultural extension services significantly improved technical efficiency of paddy farmers in southwest Bangladesh, and with Jolex (2022), who found that agricultural extension services enhanced technical efficiency of maize farmers in Malawi through improved knowledge and CSAP adoption.

Household income also emerged as a significant negative predictor of inefficiency ($p < 0.01$), suggesting that wealthier households were more technically efficient. This may have been due to their greater ability to afford improved inputs, manage risks, and adopt new CSAPs. This finding supported the work of Wei and Zhang (2025), who found that formal credit access enhanced the propensity for larger-scale farming operations, with family farms showing improved technical efficiency outcomes. In contrast, age, household size, and farming experience were positively and significantly associated with inefficiency. Older farmers and those with longer farming experience may have been less flexible in adopting new CSAPs, while larger households may have faced resource allocation and labour coordination challenges. These findings aligned with the results of Ngango and Hong (2022), who observed that younger farmers demonstrated higher technical efficiency in maize production in Rwanda, and that larger household sizes were associated with coordination challenges affecting technical efficiency in maize production.

5.8 Analysis of cost efficiency distribution

The cost efficiency distribution analysis (Table 5.6) provides compelling evidence of the transformative impact of CSAP adoption on farmers' cost optimization capabilities. The distribution reveals a substantial rightward shift from lower to higher efficiency categories, The proportion of farmers achieving less than 50% cost efficiency declined from 28.65% to 19.2% following CSAP adoption, indicating a modest but meaningful improvement in resource use among the least efficient producers. The shift toward higher efficiency categories is particularly visible in the 0.80–0.89 range, where the share of farmers nearly doubled, from 6.74% to 13.16%, reflecting gradual gains in input use and cost management. Overall, the average cost efficiency rose from 61.2% to 68.5%, consistent with findings by Zheng et al. (2024), who noted that CSAP adoption generally improves technical and allocative efficiency over time. Similarly, Nanyangwe and Tembo (2024) found that CSAP in Zambia led to significant gains in smallholder maize productivity.

The improvement in minimum cost efficiency from 23.4% to 45.6% suggests that even the least efficient farmers benefited from CSAP interventions, while the reduction in standard deviation from 16.7% to 13.4% indicates more uniform cost efficiency performance across the sample. This distributional shift provides empirical support for continued investment in climate-smart agricultural strategies. The results suggest that targeted efforts aimed at less efficient farmers may yield outsized improvements in productivity, while the broader consistency in gains points to CSAPs as a viable tool for improving sustainability and profitability among smallholder farmers, an observation also emphasized by Ma and Rahut (2024).

Table 5.6 Cost efficiency distribution

Cost efficiency category	**Before CSAP**	**After CSAP**
Less than 0.50	28.65	19.2
0.50–0.59	24.16	20.85
0.60–0.69	22.47	21.33
0.70–0.79	16.29	19.24
0.80–0.89	6.74	13.16
Above 0.90	1.69	6.42
Mean	**61.20**	**68.50**

Source: Survey data generated through Stata version 18 (2025)

5.9 Conclusion and recommendations

This study examined the economic benefits and efficiency of CSAPs adoption among smallholder maize farmers in KZN Province, using Gross Margin Analysis and Stochastic Production Function within the Production Theory framework. The findings reveal that 47.1% of farmers have adopted at least one CSAP, with drought-tolerant maize varieties being the most widely adopted practice. Economic impact analysis demonstrated substantial benefits from CSAP adoption, with adopters experiencing an average gross margin improvement of ZAR 1,012 per season, representing a substantial increase from pre-adoption levels. Key determinants of economic benefits included education level, household income, and credit access, with credit access showing the largest magnitude effect. The Stochastic Production Function analysis reveals that CSAP adopters achieve significant improvements in technical efficiency, rising from 68.5% to 85.2% after adoption, while household income, education, credit access, extension services, training access, and climate information emerge as the primary drivers of technical efficiency. The cost efficiency distribution analysis shows improvements in farmer performance, with a notable shift toward higher efficiency categories following CSAP adoption. These empirical findings strongly aligned with Production Theory's fundamental assumptions about rational farmer behaviour and profit maximization under resource constraints, validating that farmers adopt CSAPs that shift their production function favourably and that human capital and financial resources are crucial inputs for optimizing production decisions and maximizing CSAP effectiveness.

Based on these findings, several targeted recommendations are proposed to enhance CSAP adoption and maximize economic benefits among smallholder maize farmers. Enhanced educational and training programs should be developed focusing on practical demonstrations and farmer field schools that build both technical knowledge and implementation skills, given education's strong positive relationship with CSAP economic returns. Financial institutions and government agencies should design accessible agricultural credit products with flexible repayment terms aligned with harvest cycles, recognizing credit access as the most significant institutional factor determining CSAP economic benefits. Extension services should strengthen their capacity to provide comprehensive technical support that goes beyond initial information provision to include ongoing implementation guidance, addressing the knowledge-implementation gap revealed by high CSAP awareness alongside moderate adoption rates. Support for farm area expansion and cooperative arrangements should be prioritized, while quality input supply chains should be strengthened to ensure consistent access to improved seeds and fertilizers, given their significant positive effects in enhancing technical efficiency. Gender-responsive interventions should address institutional barriers particularly affecting female farmers who constitute 63% of agricultural decision-makers but face greater constraints in accessing credit, extension services, and training opportunities. District-specific approaches should be developed considering local agroecological conditions and institutional environments, with policy interventions establishing performance-based extension systems, agricultural insurance products for CSAP adopters, and marketing cooperatives that help farmers capture premium prices for sustainably produced maize. These recommendations recognize that maximizing the economic benefits of CSAP adoption requires a multi-faceted approach addressing both individual farmer capabilities and systemic institutional barriers, ultimately contributing to enhanced agricultural productivity, income generation, climate resilience, and food security in the face of climate change.

References

Abegunde, V.O., Sibanda, M. and Obi, A. (2019) 'The effects of climate change on maize production in South Africa: An econometric approach', *International Journal of Environmental Research and Public Health*, 17(1), p. 195. https://doi.org/10.3390/ijerph17010195

Abegunde, V.O., Sibanda, M. and Obi, A. (2020) 'Determinants of the adoption of climate-smart agricultural practices by small-scale farming households in King Cetshwayo District Municipality, South Africa', *Land*, 9(7), p. 223. https://doi.org/10.3390/land9070223

Aderaw, B., Girma, A. and Adugna, A. (2017) 'Determinants of livelihood strategies in Wolaita Zone, Southern Ethiopia', *Agricultural Research and Reviews*, 6(1), pp. 1-15.

Ahmed, M.H., Geleta, K.M., Tazeze, A. and Andualem, E. (2024) 'The impact of climate-smart agricultural practices on crop productivity and household welfare: Evidence from Ethiopia', *Food Policy*, 104, p. 102156. https://doi.org/10.1016/j.foodpol.2024.102156

Aigner, D., Lovell, C.A.K. and Schmidt, P. (1977) 'Formulation and estimation of stochastic frontier production function models', *Journal of Econometrics*, 6(1), pp. 21-37. https://doi.org/10.1016/0304-4076(77)90052-5

Akhtar, I. (2016) 'Research design', in *Research in social science: Interdisciplinary perspectives*. New Delhi: New Century Publications, pp. 68-84.

Amadu, F.O., McNamara, P.E. and Miller, D.C. (2020) 'Understanding the adoption of climate-smart agriculture: A farm-level typology with empirical evidence from southern Malawi', *World Development*, 126, p. 104692. https://doi.org/10.1016/j.worlddev.2019.104692

Aryal, J.P., Thapa, G. and Simtowe, F. (2021) 'Mechanisation of small-scale farms in South Asia: Empirical evidence derived from farm households survey', *Technology in Society*, 65, p. 101591. https://doi.org/10.1016/j.techsoc.2021.101591

Aryal, J.P., Thapa, G. and Simtowe, F. (2022) 'Climate change impacts and adaptation strategies by smallholder farmers in Central Nepal Himalayas', *Ecological Indicators*, 132, p. 108323. https://doi.org/10.1016/j.ecolind.2021.108323

Asante, B.O., Ma, W., Prah, S. and Temoso, O. (2024) 'Promoting the adoption of climate-smart agricultural technologies among maize farmers in Ghana: using digital advisory services', *Mitigation and Adaptation Strategies for Global Change*, 29(3), p. 19. https://doi.org/10.1007/s11027-024-10116-6

Autio, A., Johansson, T., Motaroki, L., Minoia, P. and Pellikka, P. (2021) 'Constraints for adopting climate-smart agricultural practices among smallholder farmers in Southeast Kenya', *Agricultural Systems*, 194, p. 103284. https://doi.org/10.1016/j.agsy.2021.103284

Badarch, B. (2024) 'North Dakota corn efficiency frontier: Stochastic frontier analysis', *Crop, Forage & Turfgrass Management*, 10(1). DOI: 10.1002/cft2.70005

Balana, B.B. and Oyeyemi, M.A. (2022) 'Agricultural credit constraints in smallholder farming in developing countries: Evidence from Nigeria', *World Development Sustainability*, 1, p. 100012. https://doi.org/10.1016/j.wds.2022.100012

Biswas, J.C., Rahman, M.M., et al. (2021) 'Impact of agriculture extension services on technical efficiency of rural paddy farmers in southwest Bangladesh', *Sustainable Agriculture Research*, 10(3), pp. 45-58. https://doi.org/10.1016/j.envc.2021.100261

Bond, S., Hoyle, R. and Williams, A. (2023) *Research methods in psychology: From theory to practice*, 2nd edn. London: SAGE Publications.

Cai, B., Shi, F., Meseretchanie, A., Betelhemabraham, G. and Zeng, R. (2024) 'Agricultural socialized services empowering smallholder rice producers to achieve high technical efficiency: empirical evidence from southern China', *Frontiers in Sustainable Food Systems*, 8, p. 1329872. DOI: 10.3389/fsufs.2024.1329872

Cochran, W.G. (1977) *Sampling techniques*, 3rd edn. New York: John Wiley & Sons.

Creswell, J.W. and Creswell, J.D. (2017) *Research design: Qualitative, quantitative, and mixed methods approach*, 5th edn. Thousand Oaks, CA: SAGE Publications.

Du, S. and Xiong, W. (2024) 'Weather extremes shock maize production: Current approaches and future research directions in Africa', *Plants*, 13, p. 1585. https://doi.org/10.3390/plants13121585

Food and Agriculture Organization (2018) *Climate-Smart Agriculture: Building Resilience to Climate Change*. Rome: Food and Agriculture Organization.

Food and Agriculture Organization (2022) *The State of Food Security and Nutrition in the World 2022*. Rome: Food and Agriculture Organization.

Gebeyehu, T.A. (2023) 'Adoption and impacts of conservation agriculture on smallholder farmers' livelihoods in the case of Arba Minch Zuria district of Southern Ethiopia', *Cogent Social Sciences*, 9(1), p. 2235782. https://doi.org/10.1080/23311886.2023.2235782

Haryanto, T., Wardana, W.W., Jamil, I.R., Brintanti, A.R.D. and Ibrahim, K.H. (2023) 'Impact of credit access on farm performance: Does source of credit matter?', *Heliyon*, 9(9). https://doi.org/10.1016/j.heliyon.2023.e19720

Israel, G.D. (2013) 'Determining sample size', *University of Florida Cooperative Extension Service*, Institute of Food and Agriculture Sciences, EDIS.

Jolex, A. (2022) 'Influence of agricultural extension services on technical efficiency of maize farmers in Malawi', *African Journal of Agricultural and Resource Economics*, 17(1), pp. 92-105. DOI: https://doi.org/10.53936/afjare.2022.17(1).6

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

Kemboi, E., Muendo, K. and Kiprotich, C. (2020) 'Crop diversification analysis amongst smallholder farmers in Kenya (empirical evidence from Kamariny ward, Elgeyo Marakwet County)', *Cogent Food & Agriculture*, 6(1), p. 1834669.

Khataza, R.R., Doole, G.J., Kragt, M.E. and Hailu, A. (2021) 'Information acquisition and adoption of climate-smart agriculture practices in Malawi', *Australian Journal of Agricultural and Resource Economics*, 65(2), pp. 257-281. https://doi.org/10.1111/1467-8489.12417

Kotrlik, J.W. and Higgins, C.C. (2001) 'Organizational research: Determining appropriate sample size in survey research appropriate sample size in survey research', *Information Technology, Learning, and Performance Journal*, 19(1), pp. 43-50.

Koutsos, T.M. and Menexes, G.C. (2024) 'Developing sampling frames for agricultural surveys: Methodological considerations for developing countries', *Agricultural Systems*, 214, p. 103821. https://doi.org/10.1016/j.agsy.2023.103821

Kumar, L., Chhogyel, N., Gopalakrishnan, T., Hasan, M.K., Jayasinghe, S.L., Kariyawasam, C.S., et al. (2022) 'Climate change and future of agri-food production', in *Future Foods*. Academic Press, pp. 49-79. https://doi.org/10.1016/B978-0-323-91001-9.00009-8

Kurgat, B.K., Lamanna, C., Kimaro, A., Namoi, N., Manda, L. and Rosenstock, T.S. (2020) 'Adoption of climate-smart agriculture technologies in Tanzania', *Frontiers in Sustainable Food Systems*, 4, p. 55. https://doi.org/10.3389/fsufs.2020.00055

Lipper, L., Thornton, P., Campbell, B.M., Baedeker, T., Braimoh, A., Bwalya, M., et al. (2014) 'Climate-smart agriculture for food security', *Nature Climate Change*, 4(12), pp. 1068-1072.

Lutonja, E. (2023) 'Technical efficiency of smallholder farmers in Tanzania: A stochastic frontier approach', *Asian Journal of Agricultural Extension, Economics & Sociology*, 41(12), pp. 89-105.

Ma, W. and Rahut, D.B. (2024) 'Climate-smart agriculture: adoption, impacts, and implications for sustainable development', *Mitigation and Adaptation Strategies for Global Change*, 29, p. 44. https://doi.org/10.1007/s11027-024-10139-z

Mahama, C., Pekrun, H., Lambers, E. and Kandeler, K. (2020) 'Hidden miners--the roles of cover crops and soil microorganisms in phosphorus cycling through agroecosystems', *Plant and Soil*, 434, pp. 7-45. https://doi.org/10.1007/s11104-018-3810-7

Makamane, A., Van Niekerk, J., Loki, O. and Mdoda, L. (2023) 'Determinants of Climate-Smart Agriculture (CSA) Technologies Adoption by Smallholder Food Crop Farmers in Mangaung

Metropolitan Municipality, Free State', *South African Journal of Agricultural Extension*, 51, pp. 52-74. https://doi.org/10.17159/2413-3221/2023/v51n4a16451

Mangani, R., Mkwambisi, D., Levy, C. and Wollenberg, E. (2019) 'The impacts of climate change on agricultural productivity in Malawi', *Climate and Development*, 11(7), pp. 594-602.

Maponya, P. and Agbugba, I.K. (2023) 'An assessment of smallholder farmers' status in Umzinyathi and Harry Gwala districts of KwaZulu Natal Province, South Africa', in *Agricultural Bioeconomy*. Cambridge, MA: Academic Press, pp. 85-102. https://doi.org/10.1016/B978-0-323-90569-5.00011-1

Mdoda, L., Tamako, N., Gidi, L.S. and Naidoo, D. (2025) 'Evaluating the impact of improved maize varieties on agricultural productivity and technical efficiency among smallholder farmers in the Eastern Cape, South Africa: an empirical analysis', *GM Crops & Food*, 16, pp. 272-304. https://doi.org/10.1080/21645698.2025.2476667

Meeusen, W. and van den Broeck, J. (1977) 'Efficiency estimation from Cobb-Douglas production functions with composed error', *International Economic Review*, 18(2), pp. 435-444.

Mnikathi, S.J., Hlatshwayo, S.I., Temitope, O. and Ngidi, M.S.C. (2025) 'Participation of Emerging Commercial Farmers in the Strategic Private-Sector Investment Interventions', *Agriculture*, 15(5), p. 450. https://doi.org/10.3390/agriculture15050450

Mnukwa, M.L., Mdoda, L. and Mudhara, M. (2025) 'Assessing the adoption and impact of climate-smart agricultural practices on smallholder maize farmers' livelihoods in Sub-Saharan Africa: a systematic review', *Frontiers in Sustainable Food Systems*, 9, p. 1543805. https://doi.org/10.3389/fsufs.2025.1543805

Mthethwa, K.N., Ngidi, M.S.C., Ojo, T.O. and Hlatshwayo, S.I. (2022) 'The determinants of adoption and intensity of climate-smart agricultural practices among smallholder maize farmers', *Sustainability*, 14, p. 16926. https://doi.org/10.3390/su142416926

Musafiri, C.M. (2020) 'Environmental greenhouse gas hotspots and climate change adaptation in smallholder sorghum cropping systems in Siaya county, Kenya', Doctoral dissertation, University of Nairobi.

