The Impact of Agricultural Innovation System on Productivity of Smallholder Crop Farmers in Mbombela Local Municipality

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DECLARATION:

In accordance with **Rule**, I hereby declare that the above-mentioned dissertation/ thesis is my own work and that it has not previously been submitted for assessment to another University or for another qualification.

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DEDICATION

I dedicate this dissertation to myself for the late nights, early mornings, and countless hours of persistence. This work is a testament to my strength and resilience.

To my loving parents, Mr T Vilakazi and Ms GT Monamodi, whose sacrifices and support have shaped my path, I am eternally grateful. Thank you for instilling in me the values of hard work and perseverance.

To my siblings, Ayanda, Mandisa, Sphamandla, Kwanele, and Wandile, your presence has been a constant source of motivation and joy. To my close relatives, thank you for your encouragement along this journey.

Lastly, I dedicate this work to the smallholder crop farmers in Mbombela Local Municipality. Your resilience and determination inspire this research and serve as a reminder of the vital role agriculture plays in shaping livelihoods and communities. I hope this study contributes to addressing challenges within your farming systems as much as possible.

This dissertation is dedicated to you all, with gratitude and love.

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ABSTRACT

The Agricultural Innovation System (AIS) serves as a vital mechanism for providing agricultural research-based knowledge, extension support, and introducing innovations into agricultural use. Through collaborations among multiple actors and the implementation of conducive policies, AIS helps smallholder crop farmers (SCFs) enhance productivity, promote resource efficiency, strengthen food security, foster sustainable agricultural development, and ultimately ensure sustainable livelihoods.

This study aims to investigate the impact of AIS on the productivity of smallholder crop farmers in Mbombela Local Municipality, with a focus on crop yield-increasing innovations such as improved seeds, chemical fertilisers, chemical pesticides, and irrigation systems. A quantitative research design was employed, and data were collected from 308 systematically selected SCFs' using a structured questionnaire administered through survey interviews. Descriptive statistics, including frequency counts and percentages, and inferential statistics, such as Propensity Score Matching (PSM) and binary logistic regression, were used to analyse the data through Statistical Package for the Social Sciences (SPSS) version 29.0 and STATA version 14.0.

The results indicated that farmers in the study area received extension support services in the form of input support (71.4%), financial assistance (70.1%), training (67.5%), technical advisory services (58.4%), and infrastructural support (4.5%). Propensity Score Matching results demonstrated that the use of improved seeds significantly increased crop yields across all crops, with the highest impact on tomato, cabbage, and maize (6.941 tons/ha, 8.905 tons/ha, and 3.854 tons/ha, respectively). Chemical fertilisers also showed positive effects, significantly improving yields for tomato, chilies, and maize (7.541 tons/ha, 3.318 tons/ha, and 5.022 tons/ha, respectively), but had no statistically significant effect on cabbage. Chemical pesticides increased yields for tomatoes (6.703 tons/ha) and chilies (1.294 tons/ha) but had no statistically significant effect on cabbage and maize. The use of irrigation systems resulted in yield increases for all crops, with tomato and cabbage farmers experiencing the highest gains (7.273 tons/ha and 8.851 tons/ha, respectively).

Binary logistic regression results revealed that inadequate knowledge, limited access to credit, high input costs, unfavourable climatic conditions, weak social networks, and socio-economic characteristics such as gender, age group, level of education, main source of off-farm income, and cooperative membership significantly constrained SCFs' use of agricultural innovations.

Based on the findings, the study concluded that SCFs' in the study area mostly receive input support, followed by financial support and training support, while technical advisory support is less common, and infrastructure support is the most lacking. AIS positively impacts productivity by increasing crop yields, particularly through the use of improved seeds, chemical fertilisers, chemical pesticides, and irrigation systems, with the most notable effects observed in tomato, cabbage, and maize farming. However, the ineffectiveness of chemical fertilisers and chemical pesticides for specific crops, such as cabbage and maize, requires further investigation. Additionally, SCFs in the study area face constraints that hinder SCFs ability to use these innovations.

The study recommends targeted interventions to address gaps in support services and barriers to innovation usage to enhance smallholder crop productivity and sustainability. Future research should evaluate the impacts of AIS across a broader range of agricultural innovations and geographic areas to inform policy effectively.

Keywords: Agricultural Innovation System, Smallholder Crop Farmers, Productivity, Agricultural innovations, Mbombela Local Municipality

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LIST OF ABBREVIATIONS

ABSA	Amalgamated Banks of South Africa
AgriSETA	Agriculture Sector Education Training Authority
AIS	Agricultural Innovation System
APSP	Agricultural Production Inputs Support
ARC	Agricultural Research Council
ATT	Average Treatment Effect on the Treated
CASP	Comprehensive Agricultural Support Programme
DAFF	Department of Agriculture, Forestry and Fisheries
DALRRD	Department of Agriculture, Land Reform and Rural Development
DARDLEA	Department of Agriculture, Rural Development, Land and Environmental Affairs
FNB	First National Bank
IDP	Integrated Development Plan
MADC	Mpumalanga Agricultural Development Corporation
NGO	Non-governmental Organisation
OECD	Organisation for Economic Co-operation and Development
PESI	Presidential Employment Stimulus Initiative
PSM	Propensity Score Matching
SCFs	Smallholder Crop Farmers
SEDA	Small Enterprise Development Agency
SFS	Smallholder Farmers Support
SLF	Sustainable Livelihood Framework
SPSS	Statistical Package for the Social Sciences
SSA	Sub-Saharan Africa

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

The agricultural sector is a fundamental pillar of the global economy, serving as a primary driver of economic growth and poverty alleviation. It also forms the backbone of rural livelihoods and food security. Agriculture can help reduce poverty, raise incomes, and improve food security for 80% of the world's poor, who live in rural areas and work primarily in farming (World Bank, 2024). In Africa, agriculture provides the main livelihood for over 70% of the rural population (Nguyen and Leisz, 2021). Traditionally, agricultural expansion in Africa depended largely on increasing arable land and input use. However, over the past decade there has been a noticeable shift toward enhancing productivity through innovation, such as ICT tools, precision agriculture, AI, and IoT applications, aimed at miximising output from existing resources (Ayanwale, Adekunle, and Akinola, 2013; Ayim, Kassahun, Addison, and Tekinerdogan, 2022; FAO, 2022; CeSTII, 2024).

Smallholder farming plays a vital role in food production, rural development, and livelihood support across developing countries, including South Africa (Pienaar and Traub, 2015). It remains central to poverty reduction, food security enhancement, and rural employment creation (Ogundipe, Oduntan, Ogunniyi, and Olagunju, 2017). Furthermore, smallholder farmers contribute significantly to agricultural output, particularly in rural areas where farming remains the main source of income (Poole, 2017; Fanadzo and Ncube, 2018). It is estimated that smallholder farmers produce more than 80% of the food consumed in developing countries (Mahlombe, 2018; Lowder, Sanchez, and Bertini, 2021).

Recognising the importance of smallholder agriculture, the South African National Development Plan (NDP) Vision 2030, introduced in 2013, continues to guide national efforts to promote smallholder agriculture as a driver of rural development. The NDP highlights its potential to positively impact the livelihoods of more than 370,000 people in communal areas (National Planning Commission, 2013). This vision is reinforced by the South African government's ongoing commitment to the sector, demonstrated by the allocation of over ZAR 2 billion towards targeted agricultural development programmes in recent years. Such investment places smallholder farmers at the centre of national strategies to achieve sustainable food and nutrition security (Department of Agriculture, Land Reform and Rural Development, 2023). As noted by the Food and Agriculture Organisation (FAO) (2026), the success of the 2030 Agenda for Sustainable Development is closely linked to the smallholder farming sector, particularly in relations to Sustainable Development Goals (SDGs) 1 and 2, which aim to eradicate poverty and hunger while ensuring sustainable food security.

Despite these contributions and policy-level support, many smallholder farmers in SA continue to experience persistently low crop productivity. This is largely attributed to challenges such as erratic rainfall, limited access to modern agricultural technologies and innovations, inadequate production resources, and weak extension support systems (Aliber and Mdoda 2015; FAO, 2018; Zerssa, Feyssa, Kim, and Eichler-Löbermann, 2021; Hlatshwayo, Ngidi, Ojo, Modi, Mabhaudhi, and Slotow, 2023). These are essential for efficiently utilising production inputs and adopting improved practices to enhance productivity and sustainability (Mdoda, Obi, Ncoyini-Manciya, Christian and Mayekiso, 2022). Furthermore, Nhamo, Mabhaudhi, and Modi (2019), noted that in Sub-Saharan Africa, where agriculture is predominantly smallholder-based and largely rainfed, challenges heighten household and national food security risks, especially during periods of drought.

Agricultural innovations offer promising solutions to the persistent productivity barriers faced by smallholder farmers (Danish, Ali, and Datta, 2023). In recent years, innovation has gained prominence as a critical tool for enhancing smallholder productivity and resilience in rural areas through various support mechanisms and innovations (Modirwa and Oladele, 2017). The future of food and agriculture increasingly depends on the capacity of the agricultural innovation system (AIS) to provide farmers with timely agricultural support and technological solutions (Organisation for Economic Co-operation and Development (OECD), 2018). Fostering collaboration, facilitation, and information sharing among agricultural actors have become a critical component of the innovation process (Saravanan and Suchiradipta, 2017; Gutiérrez Cano, Zartha Sossa, Orozco Mendoza, Suárez Guzmán, Agudelo Tapasco, and Quintero Saavedra, 2023).

The agricultural innovation system (AIS) framework emphasises the importance of linking smallholder farmers with key stakeholders, such as extension service providers, researchers, and private sector actors, to foster knowledge exchange, facilitate innovation adoption, and promote sustainable productivity growth (Hall, Sulaiman, and Tesfaye Beshah, 2009; Sulaiman, 2015; Department of Agriculture Extension Services Malawi, 2024). According to Zwane (2020), innovation systems provide an effective pathway for smallholder farmers to enhance productivity by generating and disseminating knowledge that supports the access, adoption, and utilisation of agricultural innovations. More broadly, innovation has long been recognised as a driver of social and economic development (Nordwig, 2015). Strengthening the AIS is therefore essential for empowering smallholder farmers to overcome production constraints, improve crop yields, and contribute meaningfully to sustainable rural development.

1.2 Problem statement

Agricultural innovations have become a promising avenue for overcoming the productivity barriers faced by smallholder farmers. Agricultural innovations continue to enhance the methods smallholder farmers use to grow food (Danish et al., 2023). The World Population Prospects (2019) indicate that by 2050, the South African population is expected to reach 75.52 million, necessitating increased food production to meet the demands of the growing population (United Nations Department of Economic and Social Affairs, 2019). The future of food and agriculture depends on the ability of AIS to provide farmers with the relevant support and innovations needed to address low productivity (OECD, 2019). Therefore, farmers, especially SCFs, require access to relevant support services and agricultural innovations that can efficiently enhance crop productivity and sustainability.

Dimitrijević (2023) identified the lack of agricultural innovations as one of the primary causes of low productivity, particularly in developing countries. To increase yield, improve food security, and enhance their overall well-being, SCFs need to adopt and use available yield-increasing innovations and have access to support services (Djoumessi, 2021). Smallholder farmers in South Africa currently rely on diverse farmer support providers for agricultural innovations and extension services (Liebenberg, 2015; Suchiradipta and Raj 2015). These providers include the government, input suppliers, commodity groups, non-governmental organisations, and private sector companies (Zwane, 2016). Leeuwis (2004) and Hall, Janssen, Pehu and Rajalahti (2006) suggest that for innovation to occur, interactions among diverse stakeholders must be dynamic.

According to Zwane (2020), AIS provides support and promote the use of innovations among rural smallholder farmers in South Africa. This support aims to help farmers address complex challenges. Despite the ability of diverse AIS stakeholders to provide innovations and assistance, the impact of these innovations on crop productivity remains unclear (Nordwig, 2015; Djoumessi, 2021). Consequently, SCFs in South Africa continue to experience lower yields. Wale and Mkuna (2023) highlight that the quality and reliability of information provided are extensively influenced by the information source. As a result, information about innovations from extension agents and agricultural agencies is considered more reliable than information from traditional sources.

Given AIS's ability to provide innovations and support services to smallholder farmers, smallholder farmers in South Africa are still regarded as resource constrained and face a wide range of challenges, including weak or absent support institutions at the local level (Muchara and Mbatha, 2016). This may constrain the accessibility and utilisation of agricultural innovations in smallholder crop farming, especially in rural areas. Considering the significant potential of AIS in enhancing smallholder farmers' productivity, it remains important for AIS stakeholders to understand farmers' needs, provide relevant support services suited to these needs, and identify the agricultural innovations accessible for use by SCFs.

Despite the recognised potential of AIS, there is limited empirical research examining its impact on the productivity of SCFs, particularly in the South African context. Existing literature on AIS in South Africa has focused on topics such as shaping AIS responsive to food insecurity and climate change (Brooks and Loevinsohn, 2011); analysis of stakeholders' collaboration in AIS (Modirwa, 2014); knowledge and attitudes towards collaboration in AIS amongst stakeholders (Modirwa and Oladele, 2017); the role of AIS in sustainable food security (Zwane, 2020); and what Mutsvangwa-Sammie and Manzungu (2021) described as "agricultural innovations as the sine qua non of sustainable rural livelihoods". However, there are no empirical studies that specifically investigate the impact of AIS on the productivity of SCFs in the study area. Therefore, this study investigates the impact of AIS on the productivity of SCFs in Mbombela Local Municipality.

1.3 Aim of the study

To investigate the impact of the Agricultural Innovation System on the productivity of smallholder crop farmers in Mbombela Local Municipality.

1.4 Research objectives

i. To investigate the agricultural support received by smallholder crop farmers through AIS.

ii. To assess the impact of selected agricultural innovations on the productivity of smallholder crop farmers.

iii. To examine the factors constraining smallholder crop farmers' use of agricultural innovations for productivity improvement.

1.5 Research questions

i. What agricultural support is received by smallholder crop farmers through AIS?

ii. What impact do the selected agricultural innovations have on the productivity of smallholder crop farmers?

iii. What factors constrain smallholder crop farmers' use of agricultural innovations for productivity improvement?

1.6 Hypotheses

- **Null Hypothesis (H_0):** The Agricultural Innovation System (AIS) does not significantly impact the productivity (crop yields) of smallholder crop farmers in Mbombela Local Municipality through the use of yield-increasing innovations, such as improved seeds, chemical fertilisers, chemical pesticides, and irrigation systems.
- **Alternative Hypothesis (H_1):** The Agricultural Innovation System (AIS) significantly impacts the productivity (crop yields) of smallholder crop farmers in Mbombela Local Municipality through the use of yield-increasing innovations, such as improved seeds, chemical fertilisers, chemical pesticides, and irrigation systems.

1.7 Significance of the study

In many parts of the world, increasing agricultural productivity has a profound impact on improving livelihoods, boosting economic growth, and achieving sustainable agricultural development goals. This research is significant because it provides empirical evidence on how AIS impact the productivity of smallholder crop farmers in Mbombela Local Municipality. Through AIS, SCFs have an opportunity to access support services and yield-increasing innovations, which are critical for overcoming productivity constraints, improving resource management, and enhancing their livelihoods.

This study aligns with the growing need for sustainable food production to meet the demands of a rapidly increasing population. By 2050, South Africa's population is projected to reach 75.52 million (World Population Prospects, 2019), requiring increased food production. The study examines the role of AIS in addressing this challenge by identifying the agricultural support services received by SCFs, assessing the impact of agricultural innovations, specifically yield-increasing innovations on productivity (crop yield), and investigating the constraints SCFs face in using these innovations. The findings provide valuable insights into how AIS can enhance smallholder productivity, which is essential for improving food security, reducing poverty, and promoting sustainable rural development. While previous studies have examined various aspects of AIS in South Africa, few have empirically assessed its impact on smallholder crop productivity. This study therefore adds to the growing body of literature by providing context-specific evidence from Mbombela Local Municipality.

Furthermore, the study has practical implications for policymakers, extension agents, researchers, and development organisations. It highlights the types of agricultural support services that are most received and effective, identifies the innovations that significantly improve crop yields, and pinpoints the barriers to innovation use. These insights can guide the design and implementation of more effective AIS strategies tailored to the needs of SCFs, especially in rural and resource-constrained areas. By advancing understanding of the role of AIS in agricultural development, this research supports efforts to achieve sustainable agricultural practices, enhance smallholder productivity, and address critical challenges in food security and rural livelihoods.

1.8 Limitations of the study

This study was conducted exclusively with SCFs registered with the Department of Agriculture, Rural Development, Land and Environmental Affairs (DARDLEA) in Mbombela Local Municipality, limiting the generalisability of the findings to other smallholder farmers in different areas or regions. AIS can operate at multiple levels for different purposes, but this study focused specifically on improving productivity through crop yield. As such, it does not address other potential purposes of AIS, such as improving farmer income or environmental sustainability.

Additionally, the study concentrated only on commonly used agricultural support programs (CASP, Ilima-Letsema programme, and Land Care) provided by the government to the targeted farmers. This may overlook other forms of agricultural support that could have influenced innovation use. Moreover, the research focused solely on specific primary yield-increasing innovations (improved seeds, chemical fertilisers, chemical pesticides, and irrigation systems) to improve crop yield while excluding other potentially impactful innovations such as mechanisation, agroforestry, and organic farming techniques. This narrowing of scope may limit the comprehensive understanding of all innovations affecting productivity in the study area.

The study employed a cross-sectional design, which restricts the ability to establish causal relationships over time and cannot account for long-term impacts or variations across different seasons. Furthermore, although probit and binary logistic regression models were used to analyse the data, certain variables determining and constraining the use of innovations were excluded due to some variables in the regression models perfectly predicted the outcomes. This may have affected the interpretation of the results and their applicability to broader agricultural contexts.

1.9 Definitions of key terms

(a) Agricultural Innovation System (AIS) – refers to the network of organisations, individuals, and institutions in the agricultural sector that generate, support, introduce, disseminate, adopt, and use innovations aimed at improving the productivity and sustainability of agricultural practices, specifically for smallholder farmers.

(b) Smallholder crop farmers (SCFs) – refers to Type 2 smallholder farmers, as defined in the South African Extension and Advisory Services Policy (National Agricultural Extension Policy of South Africa, 2016). These are rural farmers who cultivate small plots of land for household consumption but also produce surpluses for sale to generate income. These farmers typically face resource and technical constraints that limit their productivity (crop yield) and use of agricultural innovations.
(c) Productivity – refers to the economic output or crop yield per unit of land (hectare), achieved through the efficient allocation of necessary production inputs.
(d) Agricultural support – refers to the range of services received by smallholder farmers for their production through smallholder farmers sectorial support programmes.
(e) Agricultural innovations – refers to new and scientifically developed yield-increasing production inputs used by rural SCFs in their farming systems to increase crop yields. In this study, agricultural innovations specifically include improved seeds, chemical fertilisers, chemical pesticides, and irrigation systems.
(f) AIS stakeholders – refers to the public and private institutions, including government agencies, NGOs, research organisations, and agricultural service providers, that make up the agricultural innovation system and provide goods or services to SCFs to aid in the production of agricultural commodities.

1.10 Outline of chapters

The study consists of five chapters. Chapter one provides the background of the study, the statement of the problem, research objectives and questions, the significance of the study, and the definitions of key terms. In chapter two, the relevant literature review is presented based on the study objectives. A brief overview of the AIS is provided. The chapter also reviews agricultural support received by SCFs and the supporting institutions, discusses the importance of agricultural innovations in smallholder crop farming, examines available agricultural innovations for productivity improvements, and identifies factors constraining SCFs' use of agricultural innovations. The chapter further presents the conceptual framework of the study. In chapter three, the study area, research design, sampling technique, data collection method, data analysis method, and ethical considerations are discussed. Chapter four presents the study results and discusses the findings based on socio-economic characteristics, agricultural support received, the impact of agricultural innovations, and factors constraining the use of agricultural innovations. The fifth chapter provides the conclusion, recommendations, and implications for future research.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter reviews relevant literature based on the objectives of the study. It examines previous and recent literature related to smallholder crop farmers (SCFs) support, focusing on the Agricultural Innovation System (AIS). The chapter identifies the agricultural support services provided to SCFs through AIS, highlights the importance and types of agricultural innovations, and discusses their impact on productivity. Lastly, it explores the factors constraining SCFs' use of agricultural innovations.

2.2 Agricultural Innovation System

The generation and implementation of new knowledge are vital for ensuring the success, sustainability, and resilience of businesses, including agricultural enterprises (Šūmane, Kunda, Knickel, Strauss, Tisenkopfs, des Ios Rios, Rivera, Chebach, and Ashkenazy, 2018). Despite its potential to improve agricultural productivity, competitiveness, and sustainability, innovation is often underutilised on a large scale. The lack of widespread adoption has led to the development of frameworks like AIS to better understand innovation dynamics and enhance its effectiveness (Sulaiman, 2015).

The AIS concept encompasses the processes of generating, transmitting, disseminating, and storing agricultural knowledge. It includes multiple actors and systems such as research, extension, and farmer networks that interact to facilitate technology generation and transfer. According to Zwane (2020), the AIS framework is particularly relevant in the South African context as it highlights the importance of integration and collaboration among key agricultural stakeholders to address systemic constraints in smallholder farming. Historically, Rogers (1962) defined innovation as an idea, practice, or object perceived as new by individuals or groups. His "Adoption and Diffusion Theory" emphasised the role of scientists as innovators, farmers as adopters, and extension agents as intermediaries. Unlike earlier frameworks, the AIS approach integrates researchers, end users, and their interactions in the innovation process (Mapila et al., 2012).

AIS was initially designed to understand industrial innovation but has since been adapted to agriculture (Hall, Sulaiman, Beshah, Madzudo, and Puskur, 2009; Saravanan and Suchiradipta, 2017; Gardeazabal, Lunt, Jahn, Verhulst, Hellin, and Govaerts, 2023). Recent research has advanced the understanding of AIS structure and functionality (Global Forum for Rural Advisory Services (GFRAS), 2015). The Organisation for Economic Co-operation and Development (OECD) (2013) and Mapila et al. (2012) describe AIS as an interface where diverse actors such as researchers, farmers, advisors, NGOs, markets, consumers, and intermediaries collaborate to identify challenges and develop locally adapted solutions. This process enhances production and improves livelihoods.

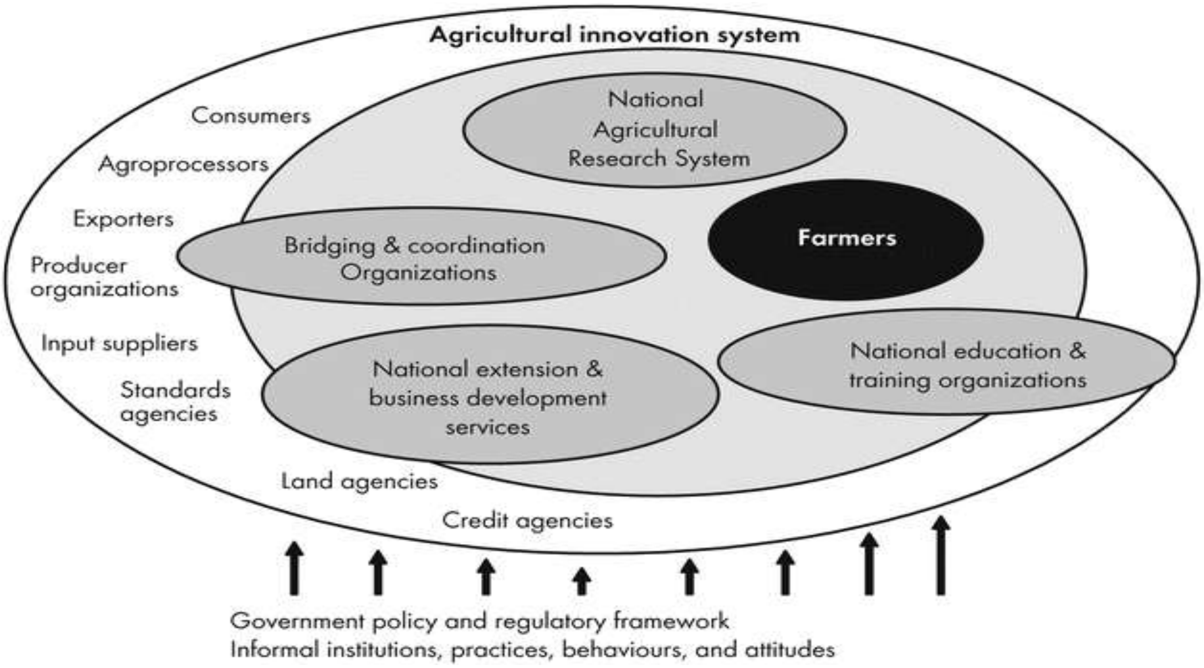


Figure 1: Agricultural Innovation System (AIS)

Source: World Bank (2012)

AIS operates as a dynamic, non-linear, and collaborative process (Anandajayasekeram, 2022). Effective innovation relies on the interaction among various actors who create, transfer, or adopt and use knowledge and technologies (OECD, 2013). However, institutional and policy barriers often hinder effective collaboration and knowledge exchange (Sulaiman, 2015). Addressing these barriers requires institutional, organisational, technical, and policy changes to foster innovation (Daglio, Gerson, and Kitchen, 2014).