Mwonge, L.A. and Naho, A. (2022) 'Smallholder farmers' perceptions towards agricultural credit in Tanzania', *Asian Journal of Economics, Business and Accounting*, 22, pp. 58-75. https://doi.org/10.9734/bpi/bmerp/v5/1860

Naicker, M., Naidoo, D., Hlatshwayo, S.I. and Ngidi, M.S. (2025) 'Factors Affecting the Choice and Level of Adaptation Strategies Among Smallholder Farmers in KwaZulu Natal Province', *Sustainability*, 17, p. 488. https://doi.org/10.3390/su17020488

Nanyangwe, V. and Tembo, R. (2024) 'Effects of Climate-Smart Agriculture on Smallholder Farmers in the Eastern Province of Zambia', *International Journal of Applied Agricultural Sciences*, 10(3), pp. 83-99.

Ncoyini-Manciya, L. (2021) 'Climate change adaptation strategies for smallholder farmers in rural South Africa', PhD thesis, University of KwaZulu-Natal.

Ngango, J. and Hong, S. (2022) 'Assessing production efficiency by farm size in Rwanda: A zero-inefficiency stochastic frontier approach', *Scientific African*, 16, p. e01143. https://doi.org/10.1016/j.sciaf.2022.e01143

Ngcamu, B.S. and Chari, F. (2022) 'Drought influences on food insecurity in Africa: A systematic literature review', *International Journal of Environmental Research and Public Health*, 19(10), p. 5897.

Oduniyi, O.S., Chagwiza, C. and Wade, T. (2022) 'Welfare impacts of conservation agriculture adoption on smallholder maize farmers in South Africa', *Renewable Agriculture and Food Systems*, 37, pp. 672-682. https://doi.org/10.1017/S1742170522000308

OECD (2016) *Agriculture and Climate Change: Towards Sustainable, Productive and Climate-Friendly Agricultural Systems*. Paris: OECD Publishing.

Ojoko, E.A., Adetoro, A.A. and Dafiewhare, A.O. (2017) 'Factors affecting adoption of climate smart agricultural practices among food crop farmers in Ondo State, Nigeria', *International Journal of Agricultural Economics*, 2(4), pp. 97-103.

Peprah, J.A., Koomson, I., Sebu, J. and Bukari, C. (2021) 'Improving productivity among smallholder farmers in Ghana: Does financial inclusion matter?', *Agricultural Finance Review*, 81(4), pp. 481-502.

Plewes, T.J. and Tourangeau, R. (2013) *Nonresponse in social science surveys: A research agenda*. National Academies Press.

Ritchie, H. (2022) 'Increasing agricultural productivity across Sub-Saharan Africa is one of the most important problems this century', *Our World in Data*. Available at: https://ourworldindata.org/africa-yields-problem

Singh, A.S. and Masuku, M.B. (2014) 'Sampling techniques & determination of sample size in applied statistics research: An overview', *International Journal of Economics, Commerce and Management*, 2(11), pp. 1-22.

Singh, K., Kumar, A. and Sharma, R. (2018) 'Impact of farmer education on farm productivity under varying technologies: Case of paddy growers in India', *Agricultural and Food Economics*, 6(1), p. 7. https://doi.org/10.1186/s40100-018-0101-9

Sinyolo, S. and Mudhara, M. (2018) 'Farmer groups and inorganic fertiliser use among smallholders in rural South Africa', *Development in Practice*, 28(2), pp. 175-184.

Sinyolo, S., Murendo, C., Nyamwanza, A.M., Sinyolo, S.A., Ndinda, C. and Nwosu, C.O. (2021) 'Farm production diversification and dietary diversity among subsistence farming households: Panel data evidence from South Africa', *Sustainability*, 13(18), p. 10325. https://doi.org/10.3390/su131810325

Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., et al. (2008) 'Greenhouse gas mitigation in agriculture', *Philosophical Transactions of the Royal Society B*, 363(1492), pp. 789-813.

Statistics South Africa (2016) *Community Survey 2016: Provincial Profile: KwaZulu-Natal*. Pretoria: Statistics South Africa.

Statistics South Africa (2019) *General Household Survey 2019*. Pretoria: Statistics South Africa.

Taherdoost, H. (2016) 'Sampling methods in research methodology; how to choose a sampling technique for research', *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.3205035

Tesfaye, K. and Tirivayi, N. (2020) 'The impacts of postharvest storage innovations on food security and welfare in Ethiopia', *Food Policy*, 75, pp. 52-67. https://doi.org/10.1016/j.foodpol.2018.01.004

Ullah, A., Mahmood, N., Zeb, A. and Kächele, H. (2020) 'Factors determining farmers' access to and sources of credit: evidence from the rain-fed zone of Pakistan', *Agriculture*, 10(12), p. 586. https://doi.org/10.3390/agriculture10120586

United Nations Conference on Trade and Development (2022) 'Revitalizing African agriculture: Time for bold action', *UN Trade and Development*. Available at: https://unctad.org/news/blog-revitalizing-african-agriculture-time-bold-action

Wei, D. and Zhang, Y. (2025) 'Impact of formal credit and social capital on the scalability of agricultural operations', *Scientific Reports*, 15, p. 6603. https://doi.org/10.1038/s41598-025-90758-x

Wekesa, B.M., Ayuya, O.I. and Lagat, J.K. (2018) 'Effect of climate-smart agricultural practices on household food security in smallholder production systems: micro-level evidence from Kenya', *Agriculture & Food Security*, 7, pp. 1-14. https://doi.org/10.1186/s40066-018-0230-0

Wekesa, B.M., Ayuya, O.I. and Lagat, J.K. (2022) 'Sustainable agricultural practices and food security among smallholder farmers: micro-level evidence from Kenya', *International Journal of Agricultural Sustainability*, 20(3), pp. 412-425.

Wudil, A.H., Usman, M., Rosak-Szyrocka, J., Pilař, L. and Boye, M. (2022) 'Reversing years for global food security: A review of the food security situation in Sub-Saharan Africa (SSA)', *International Journal of Environmental Research and Public Health*, 19(22), p. 14836. https://doi.org/10.3390/ijerph192214836

Yamane, T. (1967) *Statistics: An introductory analysis*, 2nd edn. New York: Harper and Row.

Yin, W., Chai, Q., Zhao, C., Yu, A., Fan, Z., Hu, F., et al. (2024) 'Climate-smart agriculture practices enhance soil health and crop productivity', *Agriculture, Ecosystems & Environment*, 359, p. 108741.

Yu, L., Nilsson, D., Zheng, H., Jiang, Y., Shang, L. and Wang, W. (2020) '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*, 30, p. 100247.

Zeweld, W., Van Huylenbroeck, G., Tesfay, G., Azadi, H. and Speelman, S. (2020) 'Sustainable agricultural practices, environmental risk mitigation and livelihood improvements: Empirical evidence from Northern Ethiopia', *Land Use Policy*, 95, p. 103799. https://doi.org/10.1016/j.landusepol.2019.01.002

Zheng, H., Ma, W. and He, Z. (2024) 'Climate-smart agricultural practices for enhanced farm productivity, income, resilience, and greenhouse gas mitigation: a comprehensive review', *Mitigation and Adaptation Strategies for Global Change*, 29(2), pp. 1-30. https://doi.org/10.1007/s11027-024-10124-6

Zougmore, R.B., Partey, S.T., Ouédraogo, M. and Torquebiau, E. (2018) 'Facing climate variability in sub-Saharan Africa: analysis of climate-smart agriculture opportunities to manage climate-related risks', *Cahiers Agricultures*, 27, pp. 1-9. https://doi.org/10.1051/cagri/2018019

CHAPTER 6

Assessing the Impact of Climate-Smart Agricultural Practices on Food Security among Smallholder Maize Farmers in KwaZulu-Natal, South Africa.

Abstract

Climate change poses escalating risks to agriculture globally, with smallholder farmers in developing regions particularly vulnerable due to limited adaptive capacity and resource constraints. This study assessed the welfare effects of Climate-Smart Agricultural Practices (CSAPs) adoption among smallholder maize farmers in KwaZulu-Natal, South Africa, using Random Utility Theory (RUT) as the theoretical framework and cross-sectional data from 378 farmers. An Endogenous Switching Regression (ESR) model addressed selection bias inherent in technology adoption decisions, with food security measured via the Household Dietary Diversity Score (HDDS) and Household Food Insecurity Access Scale (HFIAS). Four specific CSAPs were evaluated: drought-tolerant maize varieties, rainwater harvesting systems, maize-legume intercropping, and crop diversification strategies. Results showed a moderate 47.1% adoption rate of CSAPs among smallholder maize farmers in the study area. Adopters exhibited significantly higher dietary diversity (HDDS: 6.79 vs. 5.39; $p < 0.001$) and substantially improved food security outcomes (HFIAS: 7.67 vs. 9.73; $p < 0.001$). Key socioeconomic and institutional determinants influencing adoption decisions included land ownership status, agricultural group membership, access to climate information services, household income levels while age negatively influenced adoption decisions. Treatment effects analysis revealed contrasting welfare patterns: current adopters experienced significant food security improvements (ATT = -1.72) but minimal dietary diversity gains (ATT = 0.017), while non-adopters demonstrated substantial unrealized potential for dietary diversity enhancement (ATU = 3.035). These findings suggest that current adoption reflects crisis response mechanisms rather than proactive improvement strategies. Policy recommendations include enhanced agricultural training programs, improved credit access mechanisms, targeted technical support for current adopters experiencing negative effects, and proactive outreach initiatives to stable non-adopting households demonstrating greater welfare gain potential.

Keywords: Climate-Smart Agricultural Practices, Smallholder Farmers, Dietary Diversity, Food Security, KwaZulu-Natal, Welfare Impact

6.1 Introduction

Across Sub-Saharan Africa (SSA), agriculture serves as a fundamental pillar supporting economic stability, employment generation, and food security for millions of households (Wudil et al., 2022). The sector sustains more than 60% of the regional population, with smallholder farming systems providing essential sources of nutrition and income for rural communities (FAO, 2022). Maize stands as a particularly critical crop, representing nearly half of total cereal production and constituting the primary caloric source for vast populations (Cairns et al., 2021). Nevertheless, this vital crop faces increasing threats from climate variability and extreme weather phenomena, including prolonged droughts, devastating floods, and unpredictable rainfall distribution patterns (Du and Xiong, 2024). Such climatic disruptions extend beyond immediate yield reductions. They exacerbate rural poverty and deepen food insecurity among smallholder farming communities who lack adaptive capacity to respond effectively.

In South Africa, maize forms the cornerstone of national food security (Mdoda et al., 2025). The country produces approximately 12-16 million tons of maize annually, with smallholder farmers accounting for 4.4% of cultivation, particularly in rural areas (Oduniyi et al., 2022). This segment comprises over 2.9 million smallholder farming households that are disproportionately affected by climate-related stressors (Sinyolo, 2023). Climate change impacts on South African agriculture are already evident, with temperature increases of 1.5-2.0°C recorded over the past four decades and projections indicating further increases of 3-4°C by 2080 (Ngcamu and Chari, 2022). These stressors have resulted in average yield losses of 10-20% for maize over the past decade, with some regions experiencing losses exceeding 40% during drought years (Tantoh and McKay, 2023).

KwaZulu-Natal (KZN) Province epitomizes these challenges, experiencing particularly acute climate variability in recent years. The province has recorded temperature increases of 1.8°C since 1960, accompanied by a 15% decline in annual rainfall and increased frequency of extreme weather events (Mthethwa et al., 2022). These changes have resulted in estimated agricultural losses of ZAR 2.8 billion between 2010-2020, with maize production declining by an average of 12% annually (Kumar et al., 2022). Moreover, KZN faces high levels of poverty and food insecurity, with approximately 65.3% of households in some zones experiencing food insecurity (Aderaw et al., 2017; Mthethwa et al., 2022).

To address these challenges, Climate-Smart Agriculture (CSA) has gained traction as a strategic framework for transforming agricultural systems under climate change realities. CSA promotes practices that increase productivity sustainably, strengthen farmers' resilience to climate-related shocks, and reduce agriculture's carbon footprint (FAO, 2018; Lipper et al., 2014). For maize farmers, Climate-Smart Agricultural Practices (CSAPs) encompass various interventions. These include conservation agriculture, crop diversification, drought-tolerant varieties, organic soil amendments, agroforestry, and rainwater harvesting (Bongole et al., 2022; Mahama et al., 2020). Research indicates that drought-tolerant maize varieties can reduce yield losses by 20-30% during drought years. Conservation agriculture practices can improve soil water retention by 15-25% (Zougmore et al., 2018).

Despite this promise, significant knowledge gaps persist regarding the actual welfare effects of CSAPs on smallholder farming households. While numerous studies have documented productivity benefits and adoption patterns, there remains limited empirical evidence on how these practices translate into improved welfare outcomes, particularly food security and dietary diversity (Wekesa et al., 2018). Most existing research has focused primarily on yield improvements and income effects, with insufficient attention to the multidimensional nature of welfare. Furthermore, methodological limitations in previous studies have often failed to address selection bias inherent in technology adoption decisions, potentially leading to biased estimates of welfare impacts (Di Falco et al., 2011). Understanding the welfare effects of CSAPs is crucial for several reasons. First, the ultimate goal of agricultural development interventions is to improve the well-being of farming households. Second, food security and dietary diversity represent critical dimensions of welfare that are particularly relevant for smallholder farmers who often struggle with nutritional adequacy (Nabuuma et al., 2021). Third, evidence on welfare effects is essential for designing effective policies that can maximize the benefits of CSAPs for vulnerable farming communities.

This study aims to assess the effect of CSAPs on the welfare of smallholder maize farmers in KZN Province. Drawing on Random Utility Theory and employing an Endogenous Switching Regression model, the research seeks to generate robust empirical evidence on how CSAPs adoption influences household dietary diversity and food security among smallholder farmers. Specifically, the research seeks to: (i) determine the adoption status and patterns of CSAPs among smallholder maize farmers and (ii) evaluate the welfare effects of CSAPs adoption on household dietary diversity and food security. The findings will contribute to the growing body of literature on CSAPs welfare impacts while providing practical recommendations for policymakers, extension services, and other stakeholders working to enhance agricultural resilience and food security in the face of climate change.

6.2 Theory for assessing welfare effects of climate-smart agricultural practices among smallholder maize farmers

This study is anchored in Random Utility Theory (RUT), originally developed by McFadden (1974), to assess the welfare effects of CSAPs adoption among smallholder maize farmers. RUT provides a robust econometric basis for analysing how farmers make utility-maximizing decisions and the welfare outcomes that follow. It is particularly suitable for this research as it addresses selection bias in impact evaluations by recognizing that farmers' decisions to adopt CSAPs are systematic, not random. These decisions are influenced by the same factors that also affect welfare outcomes, including food security and dietary diversity. According to RUT, rational decision-makers select alternatives that maximize their expected utility, which consists of both observable and unobservable components (Train, 2009). In this context, CSAP adoption by smallholder farmers is modelled as a strategic choice based on anticipated utility gains, accounting for both benefits and costs.

Building on McFadden's framework, this study conceptualizes CSAP adoption as a decision where a farmer compares the utility of adopting CSAPs (U_{1i}) with that of maintaining traditional practices (U_{0i}). A farmer will adopt if $U_{1i} - U_{0i} > 0$. This logic captures their evaluation of net benefits, including expected welfare improvements from adopting drought-tolerant maize, intercropping, rainwater harvesting, or diversification. Utility is influenced by observable factors like age, education, income, household size, farm size, and institutional access, and by unobservable characteristics such as risk tolerance, ability, and motivation (Di Falco et al., 2011). These combined factors shape not only adoption behaviour but also the welfare outcomes realized thereafter. The empirical foundation involves estimating a latent variable $A_i *$, which reflects the net utility from CSAP adoption. This variable is influenced by observable characteristics (Z_i) and unobservable factors (η_i), laying the groundwork for model specification. RUT justifies evaluating welfare outcomes as the result of these utility-maximizing behaviours. HDDS and HFIAS are used as welfare indicators, which are understood as systematically distributed rather than random. The ESR model applied in this study directly stems from RUT and enables the estimation of ATT and ATU, providing robust counterfactual analysis while addressing selection bias. This ensures that estimated effects reflect genuine welfare improvements from CSAP adoption rather than artifacts of selection bias, providing a sound theoretical foundation for assessing welfare impacts on smallholder maize farmers in KZN.

6.3 Materials and methods

6.3.1 Description and study area selection

As previously mentioned in chapter three of this thesis, the study was conducted in KwaZulu-Natal Province, South Africa, specifically focusing on Harry Gwala District Municipality (HGDM) and Ugu District Municipality (UDM). For a detailed description of the study area characteristics, agro-ecological conditions, and the selection process rationale, please refer to chapter three, Section 3.3.1.

6.3.2 Research Design

A cross-sectional research design with a mixed-methods approach was utilized to gather comprehensive data on CSAP adoption patterns and their welfare effects among smallholder maize farmers. For a detailed explanation of the design choice and its theoretical justification, please refer to chapter three, Section 3.3.1.