In many OECD countries, as well as in South Africa, agricultural policies significantly influence farmers' capacity to invest in innovation and shape their production systems (OECD, 2013). Although research, education, and extension services are critical components of AIS, they are often insufficient to provide farmers and entrepreneurs with the necessary tools and services (World Bank, 2012). Feedback mechanisms within AIS ensure continuous monitoring and evaluation of interactions among actors, enabling strategies to strengthen their capacity to innovate (Mapila et al., 2012).

2.3 Support received by smallholder crop farmers

Agricultural support services comprise a diverse range of assistance, resources, and facilities aimed at enhancing farmers' productivity, sustainability, and livelihoods (De Satgé and Phuhlisani, 2020; Anang and Asante, 2020). Over the past 24 years of South Africa's democracy, numerous institutions have provided support to SCFs to improve crop production and management (Raidimi, 2015). Institutions, as defined by Madzwamuse (2010), are systems established by individuals to achieve collective goals and aspirations within personal and social contexts. Both the public and private sectors have made significant investments in implementing various support programmes to foster the development of smallholder farmers (Raidimi, 2015).

In the South African context, the government, particularly through departments like Agriculture, Rural Development, Land and Environmental Affairs (DARDLEA), is the predominant actor in the AIS, serving as the primary source of financial, technical, and input support for smallholder farmers (Raidimi and Kabiti, 2019; Yang and Ou, 2022). While other actors like NGOs, research institutions (e.g., ARC), and private companies (e.g., Timbali, Standard Bank) are present, their reach and scale of support are often limited in comparison, a reality that shapes the support landscape for farmers in municipalities like Mbombela.

Smallholder farmers primarily rely on public agricultural extension services as a key source of information, which often emphasises production-related issues (von Loeper, Drimie, and Blignaut, 2018). According to Danso-Abbeam, Ehiakpor, and Aidoo (2018), as well as Yadav, Bangari, Manukonda, and Waris (2023), extension services play a dual role. Extension services facilitate the transfer of agricultural production and management expertise to farmers while also providing institutions with valuable insights into farmers' needs and challenges to guide the formulation of agricultural policies. These services offer SCFs access to markets, production inputs, and training, while also fostering capacity building.

In South Africa, the government has introduced several initiatives to support smallholder farmers. Programmes such as the Comprehensive Agricultural Support Programme (CASP), the Ilima-Letsema Programme, and the Land Care Programme aim to provide effective agricultural extension support services. These initiatives are coordinated through the Department of Agriculture, Forestry and Fisheries (DAFF), the Department of Agriculture, Rural Development and Land Reform (DALRRD), and other stakeholders (DAFF, 2016; Mudhara and Senzanje, 2020; Kephe et al., 2020; Nkgudi, Maake, and Masekoameng, 2022).

In addition to government initiatives, various institutions have introduced programmes tailored to support smallholder farmers (Kephe, Ayisi, and Petja, 2020). For instance, CASP is designed to advance agricultural development by providing smallholder farmers with a range of support services across its priority pillars (Department of Agriculture, Forestry and Fisheries, 2013). Key agricultural extension support services available to SCFs include financial support, technical advisory services, infrastructure development, input provision, and training (Aliber and Hall, 2012; Carelsen, 2020).

2.3.1 Financial support

Agricultural financial support refers to the provision of funds, credit, or financial services to individuals and entities involved in agriculture, aiming to promote and enhance agricultural activities (Ruete, 2015). Various sources provide financial support to empower smallholder farmers, addressing their specific financial needs within the agricultural value chain (Mjonono, 2016; Savoy, 2022). This financial assistance enables farmers to overcome economic barriers, invest in sustainable practices, and enhance their livelihoods (Rob, Xiangjun, Marcela, Adolfo, and Lamon, 2014;). Support mechanisms include microcredit loans, agricultural loans, input voucher schemes, agricultural grants, and crop insurance.

However, in practice, the full suite of these financial services is often not accessible to smallholders. Support frequently materialises as input voucher schemes, a form of targeted subsidy, while more complex financial products like loans and insurance remain out of reach for the majority (Valli et al., 2022; Wong et al., 2020).

a) Microcredit loan:

A microcredit loan is a small, short-term loan designed to provide financial assistance to individuals or small businesses lacking access to traditional banking services (Bourlès, Cozarenco, Henriet, and Joutard, 2018; Aragón, Karaivanov, and Krishnaswamy, 2020). These loans are particularly valuable to smallholder farmers, financing essential agricultural inputs such as seeds, Fertilisers, chemical pesticides, and small tools for immediate farming needs (Jindo et al., 2023). Typically repaid within a few months or a couple of years, these loans align with the seasonal nature of agriculture (Jumpah, Tetteh, and Adams, 2018).

Microcredit loans are often provided by microfinance institutions, non-governmental Organisations (NGOs), private entities, and rural credit cooperatives (Mago and Hofisi, 2016; Linh et al., 2019; Nakano and Magezi, 2020). For example, the Mpumalanga Agricultural Development Corporation (MADC) offers seasonal loans, business loans, and revolving credit facilities tailored to smallholder farmers' immediate needs (Mhlongo, 2006). Similarly, the Small Enterprise Finance Agency (SEFA) supports farmers through microcredit, disbursing R2.4 billion in loans in 2023, aiming to foster economic growth despite macroeconomic challenges (Small Enterprise Finance Agency, 2023).

However, microcredit loans face challenges such as high interest rates and repayment pressures, which may strain SCFs' financial stability. As Hansrod (2019) noted, despite being small in scale, microcredit loans remain vital for improving the financial resilience of disadvantaged farmers provided by the LIMA Rural Development Foundation.

b) Agricultural loan:

Agricultural loans differ from microcredit loans by supporting a broader range of farming activities, including production inputs, infrastructure development, and long-term improvements (Röttger, 2015; Tinsley and Agapitova, 2018; Langyintuo, 2020). These loans cater to short-term, medium-term, and long-term financial needs, depending on the project and repayment structure.

Short-term crop loans often cover seasonal production costs, such as inputs and labour during planting and harvesting, with repayment due after the harvest (Mago and Hofisi, 2016; Bhanot, Farias, and Sinha, 2024). Medium-term loans are typically allocated for machinery purchases and infrastructure improvements, such as irrigation systems, with repayment periods ranging from one to five years (Reserve Bank of India (RBI), 2019).

In South Africa, agricultural loans are offered by commercial banks, agricultural development banks, cooperatives, and government schemes. Institutions like ABSA, FNB, and Standard Bank provide short-term and medium-term loans with strict eligibility criteria, including proof of land ownership and farming experience (Qwabe, 2014). For example, the Land Bank offers financing for farm purchases, production loans, and infrastructure development (Mtombeni, Bove, and Thibane, 2018). However, the requirement for collateral and the risk of high interest rates may limit accessibility for SCFs (Sebola, 2018).

c) **Input vouchers:**

Input vouchers provide targeted assistance, enabling farmers to acquire specific agricultural inputs and services (Food Security Cluster, 2020). These vouchers are part of government initiatives, such as the Presidential Employment Stimulus Initiative (PESI), aimed at boosting farmers' economic recovery post COVID-19 (South African Government, 2023). The voucher amounts range from R1,000 to R9,000, depending on the verified production activity (Food Security Cluster, 2020). The size of the non-financial e-voucher was determined after physical verifications by DALRRD (Parliamentary Monitoring Group, 2021).

Farmers can redeem these vouchers for agricultural inputs like seeds, fertilisers, chemical pesticides, and basic farming equipment including tools like wheelbarrows, hand hoes, spades, forks, rakes, pick axes, and garden hoses with connectors (Solidarity Response Fund South Africa, 2021). The redemption process, via SMS vouchers, allows farmers to access necessary supplies from local suppliers. However, the PESI program has faced challenges such as fund mismanagement and unclaimed voucher cancellations, which have impacted farmers' ability to access promised resources (Masiwa, 2024). These issues highlight the importance of governance and transparency in support initiatives to ensure equitable access.

d) **Agricultural grants:**

Agricultural grants are non-repayable financial support provided for land development, agricultural projects, or infrastructure improvements (Zolkin, Aygumov, Pakhomova, and

Bobkov, 2021). They aim to promote agricultural development, particularly for disadvantaged farmers, and address challenges like infrastructure damage caused by natural disasters (Western Cape Government, 2023). Government programs like the Land Redistribution for Agricultural Development (LRAD) initiative provide financial assistance to farmers for land purchase (Masemola, 2021). Individuals interested in farming can apply for an LRAD grant, but they are required to contribute a minimum of R5,000, either in cash or labour, with larger grant amounts requiring a higher contribution. Grant amounts range from R20,000 to R100,000 (South African Government, 2024). Additionally, the Agricultural Youth Fund is an innovative funding initiative. It was developed through a partnership between Land Bank and the National Youth Development Agency (NYDA). The initiative aims to support youth-led farming enterprises focusing on high-value vegetables. The fund aims to facilitate the growth and development of these businesses (Land Bank, 2018).

e) Crop insurance:

Crop insurance is a type of insurance policy that provides compensation to farmers in the event of crop failure due to unforeseen events such as adverse weather conditions, natural disasters, or pest and disease infestations (van Dijk, 2022). The purpose of crop insurance is to reduce the financial risk associated with farming and ensure income stability (Aditya, Khan, and Kishore, 2018; Jabbar, Wu, Peng, Sher, Imran, and Wang, 2020). Banks provide crop insurance to farmers, which is not a one-size-fits-all product but caters to individual farmers' requirements and circumstances (Ankrah, Kwapong, Eghan, Adarkwah, and Boateng-Gyambiby, 2021; Rajeev and Nagendran, 2023).

In South Africa, banks like Nedbank, FNB, and Standard Bank offer crop insurance products alongside property and asset insurance (Nedbank, 2024; FNB, 2024; Standard Bank, 2024). Land Bank also provides insurance for crops, covering damages from natural perils, pests, and diseases (Land Bank, 2018). A study by Giné and Yang (2009) conducted in Malawi found that insured SCFs are more likely to adopt and utilise new technologies and have better access to credit, enhancing their farming operations. However, the uptake of crop insurance remains low among smallholder farmers in many developing countries, including South Africa, due to high premiums, lack of awareness, and challenges in claims processing.

2.3.2 Technical advisory support

Technical advisory services are integral to agricultural extension services and serve as a vital source of information for SCFs. These services are designed to improve agricultural practices and increase overall productivity (Mmbengwa, Rambau, Rakuambo, and Qin, 2020). These services provide practical assistance, expert advice, and recommendations that empower farmers to make informed decisions and use advanced agricultural techniques and technologies (Liebenberg, 2015; Antwi-Agyei and Stringer, 2021). Extension services are typically delivered through various channels, including government departments, research institutions, NGOs, and private sector entities (Loki, Mudhara, and Pakela-Jezile, 2020).

A key aspect of technical advisory services is soil testing, where SCFs receive assistance on analysing soil properties and conditions (Lobry de Bruyn, 2019). This process helps farmers understand the nutrient content, pH level, and other characteristics of their soil, enabling them to make informed decisions regarding crop management and input applications (Montgomery and Biklé, 2021). According to Oluwole, Creamer, Leenaars, and Steverink-Mosugu (2021), agricultural departments often offer soil testing services through extension officers and agricultural laboratories. These officers collect and analyse soil samples from smallholder farms, oversee laboratory testing, interpret the results, and provide recommendations for soil management. In some instances, extension officers may offer subsidised or free soil testing services to SCFs. The Agricultural Research Council (ARC) also provides comprehensive soil testing and advisory services to farmers, including smallholders, through its laboratories and expert staff (ARC Annual Performance Plan, 2024).

Beyond soil testing, technical advisory services also assist SCFs in managing pests and diseases (Möhring, Wuepper, Musa, and Finger, 2020). Extension services offer advice on selecting appropriate crop varieties, planning crop rotations, and optimising planting schedules, which are vital for improving crop success (Buadi, Anaman, and Kwarteng, 2013; Mamun-ur-Rashid and Qijie, 2016; Kephe, Siewe, Lekalakala, Kwabena Ayisi, and Petja, 2022). This support ensures SCFs choose the right crops based on various environmental and market factors. For example, the Timbali Technology Incubator provides hands-on guidance to SCFs, assisting with crop production techniques, pest management, and disease control (Timbali Technology Incubator, 2023).

Additionally, extension services play a crucial role in advising farmers on adopting and utilising innovative practices and technologies proven effective through research (Thovhogi, Zwane, and Van Niekerk, 2022). SCFs also benefit from technical advice on managing agricultural risks such as weather challenges, pest outbreaks, and market volatility, often through the use of extension and ICT tools (Wuepper, Roleff, and Finger, 2021). The Mpumalanga Department of Agriculture, Rural Development, Land and Environmental Affairs (DARDLEA) (2015) highlights that its extension and advisory services support SCFs by providing agricultural advice aimed at mitigating the impacts of drought. This includes activities such as agricultural demonstrations, farmers' days, and support for functional commodity groups.

2.3.3 Infrastructure support

On-farm infrastructure support involves the development and enhancement of essential facilities and systems necessary for agricultural productivity (Kaiser and Barstow, 2022). This includes constructing irrigation systems, storage facilities, greenhouses, fencing, farm roads, power supply infrastructure, and water harvesting systems, all of which are critical for SCFs in rural areas (Nkanyani, 2019). Such infrastructure directly contributes to increased productivity, reduced post-harvest losses, and improved farm efficiency and sustainability.

Despite its foundational importance, infrastructure support is consistently identified as the most significant gap in service provision for smallholder farmers in South Africa (Magingxa and Kamara, 2003). The challenges in providing widespread, functional infrastructure mean that the vast majority of farmers operate without these critical facilities.

Collaborative efforts between governments and NGOs involve working with local communities to identify infrastructure needs and implement agricultural development projects (Odoom, Obeng-Baah, and Agyepong, 2022). Additionally, private sector entities, including agribusinesses, play a role in infrastructure development, enhancing connectivity and operational efficiency Additionally, private sector entities, including agribusinesses, play a role in infrastructure development, enhancing connectivity and operational efficiency (Aguera, Berglund, Chinembiri, Comninos, Gillwald, and Govan-Vassen, 2020).

The Department of Agriculture provides support for irrigation schemes to improve water availability, offering subsidies for the purchase and installation of systems such as sprinklers and drip irrigation to aid individual crop farmers, particularly in rural areas (Van Koppen, Nhamo, Cai, Gabriel, Sekgala, Shikwambana, Tshikolomo, Nevhutanda, Matlala, and Manyama, 2017). Storage and processing services are also a focus, with on-farm storage facilities constructed to assist farmers in packing their produce and minimising post-harvest losses (Tibaingana, Kele, and Makombe, 2018). Furthermore, partnerships between the Department of Agriculture and local governments aim to develop and maintain rural access roads, facilitating better connectivity and smoother transportation of goods within farming communities (DALRRD, 2016).

Infrastructure initiatives also include expanding the number of hectares under irrigation and increasing food production. The installation of water development and power supply systems for vegetable production projects has proven effective in alleviating poverty and hunger (DARDLEA, 2023). Despite these efforts, Sihlobo (2020) highlights persistent challenges faced by SCFs, including inadequate access to essential agricultural infrastructure such as irrigation systems, water and electricity supply, farm roads, and storage facilities like juice-making units, grain silos, mills, and drying equipment.

2.3.4 Input support

SCFs in rural areas receive essential agricultural inputs vital for successful and sustainable agricultural productivity (Mkhonto and Musundire, 2019). Agricultural inputs are products and resources required for farming, including improved seeds, seedlings, chemical fertilisers and chemical pesticides, and agricultural equipment and machinery (Mtombeni, Bove, Thibane, and Makgabo, 2019; Adu-Baffour, Daum, and Birner, 2019; Mistary, 2022). Government agricultural extension services play a key role in supplying these inputs, while NGOs and international organisations may collaborate to ensure a comprehensive and sustainable approach to addressing the input needs of smallholder farmers (Kimaro, 2013; Sinyolo and Mudhara, 2018; Mokgomo, Chagwiza, and Tshilowa, 2022). Governments often provide inputs through programs like the Agricultural Production Inputs Support Programme (APSP) (Mkhonto et al., 2019).

(a) Improved seeds

Improved seeds are foundational to successful crop production (Bernard, Lambert, Macours, and Vinez, 2023). These seeds are bred for superior genetic traits such as high yield potential, disease resistance, drought tolerance, and specific quality attributes desired in the market, such as taste, colour, or nutritional value (Qaim, 2020). Access to quality seeds significantly improves farmers' productivity and resilience to environmental stresses (Bernard et al., 2023). Programs like Masibuyele Emasimini, initiated by the Mpumalanga Department of Agriculture, provide drought-resistant crop varieties to SCFs (DARDLEA, 2016). However, Kansiime, Bundi, Nicodemus, Ochieng, Marandu, Njau, Kessy, Williams, Karanja, Tambo, and Romney (2021) noted that SCFs often have limited access to affordable, quality seeds, with over 90% relying on saved seeds from previous harvests, which are frequently of poor quality.

(b) Chemical fertilisers:

Fertilisers are substances added to soil to supply nutrients necessary for plant growth (Elrys, Desoky, Alnaimy, Zhang, Zhang, Cai, and Cheng, 2021). Chemical or inorganic fertilisers, such as NPK (Nitrogen, Phosphorus, Potassium), LAN/KAN (Limestone Ammonium Nitrate/Calcium Ammonium Nitrate), and lime, are commonly used by SCFs in rural areas to enhance soil fertility and crop yields (Elias, Okoth, and Smaling, 2019; Demi and Sicchia, 2021; Abebe, Tamtam, Abebe, Abtemariam, Shigut, Dejen, and Haile, 2022). Proper fertiliser use can significantly boost productivity, although excessive or inappropriate application may lead to environmental issues such as soil degradation and water contamination (Bisht and Chauhan, 2020; Darakeh, Weisany, Diyanat, and Ebrahimi, 2021). Schjoerring, Cakmak, and White (2019) and Ishfaq, Wang, Xu, Hassan, Yuan, Liu, He, Ejaz, White, Cakmak, and Chen (2023) emphasised that fertilisers optimise nutrient level for robust crop growth, which is essential for sustaining agricultural productivity.

(c) Chemical pesticides:

Chemical pesticides are chemicals or biological agents used to kill pests and control diseases and weeds that threaten crops. They include herbicides (for weed control), insecticides (for insect pest control), fungicides (for fungal disease control), and other types designed to target specific threats (Tudi, Daniel Ruan, Wang, Lyu, Sadler, Connell, Chu, and Phung, 2021). While chemical pesticides can greatly reduce crop losses and improve yields (Sarkar, Gil, Keeley, and Jansen, 2021), their use must be carefully managed to avoid negative impacts on human health, beneficial organisms, and the environment (Pelosi, Bertrand, Daniele, Coeurdassier, Benoit, Nélieu, Lafay, Bretagnolle, Gaba, Vulliet, and Fritsch, 2021). According to Sarkar, Gil, Keeley, and Jansen (2021), the provision of chemical pesticides form a crucial part of agricultural input support, ensuring crop protection for better crop quality and productivity.

(d) Agricultural equipment and machinery:

SCFs benefit significantly from agricultural equipment and mechanised tools, which modernise farming operations and reduce labour intensity (Adu-Baffour, Daum, and Birner, 2019; Peng et al., 2022). Mostly provided agricultural equipment includes tractors and other mechanised implements, particularly for labour intensive tasks like ploughing (Mdletshe, Dyiki, and Gidi, 2022). Despite these benefits, agricultural machinery remains insufficient in many parts of South Africa to sustain local production (Mtombeni et al., 2019). Government programs and non-governmental organisations (NGOs) often collaborate to provide equipment and training on its use (Sims and Kienzle, 2016). For instance, DALRRD (2019) handed over farming equipment, including tractors and mechanised implements, to deserving SCFs in

Limpopo, showcasing a commitment to supporting mechanisation in rural farming communities.

2.3.5 Training and capacity-building support

Training and capacity-building refers to structured educational programs designed to equip individuals with specific skills and knowledge necessary to perform specific tasks effectively over time (Gwivaha, 2015; Wonde, Tsehay, and Lemma, 2022). Training provided to SCFs can take both formal and informal forms (Gwivaha, 2015). These programs often include hands-on training sessions where SCFs learn practical skills, such as selecting crops to plant, plant techniques, applying fertilisers, controlling pests, and operating and maintaining farm machinery (Daum and Birner, 2017). Additionally, SCFs may participate in courses that cover financial management, modern farming techniques, business management, and sustainable agricultural practices to enhance productivity and overall farm management (Kirui and Kozicka, 2018).

Tamako, Thamaga-Chitja, and Mudhara (2022) found that the technical knowledge gained through training and demonstrations significantly enhanced SCFs' skills in field activities, bringing about improved crop yields. Similarly, Daum and Birner (2017) highlighted that importance of machinery training within these programs, which equips farmers with the ability to operate and maintain equipment effectively, maximise the benefits of mechanised farming. Banerjee, Hussain, Tuladhar, and Mishra (2019) and Tuffour, Amoako, and Amartey (2022), emphasised the value of financial literacy training, which helps farmers in budgeting, financial planning, and accessing credit. Furthermore, Rwelamira (2015) pointed out that training in market-oriented strategies empower smallholder farmers to navigate market dynamics, negotiate better prices, and establish stronger links with buyers. However, Kroesen et al. (2015) argued that training programs often focus only on technical knowledge and skills, neglecting cultural aspects such as farmers' values, needs, and attitudes, which are important for effective capacity-building.

Various stakeholders provide training and capacity-building support to SCFs, including government agricultural extension services, NGOs, and development agencies (Raidimi and Kabiti, 2019; DALRRD, 2022; Chanza, Tchuwa, Anugwa, Liverpool-Tasie, Ukamaka, Agwu, Suvedi, and Sasidhar, 2023). These organisations design and implement programs that enhance farmers' skills, knowledge, and capabilities, tailoring them to the specific needs of local farming communities. For example, Timbali Technology Incubator has offered training to 151 smallholder farmers, focusing on agri-business value chains, including farming techniques and market access (Timbali, 2023). Similarly, DARDLEA (2016) reported providing training on drought management through its extension and advisory services sub-program, thereby supporting SCFs in addressing challenges posed by severe drought conditions.

2.4 The importance of agricultural innovations in crop production

Agricultural innovations play a transformative role in enhancing on productivity and hold significant potential to improve the agricultural sector's overall performance (Mutsvangwa-Sammie, Manzungu, and Siziba, 2018). Agricultural innovations increase crop yields, optimise resource utilisation, mitigate risks, improve product quality, promote sustainability, and provide market access (Bessant, Lamming, Noke, and Phillips, 2005; Bareghen, Rowley and Sambrook, 2009). They also drive economic development by empowering farmers to achieve higher productivity levels, improve their livelihoods, and contribute to food security and economic growth (Godin, 2008; Esparcia, 2014). The following are key benefits of agricultural innovations.

2.4.1 Increasing crop yield

Agricultural innovations, including improved seed varieties and advanced farming technologies, have been shown to significantly boost crop yields (Karunathilake et al., 2023). Improved seed varieties play a crucial role in increasing crop yields by incorporating genetic and agronomic traits such as higher yielding, drought tolerance, and disease resistance (Qaim, 2020). Smallholder crop farmers in rural areas normally cultivate vegetables such as spinach, butternut, beetroot, cabbage, chillies, onions, and tomatoes, as well as agronomic crops such as maize, cassava, and other staples (Manyevere, Muchaonyerwa, Laker, and Mnkeni, 2014; Christian and Obi, 2018). High-yielding crop varieties exhibit desirable traits such as faster growth, larger fruits, and higher grain yields, which directly contribute to increased crop output per unit of land (Abdelrahman et al., 2018; Gómez-Fernández and Milla, 2022). Rahman and Connor (2022) found that farms using high-yielding varieties experienced approximately 35% higher yields and 76% greater profits from Aman rice compared to non-adopting farms.