6.3.3 Sampling technique and data collection

The results presented here are based on a sample of 378 smallholder maize farmers from both HGDM and UDM, selected through a multi-stage sampling procedure to ensure representativeness across the two contrasting agro-ecological zones. Data was collected through structured questionnaires administered via face-to-face interviews, translated into isiZulu where necessary, to ensure clarity and gather detailed information on farmers' demographic and socioeconomic characteristics, farm characteristics, institutional factors, and welfare outcomes measured through the Household Dietary Diversity Score (HDDS) and Household Food Insecurity Access Scale (HFIAS). A pre-testing phase with 38 respondents tested the questionnaire's validity and reliability but was excluded from the final analysis to maintain research integrity. The surveys captured comprehensive information on CSAPs adoption patterns, welfare indicators, and factors influencing adoption decisions among smallholder farmers. Refer to Chapter Three (Sections 3.3.2 and 3.3.3) for detailed information on the sampling methodology, sample size calculation, and data collection procedures for this study.

6.3.4 Data analysis

This paper assessed the effect of CSAPs on the welfare of smallholder maize farmers. The collected survey data was organized and initially processed using Microsoft Excel spreadsheets for data entry and preliminary cleaning. For comprehensive statistical analysis, Stata version 18 was employed. The study employed a cross-sectional research design with a mixed-methods approach to gather comprehensive data on CSAP adoption patterns and their welfare effects among smallholder maize farmers. This design facilitated the assessment of how CSAPs affect farmer welfare through the Household Dietary Diversity Score (HDDS) as a welfare indicator and the ESR model to evaluate the causal impact of CSAP adoption on welfare outcomes, providing crucial insights into the welfare effects of CSAPs adoption in climatically vulnerable production systems.

6.3.5 Descriptive statistics

Descriptive statistics were employed to characterize smallholder maize farmers' demographic and socioeconomic profiles. The descriptive analysis encompassed frequency distributions (percentages) and measures of central tendency (means, ranges, and standard deviations). The data were presented through tables and figures to provide a clear visual representation of the findings. This approach was particularly important as study by Autio et al. (2021) and Ojoko et al. (2017) indicated that many smallholder farmers unconsciously practice CSA as part of their traditional farming systems. Therefore, it was critical to identify and assess the frequency of farmers using specific CSAPs such as drought-tolerant maize varieties, maize-legume intercropping, rainwater harvesting, and crop diversification. The descriptive statistics provided the key socioeconomic characteristics of sampled smallholder farmers.

6.4.1 The Household Dietary Diversity Score (HDDS)

The HDDS was selected as a complementary measurement tool to assess dietary diversity as a proxy indicator for diet quality and the utilization dimension of food security, providing crucial insights into the quality and variety of household food consumption patterns among smallholder farmers. While food security encompasses multiple dimensions, dietary diversity serves as a proxy indicator for diet quality and micronutrient adequacy, which are essential components of the utilization pillar of food security (Mohamed et al., 2020). The HDDS is particularly valuable for evaluating the welfare impacts of CSAPs because it captures how these interventions affect not just food access, but also the nutritional quality of household diets. Muthini et al. (2020) employed it to evaluate the association between farm production diversity and dietary diversity among smallholder households in Kenya. Kuma et al. (2021) applied HDDS to assess the relationship between market access and dietary diversity among smallholder coffee producers in southwestern Ethiopia. The HDDS measures dietary diversity by calculating the number of different food groups consumed rather than the number of different individual foods consumed (Bilinsky and Swindale, 2006). HDDS was measured using a three-point scale classification (1–4 for low dietary diversity, 5–8 for medium dietary diversity, and >9 for high dietary diversity), following the approach established by Suneetha and Rahul (2012). A scale of 12 food groups was used to assess dietary diversity, following the approach established by Damman et al. (2008), with a single point awarded to each food group consumed over the reference period, giving a maximum total dietary diversity score of 12 points for each household. Respondents were asked to recall all foods consumed during the previous 24 hours, as FAO recommends the 24-hour recall period because it is less subject to recall error and less burdensome for respondents. The study contrasted smallholder maize farmers who adopted CSAPs with those who did not, specifically in terms of their HDDS, providing an estimate of the association between CSAP adoption and dietary diversity among smallholder maize farmers.

Table 6.1 Food groups used for calculating the HDDS.

Food groups	Number
1. Any bread, rice, or any other foods made from millet, sorghum, maize, wheat, or any other locally available grain	A
2. Any potatoes, yams, cassava, or any other foods made from roots or tubers	B
3. Any vegetables	C
4. Any fruits	D
5. Any beef, pork, lamb, rabbit, chicken, duck, other birds, and organ meats	E
6. Any eggs	F
7. Any fresh or dried fish, or shellfish	G
8. Any foods made from beans, peas, and lentils	H
9. Any yoghurt, milk, or milk products	I
10. Any food made with oil, fat or butter	K
11. Any sugar	K
12. Any food such as coffee or tea	L

Note if the answer was yes, awarded 1 point, and if the answer was no, awarded 0 point

Source: Adapted from Swindale and Bilinsky (2006)

6.4.2 The Household Food Insecurity Access Scale (HFIAS)

The HFIAS was selected as the tool for measuring household food access insecurity, serving as a direct indicator of the access dimension of food security which is fundamental to evaluating household welfare outcomes among smallholder farmers (Addai et al., 2024). Unlike simple measures of food availability or consumption, HFIAS captures the lived experiences of households regarding food insecurity, including behavioural and psychological manifestations such as worrying about food, compromising on food quality and quantity, and experiencing hunger due to limited access to food resources (Coates et al., 2007). This experiential approach is particularly relevant for smallholder farming households who may produce food but still face access challenges due to market failures, seasonal variations, or economic constraints. The HFIAS is a validated measurement tool developed by the Food and Nutrition Technical Assistance (FANTA) project and has been successfully employed in agricultural research contexts. Sibhatu and Qaim (2018) used HFIAS to examine farm production diversity and dietary quality linkages among smallholder households. Addai et al. (2024) utilized HFIAS to examine the impact of farmer organization membership on food security among rural rice farmers in Northern Ghana. Kuma et al. (2021) employed HFIAS to assess market access effects on food security among smallholder coffee producers in southwestern Ethiopia.

The HFIAS indicator instrument comprises nine occurrence questions that capture behavioural responses and experiences related to food insecurity during the previous 30 days, with each occurrence question followed by a frequency-of-occurrence question to determine how often the condition occurred (Pourmotabbed et al. 2020). The HFIAS measures three domains of food insecurity: anxiety and uncertainty about household food supply, insufficient food quality (including variety and preferences), and insufficient food intake and its physical consequences (Coates et al., 2007). The measured results were assigned either categorical designations (food secure, mildly food insecure, moderately food insecure, or severely food insecure) or numerical values ranging from 0-27, with higher scores representing greater food insecurity levels. Response options were coded as: 0-Never, 1-Rarely (once or twice in the past 30 days), 2-Sometimes (three to ten times in the past 30 days), 3-Often (more than ten times in the past 30 days), with the maximum possible score being 27 and the minimum being 0, where higher scores indicate greater food insecurity and lower scores indicate better food security status (Coates et al., 2007).

Table 6.2 The Household Food Insecurity Access Scale (HFIAS) Generic Questions.

Number	Occurrence Question
1	In the past four weeks, did you worry that your household would not have enough food?
2	In the past four weeks, were you or any household member not able to eat the kinds of foods you preferred because of a lack of resources?
3	In the past four weeks, did you or any household member have to eat a limited variety of foods due to a lack of resources?
4	In the past four weeks, did you or any household member have to eat some foods that you really did not want to eat because of a lack of resources to obtain other types of food?
5	In the past four weeks, did you or any household member have to eat a smaller meal than you felt you needed because there was not enough food?
6	In the past four weeks, did you or any household member have to eat fewer meals in a day because there was not enough food?
7	In the past four weeks, was there ever no food to eat of any kind in your household because of lack of resources to get food?
8	In the past four weeks, did you or any household member go to sleep at night hungry because there was not enough food?
9	In the past four weeks, did you or any household member go a whole day and night without eating anything because there was not enough food?

Source: Adapted from FAO (2021)

6.4.3 Endogeneity Switching Regression

The ESR model was selected as the primary analytical framework for assessing the welfare impact of CSAPs on smallholder maize farmers because it addresses critical methodological challenges inherent in impact evaluation studies. The choice to adopt CSAPs is not random but depends on observable and unobservable farmer characteristics, creating potential selection bias that can lead to biased estimates of treatment effects (Di Falco et al., 2011). The ESR model is particularly well-suited for this study as it accounts for both observed and unobserved heterogeneity between CSAP adopters and non-adopters, providing more robust and reliable estimates of welfare impacts compared to conventional econometric approaches. Unlike simple comparison methods, the ESR model explicitly addresses the endogeneity problem by modelling the adoption decision and welfare outcomes simultaneously, recognizing that farmers who adopt CSAPs may have fundamentally different characteristics from non-adopters that also influence their welfare outcomes (Carter and Milon, 2005).

Recent studies have successfully employed ESR models in similar agricultural contexts. Wekesa et al. (2018) utilized ESR to assess the effect of CSAPs on household food security among smallholder farmers in Kenya, finding significant positive impacts while controlling for selection bias. Oduniyi et al. (2022) applied ESR to evaluate the welfare impacts of conservation agriculture adoption on smallholder maize farmers in South Africa. The study employed the ESR model to assess the impact of CSAPs on smallholder maize farmers' welfare, with welfare measured through both HDDS and HFIAS as complementary indicators. The CSAPs examined included drought-tolerant maize varieties, rainwater harvesting, maize-legume intercropping, and crop diversification. The ESR model addresses potential selection bias by estimating separate regression models for CSAP adopters and non-adopters, allowing each variable to have different coefficients for each group. Following McFadden's random utility theory, the model assumes that rational farmers choose to adopt CSAPs if the choice provides the highest utility among available alternatives (McFadden, 1974). The model denotes the benefits of adopting CSAPs by U_1 while the benefits of smallholder maize farmers that did not adopt CSAPs are denoted by U_0 Smallholder maize farmers will choose to adopt CSAPs if the benefit of participation is positive $(A_i^* - U_1 - U_0 > 0)$. The latent variable A_i^* captures the expected net benefits to household i from CSAPs adoption and is specified in Eq. (1) as follows:

$$A_i^* = Z_{i\alpha} + \eta_i \text{ with } A_i = \begin{cases} 1 \; if \; A_i^* > 0 \\ 0 \; otherwise \end{cases} \ldots\ldots (1)$$

Where Z represents vectors of variables that affect the decision to adopt CSAPs; η_i represents the error term; and smallholder maize farmers i chooses $(A_1 = 1)$ if they experience a positive net benefit from it $(A_i > 0)$

In the second stage the welfare outcomes (HDDS and HFIAS) of CSAPs adopters and non-adopters are estimated separately. Eqs. (2) and (3) define these two ESR regimes:

$$\text{Regime 1: } Y_{1i} = \beta_1 X_{1i} + \sigma_1 \lambda_{1i} + \varepsilon_{1i} +, A_i = 1 \ldots\ldots (2)$$

$$\text{Regime 2: } Y_{0i} = \beta_0 X_{0i} + \sigma_0 \lambda_{0i} + \varepsilon_{0i}, A_i = 0 \ldots\ldots (3)$$

Where Y_{1i} and Y_{0i} are welfare outcomes (HDDS or HFIAS scores) of household i; X is a vector of explanatory variables; λ is the estimated inverse Mills' ratio obtained from Eq. (1); ε_{1i} and ε_{0i}, are vectors of error terms with expected values of zero; and β_0 are a vector of unknown parameters to be estimated.

The ESR model's ability to address selection bias, account for heterogeneous treatment effects, enable counterfactual analysis, and mitigate endogeneity concerns makes it a robust and effective tool for assessing the welfare impacts of CSAPs on smallholder farmers. Its application provides policymakers and researchers with more reliable and nuanced insights into the true effects of CSAPs adoption, facilitating better-informed decision-making in agricultural development and climate change adaptation strategies. This approach is particularly valuable for this study as it allows for the estimation of average treatment effects on the treated (ATT) and average treatment effects on the untreated (ATU), providing comprehensive insights into the potential welfare gains from scaling up CSAP adoption among smallholder maize farmers in KZN.

6.5 Description of the explanatory variables used in the Endogenous Switching Regression model and their expected outcomes

Table 6.3 summarizes the explanatory variables included in the ESR model to assess the welfare effects of CSAP adoption among smallholder maize farmers in KZN. The ESR model comprises two stages: the first stage models the adoption decision (selection equation), while the second stage estimates the welfare outcomes (HDDS and HFIAS) for both adopters and non-adopters (outcome equations). These variables are hypothesized to influence both the decision to adopt CSAPs and the resulting welfare outcomes among smallholder maize farmers. Diagnostic checks were conducted for the linear outcome equations of the ESR model to ensure model validity. Variance Inflation Factor (VIF) values were below 10, indicating no multicollinearity, and the Breusch–Pagan test confirmed the absence of heteroscedasticity.

Table 6.3 Explanatory variables used in the Endogenous Switching Regression Model to assess welfare effects of climate-smart agriculture practices adoption

Variable	Description and measurement (Type)	Expected outcome (+/-)
Gender	Smallholder farmer's gender (female = 0; male = 1) (dummy)	+
Marital status	Marital status of the Smallholder farmer (single = 0; wedded (married, divorced, widowed) = 1) (dummy)	+/-
Age	Age of the smallholder farmer in years (continuous)	+/-
Education	Number of years of formal schooling by the smallholder farmer (continuous)	+
Family Size	Number of members in the smallholder farmer's household (continuous)	+

Household income	Total household income of the smallholder farmer (continuous)	+
Farm Size	Size of the smallholder farmer's land in hectares (continuous)	+
Farming Years	Number of years of farming experience by the smallholder farmer (continuous)	+
Average Distance to Farm	The distance from home to the farm site in kilometres (continuous)	-
Access to Climate Information	Whether the smallholder farmer has access to climate information (no = 0; yes = 1) (dummy)	+
Access to Agricultural Credit	Whether the smallholder farmer has access to agricultural credit (no = 0; yes = 1) (dummy)	+
Membership in Agricultural Group	Whether the smallholder farmer belonged to an agricultural-related group or association (no = 0; yes = 1) (dummy)	+
Access to Extension Services	Whether the smallholder farmer has access to extension services (no = 0; yes = 1) (dummy)	+
Agricultural Training	Whether the smallholder farmer received specialized agricultural training (no = 0; yes = 1) (dummy)	+
Employment Status	Employment status of the smallholder farmer (unemployed = 0; employed = 1) (dummy)	+/-
Land Ownership	Land tenure status of the smallholder farmer (not owned = 0; owned = 1) (dummy)	+

Note +/− Depicts the direction of influence (**positive/negative**)

Source: Authors (2025)

6.6 Results and discussion

This section presents findings from 378 smallholder maize farmers in KZN Province, examining the welfare effects of CSAPs adoption. The results cover demographic profiles, CSAP adoption patterns, welfare outcome analysis through HDDS and HFIAS, and ESR model results addressing selection bias. Key findings include comparative welfare analysis between adopters and non-adopters, determinants of adoption decisions, treatment effects analysis, and identification of heterogeneous welfare impacts. Each subsection combines empirical findings with relevant discussion and comparison to existing literature.

6.6.1 Demographic characteristics of the sampled smallholder maize farmers in KwaZulu-Natal

The sample distribution reveals a significant gender imbalance, with females constituting the majority (63%) of respondents compared to males (37%), though this distribution remains similar between adopters (62% female) and non-adopters (64% female), suggesting that gender alone does not significantly differentiate adoption behaviour. This female dominance in smallholder agriculture aligns with findings by Mthethwa et al. (2022) in KZN, who reported that women constitute the majority of smallholder farmers in the province. Key demographic differences emerge between the groups across multiple socioeconomic dimensions, with adopters demonstrating clear advantages in human capital, being younger (mean 49 years vs 54 years) and more educated (mean 11 vs 9 years of schooling), indicating that age and education play crucial roles in CSAPs adoption decisions. These findings are consistent with Mutengwa et al. (2023) who emphasized that younger, more educated farmers in are more receptive to CSAPs due to their greater risk tolerance and information processing capabilities.

The age profile indicates a mature farming population with an average of 52 years (SD=17.04). This middle-aged demographic pattern suggests that many farmers have extensive agricultural experience but may face challenges in adopting CSAPs. Combined with moderate educational attainment, this age profile may influence farmers' capacity to comprehend and implement complex CSAPs. These demographic characteristics suggest that extension services should prioritize simplified approaches and hands-on demonstration methods rather than text-based information delivery to effectively reach this farming population. This aligns with recommendations by Makamane et al. (2023) who advocated for age-appropriate extension methodologies that accommodate varying educational backgrounds among smallholder farmers. Economic vulnerability significantly constrains adoption capacity, with adopters having substantially higher household incomes (ZAR12,450 vs ZAR9,126 per month), confirming that financial capacity remains a critical determinant of CSAP adoption. This income disparity mirrors findings by Sinyolo (2023) who identified financial constraints as the primary barrier to CSAPs among South African smallholder farmers.