Drought-tolerant seeds enable crops to maintain productivity under challenging environmental conditions, especially in regions affected by water scarcity (Begna, 2023). Tesfaye et al. (2018) found that incorporating drought and heat tolerance traits into maize varieties increased simulated yields and sustained maize productivity under climate change conditions in vulnerable areas. Similarly, Islam et al. (2016) highlighted that drought and heat-resistant seeds could increase yields by up to 25% under the climate patterns predicted for Africa by 2050 (RCP 8.5), compared to yields from current seeds varieties. Additionally, Simtowe et al. (2019) reported that the use of drought-tolerant maize varieties resulted in a 15% yield increase and reduced the probability of crop failure by 30%.

Disease-resistant seeds help reduce crop losses caused by infections, allowing plants to grow and mature without succumbing to diseases. This is particularly crucial for food security in regions prone to specific pathogens (Dong and Ronald, 2019; Rizzo, Migliore, Schifani, and

Vecchio, 2024). These seeds are developed through selective breeding, genetic engineering, or a combination of both, incorporating traits that allow crops to withstand attacks by pathogens such as viruses, bacteria, fungi, and nematodes (Deng et al., 2020). Deng et al. (2020) also highlighted that improving disease resistance in crops has the potential to significantly increase productivity by preventing the substantial losses caused by various pathogens, including fungi, bacteria, nematodes, and viruses.

2.4.2 Optimise resource use

Agricultural innovations play a crucial role in optimising resource use, enabling farmers to produce more with less and in a sustainable manner (Zwane, 2020; Javaid et al., 2022). Through the adoption and use of precision agriculture technologies, such as GPS mapping, soil sensors, and drone surveillance, SCFs can accurately assess the needs of their crops and apply water, fertilisers, and chemical pesticides in precise amounts and locations (Rock, 2023). This not only reduces production costs but also minimises environmental impact, making agriculture more sustainable and enhancing overall productivity (Wiggins, Glover, and Dorgan, 2021).

Innovations in crop genetics have led to the development of high-yield and disease-resistant seed varieties that require fewer inputs to thrive (Naqvi, Siddiqui, Mahmood, Najeebullah, Ehsan, Azhar, Farooq, Amin, Asad, Mukhtar, and Mansoor, 2022). Muzhinji and Ntuli (2021) and Caradus (2023) further highlighted that biotechnology innovations, such as genetically modified (GM) crops, have made crops more resistant to pests and diseases, reducing the need for chemical inputs.

Additionally, advancements in irrigation technologies, such as drip and micro-sprinkler systems, deliver water directly to plant roots, enhancing water-use efficiency and conservation (Yang et al., 2023; Pereira, Leitao, Gaspar, Fael, Falorca, Khairy, Wahid, El Yousfi, Bouazzama, Siering, and Hansmann, 2023). Farm automation and robotics further contribute to resource optimisation by automating tasks such as planting, weeding, and harvesting, saving time and reducing the need for manual labour (Santos Valle and Kienzle, 2020). Innovations in agricultural machinery, such as smart tractors equipped with GPS and automation systems, increase the efficiency of farm work and reduce fuel consumption (Rock, 2023). These advancements provide a pathway for SCFs to achieve greater productivity and sustainability.

2.4.3 Risk mitigation

Agricultural production relies heavily on natural resources and climate conditions, exposing farmers to risks from weather variability, natural hazards, pests, and diseases (OECD, 2018). Agricultural innovations provide solutions to mitigate these risks. According to Lybbert and Sumner (2010), innovations such as climate-resilient crops and varieties help farmers cope with abiotic stresses, including drought. Acevedo, Pixley, Zinyengere, Meng, Tufan, Cichy, Bizikova, Isaacs, Ghezzi-Kopel, and Porciello (2020), found that climate-resilient crops and crop varieties were used by smallholder farmers to cope with abiotic stresses such as drought, heat, flooding, salinity, and shorter growing season. Early-maturing crops and pest-resistant varieties have also helped SCFs adapt to change in climate and weather patterns. Devot, Royer, Arvis, Deryng, Caron Giauffret, Giraud, Ayral, and Rouillard (2023) highlighted that climatic changes increase risks associated with crop production in certain regions, but early detection systems enable SCFs to implement local adaptation measures to minimise crop losses. For instance, improved weather forecasting tools allow SCFs anticipate and respond proactively to adverse conditions, reducing risks associated with uncertainty.

2.4.4 Improve product quality

Innovations in harvesting and handling equipment reduce crop damage during the harvesting process, enhancing product quality and enabling SCFs to access premium markets (Nissen, Bound, Adhikari, and Cover, 2018). Improved product quality allows farmers to command better prices, increasing their profitability and productivity (Bold, Ghisolfi, Nsonzi, and Svensson, 2022). Maier and Chikez (2021) emphasised that innovations in post-harvest handling techniques, such as modified-atmosphere packaging and controlled storage environments, extend shelf life and maintain the quality of produce, which is particularly beneficial for SCFs.

Muzhinji and Ntuli (2021) and Caradus (2023) highlighted that advances in crop breeding and biotechnology have resulted in new varieties that produce higher-quality crops. Hasan (2017) reported that innovations in pest and disease management lead to healthier crops and improved product quality. SCFs use integrated pest management (IPM) practices to monitor pest population, implementing cultural practices that reduce pest habitats, and use biological controls by introducing natural predictors to pests (Baker, Green, and Loker, 2020; Dara, 2019).

Chemical pesticides are used as a last resort, targeting specific pests with low-risk chemical pesticides (Jepson, Murray, Bach, Bonilla, and Neumeister, 2020). Angon, Mondal, Jahan, Datto, Antu, Ayshi, and Islam (2023) concluded that IPM is not only a resource-saving technique but also integral to maintaining high product quality and sustainability. These innovations collectively enable SCFs to produce crops of superior quality while reducing environmental impact.

2.4.5 Promote sustainability

Agricultural innovations promote the adoption of sustainable farming practices that preserve natural resources, protect the environment, and ensure long-term productivity (Rizzo et al., 2024). Practices such as organic farming, conservation agriculture, agroforestry, and water management techniques contribute to soil health, biodiversity conservation, and ecosystem resilience (Telo da Gama, 2023). By integrating sustainable practices, farmers can maintain productivity while minimising negative environmental impacts (Muhie, 2022; Gamage, Gangahagedara, Gamage, Jayasinghe, Kodikara, Suraweera, and Merah, 2023).

Organic farming, as highlighted by Gamage et al. (2023), reduces the use of synthetic chemicals and fertilisers, thereby minimising environmental pollution and protecting biodiversity. Conservation agriculture helps prevent soil erosion, enhances water retention, and promotes carbon sequestration in soils, which contributes to improved soil structure and fertility (Sairam, Mondal, Gaikwad, Pramanick, and Maitra, 2023). Diversified crop rotations, a key component of conservation agriculture, aid in pest control, nutrient management, and building resilient farming systems that prioritise environmental health and long-term sustainability (Thierfelder, Baudron, Setimela, Nyagumbo, Mupangwa, Mhlanga, Lee, and Gérard, 2018; Shah, Modi, Pandey, Subedi, Aryal, Pandey, and Shrestha, 2021).

Agroforestry integrates trees and shrubs into traditional farming systems, which enhances biodiversity and ecosystem resilience (Wilson and Lovell, 2016). Tomar, Ahmed, Bhat, Kaushal, Shukla, and Kumar (2021) further emphasised that agroforestry improves soil fertility, conserves water, and sequesters carbon, making it a key practice for environmental sustainability. Similarly, water management innovations such as drip irrigation, rainwater harvesting, and precision irrigation optimise water use, minimise wastage, and ensure an adequate supply for crops, which enhances productivity while conserving water resources (Mallareddy, Thirumalaikumar, Balasubramanian, Naseeruddin, Nithya, Mariadoss, Eazhilkrishna, Choudhary, Deiveegan, Subramanian, and Padmaja, 2023; Ingrao, Strippoli, Lagioia, and Huisingh, 2023). These approaches create a more sustainable and resilient agricultural system (Ncube and Shikwambana, 2016; López-Felices, Aznar-Sánchez, Velasco-Muñoz, and Mesa-Vázquez, 2023).

2.4.6 Economic development and poverty alleviation

Agricultural innovations are transformative in driving economic development and alleviating poverty by fostering increased productivity, creating new economic opportunities, and enhancing food security (Yin, Chen, and Li, 2022). Wiggins et al. (2021) found that technical innovations not only drive production but also significantly impact farm incomes. Hosono (2022) underscored that precision farming and sustainable practices contribute to a more resilient agricultural sector, which in turn stimulates economic growth by increasing farm incomes, creating employment opportunities, and supporting agribusiness development.

Innovations enhance productivity, efficiency, and sustainability, allowing SCFs to boost their income levels and improve food security, particularly for rural populations (Zwane, 2020). By producing more food with fewer inputs, SCFs' lower production costs and increase profitability (Krejci and Beamon, 2015; Brzezina, Kopainsky, and Mathijs, 2016). Moreover, agricultural innovations often create new market opportunities and value chains, enabling SCFs to access broader markets and negotiate higher prices for their produce, which contributes to rural economic development and poverty reduction (Devaux, Torero, Donovan, and Horton, 2018; Das Nair and Landani, 2020).

Zwane (2020) concluded that innovations empower rural farming communities to address challenges, capitalise on market opportunities, create wealth, improve livelihoods, and ensure food security. By fostering economic development, agricultural innovations play an essential role in reducing poverty and improving the quality of life for SCFs.

2.5 Agricultural innovations for productivity improvement

Innovations are essential for improving all aspects of agriculture, from increasing productivity and food security to promoting sustainability and resilience in agricultural industry (FAO, 2018). Agricultural innovations involve new or improved goods, services, or processes that address the distinct challenges of SCFs, enhancing their productivity (Barrientos-Fuentes and Berg, 2013; Ayim et al, 2022). In this study, agricultural innovations are analysed in relation to their influence on crop productivity, which refers to the yield obtained from a given area of land within a specific period (Hlatshwayo, Ngidi, Ojo, Modi, Mabhaudhi, and Slotow, 2023). A large body of empirical literature agrees that traditional inputs alone cannot ensure sustainable crop productivity over time. For instance, Adego, Simane, and Woldie (2019) found that the adoption of modern agricultural technologies significantly improved maize yields compared to traditional practices in Ethiopia. Caunedo and Kala (2021) analysed the effects of mechanisation on farm performance in India. Their results showed that mechanisation increased equipment use but did not significantly raise output per acre on average. However, modelling results indicated positive returns to merchandisable tasks and an estimated productivity increase of about 8 to 9 percent, suggesting that the benefits of innovation depend on how and where the technologies are applied. Similarly, studies by Mdoda, Mdletshe, Dyiki, and Gidi (2022); Andrianarison, Kamdem, and Che Kameni (2022); Sedebo, Li, Etea, Abebe, Ahiakpa, Arega, and Anran (2022); Peng, Zhao, and Liu (2022) and Zegeye, Asratie, Getahun, and Deredera (2023), which measured productivity through crop yield per unit area, reported that the adoption of agricultural innovations such as improved seeds, fertilizers, and irrigation systems led to significant yield increases among smallholder farmers across different contexts. These studies collectively demonstrate that integrating agricultural innovations is essential for enhancing and sustaining smallholder crop productivity. According to Sunding and Zilberman (2001) and Djoumessi (2021), yield-increasing innovations that impact on SCFs' productivity include improved seeds, chemical fertilisers, chemical pesticides, and irrigation systems. Therefore, this study considered crop yield per hectare as a proxy to measure productivity and only focused on the available yield-increasing innovations impacting productivity of SCFs in the study area.

2.5.1 Yield-increasing innovations

(a) Improved seed varieties:

The use of seeds varieties that are adapted to local conditions, including traditional or regionally improved types that tolerate local pests, diseases and drought, can significantly enhance crop yields (Joshi and Braun, 2022). In contrast, improved quality seeds are the products of formal breeding programs that internationally select for desirable agronomic traits such as higher yield potential, pest and disease resistance, drought tolerance, and enhanced nutritional content (Qaim, 2020).

According to Bernard, Lambert, Macours, and Vinez (2023), improved seeds combine these advantages with adaptability to local conditions, offering various benefits that contribute to increased productivity among smallholder farmers. Nabuuma, Reimers, Hoang, Stomph, Swaans, and Raneri (2022) further highlight that improved seeds are a foundational component of modern agriculture, essential for achieving sustainable food production under increasing resource constraints.

The yield-enhancing potential of improved seeds is well-documented. Research consistently show significant yield increases for key staple and cash crops when farmers switch to improved varieties (Hemming et al., 2018). However, as Wiggins and Brooks (2012) note, the realisation of this potential is often hampered by affordability and accessibility issues for smallholders.