The household composition shows adopters maintaining larger households (7 vs 6 members per household), potentially providing enhanced labour capacity for CSAPs implementation, though this advantage is severely constrained by extremely limited landholdings (mean 0.01 ha) affecting both groups. The small farm sizes reflect the broader land tenure challenges in South Africa, as documented by Oduniyi et al. (2022). Most striking are the institutional access disparities, where adopters consistently demonstrate superior access across all support systems, particularly in agricultural credit access (50% vs 36%) and training (38% vs 25%), while climate information access remains relatively high for both groups (76% vs 67%). These institutional gaps echo findings by Mdoda et al. (2025) who identified weak extension services and limited credit access as major constraints to agricultural innovation in South Africa.

These findings reveal a profound knowledge-implementation gap where high CSAPs awareness (80%) exists alongside significant institutional barriers, particularly affecting the 63% female agricultural decision-makers who face greater constraints in accessing credit, extension services, and training. This awareness-adoption gap has been consistently reported across SSA, with Zheng et al. (2024) noting that knowledge alone is insufficient without supportive institutional frameworks. The substantial institutional void, combined with moderate educational attainment and economic vulnerability, explains why adoption rates remain moderate (47%) despite high awareness levels, supporting the theoretical framework that successful CSAP adoption requires convergence of awareness, resources, and institutional support (Tantoh and McKay, 2023).

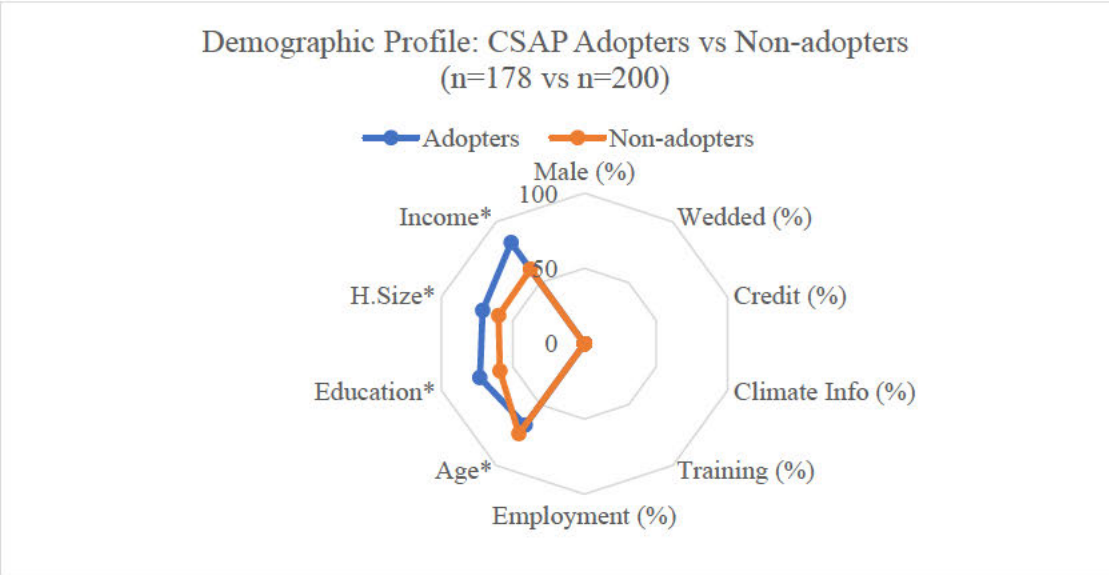

Figure 6.1 Demographic and socioeconomic profile comparison between CSAP adopters and non-adopters among smallholder farmers
Source: Survey data generated through Stata version 18 (2025)

6.6.2 Status of climate-smart agriculture practices adopted by smallholder maize farmers in KwaZulu-Natal

The adoption status among smallholder maize farmers indicated a moderate level of CSAP uptake, with 178 farmers (47%) having adopted at least one practice, while 200 farmers (53%) remained non-adopters. This distribution indicates that while CSAPs are becoming more accepted among farmers, major obstacles still limit widespread adoption throughout the study group. The relatively balanced distribution between adopters and non-adopters of CSAPs provides a robust foundation for the subsequent ESR model, enabling meaningful comparisons between these two groups to assess the welfare effects of CSAPs adoption on smallholder farmers. The empirical evidence from recent studies (2020-2022) provides support for the current findings regarding CSAP adoption patterns. The 47.1% adoption rate observed in this study falls squarely within the documented range of 39-53% reported in comparable studies across developing regions (Aryal et al., 2021; Kurgat et al., 2020; Amadu et al., 2020; Zeweld et al., 2020; Tesfaye & Tirivayi, 2020). This consistency across diverse geographical and agricultural contexts strengthens the validity of the current findings and suggests that the identified adoption patterns reflect fundamental dynamics in smallholder decision-making regarding CSAPs. The substantial proportion of non-adopters (53%) underscores the critical importance of targeted interventions to address barriers to adoption, particularly information access (Khataza et al., 2021), financial constraints (Amadu et al., 2020), and technical knowledge gaps (Aryal et al., 2022; Zeweld et al., 2020). As climate change impacts intensify, bridging these adoption gaps becomes increasingly urgent for enhancing agricultural resilience.

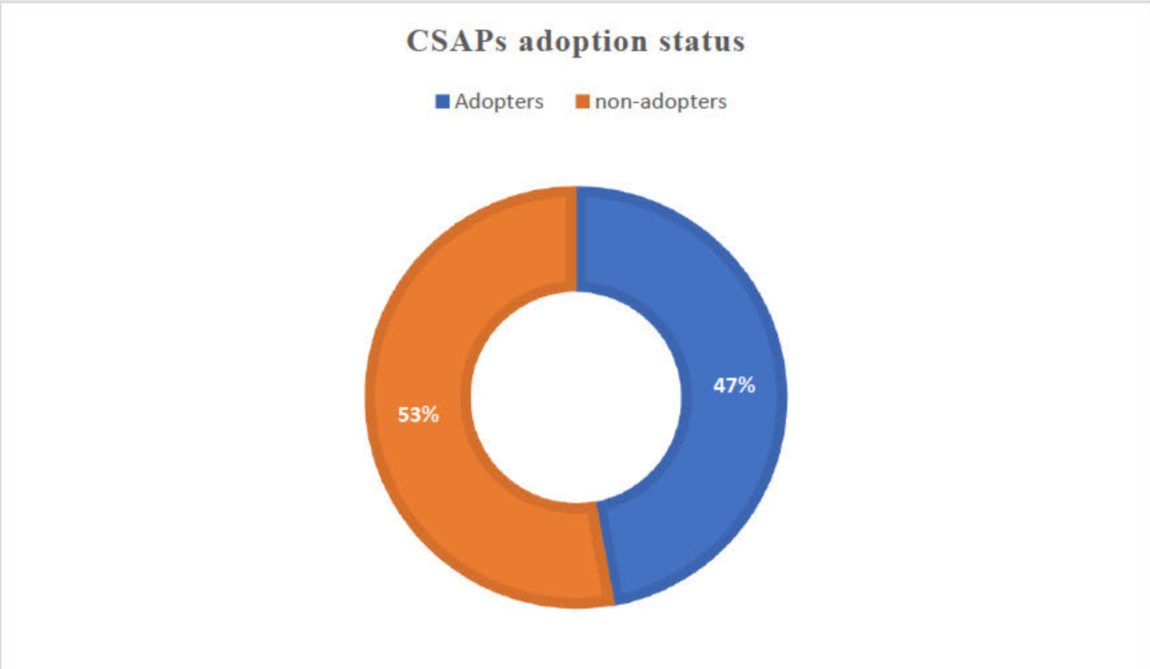

Figure 6.2 Distribution of CSAP adoption status among smallholder maize farmers in KZN
Source: Survey data generated through Stata version 18 (2025)

6.7.1 Household food insecurity analysis by climate-smart agriculture practices adoption status

Table 6.4 below shows that the HFIAS analysis provides compelling evidence of improved food security among CSAPs adopters compared to non-adopters, with adopters recording significantly lower food insecurity scores (8 vs 10, $t = 4.13$, $p < 0.001$), representing a 2.06-point (21%) reduction in food insecurity. This constitutes a meaningful welfare gain, as lower

HFIAS scores reflect better household food access and fewer experiences of food-related anxiety, dietary compromises, and hunger. The categorical analysis further highlights stark contrasts in food security status: while 47.5% of non-adopters face moderate food insecurity and 3.0% severe food insecurity, 67% of adopters experience only mild food insecurity, with non adopters classified as severely food insecure. Moreover, while none of the non-adopters achieved complete food security, the adopter group includes at least one household with perfect food security (HFIAS = 0). These results align with the theoretical framework linking CSAPs to welfare improvements, as these practices enhance agricultural resilience, diversify production, and increase yields, thereby improving household food access and reducing reliance on negative coping strategies (Zheng et al., 2024; Mujeyi et al., 2021). The broader welfare implications are also significant, as reduced HFIAS scores indicate lower psychological stress and fewer hunger experiences, which is critical in the face of climate-related stressors that exacerbate social and emotional challenges such as inequity, alienation, and economic hardship (Ogundeji, 2022).

Table 6.4 Household food insecurity access scale by CSAP adoption status

Variable	**Non-Adopters (n=200)**	**CSAP Adopters (n=178)**	**Mean Difference**	**t-statistic**	**p-value**
HFIAS Score					
Mean (SD)	9.73 (5.20)	7.67 (4.41)	2.06***	4.13	<0.001
95% CI	[9.01, 10.45]	[7.02, 8.32]	[1.08, 3.04]		
Range	1 - 24	0 - 16			
HFIAS Categories	**n (%)**	**n (%)**			
Food Secure (0)	0 (0.0)	1 (0.6)			
Mildly Insecure (1-9)	99 (49.5)	120 (67.4)			
Moderately Insecure (10-18)	95 (47.5)	57 (32.0)			
Severely Insecure (19-27)	6 (3.0)	0 (0.0)			

Notes HFIAS = Household Food Insecurity Access Scale (range: 0-27, lower scores indicate better food security); SD = Standard Deviation; CI = Confidence Interval. ***$p < 0.001$. Chi-square test for categorical distribution: $\chi^2 = 17.29$, $p = 0.001$

Source: Survey data generated through Stata version 18 (2025)

6.7.2 Dietary diversity analysis by climate-smart agriculture practices adoption status

The analysis of household dietary diversity (Table 6.5) reveals statistically and practically significant differences between CSAP adopters and non-adopters in KwaZulu-Natal. On average, adopters reported substantially higher Household Dietary Diversity Scores (HDDS) of 6.79 compared to 5.39 for non-adopters ($t = -5.18$, $p < 0.001$), marking a 1.41-point or 26% improvement in dietary diversity. This reflects meaningful welfare gains linked to CSAP adoption. The categorical distribution of dietary diversity further illustrates these gains: while nearly half of non-adopters (49.5%) fell within the low dietary diversity category (HDDS 1–4), only 23.6% of adopters did. In contrast, 26.4% of adopters attained high dietary diversity, compared to just 17.0% of non-adopters. This distribution was statistically significant ($\chi^2 = 28.46$, $p < 0.001$), confirming a strong association between CSAP adoption and improved dietary outcomes. These findings carry critical welfare implications, as dietary diversity is widely recognized as a proxy for micronutrient adequacy and overall diet quality (Verger et al., 2021). The observed improvements are consistent with empirical evidence that CSAPs enhance food security and nutritional outcomes through increased crop productivity and household income (Ma & Rahut, 2024; Teklewold et al., 2019). Notably, the range analysis underscores food security vulnerabilities among non-adopters, including households with zero dietary diversity, signaling severe nutritional risk. In contrast, all adopters recorded at least an HDDS score of 1, indicating that CSAPs provide a protective buffer against extreme dietary deprivation (Wekesa et al., 2018). These outcomes affirm that the benefits of CSAPs extend beyond the most vulnerable, with adopters consistently exhibiting better dietary outcomes across the distribution, ultimately reinforcing the role of CSAPs in building farmer resilience through enhanced food consumption, dietary diversity, and food security (Zheng et al., 2024).

Table 6.5 Household dietary diversity score by climate-smart agriculture practices adoption status

Variable	**Non-Adopters (n=200)**	**CSAP Adopters (n=178)**	**Mean Difference**	**t-statistic**	**p-value**
HDDS Score					
Mean (SD)	5.39 (2.81)	6.79 (2.42)	1.41***	-5.18	<0.001
95% CI	[4.99, 5.78]	[6.43, 7.15]	[0.87, 1.94]		
Range	0 - 12	1 - 12			
HDDS Categories	n (%)	n (%)			
Low (1-4)	99 (49.5)	42 (23.6)			
Medium (5-8)	67 (33.5)	89 (50.0)			
High (9-12)	34 (17.0)	47 (26.4)			

Note HDDS = Household Dietary Diversity Score (range: 0-12)

Source: Survey data generated through Stata version 18 (2025)

6.8 Factors influencing adoption and the welfare effect of smallholder maize farmers in KwaZulu-Natal

Table 6.6 presents the selection equation results, identifying the factors that determine CSAP adoption decisions among smallholder maize farmers. The ESR approach examines factors influencing CSAPs adoption decisions and their welfare effects on smallholder maize farmers across two distinct regimes, while addressing potential selection bias in the adoption process. The model demonstrates excellent statistical fit with significant Wald χ^2 statistics for both welfare indicators: HDDS ($\chi^2 = 710.36$, $p < 0.001$) and HFIAS ($\chi^2 = 632.92$, $p < 0.001$). The Wald test of independence confirms significant selection bias for dietary diversity outcomes ($\chi^2(2) = 6.07$, $p = 0.048$) but not for food insecurity ($\chi^2(2) = 1.29$, $p = 0.525$). This indicates that unobserved factors systematically influence dietary diversity achievements among adopters, validating the ESR approach for dietary diversity analysis while suggesting that simpler models may suffice for food security analysis. The presence of selection bias for HDDS confirms that farmers who adopt CSAPs differ systematically from non-adopters in ways that affect their dietary diversity outcomes, making the two-regime framework essential for unbiased impact estimation.

Table 6.6 Factors influencing climate-smart agriculture practices adoption (Selection equation results)

Variable	**Coefficient**	**Standard Error**	**p-value**
Age	-0.0157	0.008	0.049**
Education	0.0262	0.030	0.383
Family Size	0.0134	0.020	0.503
Household Income	0.000053	0.000016	0.001***
Farming Years	0.0165	0.010	0.112
Gender	0.1055	0.180	0.559
Marital Status	-0.0989	0.133	0.456
Employment	0.1692	0.103	0.100
Farm Size	-0.1372	0.443	0.757
Access Distance	-0.0350	0.053	0.513
Climate Information	0.7722	0.182	<0.001***
Agricultural Training	0.2689	0.214	0.209
Agricultural Group	0.9973	0.201	<0.001***
Credit Access	0.0997	0.202	0.622
Extension Services	-0.0102	0.188	0.957
Land Ownership	1.1152	0.180	<0.001***
Income Source: Maize Sales	1.4558	0.251	<0.001***
Constant	-2.8238	0.609	<0.001***
Model Diagnostics			
Observations	378		
Wald χ^2 (HDDS)	710.36		<0.001***
Wald χ^2 (HFIAS)	632.92		<0.001***
Wald test of independence (HDDS)	χ^2 (2) = 6.07		0.048**

Note *, **, & *** show statistical significance at the 10% , 5% and 1% levels, respectively

Source: Survey data generated through Stata version 18 (2025)

The selection equation identifies six significant factors influencing CSAP adoption decisions among smallholder maize farmers. Income from maize sales was positive and statistically significant at the 1% level ($p < 0.001$) with a coefficient of 1.456. This indicates that farmers with income from maize sales have a probability of adopting CSAPs that is 1.456 units higher than those without maize sales income. This finding suggests that market-oriented farmers are significantly more likely to adopt CSAPs than subsistence farmers, highlighting the importance of agricultural commercialization in driving CSAP adoption. However, this finding contrasts with Mthethwa et al. (2022), who found that income had a negative and significant impact on CSAP adoption, suggesting context-specific variations in income effects. Land ownership was positive and statistically significant at the 1% level ($p < 0.001$) with a coefficient of 1.115. This means that farmers with secure land tenure have a probability of adopting CSAPs that is 1.115 units higher than those without land ownership. Samim et al. (2025) confirmed heterogeneous impacts of land tenure security on the adoption intensity of CSAPs in Afghanistan, supporting the universal importance of land tenure across different contexts. This finding emphasizes the critical role of secure tenure in encouraging long-term agricultural investments and CSAP adoption decisions.

Agricultural group membership was positive and statistically significant at the 1% level ($p < 0.001$) with a coefficient of 0.997. This indicates that farmers belonging to agricultural groups have a probability of adopting CSAPs that is 0.997 units higher than non-members. This result highlights the importance of social capital and collective action in facilitating CSAP transfer and knowledge sharing among farming communities. Zhou et al. (2024) found that cooperative membership significantly increases the adoption of CSAPs among banana-producing farmers in China. Climate information access was positive and statistically significant at the 1% level ($p < 0.001$) with a coefficient of 0.772. This means that farmers with access to climate information have a probability of adopting CSAPs that is 0.772 units higher than those without such access. This finding demonstrates how information access enables informed decision-making and motivates proactive adaptation strategies. Asante et al. (2024) supported this finding by demonstrating that leveraging the growth of information and communication technologies, such as smartphones, digital advisory services help Ghanaian farmers adopt CSAPs by reducing information asymmetry and providing climate-smart information to smallholder farmers. Household income was positive and statistically significant at the 1% level ($p = 0.001$) with a coefficient of 0.000053. While the coefficient appears small, it indicates that each unit increase in household income increases the probability of adopting CSAPs by 0.000053 units. This finding confirms that financial capacity facilitates CSAPs adoption by enabling farmers to overcome initial investment barriers. This aligns with Khoza et al. (2021)

research demonstrating that financial resources significantly shape farmers' perceptions of implementation feasibility. Age was negative and statistically significant at the 5% level ($p = 0.049$) with a coefficient of -0.016. This indicates that for each additional year in age, the probability of adopting CSAPs decreases by 0.016 units. This finding suggests that younger farmers are more receptive to new CSAPs, possibly due to greater risk tolerance and longer time horizons for investment recovery. However, this contradicts findings by Masud et al. (2017) who found that ageing farmers in Malaysia have a higher likelihood of adopting CSAPs.

6.9 Welfare effects among non-adopters (Regime 1)

6.9.1 The Household Dietary Diversity Score results

Household income was positive and statistically significant at the 1% level ($p < 0.001$) with a coefficient of 0.0003. This indicates that each unit increase in household income increases dietary diversity scores by 0.0003 units among non-adopters. Amadu et al. (2020) found similar patterns in Malawi, where income diversification strategies enabled households to achieve better dietary outcomes even without CSAPs. Farming years was positive and statistically significant at the 5% level ($p = 0.037$) with a coefficient of 0.024. This means that each additional year of farming experience increases dietary diversity scores by 0.024 units among non-adopters. Sanogo et al. (2023) asserted that experienced farmers develop confidence in managing agricultural risks and optimizing crop performance through accumulated knowledge, supporting the experience-outcome relationship. Agricultural training was positive and statistically significant at the 10% level ($p = 0.098$) with a coefficient of 0.4388. This means that receiving agricultural training increases dietary diversity scores by 0.4388 units. Sisay et al. (2023) confirmed that various studies consistently demonstrate the significant and favourable impact of training on the utilization of diverse agricultural practices, even traditional ones. This result suggests that accumulated agricultural knowledge and skills enable better food production outcomes even without CSAPs.

6.9.2 Food security (The Household Food Insecurity Access Scale results)

Household income was negative and statistically significant at the 1% level ($p < 0.001$) with a coefficient of -0.0005. This indicates that each unit increase in household income reduces food insecurity scores by 0.0005 units among non-adopters. This finding confirms that higher income substantially improves food security among conventional farming households. Recent evidence from Ethiopia shows similar patterns where income significantly reduces food insecurity (Ahmed et al., 2023). Gender was positive and statistically significant at the 10% level (p = 0.087) with a coefficient of 0.7723. This means that being female increases food insecurity scores by 0.7723 units compared to males. Recent systematic reviews confirm that gender disparities are evident in food security outcomes, with female farmers showing different vulnerability patterns compared to male farmers (Mnukwa et al., 2025). Employment was positive and statistically significant at the 1% level (p = 0.003) with a coefficient of 0.766. This indicates that employed farmers have food insecurity scores that are 0.766 units higher than unemployed farmers among non-adopters. Unicef (2024). reported that agricultural employment alone may not guarantee food security, particularly where wages are low and employment is seasonal. Farm size was positive and statistically significant at the 1% level (p = 0.004) with a coefficient of 4.189. This means that each additional unit of farm size increases food insecurity scores by 4.189 units among non-adopters. This unexpected result suggests that larger farms may require more intensive management and higher input costs without corresponding welfare improvements under conventional farming practices. Kurgat et al. (2020) noted that larger farms often require more capital-intensive approaches that can strain household resources without guaranteed returns.

Table 6.7 Endogenous Switching Regression results - Outcome equations for non-adopters (Regime 1)

Variable	**HDDS**			**HFIAS**		
	Coefficient	**Standard Error**	**p-value**	**Coefficient**	**Standard Error**	**p-value**
Age	-0.0045	0.008	0.577	0.0148	0.019	0.434
Education	0.0580	0.043	0.177	0.0140	0.071	0.844
Family Size	0.0353	0.029	0.220	0.0695	0.053	0.187
Household Income	0.0003	0.000026	<0.001***	-0.0005	0.000040	<0.001***
Farming Years	0.0242	0.012	0.037**	-0.0125	0.020	0.533
Gender	0.1183	0.265	0.655	0.7723	0.452	0.087*
Marital Status	-0.1000	0.200	0.616	0.3155	0.292	0.280
Employment	0.1367	0.121	0.257	0.7656	0.255	0.003***
Farm Size	-1.4639	1.072	0.172	4.1886	1.472	0.004***
Access Distance	-0.0462	0.073	0.524	0.1086	0.115	0.346
Climate Information	0.2895	0.326	0.374	0.9675	0.804	0.229

Agricultural Training	0.4388	0.265	0.098*	0.2761	0.731	0.706
Agricultural Group	-0.2362	0.290	0.416	0.3166	0.745	0.671
Credit Access	0.1315	0.310	0.671	-0.4466	0.554	0.420
Extension Services	-0.0821	0.253	0.745	0.7381	0.504	0.143
Land Ownership	-0.0510	0.369	0.890	0.7063	0.935	0.450
Constant	1.608	0.836	0.055*	9.824	1.512	<0.001***
Model Diagnostics						
Observations	200			200		
Log pseudolikelihood	-839.83			-1021.11		

Note *, **, & *** show statistical significance at the 10%, 5% and 1% levels, respectively

Source: Survey data generated through Stata version 18 (2025)

6.10 Welfare effects among adopters (Regime 2)

6.10.1 The Household Dietary Diversity Score results

Household income was positive and statistically significant at the 1% level ($p < 0.001$) with a coefficient of 0.0002. This indicates that each additional unit increase in income increases dietary diversity scores by 0.0002 units among adopters. Santalucia and Sibhatu (2023) found that adoption of CSAPs increases household dietary diversity among smallholders, supporting the notion that CSAPs provide alternative pathways to nutrition security. Family size was negative and statistically significant at the 1% level ($p = 0.001$) with a coefficient of -0.125. This indicates that each additional household member reduces dietary diversity scores by 0.125 units among adopters. Okoronkwo et al. (2024) noted that the substantial household sizes serve as a valuable labour reservoir for agricultural activities, but larger households often face challenges in maintaining dietary quality. This finding reveals important resource dilution effects where larger families struggle to maintain dietary quality despite CSAP adoption. Climate information access was negative and statistically significant at the 5% level ($p = 0.033$) with a coefficient of -0.627. This indicates that adopters with climate information access have dietary diversity scores that are 0.627 units lower than those without such access. This counterintuitive finding suggests that farmers may adopt CSAPs reactively in response to climate stress rather than proactively for improvement. Fagariba et al. (2018) noted that the inadequacy, inaccuracy, and inconsistency of climatic information available to farmers pose constraints in weather forecasting as an adaptation strategy.

Agricultural group was positive and statistically significant at the 10% level ($p = 0.066$) with a coefficient of 0.8657. This means that being part of an agricultural group increases dietary diversity scores by 0.8657 units compared to those not in agricultural groups. Ma and Zheng (2023) demonstrated that agricultural cooperatives facilitate knowledge sharing about diverse crop production systems, supporting the group membership benefit. Farm size was negative and statistically significant at the 5% level ($p = 0.040$) with a coefficient of -0.821. This means that each additional unit of farm size reduces dietary diversity scores by 0.821 units among adopters. This result suggests that larger farms may face greater challenges in optimizing CSAP benefits across expanded production areas. This is consistent with Ogada et al. (2020), who found that larger farms may require more intensive management and higher input costs without corresponding welfare improvements under conventional farming practices. Land ownership was positive and significant at the 10% level ($p = 0.071$) with a coefficient of 0.6164. This indicates that households with land ownership have dietary diversity scores that are 0.6164 units higher than households without land ownership among adopters. Ekesa et al. (2020) found that land tenure insecurity reduced dietary diversity, while land policy reforms that strengthen tenure security contribute positively to dietary diversity and improved food security in rural communities.

6.10.2 Food security (The Household Food Insecurity Access Scale results)

Household income was negative and statistically significant at the 1% level ($p < 0.001$) with a coefficient of -0.0004. This indicates that income reduces food insecurity among adopters, though the effect is smaller than for non-adopters (-0.0005), suggesting CSAPs provide alternative pathways to food security beyond income effects. Ahmed et al. (2023) found that adoption of CSAPs had a positive impact on food and nutritional security status of rural families. Employment was positive and significant at the 10% level ($p = 0.072$) with a coefficient of 0.430. This indicates that employed adopters have food insecurity scores that are 0.430 units higher than unemployed adopters, showing a similar but smaller effect compared to non-adopters. FAO (2024) reported that agricultural employment alone may not guarantee food security, particularly where wages are low and employment is seasonal, supporting the positive association between employment and food insecurity.

These ESR results provide strong empirical validation for the RUT framework employed in this study. The significant selection equation coefficients for land ownership, agricultural group membership, and climate information access confirm RUT's core assumption that farmers make systematic utility-maximizing decisions when adopting CSAPs. The different welfare determinants across regimes (income and training for non-adopters vs. family size and group membership for adopters) validate RUT's recognition that the same variables can have heterogeneous effects depending on farmers' adoption status, reflecting different utility functions across these groups.

Table 6.8 Endogenous Switching Regression results - Outcome equations for adopters (Regime 2)

Variable	HDDS			HFIAS		
	Coefficient	**Standard Error**	**p-value**	**Coefficient**	**Standard Error**	**p-value**
Age	-0.0099	0.012	0.404	-0.0041	0.018	0.817
Education	-0.0549	0.044	0.209	-0.0964	0.072	0.182
Family Size	-0.1247	0.039	0.001***	0.0441	0.053	0.403
Household Income	0.0002	0.000023	<0.001***	-0.0004	0.000040	<0.001***
Farming Years	0.0174	0.018	0.344	0.0176	0.028	0.529
Gender	0.0441	0.289	0.879	0.1477	0.390	0.705
Marital Status	-0.0211	0.201	0.916	0.0753	0.296	0.799
Employment	0.0073	0.143	0.959	0.4303	0.239	0.072*
Farm Size	-0.8210	0.401	0.040**	0.0436	0.639	0.946
Access Distance	-0.1469	0.107	0.170	0.1263	0.155	0.416
Climate Information	-0.6271	0.294	0.033**	-0.6167	0.600	0.304
Agricultural Training	-0.2050	0.393	0.602	-0.2517	0.535	0.638
Agricultural Group	0.8657	0.471	0.066*	0.4391	0.753	0.560
Credit Access	-0.4346	0.363	0.231	-0.2135	0.563	0.704
Extension Services	0.3534	0.366	0.334	-0.4173	0.656	0.525
Land Ownership	0.6164	0.342	0.071*	-0.5865	0.593	0.323
Constant	8.671	1.118	<0.001***	12.937	2.241	<0.001***

Model Diagnostics						
Observations	178			178		
Log pseudolikelihood	-839.83			-1021.11		

Note *, **, & *** show statistical significance at the 10%, 5% and 1% levels, respectively

Source: Survey data generated through Stata version 18 (2025)

3.11 Average treatment effect of climate-smart agriculture practices adoption on food security

The estimates of the treatment effects of the adoption of CSAPs on food security are reported in Table 6.9. The Average Treatment Effect on the Treated (ATT) measures the difference between the food security outcomes of the adopters and what they would have achieved if they had not adopted CSAPs. The Average Treatment Effect on the Untreated (ATU), on the other hand, assesses the difference between the food security outcomes of non-adopters and their counterfactuals if they had adopted CSAPs. The Average Treatment Effect (ATE) represents the population-weighted average treatment effect, capturing the overall impact of CSAP adoption across all farmers in the sample. The analysis used ESR to address selection bias and examined two food security dimensions: food access security (HFIAS - lower scores indicate better security) and dietary diversity (HDDS - higher scores indicate better quality) among smallholder maize farmers in KZN Province.

Table 6.9 Average treatment effect of climate-smart agriculture practices adoption on food security

Index	**HFIAS**				**HDDS**			
	Estimate	Std Err.	t value	p-value	Estimate	Std Err.	t value	p-value
ATT	-1.722	0.107	-16.14	<0.001***	0.017	0.150	0.11	0.912
ATU	0.423	0.095	4.45	<0.001***	3.035	0.140	21.68	<0.001***
ATE	-0.587	0.090	-6.535	<0.001***	1.613	0.129	12.51	<0.001***

Note *** show statistical significance at the 1% level

Source: Survey data generated through Stata version 18 (2025)

The HFIAS results reveal profound welfare improvements in food security access, with distinct patterns between adopters and potential adopters. The ATT demonstrates that current CSAP adopters experience a statistically significant 1.722-point reduction in food insecurity scores compared to their counterfactual non-adoption scenario ($t = -16.14$, $p < 0.001$). This substantial improvement indicates that CSAPs effectively enhance food access and dramatically reduce household food insecurity among participating farmers. These findings align with recent studies that report enhanced outcomes in food consumption when farmers adopt CSAPs compared to non-adopters, with CSAPs playing a critical role in improving food security among smallholder farmers (Khumalo et al., 2025). Similar evidence from Ethiopia shows that CSAPs adopters demonstrate significantly higher resilience gains compared to non-adopters (Berhanu et al., 2024). The ATU shows that current non-adopters would experience a significant 0.423-point reduction in food insecurity if they adopted CSAPs ($t = 4.45$, $p < 0.001$), demonstrating substantial unrealized welfare potential among the 53% of farmers who have not yet adopted CSAPs. Research from West Africa confirms positive associations between CSAPs adoption and food consumption scores, demonstrating that CSAP adoption is beneficial not only to current adopters but could potentially benefit non-adopters should they adopt (Tabe-Ojong et al., 2023). The contrasting magnitudes between ATT (-1.722) and ATU (0.423) reveal important treatment effect heterogeneity, indicating that current adopters derive substantially greater food security benefits from CSAP adoption than potential adopters would. Studies emphasize that heterogeneous characteristics of smallholder farmers, such as their level of education and local knowledge, impact their engagement with CSAPs, allowing some but not all farmers to build adaptive capacities (Finizola e Silva et al., 2024; Kassie et al., 2024).

The HDDS analysis provides the most striking evidence of treatment effect heterogeneity, revealing dramatically different patterns between current adopters and potential adopters. The ATT shows that current CSAP adopters experience only a minimal 0.017-point improvement in dietary diversity ($t = 0.11$, $p = 0.912$), suggesting farmers who have already adopted CSAPs gain little additional dietary diversity benefit from their current practices. In stark contrast, the ATU reveals that current non-adopters would experience a substantial 3.035-point improvement in dietary diversity if they adopted CSAPs ($t = 21.68$, $p < 0.001$). This represents one of the largest treatment effects observed and indicates enormous unrealized potential for dietary quality improvements among non-adopting farmers. Supporting evidence from Ethiopia's Central Rift Valley shows that CSAP adopter households demonstrate higher dietary diversity scores than non-adopters, with CSAPs adoption improving households' food security across multiple dimensions (Ali et al., 2022). The observed heterogeneity patterns reveal important insights about CSAP effectiveness and adoption dynamics. For food access (HFIAS), current adopters benefit more than potential adopters would, suggesting that adopters may possess complementary assets, skills, or resources that enhance the food security benefits of CSAPs. Recent systematic reviews confirm that variables including education, land tenure security, access to extension services, agricultural training, and membership in farmers' organizations consistently have positive impacts on CSAP adoption, explaining why some farmers derive greater benefits (Kassie et al., 2024). For dietary diversity (HDDS), the opposite pattern emerges, non-adopters show enormous potential gains while current adopters derive minimal benefits. This suggests current adopters may have already achieved near-optimal dietary diversity levels, or may have focused primarily on productivity gains rather than diversifying production for dietary variety. Evidence from multiple African countries shows that approximately 90% of farmers who adopted CSAPs reported positive results in terms of improving food access and diversity, but with significant variation (8 to 88%) across different CSAPs (Ariom et al., 2022).