(b) Chemical fertilisers:

SCFs can benefit from the adoption and utilisation of integrated soil fertility management practices (Kwadzo and Quayson, 2021). These include the use of chemical or inorganic fertilisers to improve soil fertility and nutrient availability for crops (Roobroeck, Van Asten, Jama, Harawa, and Vanlauwe, 2015). In recent years, the use of chemical fertiliser among smallholder crop farm households in Sub-Saharan Africa (SSA) has increased (Ricker-Gilbert, 2020). However, Walling and Vaneeckhaute (2020) argue that the use of chemical fertiliser can contribute to greenhouse gas emissions, though it has become an essential part of our global food supply chain. Chemical fertiliser is crop yield-enhancing technology for improving SCFs' income and food security by enhancing land productivity (Andani, Moro, and Issahaku, 2020). Furthermore, chemical fertiliser comprises a range of minerals and synthetic chemicals

(Ghimire, 2023). A study conducted by Ricker-Gilbert (2020) highlighted that chemical fertiliser is the primary mechanism for increasing agricultural productivity among SCFs. Musafiri, Kiboi, Macharia, Ng'etich, Okoti, Mulianga, Kosgei, Zeila, and Ngetich (2023) stated that using chemical fertilisers could improve the livelihoods of SCFs through improved soil health and crop yields. Furthermore, Elkholy, Mahrous, and El-Tohamy (2010) highlighted that chemical fertilisers have a higher positive effect on microbial biomass and enhances soil health. SCFs can achieve better crop growth and yields by ensuring adequate soil fertility (Mugwe, Ngetich, and Otieno, 2019).

(c) Chemical pesticides:

Chemical pesticides have significantly contributed to increased productivity and quality of produce worldwide (Qaim, 2020). However, chemical pesticides are perhaps one of the most misunderstood technologies used in modern agriculture. Chemical pesticides and other plant science innovations are too often criticised as a threat to sustainable agricultural productivity, in spite of evidence to the contrary (Tudi, Daniel Ruan, Wang, Lyu, Sadler, Connell, Chu, and Phung, 2021). The reduction of current yield losses caused by pests is a major challenge to agricultural production, and farmers consequently tend to minimise it by using chemical pesticides (Oerke, 2006; European Commission, 2022). All farmers use chemical pesticides, including organic farmers. Whether from synthetic or natural sources, chemical pesticides are used by all farmers. The difference is that organic farmers can only use chemical pesticides from natural sources, but both synthetic and natural chemical pesticides have various levels of toxicity (Popp, Pető, and Nagy, 2013).

Popp et al. (2013) highlighted that without chemical pesticides, food production would drop and food prices would increase. With lower production and higher prices, smallholder farmers would be less competitive in global markets for major commodities. Without the use of chemical pesticides, more than half of the farmers' crops would be lost to pests and diseases (OECD-FAO, 2012). Between 26% and 40% of the world's potential crop production is lost annually because of weeds, pests and diseases. Without crop protection, these losses could easily double. Furthermore, Gianessi and Reigner (2005) also stated that crop quantity and quality rely on crop protection.

(d) Irrigation systems:

Agriculture is the largest water user and consumes over 70% of the abstracted freshwater globally, and a significant portion of the water used for irrigation is not effectively utilised (Singh, 2015). Hence, there is a need for adopting and utilising water-saving irrigation methods and technologies in agriculture to conserve and use water more efficiently. Access to efficient irrigation systems can significantly enhance productivity, especially in areas with unreliable rainfall patterns (Nikolaou, Neocleous, Christou, Kitta, and Katsoulas, 2020). SCFs use accessible water management technologies, such as drip irrigation and sprinkler systems, which help them optimise water use and ensure efficient irrigation (Pereira et al., 2023).

The productivity gains from irrigation, particularly for high-value vegetables, are substantial. Research confirms that access to reliable irrigation is one of the most impactful innovations for smallholders, often leading to the highest yield increases compared to other inputs (Nakawuka et al., 2018). Yang et al (2023) found that technologies like drip irrigation are particularly effective in optimising water use and boosting yields.

Drip irrigation systems are a type of irrigation technology that function by evenly applying a small amount of water directly to the crop roots and, in some cases, fertiliser to a particular location (Yang et al., 2023). As one of the highest-efficiency water-saving irrigation techniques, sprinkler irrigation has been widely promoted all over the world due to its advantages of strong adaptability, labour-saving, and yield increase (Li and Ren, 2022). According to Darko, Liu, Yuan, Sam-Amoah, and Yan (2020), SCFs can use technologies such as drip irrigation and sprinkler irrigation to ensure adequate water supply to their crops, thereby increasing yields and reducing water wastage. Furthermore, a study by Nhamo, Mabhaudhi, and Magombeyi (2016) highlighted that proper water management enhances crop growth and productivity, particularly in areas with limited water resources. Ricker-Gilbert (2020) emphasised that water control is crucial for plant growth and for the economic returns on using fertiliser. Ahmed, Gui, Murtaza, Yunfei, and Ali, (2023) stated that timely and efficient irrigation, especially in regions with unpredictable rainfall patterns, allows farmers to maintain consistent soil moisture levels and ensure that crops receive the optimal amount of water precisely when needed. This minimises water stress and water wastage. Rockström, Barron, and Fox (2003) stated that lack of access to reliable irrigation systems and water management techniques can limit SCFs' ability to sustain crop production during dry spells or in water-scarce areas. This can result in water stress for crops, reduced yields, and lower productivity overall.

2.6 Factors constraining the use of agricultural innovations

Agricultural innovation is widely recognised as essential for enhancing productivity, sustainability, and resilience in the face of evolving global challenges (Danish et al., 2023). However, SCFs, who form the backbone of food production in many regions, often face significant constraints when attempting to adopt and utilise these innovations (Chindasombatcharoen et al., 2024). This study adopts the asset pentagon from the Sustainable Livelihood Framework (SLF) to categorise these constraints. The SLF identifies five key types of livelihood assets namely, human, social, natural, physical, and financial which collectively influence productivity (Chambers and Conway,1992).

2.6.1 Human constraints

(a) Age:

Age is a critical factor in the utilisation of agricultural innovations. Older farmers may be less inclined to invest in new technologies and inputs due to a stronger attachment to traditional farming practices, lower flexibility, and shorter investment horizons (Baumgart-Getz, Prokopy, and Floress, 2012; Ndiritu, Kassie, and Shiferaw, 2014). In contrast, younger farmers tend to be more open to using new technologies, likely due to higher risk tolerance, familiarity with modern techniques, and greater exposure to information (Mwangi and Kariuki, 2015). This generational difference in attitude towards innovation highlight a potential barrier for older farmers in the implementation process (Adesina and Baidu-Forson, 1995).

The relationship between age and innovation use is not linear and can vary by the type of innovation. For instance, older, experienced farmers may be more likely to adopt certain yield-increasing inputs like improved seeds due to their accumulated knowledge, while simultaneously, age can be a broader barrier due to stronger attachment to traditional practices and a shorter investment horizon (Baumgart-Getz et al., 2012). This highlights the context-dependent nature of age as a factor. While older farmers are often characterised as more risk-averse, this is not universal. For capital-intensive, long-term innovations like irrigation systems, older farmers with accumulated experience and resources may be more likely to adopt, as they have a longer-term perspective on their land and have witnessed the benefits of reliable water access (Daniel, 2011; Jiba et al., 2024).

(b) Gender:

The gender of the farmer can significantly influence the adoption and use of agricultural inputs. In many contexts, female farmers face disproportionate constraints due to limited access to resources, information, and capital. For instance, studies by Diiro, Ker, and San (2015) and Wossen (2018) have highlighted that male-headed households are significantly more likely to use inorganic fertiliser than female-headed households, often due to men's greater access to credit and extension services.

(c) Farmer's education:

Limited formal education can be a significant barrier to utilising agricultural innovations. Farmers with lower levels of education may struggle to understand and implement modern farming practices (Silva and Broekel, 2016). Higher education, on the other hand, enhances farmers' ability to analyse the benefits of new technologies, making them more open to using innovations (Muzari et al., 2012). Educated farmers are better equipped to obtain, process, and use information relevant to the utilisation of new technologies, facilitating the implementation process (Adebiyi and Okunlola, 2010; Mignouna et al., 2011; Lavison 2013). A lack of education may result in a knowledge gap, impeding farmers' ability to effectively use new technologies even if they are accessible (Antwi-Agyei and Stringer, 2021).

(d) Knowledge gap:

Inadequate knowledge about the proper use of agricultural inputs such as seeds, fertilisers, and chemical pesticides discourages farmers from utilising them effectively (Mkenda, Ndakidemi, Stevenson, Arnold, Darbyshire, Belmain, Priebe, Johnson, Tumbo, and Gurr, 2020). Similarly, a lack of technical skills for operating irrigation systems hinders their use in many farming operations (Levidow, Zaccaria, Maia, Vivas, Todorovic, and Scardigno, 2014). Smallholder farmers often face significant knowledge gaps and lack the technical capacity to utilise agricultural innovations (Autio, Johansson, Motaroki, Minoia, and Pellikka, 2021). Additionally, insufficient training and education opportunities, limited access to technical expertise, and a lack of capacity-building programs can further impede the implementation process (Viatte, 2001; Slayi, Zhou, and Jaja, 2023). Extension services are critical in addressing these gaps by providing knowledge, training, and technical support. However, inadequate coverage, limited personnel, and low-quality advisory services in rural areas hinder effective dissemination of innovation (Anderson and Feder, 2004). Furthermore, this knowledge gap is particularly detrimental for inputs like improved seeds, where farmers may not understand the yield and resilience benefits compared to traditional varieties, leading to underutilisation (Mutyasira et al., 2018).

(e) Farmers attitude:

Smallholder farmers' attitudes significantly influence their access to agricultural innovations. Positive attitudes, such as openness to change and willingness to experiment, can facilitate the utilisation of new technologies (Zossou, Arouna, Diagne, and Agboh-Noameshie, 2020; Pfeiffer, Gabriel, and Gandorfer, 2021). Conversely, negative attitudes, such as resistance to change or a lack of awareness regarding the potential benefits of new technologies, can create substantial barriers to utilisation (Kim, Seo, Zo, and Lee, 2021; Huang, Jin, and Coghlan, 2021). Smallholder farmers' perceptions of the potential benefits of innovations play a crucial role in shaping their willingness to use them.

(f) Perceived risk:

Smallholder farmers often perceive the utilisation of new technologies as risky, particularly due to the potential failure of new inputs or practices. High perceived risks can limit farmers' willingness to invest in innovations, even when they have the potential to improve productivity (Duong, Brewer, Luck, and Zander, 2019). Studies have shown that farmers' perceptions of risk, uncertainty, or the complexity of innovations significantly impact their willingness to explore and implement new agricultural practices (Benitez-Altuna, Trienekens, Materia, and Bijman, 2021). Farmers may fear that failure could result in substantial financial losses or wasted time (Chi and Yamada, 2002). This fear of failure often stifles innovation utilisation, as farmers are hesitant to take risks. However, when innovations align with farmers' needs and environmental conditions, they are more likely to perceive them as a worthwhile investment (Mignouna, Manyong, Rusike, Mutabazi, and Senkondo, 2011). The perceived benefits of innovations, as well as trust in their effectiveness, are crucial factors in overcoming the perceived risks associated with their utilisation (Eastwood and Renwick, 2020; Li and Li, 2023). Moreover, a barrier consistently identified in adoption studies by Dessart et al (2019), Savari and Gharechaee (2020), and Xiang et al (2021), reported that fear of failure is particularly potent for inputs requiring significant financial investment, such as chemical fertilisers. Farmers may perceive a high risk of financial loss if the fertiliser does not perform as expected due to weather variability or improper application.

2.6.2 Financial constraints

(a) Inadequate access to credit:

Inadequate access to credit serves as a significant barrier to SCFs' ability to access and use agricultural innovations. Many smallholder farmers lack access to formal credit facilities, hindering their ability to secure loans for purchasing innovative agricultural technologies and inputs (Langyintuo, 2020). Credit is essential for bridging this financial gap, enabling farmers to make upfront investments in innovative agricultural practices (Chandio, Jiang, Rehman, Twumasi, Pathan, and Mohsin, 2020). Without sufficient credit, smallholder farmers may struggle to invest in technologies requiring upfront capital, limiting their use of innovations (Makate, Makate, Mango, and Siziba, 2019). Furthermore, limited access to credit restricts farmers' ability to navigate unforeseen challenges, such as climate-related risks or fall back options in case new technologies fail (Oyinbo, Chamberlin, Vanlauwe, Vranken, Amara, Craufurd, and Maertens, 2019).