The ESR results provide strong empirical validation for the RUT framework employed in this study. The significant selection equation coefficients for land ownership, agricultural group membership, climate information access, household income, and age confirm RUT's core assumption that farmers make systematic utility-maximizing decisions when adopting CSAPs rather than random choices. The contrasting welfare determinants across regimes (where different factors influence outcomes for adopters versus non-adopters) validates RUT's recognition that utility functions differ systematically between adoption groups. Furthermore, the heterogeneous treatment effects observed, particularly the contrasting ATT and ATU patterns for both HDDS and HFIAS outcomes, provide empirical evidence for RUT's premise that adoption decisions reflect rational evaluation of expected net benefits. This theoretical consistency strengthens confidence in the estimated welfare impacts and supports the robustness of the ESR modelling approach.

6.12 Conclusion and recommendations

This study assessed the welfare effects of CSAPs on smallholder maize farmers in KZN, employing an ESR model grounded in RUT to address selection bias concerns. The findings reveal that 47.1% of farmers have adopted at least one CSAP, with significant welfare disparities existing between adopters and non-adopters. Adopters demonstrate substantially higher household dietary diversity and better food security status compared to their non-adopting counterparts. The ESR model results reveal distinct welfare determinants across the two regimes, with income, farming experience, and agricultural training significantly influencing dietary diversity among non-adopters, while family size, climate information access, agricultural group membership, and farm size affect welfare outcomes among adopters. The treatment effects analysis provides crucial insights, revealing that current adopters experience meaningful food security improvements but minimal additional dietary diversity gains, while non-adopters show enormous potential for dietary diversity enhancement if they were to adopt CSAPs. These contrasting patterns indicate that current adoption may be predominantly stress-driven rather than opportunity-driven, with farmers adopting practices in response to crises rather than for proactive welfare enhancement. The heterogeneous welfare effects demonstrate the complexity of CSAP impacts as context-dependent outcomes, providing empirical validation for the RUT framework employed. The study reveals that welfare effects of CSAPs vary significantly across farmer groups, with current adopters having already achieved substantial food security benefits while non-adopters represent untapped potential for comprehensive welfare enhancement through targeted interventions.

Based on the research findings, several targeted recommendations are proposed to enhance welfare outcomes from CSAPs adoption among smallholder maize farmers. Enhanced agricultural training programs should be developed and expanded, focusing on practical demonstrations of welfare-enhancing practices, farmer field schools, and peer-learning opportunities that emphasize not only technical implementation but also the pathways through which CSAPs improve household nutrition and food security. Financial institutions and government agencies should design accessible and affordable credit products specifically for smallholder farmers, with flexible repayment terms aligned with harvest cycles and reduced collateral requirements, enabling farmers to adopt CSAPs proactively rather than reactively during crisis periods. Extension services should strengthen the communication of welfare benefits from CSAPs through multiple channels, including mobile platforms, community radio, and farmer groups, presenting evidence-based information on dietary diversity and food security improvements in formats that are accessible to farmers with varying education levels. Targeted support should be provided to current CSAPs adopters to help them optimize implementation and maximize welfare benefits from their technology investments, including intensive technical assistance, follow-up training, and resource support to address any challenges they may be experiencing. Proactive outreach programs should prioritize stable, non-adopting households who demonstrate greater potential for welfare gains, focusing on demonstrating the food security and nutritional benefits of CSAPs rather than merely promoting adoption for crisis response. Integrated approaches should promote complementary CSAPs packages that maximize welfare benefits while providing guidance on sequencing practices to optimize dietary diversity and food security outcomes for resource-constrained farmers. These recommendations recognize that enhancing welfare through CSAPs requires addressing both the optimization needs of current adopters and the untapped potential among non-adopters, ultimately contributing to improved food security, dietary diversity, and household well-being in climate-vulnerable farming communities.

References

Abegunde, V.O., Sibanda, M. and Obi, A. (2019) 'Determinants of the adoption of climate-smart agricultural practices by small-scale farming households in King Cetshwayo District Municipality, South Africa', *Sustainability*, 12, p. 195. https://doi.org/10.3390/su12010195

Addai, B., Osei-Amponsah, R., Asante, I.K. and Egyir, I.S. (2024) 'Can farmer organization membership improve household food security and nutrition? Evidence from Northern Ghana', *World Food Policy*, 10(1), pp. 7-35. https://doi.org/10.1002/wfp2.12076

Aderaw, Z., Ali, A., Worku, A. and Simanie, B. (2017) 'Spatial variations of household food insecurity in East Gojjam Zone, Amhara region, Ethiopia: implications for agroecosystem-based interventions', *Agriculture & Food Security*, 6, pp. 1-9. https://doi.org/10.1186/s40066-017-0113-9

Ali, H., Menza, M., Hagos, F. and Haileslassie, A. (2022) 'Impact of climate-smart agriculture adoption on food security and multidimensional poverty of rural farm households in the Central Rift Valley of Ethiopia', *Agriculture & Food Security*, 11(1), 54. https://doi.org/10.1186/s40066-022-00401-5

Amadu, F.O., McNamara, P.E. and Miller, D.C. (2020) 'Understanding the adoption of climate-smart agriculture: A farm-level typology with empirical evidence from southern Malawi', *World Development*, 126, p. 104692. https://doi.org/10.1016/j.worlddev.2019.104692

Ariom, T.O., Dimon, E., Nambeye, E., Diouf, N.S., Adelusi, O.O. and Boudalia, S. (2022) 'Climate-Smart Agriculture in African Countries: A Review of Strategies and Impacts on Smallholder Farmers', *Sustainability*, 14(18), 11370. https://doi.org/10.3390/su141811370

Aryal, J.P., Thapa, G. and Simtowe, F. (2021) 'Mechanisation of small-scale farms in South Asia: Empirical evidence derived from farm households survey', *Technology in Society*, 65, p. 101591. https://doi.org/10.1016/j.techsoc.2021.101591

Asante, B.O., Ma, W., Prah, S. and Temoso, O. (2024) 'Promoting the adoption of climate-smart agricultural technologies among maize farmers in Ghana: using digital advisory services', *Mitigation and Adaptation Strategies for Global Change*, 29(3), p. 19. https://doi.org/10.1007/s11027-024-10116-6

Berhanu, A.A., Ayele, Z.B. and Dagnew, D.C. (2024) 'Impact of climate-smart agricultural practices on smallholder farmers' resilience in Ethiopia', *Heliyon*, 10(17), e37374. https://doi.org/10.1016/j.heliyon.2024.e37374

Coates, J., Swindale, A. and Bilinsky, P. (2007) *Household Food Insecurity Access Scale (HFIAS) for measurement of food access: indicator guide*. Washington, DC: Food and Nutrition Technical Assistance Project, Academy for Educational Development.

Damman, S., Eide, W.B. and Kuhnlein, H.V. (2008) 'Indigenous peoples' nutrition transition in a right to food perspective', *Food Policy*, 33(2), pp. 135-155. https://doi.org/10.1016/j.foodpol.2007.08.002

Di Falco, S., Veronesi, M. and Yesuf, M. (2011) 'Does adaptation to climate change provide food security? A micro-perspective from Ethiopia', *American Journal of Agricultural Economics*, 93(3), pp. 829-846.

Du, S. and Xiong, W. (2024) 'Weather extremes shock maize production: Current approaches and future research directions in Africa', *Plants*, 13, p. 1585. https://doi.org/10.3390/plants13121585

Ekesa, B., Ariong, R.M., Kennedy, G., Baganizi, M. and Dolan, I. (2020) 'Relationships between land tenure insecurity, agrobiodiversity, and dietary diversity of women of reproductive age: Evidence from Acholi and Teso subregions of Uganda', *Maternal & Child Nutrition*, 16, p.e12965. https://doi.org/10.1111/mcn.12965

Fagariba, C.J., Song, S. and Soule Baoro, S.K.G. (2018) 'Climate change adaptation strategies and constraints in Northern Ghana: Evidence of farmers in Sissala West District', *Sustainability*, 10(5), p. 1484. https://doi.org/10.3390/su10051484

FAO (2018) *Climate-Smart Agriculture: Building Resilience to Climate Change*. Rome: Food and Agriculture Organization.

Finizola e Silva, M., Van Schoubroeck, S., Cools, J. and Van Passel, S. (2024) 'A systematic review identifying the drivers and barriers to the adoption of climate-smart agriculture by smallholder farmers in Africa', *Frontiers in Environmental Economics*, 3, p. 1356335. https://doi.org/10.3389/frevc.2024.1356335

Hou, H. (2025) 'Utility Theory Application in Decision-Making Behavior for Energy Use and Management: A Systematic Review', *Energies*, 18(8), p. 2125. https://doi.org/10.3390/en18082125

Kassie, G.T., Ayal, D.Y., Desta, G.A., Warku, M.A. and Teka, A.H. (2024) 'A systematic review identifying the drivers and barriers to the adoption of climate-smart agriculture by smallholder farmers in Africa', *Frontiers in Environmental Economics*, 3, 1356335. https://doi.org/10.3389/frevc.2024.1356335

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

Khumalo, N.Z., Sibanda, M. and Mdoda, L. (2025) 'The effect of heterogeneous adoption of climate-smart agriculture practices on household food and nutrition security of small-scale urban crop farmers in eThekwini Municipality', *PLOS Climate*, 4(1), e0000551. https://doi.org/10.1371/journal.pclm.0000551

Khoza, S., de Beer, L.T., van Niekerk, D. and Nemakonde, L. (2021) 'A gender-differentiated analysis of climate-smart agriculture adoption by smallholder farmers: Application of the extended technology acceptance model', *Gender, Technology and Development*, 25(1), pp. 1-21. https://doi.org/10.1080/09718524.2020.1830338

Kuma, T., Dereje, M., Hirvonen, K. and Minten, B. (2021) 'Does market access improve dietary diversity and food security? Evidence from Southwestern Ethiopian smallholder coffee producers', *Agricultural and Food Economics*, 9, p. 18.

Kumar, L., Chhogyel, N., Gopalakrishnan, T., Hasan, M.K., Jayasinghe, S.L., Kariyawasam, C.S., et al. (2022) 'Climate change and future of agri-food production', in *Future Foods*. Academic Press, pp. 49-79. https://doi.org/10.1016/B978-0-323-91001-9.00009-8

Kurgat, B.K., Lamanna, C., Kimaro, A., Namoi, N., Manda, L. and Rosenstock, T.S. (2020) 'Adoption of climate-smart agriculture technologies in Tanzania', *Frontiers in Sustainable Food Systems*, 4, p. 55. https://doi.org/10.3389/fsufs.2020.00055

Lipper, L., Thornton, P., Campbell, B.M., Baedeker, T., Braimoh, A., Bwalya, M., et al. (2014) 'Climate-smart agriculture for food security', *Nature Climate Change*, 4, pp. 1068-1072. http://www.nature.com/doifinder/10.1038/nclimate

Ma, W. and Rahut, D.B. (2024) 'Climate-smart agriculture: adoption, impacts, and implications for sustainable development', *Mitigation and Adaptation Strategies for Global Change*, 29, p. 44. https://doi.org/10.1007/s11027-024-10139-z

Ma, W. and Zheng, H. (2023) 'Cooperative membership and adoption of green pest control practices: Insights from rice farmers', *Australian Journal of Agricultural and Resource Economics*, 67(3), pp. 459-479.

Mahama, C., Pekrun, H., Lambers, E. and Kandeler, K. (2020) 'Hidden miners--the roles of cover crops and soil microorganisms in phosphorus cycling through agroecosystems', *Plant and Soil*, 434, pp. 7-45. https://doi.org/10.1007/s11104-018-3810-7

Makamane, A., Van Niekerk, J., Loki, O. and Mdoda, L. (2023) 'Determinants of Climate-Smart Agriculture (CSA) Technologies Adoption by Smallholder Food Crop Farmers in Mangaung Metropolitan Municipality, Free State', *South African Journal of Agricultural Extension*, 51, pp. 52-74. https://doi.org/10.17159/2413-3221/2023/v51n4a16451

Mamahit, A.Y., Sudarmi, N.W., Mautang, T.W.E., Rende, D.C. and Suryani, D. (2024) 'Factors related to household dietary diversity score (HDDS) as nutrition outcomes in Eastern Indonesia', *PREPOTIF: Jurnal Kesehatan Masyarakat*, 8(1), pp. 585-592.

Maponya, P. and Agbugba, I.K. (2023) 'An assessment of smallholder farmers' status in Umzinyathi and Harry Gwala districts of KwaZulu Natal Province, South Africa', in *Agricultural Bioeconomy*. Cambridge, MA: Academic Press, pp. 85-102. https://doi.org/10.1016/B978-0-323-90569-5.00011-1

Masud, M.M., Azam, M.N., Mohiuddin, M., Banna, H., Akhtar, R., Alam, A.F. and Begum, H. (2017) 'Adaptation barriers and strategies towards climate change: Challenges in the agricultural sector', *Journal of Cleaner Production*, 156, pp. 698-706. https://doi.org/10.1016/j.jclepro.2017.04.060

McFadden, D. (1974) 'Conditional logit analysis of qualitative choice behavior', in Zarembka, P. (ed.) *Frontiers in Econometrics*. New York: Academic Press, pp. 105-142.

Mdoda, L., Tamako, N., Gidi, L.S. and Naidoo, D. (2025) 'Evaluating the impact of improved maize varieties on agricultural productivity and technical efficiency among smallholder farmers in the Eastern Cape, South Africa: an empirical analysis', *GM Crops & Food*, 16, pp. 272-304. https://doi.org/10.1080/21645698.2025.2476667

Mnukwa, M.L., Mdoda, L. and Mudhara, M. (2025) 'Assessing the adoption and impact of climate-smart agricultural practices on smallholder maize farmers' livelihoods in Sub-Saharan Africa: a systematic review', *Frontiers in Sustainable Food Systems*, 9, p. 1543805. https://doi.org/10.3389/fsufs.2025.1543805

Mohamed, A.A., Iannotti, L., Ganaba, R., Verhoef, H. and Bassiahi Soura, A. (2020) 'Household dietary diversity score and child nutrition status among settled and nomadic Fulani in Burkina Faso', *Food and Nutrition Bulletin*, 41(3), pp. 333-350.

Mthethwa, K.N., Ngidi, M.S.C., Ojo, T.O. and Hlatshwayo, S.I. (2022) 'The determinants of adoption and intensity of climate-smart agricultural practices among smallholder maize farmers', *Sustainability*, 14, p. 16926. https://doi.org/10.3390/su142416926

Mujeyi, A., Mudhara, M. and Mutenje, M. (2021) 'The impact of climate smart agriculture on household welfare in smallholder integrated crop--livestock farming systems: evidence from Zimbabwe', *Agriculture & Food Security*, 10, pp. 1-15. https://doi.org/10.1186/s40066-020-00277-3

Mutengwa, C.S., Mnkeni, P. and Kondwakwenda, A. (2023) 'Climate-smart agriculture and food security in southern Africa: a review of the vulnerability of smallholder agriculture and food security to climate change', *Sustainability*, 15, p. 2882. https://doi.org/10.3390/su15042882

Muthini, D., Nzuma, J. and Nyikal, R. (2020) 'Farm production diversity and its association with dietary diversity in Kenya', *Food Security*, 12(5), pp. 1107-1120. https://doi.org/10.1007/s12571-020-01030-1

Naicker, M., Naidoo, D., Hlatshwayo, S.I. and Ngidi, M.S. (2025) 'Factors Affecting the Choice and Level of Adaptation Strategies Among Smallholder Farmers in KwaZulu Natal Province', *Sustainability*, 17, p. 488. https://doi.org/10.3390/su17020488

Ndlovu, M., Clulow, A.D., Savage, M.J., Nhamo, L., Magidi, J. and Mabhaudhi, T. (2021) 'An assessment of the impacts of climate variability and change in KwaZulu-Natal Province, South Africa', *Atmosphere*, 12, p. 427. https://doi.org/10.3390/atmos12040427

Ngidi, M.S.C. (2023) 'The Role of Traditional Leafy Vegetables on Household Food Security in Umdoni Municipality of the KwaZulu Natal Province, South Africa', *Foods*, 12, p. 3918. https://doi.org/10.3390/foods12213918

Oduniyi, O.S., Chagwiza, C. and Wade, T. (2022) 'Welfare impacts of conservation agriculture adoption on smallholder maize farmers in South Africa', *Renewable Agriculture and Food Systems*, 37, pp. 672-682. https://doi.org/10.1017/S1742170522000308

Ogundeji, A.A. (2022) 'Adaptation to climate change and impact on smallholder farmers' food security in South Africa', *Agriculture*, 12(5), p. 589. https://doi.org/10.3390/agriculture12050589

Okoronkwo, D.J., Ozioko, R.I., Ugwoke, R.U., Nwagbo, U.V., Nwobodo, C., Ugwu, C.H., Okoro, G.G. and Mbah, E.C. (2024) 'Climate smart agriculture? Adaptation strategies of traditional agriculture to climate change in sub-Saharan Africa', *Frontiers in Climate*, 6, p. 1272320. https://doi.org/10.3389/fclim.2024.1272320

Pourmotabbed, A., Moradi, S., Babaei, A., Ghavami, A., Mohammadi, H., Jalili, C., Symonds, M.E. and Miraghajani, M. (2020) 'Food insecurity and mental health: a systematic review and meta-analysis', *Public Health Nutrition*, 23(10), pp. 1778-1790. https://doi.org/10.1017/S136898001900435X

Samim, S.A., Deng, X., Chandio, A.A. and Li, Z. (2025) 'Heterogeneous impacts of land tenure on the adoption intensity of climate-smart agricultural practices in small-scale farming in Afghanistan', *Environment, Development and Sustainability*, pp. 1-31. https://doi.org/10.1007/s10668-025-06062-1

Sanogo, K., Touré, I., Arinloye, D.D.A., Dossou-Yovo, E.R. and Bayala, J. (2023) 'Factors affecting the adoption of climate-smart agriculture technologies in rice farming systems in Mali, West Africa', *Smart Agricultural Technology*, 5, p. 100283. https://doi.org/10.1016/j.atech.2023.100283

Santalucia, S. and Sibhatu, K.T. (2024) 'Nourishing the farms, nourishing the plates: Association of climate-smart agricultural practices with household dietary diversity and food security in smallholders', *Agribusiness*, 40(2), pp. 513-533. https://doi.org/10.1002/agr.21892

Sibhatu, K.T. and Qaim, M. (2018) 'Farm production diversity and dietary quality: linkages and measurement issues', *Food Security*, 10(1), pp. 47-59. https://doi.org/10.1007/s12571-017-0762-3

Sisay, T., Tesfaye, K., Ketema, M., Dechassa, N. and Getnet, M. (2023) 'Climate smart agriculture technologies and determinants of farmers' adoption decisions in the Great Rift Valley of Ethiopia', *Sustainability*, 15, p. 3471. https://doi.org/10.3390/su15043471

Suneetha, V. and Rahul, C. (2012) 'Food security and coping strategies of dairy farmers: A micro level study in Chittoor district of Andhra Pradesh', *Agricultural Economics Research Review*, 25(2), pp. 319-326.

Swindale, A. and Bilinsky, P. (2006) *Household Dietary Diversity Score (HDDS) for Measurement of Household Food Access: Indicator Guide (Version 2)*. Washington, D.C.: Food and Nutrition Technical Assistance Project, Academy for Educational Development.

Tabe-Ojong, M.P., Aihounton, G.B.D. and Lokossou, J.C. (2023) 'Climate-smart agriculture and food security: Cross-country evidence from West Africa', *Global Environmental Change*, 81, 102697. https://doi.org/10.1016/j.gloenvcha.2023.102697

Teklewold, H., Gebrehiwot, T. and Bezabih, M. (2019) 'Climate smart agricultural practices and gender differentiated nutrition outcome: empirical evidence from Ethiopia', *World Development*, 122, pp. 38-53.

Tesfaye, W. and Tirivayi, N. (2020) 'Crop diversity, household welfare and consumption smoothing under risk: Evidence from rural Uganda', *World Development*, 125, p. 104686. https://doi.org/10.1016/j.worlddev.2019.104686

UNICEF (2024) *The State of Food Security and Nutrition in the World 2024*.

Verger, E.O., Le Port, A., Borderon, A., Bourbon, G., Moursi, M., Savy, M., Mariotti, F. and Martin-Prevel, Y. (2021) 'Dietary diversity indicators and their associations with dietary adequacy and health outcomes: a systematic scoping review', *Advances in Nutrition*, 12(5), pp. 1659-1672. https://doi.org/10.1093/advances/nmab009

Wekesa, B.M., Ayuya, O.I. and Lagat, J.K. (2018) 'Effect of climate-smart agricultural practices on household food security in smallholder production systems: micro-level evidence from Kenya', *Agriculture & Food Security*, 7, pp. 1-14. https://doi.org/10.1186/s40066-018-0230-0

Zeweld, W., Van Huylenbroeck, G., Tesfay, G., Azadi, H. and Speelman, S. (2020) 'Sustainable agricultural practices, environmental risk mitigation and livelihood improvements: Empirical evidence from Northern Ethiopia', *Land Use Policy*, 95, p. 103799. https://doi.org/10.1016/j.landusepol.2019.01.002

Zheng, H., Ma, W. and He, Z. (2024) 'Climate-smart agricultural practices for enhanced farm productivity, income, resilience, and greenhouse gas mitigation: a comprehensive review', *Mitigation and Adaptation Strategies for Global Change*, 29(2), pp. 1-30. https://doi.org/10.1007/s11027-024-10124-6

Zhou, X., Ma, W., Zheng, H., Li, J. and Zhu, H. (2024) 'Promoting banana farmers' adoption of climate-smart agricultural practices: the role of agricultural cooperatives', *Climate and Development*, 16(4), pp. 301-310. https://doi.org/10.1080/17565529.2023.2218333

Zougmore, R.B., Partey, S.T., Ouédraogo, M. and Torquebiau, E. (2018) 'Facing climate variability in sub-Saharan Africa: analysis of climate-smart agriculture opportunities to manage climate-related risks', *Cahiers Agricultures*, 27, pp. 1-9. https://doi.org/10.1051/cagri/2018019

CHAPTER 7

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

7.1 Introduction

This chapter presents the summary and synthesis of the study. The chapter focuses on the key results, conclusions and recommendations based on the study's aim and objectives.

7.2 Summary

Climate change significantly threatens agricultural systems in developing regions, particularly for smallholder farmers who face increased vulnerability to shifting weather patterns, droughts, and extreme weather events. In SSA, where agriculture serves as the economic backbone for the majority of the population, climate variability and extreme weather events are already disrupting traditional farming practices and exacerbating rural poverty and food insecurity. Maize, which serves as a fundamental food crop throughout East and Southern Africa and provides a substantial portion of dietary calories across SSA, exemplifies these vulnerabilities due to its sensitivity to temperature variations and water stress. CSAPs offer promising solutions to enhance resilience and productivity through practices such as drought-tolerant varieties, conservation agriculture, rainwater harvesting, and crop diversification, yet their adoption remains low among smallholder farmers. Despite documented potential for these practices to significantly reduce yield losses during drought years and improve soil water retention, adoption rates remain suboptimal across different provinces in South Africa. In KZN Province, where this study was conducted, climate change impacts are particularly acute, with rising temperatures, declining annual rainfall, and substantial estimated agricultural losses over the past decade.

7.3 Study objectives

The overall objective of the study was to assess the perceptions, adoption decisions, and effects of CSAPs on the livelihoods of smallholder maize farmers in KZN Province.

Specific objectives are as follows:

I. To examine the perceptions and attitudes toward CSAPs among smallholder maize farmers
II. To investigate the determinants of the decision to adopt and intensity of use of CSAPs by smallholder maize farmers
III. To measure the economic benefits (maize production/farm income) and efficiency of adopting CSAPs by smallholder maize farmers
IV. To assess the effect of CSAPs on the welfare (food security) of smallholder maize farmers

This study employed a mixed-methods research approach using econometric models to analyse the determinants, perceptions, welfare effects, and economic benefits of CSAPs adoption among smallholder maize farmers in KZN Province, South Africa. A cross-sectional research design was chosen for its time and cost-effectiveness, enabling the study to draw rational and sound conclusions across multiple research objectives. Data were collected from 378 smallholder maize farmers within HGDM and UDM. A multi-stage sampling technique combined purposive, random, and stratified sampling methods to ensure representativeness and enhance generalisability of findings.

The study employed econometric models to address the research objectives systematically. Descriptive statistics were used to characterize farmers' demographic and socioeconomic profiles and assess CSAP adoption patterns. The Theory of Planned Behaviour framework guided the analysis of farmers' perceptions and attitudes towards CSAPs, with Tobit regression models employed to analyse determinants of perception and attitude indices while controlling for censored data characteristics. A double-hurdle approach was applied to examine both the choice to adopt and the intensity of CSAP adoption, with a probit model examining initial adoption decisions and a truncated regression analysing adoption intensity among existing adopters. Gross margin analysis and stochastic production function analysis, anchored in Production Theory, were used to measure direct economic benefits and technical efficiency gains from CSAP adoption respectively. The endogenous switching regression model, grounded in Random Utility Theory, was employed to assess welfare effects on household dietary diversity and food security while addressing selection bias inherent in technology adoption decisions.

This study significantly contributes to the CSAP literature by providing comprehensive empirical evidence on multiple dimensions of CSAP adoption among smallholder maize farmers in a climate-vulnerable region. While existing literature often examines individual aspects of CSAP adoption in isolation, this research provides integrated insights into how farmer characteristics, institutional factors, and socioeconomic conditions collectively influence adoption decisions, perceptions, welfare outcomes, and economic performance. The study uniquely demonstrates the heterogeneous effects of CSAP adoption across different farmer groups, revealing that current adopters experience significant food security improvements but minimal dietary diversity gains, while non-adopters show enormous unrealized potential for comprehensive welfare enhancement. The research further reveals substantial economic benefits from CSAP adoption, with adopters achieving significant gross margin improvements and technical efficiency gains, while identifying credit access, education, and extension services as the most critical determinants of successful implementation. Methodologically, the study integrates various econometric approaches including, double-hurdle models, and stochastic frontier analysis to provide robust and comprehensive assessment of CSAP adoption dynamics. This interdisciplinary approach strengthens the study's empirical contributions, offering theoretical validation and practical insights for policymakers, extension services, and development organizations working to enhance agricultural resilience and food security in climate-vulnerable smallholder farming systems across Sub-Saharan Africa.

7.4 Summary of the key primary findings and conclusion

This section presents key findings from 378 smallholder maize farmers in KZN Province across four chapters.

7.4.1 Smallholder maize farmers' perceptions and attitudes towards climate-smart agricultural practices in KwaZulu-Natal

Findings showed that smallholder maize farmers in KZN Province demonstrated a significant divide between CSAPs adopters (47.1%) and non-adopters (52.9%), with adopters consistently exhibiting more positive perceptions and attitudes across all measured variables. Despite high awareness levels (80%) of CSAPs including drought-tolerant maize varieties, maize-legume intercropping, rainwater harvesting, and crop diversification, substantial adoption gaps persisted due to complex socioeconomic and psychological barriers. Age emerged as a significant negative predictor of both perceptions and attitudes, indicating that younger farmers were more receptive to CSAPs, while education level and household income showed strong positive relationships with adoption, with income exhibiting particularly strong influence on farmer decision-making. Institutional factors proved critical as enablers, with access to extension services, agricultural credit, climate information, and membership in farmer groups all significantly enhancing farmers' perceptions and attitudes toward CSAPs. A striking finding revealed that both adopters and non-adopters expressed similar reluctance to implement CSAPs without financial support, highlighting economic constraints as the primary adoption barrier regardless of psychological factors and underscoring the necessity of targeted subsidies and microfinance mechanisms. Farmers demonstrated strong awareness of climate change impacts, with 82% reporting decreased maize yields, 78% observing increased summer temperatures, and 84% noting declining summer rainfall patterns over the past decade, providing a solid foundation for CSAPs promotion despite the persistent awareness-action gap caused by resource limitations and implementation challenges in smallholder farming systems.

7.4.2 The determinants of adoption and intensity of climate-smart agricultural practices among smallholder maize farmers in KwaZulu-Natal

Findings showed that the double-hurdle analysis revealed distinct factors influencing initial adoption decisions versus adoption intensity, validating the Technology Acceptance Model framework's two-stage decision-making process. The first hurdle identified seven significant adoption determinants: marital status, education, household income, access to climate information, credit access, and agricultural training all positively influenced adoption, while age demonstrated a negative effect. Married farmers showed higher adoption probabilities due to enhanced household stability and resource pooling, while younger farmers proved more receptive to CSAPs. Education and income emerged as critical enablers, with higher education enhancing farmers' ability to comprehend CSAP benefits and increased income facilitating the financial capacity to overcome initial investment barriers. Access to climate information, agricultural credit, and specialized training significantly enhanced adoption likelihood by addressing knowledge gaps, financial constraints, and technical implementation challenges. The second hurdle revealed that agricultural training was the only factor significant in both stages, highlighting its fundamental importance throughout the entire adoption process. Among existing adopters, age positively influenced adoption intensity, suggesting that older farmers who overcome initial barriers tend to implement multiple practices simultaneously. However, family size, farming experience, and distance to farm all negatively affected adoption intensity, indicating that larger households face greater resource pressures, experienced farmers exhibit stronger attachment to traditional methods, and spatial constraints create practical implementation challenges that discourage comprehensive CSAP adoption.

7.4.3 The economic benefits and efficiency of climate-smart agricultural practices adoption by smallholder maize farmers in KwaZulu-Natal

Findings showed that the economic analysis revealed substantial benefits from CSAPs adoption among smallholder maize farmers in KZN. Adopters experienced significant gross margin improvements driven primarily by enhanced productivity and improved market access while variable costs increased only modestly. The determinants analysis identified education level, household income, and credit access as key factors influencing economic benefits, with credit access demonstrating the largest magnitude effect. Extension services, agricultural training, and climate information access also emerged as important institutional factors enhancing CSAP economic returns. The Stochastic Production Function analysis revealed remarkable improvements in technical efficiency following CSAP adoption, with all key production inputs becoming more productive post-adoption. Fertilizer showed the most pronounced increase in elasticity, suggesting that CSAPs enhanced nutrient use efficiency through improved soil health and conservation practices. The inefficiency analysis demonstrated that education, household income, credit access, extension services, training, and climate information consistently reduced technical inefficiency, while age, household size, and farming experience were positively associated with inefficiency, indicating challenges for older farmers and larger households in optimizing CSAP implementation. Cost efficiency distribution analysis showed meaningful improvements in farmer performance following CSAP adoption.

7.4.4 Assessing the impact of climate-smart agricultural practices on Food Security among smallholder maize farmers in KwaZulu-Natal

Findings showed that the Endogenous Switching Regression analysis revealed significant welfare disparities between CSAPs adopters and non-adopters among smallholder maize farmers in KZN Province. Adopters demonstrated substantially higher household dietary diversity scores and better food security status, representing meaningful welfare improvements. The selection equation identified six significant factors influencing CSAP adoption decisions: income from maize sales, land ownership, agricultural group membership, and access to climate information all positively influenced adoption, while age demonstrated negative influence. The treatment effects analysis revealed contrasting welfare patterns between current adopters and potential adopters. Current adopters experienced significant food security improvements but showed minimal dietary diversity gains, while non-adopters demonstrated enormous unrealized potential for dietary diversity enhancement. These contrasting patterns indicated that current adoption may be predominantly crisis-driven rather than opportunity-driven, with farmers adopting practices reactively in response to food security challenges rather than proactively for comprehensive welfare enhancement. The heterogeneous treatment effects demonstrated that welfare benefits varied significantly across farmer groups, with current adopters having achieved substantial food security gains while non-adopters represented untapped potential for dietary quality improvements through targeted interventions.

7.5 Recommendations

Based on the study findings, the following policy recommendations are proposed to enhance the adoption and effectiveness of CSAPs among smallholder maize farmers in KZN:

- ✓ Enhancing access to agricultural credit is essential for supporting widespread CSAP adoption among smallholder farmers. Policymakers should develop tailored financial support mechanisms, including low-interest agricultural loans, grant programs, and microfinance initiatives with flexible repayment terms aligned with harvest cycles. Given that credit access demonstrated the largest magnitude effect on economic benefits and adoption decisions across all studies, establishing reduced collateral requirements and cooperative savings programs will be crucial for improving financial inclusivity and enabling farmers to transition to climate-smart practices effectively.
- ✓ Improving extension services and technical support is crucial for ensuring farmers access relevant knowledge and skills to implement CSAPs effectively. Policymakers should strengthen investment in agricultural extension programs, including farmer training workshops, field demonstrations, and digital advisory platforms. The studies revealed that extension access significantly improved both adoption rates and economic returns, making it essential to establish dedicated CSAP support centres and foster collaborations between government agencies, research institutions, and farmer associations to ensure comprehensive technical assistance is readily available for bridging the knowledge-implementation gap.
- ✓ Facilitating educational and training programs is necessary to build farmer capacity and optimize CSAP implementation. Local governments should establish farmer field schools emphasizing practical demonstrations and age-appropriate extension methodologies that accommodate varying educational backgrounds through hands-on

approaches rather than text-based methods. Given that education emerged as a consistent positive determinant across all studies, specialized training programs should integrate peer-to-peer learning networks leveraging successful adopters as demonstration farmers to maximize knowledge transfer effectiveness and build both technical knowledge and implementation skills.