This barrier directly affects the ability to purchase quality inputs. Studies by Abate et al (2016) and Khandker and Koolwal (2016) consistently show that limited access to credit is a primary obstacle to the use of improved seeds, which often have a higher upfront cost than saved seeds. This limitation is particularly acute for specific inputs like chemical fertilisers. Okoboi and Barungi (2012) and Balana and Oyeyemi (2022) identified limited access to credit as a primary barrier to fertiliser use, noting that the high upfront cost places this essential input out of reach for cash-constrained smallholders without financial support.

The International Finance Corporation (IFC) (2014) highlighted that smallholders typically have little or no access to formal credit, restricting their capacity to invest in the technologies and inputs needed to increase yields and incomes. Habtemariam et al. (2019) and Makate et al. (2019). argued that access to credit provides farmers with the capital to make efficient and potentially profitable investments in innovations. However, Fan and Rue (2020) pointed out that many SCFs are excluded from productivity enhancing financial services, such as loans and saving accounts, and are thus unable to secure much needed capital and lack the buffer against adversity and shocks that financial services offer.

In the South African context, Myeni et al. (2019) found that only 2% of farmers had access to farm credit, while the majority of farmers (98%) had never received credit for crop production. These results confirm that South African smallholder farmers have very limited access to credit as a result of low income, old age and low level of education, which hinder their ability to meet basic credit requirements (Khapayi and Celliers, 2016). Another major constraint is the lack of collateral, as most smallholder farmers operate on communal land without formal title deeds that can be used as security for loans (Khan, Nouman, Negrut, Abban, Cismas, and Siddiqi, 2024). Sebola (2018) emphasised that the requirements for obtaining funding from both the development finance institutions and government funding programmes are not lenient but rather stringent or challenging for smallholder beneficiaries. This observation highlights a discrepancy between expectations and reality in the accessibility of financial support for SCFs from these institutions and programmes. Carelsen, Ncube, and Fanadzo (2023) concluded that SCFs with access to credit were more strongly equipped to handle disasters like droughts than farmers without credit facilities.

Furthermore, the source and stability of a farmer's income play a role. A heavy reliance on off-farm income, such as pensions or grants, may reduce the propensity to invest in agricultural inputs. This can be due to a substitution effect, where off-farm funds are prioritised for household consumption or other non-farm investments over production costs like chemical pesticides (Migheli, 2017). However, the relationship can be complex, as higher incomes can also sometimes facilitate input purchase, indicating that the type and management of off-farm income are critical factors (Huang et al., 2020).

(b) Dependence on input subsidies:

Reliance on government-provided input subsidies can discourage farmers from seeking out and purchasing additional production inputs. This dependence can limit their willingness to explore and use new, potentially more effective, innovations (Duenas, Ruffhead, Wakefield, Roberts, Hemming, and Diaz-Soltero, 2018). Many SCFs wait for subsidised products instead of purchasing them at market prices, creating delays and limits usage rates, particularly for fertilisers and improved seeds (Mason et al., 2017). Additionally, this reliance on subsidies can lead to dependency, diminishing motivation to seek innovative agricultural inputs independently (Jayne et al., 2018). Addressing this issue requires balancing short-term support with initiatives promoting sustainable, independent input acquisition.

(c) High input costs:

Smallholder farmers often operate within tight budget constraints, with limited income streams and minimal savings (Mwangi and Kariuki, 2015; Smidt and Jokonya, 2022). The high costs associated with using new technologies, such as advanced seeds or modern farming equipment, are often prohibitive (Tesfaye, Balana, and Bizimana, 2021). This financial constraint restricts their ability to purchase innovative tools and resources and limits their participation in training programs and workshops that could enhance their understanding and utilisation of these innovations (Nxumalo and Oladele, 2013; Isaga, 2018).

Without adequate finances, SCFs may find themselves caught in a cycle where upfront costs act as barriers to using innovations, consequently limiting their productivity and income potential (Kapari, Hlophe-Ginindza, Nhamo, and Mpandeli, 2023). Michalscheck et al. (2018) and Akrofi et al. (2019) reported that high costs often discouraged the utilisation of agricultural technologies. Similarly, Senyolo, Long, Blok, and Omta (2018) observed that smallholder farmers tend to avoid costly practices and technologies due to affordability concerns. Reducing input costs through subsidies, cooperatives, or shared ownership models could alleviate these barriers.

2.6.3 Physical constraints

(a) Infrastructure:

Poor physical infrastructure presents a significant obstacle to SCFs seeking to use agricultural innovations (Selepe, Sabela, and Masuku, 2014; Mazibuko and Antwi, 2019; Rukasha, Nyagadza, Pashapa, and Muposhi, 2021; Kaiser and Barstow, 2022). The lack of proper storage and processing facilities exacerbates post-harvest losses and reduces the overall efficiency of the agricultural supply chain. Hence, poor storage facilities hamper farmers' ability to preserve harvested crops leading to post-harvest losses and reduces the incentives for farmers to purchase technologies that improve productivity (Kumar and Kalita, 2017; Das Nair and Landani, 2020).

Limited access to electricity further hinders the utilisation of modern technologies, as many innovations require reliable power sources for operation (Blimpo and Cosgrove-Davies, 2019). Moreover, poor rural road networks impede farmers' access to markets and agricultural inputs. Haile and Dachito (2020) found that a lack of all-weather roads restricts farmers' mobility and access to critical resources. Similarly, Workman, Kominek, Hine, and Shah (2020) and Damania, Berg, Russ, Federico Barra, Nash, and Ali (2017) emphasised that inadequate transportation infrastructure separates SCFs from essential tools and strategies, leaving farmers locked in cycle of poverty. Ngcobo (2012) argued that inadequate infrastructure hinders economic development and poverty reduction efforts. Improving rural infrastructure, such as roads, storage facilities, and access to electricity, is crucial for supporting SCFs in using agricultural innovations.

(b) Market constraints:

Limited market access and price volatility discourage farmers from using new technologies, especially when uncertainties surround the demand and pricing of their produce (Assouto, Houensou, and Semedo, 2020). SCFs in remote areas face challenges in accessing markets to sell their produce and acquire essential inputs (Kyaw, Ahn, and Lee, 2018). These barriers make it difficult for farmers to justify investments in agricultural innovations that carry financial risks (Bridle, Magruder, McIntosh, and Suri, 2020; Masere and Worth, 2022).

Branca, Cacchiarelli, Haug, and Sorrentino (2022) highlighted that constraints in market access and value chain integration significantly reduce smallholder farmers' motivation use innovations. Masere and Worth (2022) further noted that limited market opportunities, lack of linkages, price volatility, and insufficient market information discourage farmers from investing in innovations.

2.6.4 Natural constraints

(a) Farm size:

The size of a farm can influence the viability of using specific agricultural innovations (Massresha et al., 2021). Innovations that require large-scale implementation might not be feasible for smallholder farmers with limited resources (Teklu, Simane, and Bezabih, 2023). Hence, the majority of SCFs typically operate on small plots of land. The limited land available to them can be a constraint to agricultural innovation practices that require larger land holdings. Small farm size can lead to resource constraints, limiting the use of innovative methods (Udimal et al., 2017; Hu et al., 2022). Hu, Li, Zhang, and Wang (2022) and Jones-Garcia and Krishna (2021) have shown that farmers with large farm sizes are likely to use new technology as they can afford to devote part of their land to try new technology, unlike those with smaller farm sizes. Hence, according to Liu, Bruins, and Heberling (2018), the size and diversity of farms are crucial factors that impact the feasibility and success of using specific innovations in agriculture. Mwangi and Kariuki (2015) have highlighted that tailoring innovations to the unique needs and constraints of different farm sizes, crop compositions, and local contexts is essential for achieving widespread and effective utilisation.

(b) Land ownership:

Land ownership plays a crucial role in innovation implementation. Secure land tenure encourages long-term investments in land improvement and the usage of innovations (Amani, 2004). Farmers with secure land tenure are more likely to invest in long-term innovations like irrigation systems, as they are confident of reaping future benefits (Feder et al., 1988). On the other hand, smallholder farmers without secure land ownership often lack the incentives or resources to use these technologies (Place, 2009).

(c) Climate conditions:

Smallholder farmers' decisions to use chemical fertilisers are highly influenced by climate variability (Heisse and Morimoto, 2024). Unfavourable climatic conditions make it challenging for SCFs to obtain necessary inputs like seeds, which may not perform well under adverse weather (Arslan, Belotti, and Lipper, 2017). Innovations like irrigation systems or chemical fertilisers are seen as high-risk investments when weather patterns are highly uncertain (Deressa et al., 2009). Moreover, regions prone to climate variability face additional challenges in accessing climate-resilient technologies (Shiferaw et al., 2014).

Environmental conditions pose an inherent risk to agriculture, and environmental conditions determine, in part, the type and amount of inputs chosen for production. Farmers' decisions to use chemical fertilisers are highly influenced by climate variability (Heisse and Morimoto, 2024). These findings concur with findings from Dercon and Christiaensen (2011) and Arslan, Belotti, and Lipper (2017) who reported that higher rainfall and temperatures variability reduces the probability that farmers will apply chemical fertiliser on their crops in any given year.

(d) Water Resources:

Insufficient water supply limits the use of irrigation systems and other production inputs, affecting smallholder farmers' ability to grow crops effectively (Chikozho, Managa, and Dabata, 2020). Investments in water infrastructure, such as irrigation systems, and promoting water conservation techniques are crucial for enhancing water access and utilisation (Ingrao, Strippoli, Lagioia, and Huisingh, 2023). According to Namara, Horowitz, Nyamadi, and Barry (2011), limited or unreliable water supply discourages investment in irrigation technologies, particularly in semi-arid or water-scarce regions. SCFs who rely on rainfed agriculture face significant barriers to integrating water-based innovations (Mutiro and Lautze, 2015). This creates a critical barrier to adopting irrigation technologies. Farmers who face an insufficient or unreliable primary water supply are logically discouraged from investing in irrigation systems, as the foundational resource is not secure (Namara et al., 2011; Mutiro and Lautze, 2015).

2.6.5 Social constraints

(a) Social connections and trust:

Limited social connections can restrict smallholder farmers' access to information about innovations (Chindasombatcharoen, Tsolakis, Kumar, and O'Sullivan, 2024). Strong social networks and information-sharing platforms can enhance farmers' awareness and understanding of innovations. (Sponsler, Grozinger, Hitaj, Rundlöf, Botías, Code, Lonsdorf, Melathopoulos, Smith, Suryanarayanan, and Thogmartin, 2019). According to Hu (2020), SCFs apply chemical pesticides based on associated information. Smallholder farmers who are well-integrated into social networks often gain access to information, resources, and peer experiences that encourage the use of new technologies (Bandiera and Rasul, 2006).

(b) Cooperative membership:

Membership in agricultural cooperatives is associated with increased innovation use, as cooperatives provide essential resources, improve bargaining power, and ultimately enhance crop productivity (Mzuyanda, 2014; Zhu and Wang, 2024). However, when smallholder farmers are excluded from cooperatives due to financial or logistical barriers, they lose out on these benefits, which limits their capacity to use innovations (Wossen et al., 2017). Additionally, poorly managed cooperatives may fail to deliver the intended support to their members (Barham and Chitemi, 2009).

2.7 Conceptual framework

SCFs in South Africa continue to face persistent challenges such as low productivity, limited access to agricultural resources, and inadequate support services. Despite significant government investments in AIS aimed at addressing these issues, productivity levels among SCFs remain suboptimal. This conceptual framework illustrates the presumed relationships among key components of AIS and their impact on SCFs' productivity outcomes.

AIS serves as a central driver in enabling SCFs to access and adopt agricultural innovations. The system facilitates the development, dissemination, and use of innovations such as improved seeds, chemical fertilisers, chemical pesticides, and irrigation systems. AIS operates through a collaborative network of stakeholders, including government agencies (DARDLEA, AgriSETA, and SEDA), research institutions (ARC), private organisations (Standard Bank), and NGOs (Timbali Technology Incubators). These stakeholders deliver essential support services, including financial assistance, technical advisory services, provision of inputs, infrastructure development, and training, all of which empower SCFs to adopt and effectively use these innovations.