- ✓ Addressing gender-responsive interventions is vital for ensuring equitable access to CSAPs among all farming communities. Policymakers should design targeted programs addressing institutional barriers particularly affecting the 63% female agricultural decision-makers who face greater constraints in accessing credit, extension services, and training opportunities. Establishing women-focused agricultural groups, gender-sensitive communication strategies, and dedicated support mechanisms will be essential for creating inclusive agricultural development that maximizes the potential of all farming households.
- ✓ Strengthening climate information and early warning systems is fundamental for enabling informed CSAP decision-making. Government agencies should develop localized weather forecasting and climate advisory services delivered through multiple channels including mobile platforms, community radio, and farmer groups. Creating digital advisory services that provide real-time guidance on CSAP implementation timing and techniques is crucial, as the studies demonstrated that climate information access significantly influenced both adoption decisions and economic outcomes, making reliable and accessible climate services essential for farmer success.
- ✓ Promoting institutional coordination and market development is necessary to create sustainable economic opportunities and encourage comprehensive CSAP adoption. Local governments should establish farmer cooperatives and marketing cooperatives that help farmers capture premium prices for sustainably produced maize, while developing quality input supply chains ensuring consistent access to improved seeds, fertilizers, and equipment. Creating coordination mechanisms between government agencies, NGOs, and private sector actors will ensure comprehensive and sustained support for farming communities transitioning to CSAPs.

7.6 Limitations of the study

This study acknowledges several limitations that may affect the generalizability and scope of findings. The cross-sectional design captures data at a single point in time, limiting the ability to establish causal relationships and observe long-term impacts of CSAP adoption on farmer livelihoods. The study was geographically constrained to two districts within KZN Province, which may limit the applicability of findings to other provinces or agro-ecological zones in South Africa. The sample size of 378 farmers, while statistically adequate, may not fully capture the heterogeneity of smallholder farming systems across the broader region. Self-reported data on economic benefits and welfare outcomes may be subject to recall bias and social desirability bias, particularly regarding income and food security measures. The study focused on four specific CSAPs, potentially overlooking other relevant CSAPs that farmers may be implementing. Additionally, the analysis did not fully account for seasonal variations in agricultural performance.

7.7 Future research direction

Future research should employ longitudinal study designs to track CSAP adoption patterns and their long-term impacts on farmer livelihoods, enabling better understanding of sustainability and adaptation pathways over time. Expanding the geographical scope to include multiple provinces and diverse agro-ecological zones would enhance the generalizability of findings and enable comparative analysis across different farming contexts. Research should investigate the adoption and effectiveness of additional CSAPs beyond the four practices examined in this study, including agroforestry, integrated pest management, and precision agriculture techniques. Studies should explore the role of emerging technologies such as digital advisory services, mobile banking, and remote sensing in facilitating CSAP adoption among smallholder farmers. Gender-differentiated analysis should be prioritized to better understand how CSAPs affect male and female farmers differently and identify targeted intervention strategies. Future research should also examine the environmental impacts of CSAP adoption, including greenhouse gas emissions, soil health, and biodiversity conservation. Cost-benefit analysis incorporating environmental externalities would provide more comprehensive economic assessments. Additionally, research should investigate scaling mechanisms and institutional innovations that could accelerate CSAP adoption rates while maintaining effectiveness and sustainability across diverse smallholder farming communities.

Appendix I: Survey Questionnaire

UNIVERSITY OF
KWAZULU-NATAL

School of Agricultural, Earth and Environmental Sciences

College of Agricultural, Engineering, and Science

Household Survey Questionnaire:

Date of interview……………….... Questionnaire number……………

Evaluation of Perceptions, Adoption Decisions, and Impact of Climate-Smart Agricultural Practices on Smallholder Maize Farmers' Livelihoods in KwaZulu-Natal Province. South Africa.

Dear participant

This research study is instituted by the University of KwaZulu-Natal under the auspices of the Discipline of Agricultural Economics. I am a PhD student at the University of KwaZulu Natal, conducting a study on the 'Evaluation of Perceptions, Adoption Decisions, and Impact of Climate-Smart Agricultural Practices on Smallholder Maize Farmers' Livelihoods in KwaZulu-Natal Province. Participating in the research will help me better understand and achieve the objectives of the research. Your contribution to this research is voluntary, and should you wish to discontinue participation in the research, you may do so. High levels of confidentiality will be observed in this study and your identity will remain anonymous. The data gathered by this tool will be used solely for the purpose of this intended evaluation and nothing else. For any concerns, questions and/or further information please feel free to kindly contact the below mentioned.

Kind Regards,

Mnukwa M.L ([redacted] ; Cell: +[redacted])

District Municipality …………………………… Local Municipality ………….……………Village ……………………………

SECTION A: DEMOGRAPHIC INFORMATION

A1.1 Gender **1**: Male **0**: Female	**A1.2** Age of the household head (actual years)	**A1.3** Years spent in School. (actual years)	**A1.4** Family size (actual number)	**A1.5** Age distribution of household members. (No. of Adults & kids)	**A1.6** Marital status **1**: Married, **2**: Single, **0**: Otherwise	**A1.7** Source of income **1**: Social grant **2**: Maize sales **3**: Remittances **4**: Salary **5**: Other	**A1.8** Employment **0**: Full-time **1**: Part-time **2**: Self-employed **3**: Unemployed	**A1.9** Total household income (R)	**A1.10** What is the total size of your farm? **0**: <1 ha **1**: 1-2 ha **2**:>3 ha	**A1.11** How many years have you been farming maize (actual years)

SECTION B: TO EXAMINE THE PERCEPTIONS AND ATTITUDES TOWARD CSAPs AMONG SMALLHOLDER MAIZE FARMERS.

B1.1 Are you aware of CSAPs? (**0**: No **1**: Yes)

B1.2 If yes, how did you first learn about CSAPs (Select one or select all that apply).

0: Extension services	**1**: Farmer cooperatives/meetings	**2**: Media (TV, radio, newspapers)	**3**: Internet and social media	**4**: Other (please specify)

B1.3 Select CSAPs you are familiar with. (Select one or select all that apply).

0: Drought-Tolerant Maize Varieties	**1**: Maize-Legume Intercropping	**2**: Rainwater Harvesting techniques	**3**: Crop Diversification:	**4**: Other (please specify)

B2.1 Please rate your agreement with the following statements:

0 = Strongly Disagree, **1** = Disagree, **2** = Neutral, **3** = Agree, **4** = Strongly Agree

Statement	**0**	**1**	**2**	**3**	**4**
Attitudes					
I am willing to adopt CSAPs with or without financial support					
I am eager to learn more about CSAPs					
CSAPs are necessary for improving maize productivity					
I receive personal satisfaction from applying CSAPs					
CSAPs will increase my farm income					
The use of any CSAPs makes me popular among my peers					
My farmer friends who use CSAPs influence me to do the same					
I feel motivated by extension agents to adopt CSAPs					
I enjoy discussing about CSAPs currently promoted by the local extension services					
I have the skills necessary to implement CSAPs					
Resources to implement CSAPs on my farm are available					
CSAPs align well with my maize farming goals					
Perceptions					
CSAPs will improve my household's food security					
CSAPs are effective in addressing the increased temperatures we've experienced over the last 30 years					
CSAPs can help manage the increasingly unpredictable rainfall patterns we've been experiencing					

CSAPs are useful in mitigating the effects of more frequent droughts					
CSAPs can effectively help control the increased pest and disease emergence in maize					
CSAPs can reverse the trend of reduced maize productivity we've seen in recent years					
CSAPs reduce the cost of maize production					
CSAPs increase soil fertility in maize fields					
CSAPs reduce soil erosion in maize fields					
CSAPs lead to reduced water usage in maize farming					
CSAPs improve pest and disease management in maize					
CSAPs preserve land quality for maize cultivation					
CSAPs are environmentally friendly					
CSAPs reduce the amount of chemical fertilizer needed for maize					

B2.2 How would you describe your experience with the last CSAPs you've used and what are your overall perceptions & attitudes towards implementing CSAPs on your farm?

0: Very Negative	**1**: Negative	**2**: Neutral	**3**: Positive	**4**: Very positive

SECTION C: TO INVESTIGATE THE DETERMINANTS OF THE DECISION TO ADOPT AND INTENSITY OF USE OF CSAPs BY SMALLHOLDER MAIZE FARMERS.

C1.1 Have you adopted any CSAPs on your maize farm? **0**: No **1**: Yes	**C1.2** If yes, which CSAPs you have adopted?	**C1.3** Please provide any comments about factors that influenced your choice to adopt CSAPs?	**C1.4** Can you describe any specific benefits or positive outcomes you've observed or expect from adopting CSAPs?	**C1.5** Do you have access to credit or loans for farming activities? **0**: No **1**: Yes	**C1.6** Were there any government incentives or support programs that affected your choice to adopt CSAPs?	**C1.7** Farming maize mainly for selling or for consumption? **0**: No **1**: Yes **2**: Both	**C1.8** Level of participation in maize farming **0**: Part-time **1**: Full time

C2.1 What are the primary barriers or challenges you faced when considering the adoption of CSAPs?

……
……

C2.2 On a scale of 1-5, how significant are the following barriers to your adoption of CSAPs?

(1 = Not at all significant, 5 = Extremely significant)

Financial constraints	Lack of technical knowledge	Risk and uncertainty	Lack of visible benefits in the short term	Socio-Cultural Challenges

C2.3 How likely are you to adopt or expand the use of CSAPs on your farm in the next 3-5 years?

0: Very unlikely	**1**: Somewhat unlikely	**2**: Neutral	**3**: Somewhat likely	**4**: Very likely

C2.4 To what extent have you adopted the following CSAPs on your farm? (Rate on a scale of 1 to 5, where 1 is not at all and 5 is fully adopted)

Drought-Tolerant Maize Varieties	Maize-Legume Intercropping	Water harvesting techniques	Crop Diversification:	Other (please specify)

C2.5 What percentage of your total maize farm area is under CSAPs? (0-100%)

0: 0-20%	**1**: 21-40%	**2**:41-60%	**3**: 61-80%	**4**: 81-100%

C2.6 For each CSAP you've adopted, how many consecutive growing seasons have you been using CSAPs?

0: 1 season	**1**: 2-3 seasons	**2**:4-5 seasons	**3**: 6-7 seasons	**4**: 8 or more seasons

C2.7 How many hours per week do you dedicate specifically to implementing and managing CSAPs?

0: 0-5 hours	**1**: 6-10 hours	**2**:11-15 hours	**3**: 16-20 hours	**4**: More than 20 hours

SECTION D: TO MEASURE THE ECONOMIC BENEFITS (MAIZE PRODUCTION/FARM INCOME) OF ADOPTING CSAPs BY SMALLHOLDER MAIZE FARMERS.

D1.1 Production Inputs, Costs & Production Output before and after CSAPs adoption

Category	Last Season Before CSAPs (Year:)	Recent Season After CSAPs (Year:)
Area under maize (ha)		
Maize yield (kg/ local unit)		
Price per (kg)		
A. Total maize revenue (Rand)		
Variable Costs (Rand):		
- Seeds		
- Fertilizer		
- Pesticides/Herbicides		
- Hired labour (If Applicable)		
- Tractor/Equipment hire (If Applicable)		
- Transport and storage		
B. Total Variable Costs		
Gross Margin (A - B)		
Additional Income (Rand)		
Income from intercropped legumes (If Applicable)	N/A	
Income from other crops diversified	N/A	
CSAPs Adopted:	N/A	□ Drought-tolerant maize
		□ Maize-legume intercrop
		□ Rainwater harvesting
		□ Crop diversification
		□ Other

D2.1 How has your yield changed since adopting CSAPs? Decreased significantly/Decreased slightly/No change/Increased slightly/Increased significantly

D2.2 How has your input use (e.g., fertilizer, water) changed since adopting CSAPs? Decreased significantly/Decreased slightly/No change/Increased slightly/Increased significantly

D2.3 Have you noticed any change in the quality of your maize since adopting CSAPs? Yes/No, if yes, has this affected the price you receive? Yes/No

D2.4 After adopting CSAPs, have you noticed fewer crop damages from bad weather like droughts or heavy rains? Yes/No. If yes, can you estimate the value of crops saved? ________ (local currency)

D2.5 What economic benefits have you experienced since adopting CSAPs? (Select all that apply) Increased income from maize sales/ Reduced costs of inputs/ Higher market prices for better quality maize/ Diversification of income sources/ Improved financial stability/Other (please specify)

D2.6 Have you been able to invest more in your farm (e.g., buying new equipment, expanding land) since adopting CSAPs? ________

D2.7 How would you rate the overall impact of CSAPs on your farm's profitability? Very negative/Somewhat negative/No impact/Somewhat positive/Very positive

D2.8 How do you compare the costs and benefits of adopting CSAPs on your farm?

0: Costs far outweigh the benefits	**1**: Costs slightly outweigh the benefits	**2**: Costs and benefits are about the same	**3**: Benefits slightly outweigh the costs	**4**: Benefits far outweigh the costs

SECTION E: TO ASSESS THE EFFECT OF CSAPs ON THE WELFARE (FOOD SECURITY) OF SMALLHOLDER MAIZE FARMERS.

Food groups used for calculating the HDDS.

E1.1 Did you consume any of different foods mentioned? *(Recall period:24 hours)

Food groups	Code 0/1 **0**: No **1**: Yes
1. Any bread, rice, or any other foods made from millet, sorghum, maize, wheat, or any other locally available grain	
2. Any potatoes, yams, cassava, or any other foods made from roots or tubers	
3. Any vegetables	
4. Any fruits	
5. Any beef, pork, lamb, rabbit, chicken, duck, other birds, and organ meats	
6. Any eggs	
7. Any fresh or dried fish, or shellfish	
8. Any foods made from beans, peas, and lentils	
9. Any yoghurt, milk, or milk products	
10. Any food made with oil, fat or butter	
11. Any sugar	
12. Any food such as coffee or tea	

*3-point scale (**1-3** for low dietary diversity; **4-5** for medium dietary diversity, and **6 or more** for high dietary diversity

E1.2 Please answer the questions on the below table. (The Household Food Insecurity Access Scale (HFIAS) Generic Questions)

Occurrence Question	**0**: Never	**1**: Rarely	**2**: Sometimes	**3**: Often
In the past four weeks, did you worry that your household would not have enough food?				
In the past four weeks, were you or any household member not able to eat the kinds of foods you preferred because of a lack of resources?				
In the past four weeks, did you or any household member have to eat a limited variety of foods due to a lack of resources?				
In the past four weeks, did you or any household member have to eat some foods that you really did not want to eat because of a lack of resources to obtain other types of food?				
In the past four weeks, did you or any household member have to eat a smaller meal than you felt you needed because there was not enough food?				
In the past four weeks, did you or any household member have to eat fewer meals in a day because there was not enough food?				
In the past four weeks, was there ever no food to eat of any kind in your household because of lack of resources to get food?				
In the past four weeks, did you or any household member go to sleep at night hungry because there was not enough food?				
In the past four weeks, did you or any household member go a whole day and night without eating anything because there was not enough food?				

*(**Never**);(**Rarely-**once or twice in the past 30 days); (**Sometimes -**three to ten times in the past 30 days) ;(**Often-**more than ten times in the past 30 days)

Thank you for your participation

Appendix II: Ethical Clearance

UNIVERSITY OF KWAZULU-NATAL™
INYUVESI YAKWAZULU-NATALI

01 November 2024

Minentle Lwando Mnukwa (222094769)
School of Agri Earth & Env Sc
Pietermaritzburg Campus

Dear ML Mnukwa,

Protocol reference number: HSSREC/00007887/2024
Project title: Evaluation of perceptions, adoption decisions, and impact of climate-smart agricultural practices on smallholder maize farmers' livelihoods in KwaZulu-Natal province, South Africa
Degree: PhD

Approval Notification – Expedited Application

This letter serves to notify you that your application received on 18 October 2024 in connection with the above, was reviewed by the Humanities and Social Sciences Research Ethics Committee (HSSREC) and the protocol has been granted **FULL APPROVAL**.

Any alteration/s to the approved research protocol i.e. Questionnaire/Interview Schedule, Informed Consent Form, Title of the Project, Location of the Study, Research Approach and Methods must be reviewed and approved through the amendment/modification prior to its implementation. In case you have further queries, please quote the above reference number.

PLEASE NOTE: Research data should be securely stored in the discipline/department for a period of 5 years.

Incidents of adverse events and serious adverse events (AEs and SAEs) should be reported in writing to HSSREC, the study sponsors, and any regulatory authority (where appropriate), within 7 working days of the occurrence for local sites and 14 days for all other South African sites.

This approval is valid until 01 November 2025.
To ensure uninterrupted approval of this study beyond the approval expiry date, a progress report must be submitted to the Research Office on the appropriate form 2 - 3 months before the expiry date. A close-out report to be submitted when study is finished.

HSSREC is registered with the South African National Health Research Ethics Council (REC-040414-040).

Yours sincerely,

[redacted]

Professor Dipane Hlalele (Chair)
/nng

Humanities and Social Sciences Research Ethics Committee
Postal Address: Private Bag X54001, Durban, 4000, South Africa
Telephone: +27 (0)31 260 8350/4557/3587 **Email:** hssrec@ukzn.ac.za **Website:** http://research.ukzn.ac.za/Research-Ethics