The support services provided by AIS equip SCFs with the resources required to adopt and utilise agricultural innovations effectively. These innovations such as improved seeds, chemical fertilisers, chemical pesticides, and irrigation systems enhance productivity by increasing crop yields and quality, promoting resource efficiency through optimal resource use, ensuring food security, and supporting sustainable livelihoods. However, various constraints within the AIS and the farming community can hinder the effectiveness of AIS and innovations use. Barriers such as socioeconomic factors (age, education, and gender), structural and financial challenges (limited access to credit and high input costs), knowledge gaps, and others all contribute to limiting the impact of AIS support services. These challenges impede the use of innovations and, in turn, negatively affect productivity outcomes.

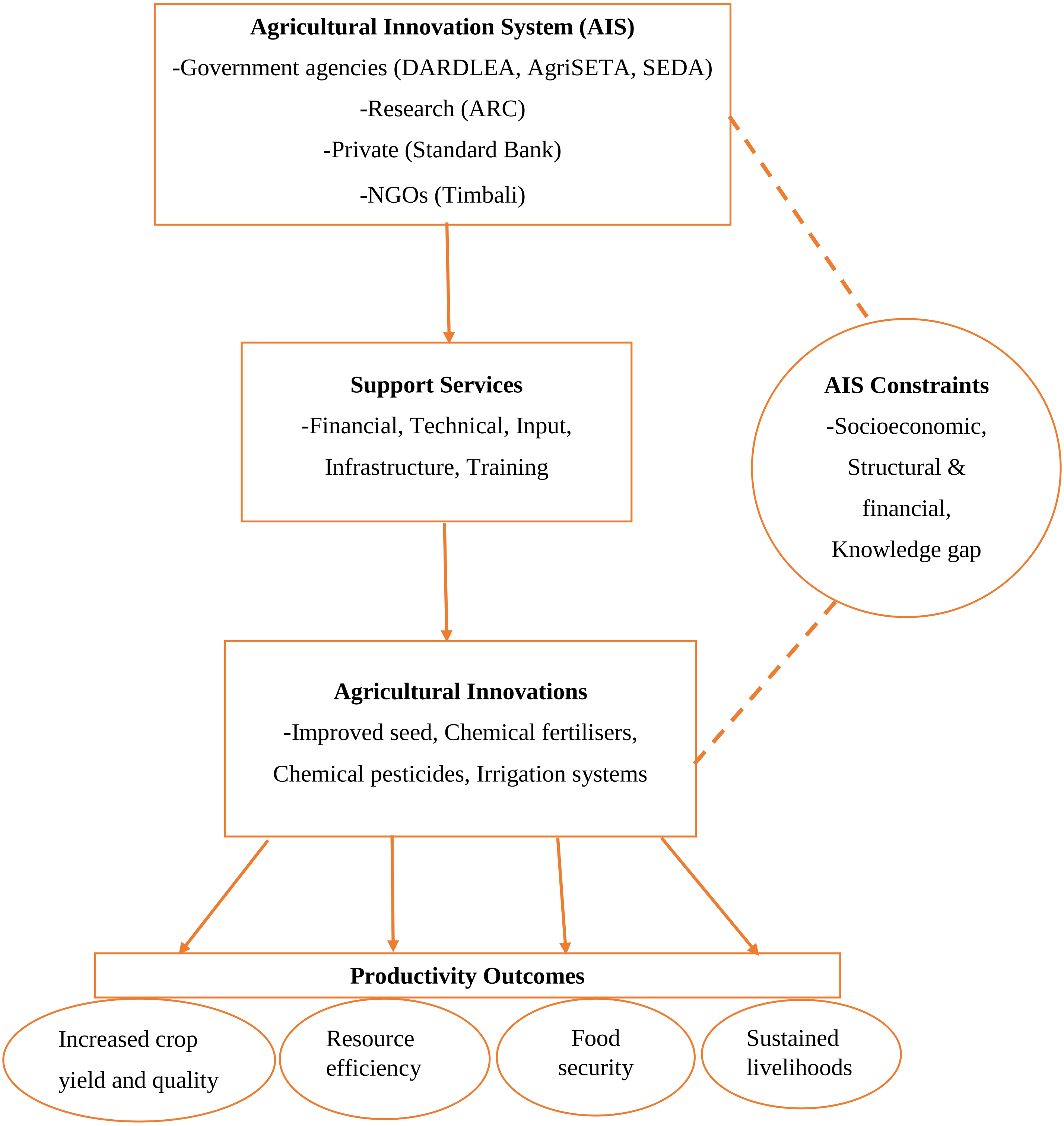


Figure 2: Conceptual framework of the study on Agricultural Innovation Systems (AIS) and Smallholder Crop Farmers (SCFs)

Source: Author's own compilation (2024)

2.8 Chapter summary

This chapter provided a comprehensive review of previous and recent literature relevant to the study, focusing on smallholder crop farmer support within the context of AIS. The review elaborated on the AIS framework and its role in delivering agricultural support services to SCFs. The types of support discussed include financial aid, technical assistance, access to inputs, infrastructure, and training, all of which are critical for enhancing farming operations. The chapter also explored the impact of agricultural innovations on productivity, emphasising their importance in smallholder farming. Key innovations discussed included improved seeds, chemical fertilisers, chemical pesticides, and irrigation systems. The review highlighted how these innovations contribute to increased crop yields, better resource efficiency, and improved livelihoods for farmers. Lastly, the chapter examined the factors constraining SCFs' use of agricultural innovations. These constraints included socioeconomic factors (such as age, education, farm size, land ownership, and cooperative membership), knowledge gaps, dependence on input subsidies, limited access to credit and water resources, climate variability, inadequate extension services, poor infrastructure, market constraints, lack of trust in support systems, and high input costs.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

This chapter outlines the research methodology employed to achieve the study's objectives. The chapter begins by providing an overview of the study area, highlighting its geographic, economic, and agricultural potential. It then details the research design, sampling techniques, and methods used to select participants, followed by a description of the data collection procedures. A comprehensive explanation of the data analysis methods employed for each research objective is also provided. Finally, the chapter concludes with a discussion of ethical considerations.

3.2 Study area

The study was conducted in 16 villages within the Mbombela Local Municipality, located in the Mpumalanga Province, South Africa (Figure 3). Mbombela forms part of the Ehlanzeni District Municipality and serves as the capital city of Mpumalanga (Ehlanzeni District Profile and Analysis Development Model, 2020). Geographically, the municipality lies in the north-eastern part of South Africa within the Lowveld sub-region, with approximate coordinates of 25.4° South and 30.9° East. It covers a total area of approximately 7152 km2 (Integrated Development Plan (IDP), 2022-2027). The climate in Mbombela is classified as subtropical, characterised by hot, wet summers and mild, dry winters, with average annual rainfall ranging between 600 mm and 1000 mm (Masereka, Ochieng, and Snyman, 2018).

According to Statistics South Africa (Stats SA, 2022). Mbombela has a population of approximately 818,925, the majority of whom are Black African (94.6%). IsiSwati is the most widely spoken language in the municipality. The area is predominantly rural, and agriculture remains the primary livelihood strategy for most households (Mathews, 2010). Smallholder farmers in the rural parts of the municipality primarily cultivate vegetables and other agronomic crops for both household consumption and income generation (Zenda, Rudolph, and Harley, 2024).

According to the Local Government Treasury (2021), agriculture is one of the primary economic activities in the area. Although the agricultural sector in Mbombela has experienced a gradual decline, the municipality still holds substantial potential for agricultural growth, particularly through the adoption of innovative farming practices, which offers opportunities to increase crop productivity, enhance resilience to climate variability, and stimulate rural livelihoods (Ehlanzeni District Municipality, 2025).

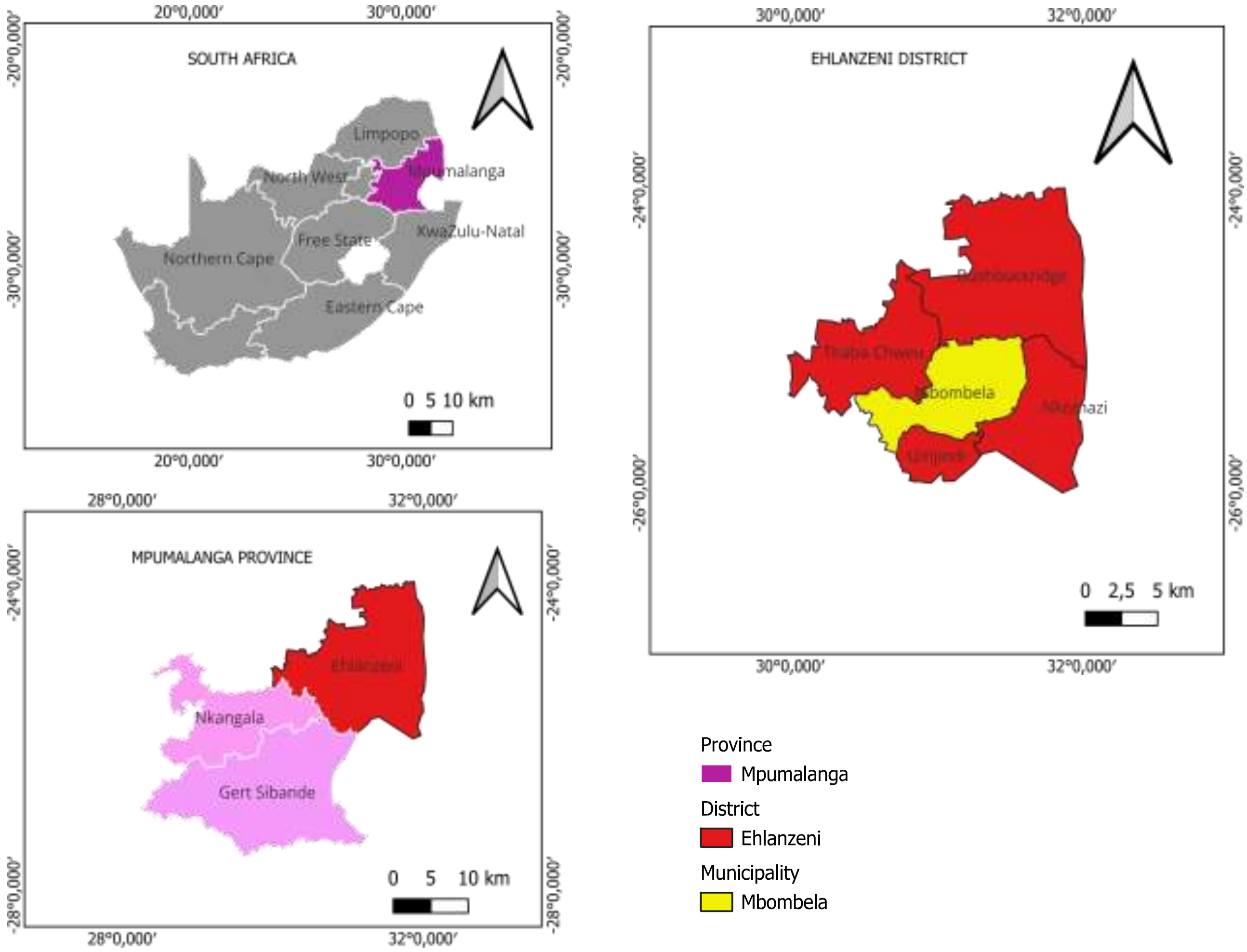


Figure 3: Map of Mbombela Local Municipality

Source: Author's own compilation using QGIS (2025)

3.3 Research design

The study employed a quantitative research approach, using a descriptive and cross-sectional design to achieve its objectives. Quantitative research produces discrete numerical data, making it suitable for analysing measurable variables (Mohajan, 2020). Quantitative research can be defined as the examination of social or human problems based on testing a theory composed of variables measured with statistical numbers and analysed using statistical procedures (Bauer, Churchill, Mahendran, Walwyn, Lizotte and Villa-Rueda, 2021).

Quantitative design was appropriate for the study as it focused on assessing the impact of agricultural innovations on smallholder crop productivity, which involves quantifiable data such as crop yields, innovation usage, and socioeconomic characteristics. Quantitative research typically involves larger sample sizes, providing representative data and increasing the generalisability of findings (Rahman, 2016). This is particularly important given the study's aim to draw reliable and objective conclusions applicable to smallholder crop farmers (SCFs) in Mbombela Local Municipality.

Moreover, the use of statistical analysis techniques to identify patterns, relationships, and trends in the data aligns with the study's objective of assessing the impacts of specific agricultural innovations. The efficiency of quantitative methods in data collection and the use of standardised instruments also supported the feasibility of conducting the study across multiple villages within the study area (Eyisi, 2016; Story and Tait, 2019).

3.4 Sample selection and sampling procedure

3.4.1 Target population

The target population refers to the group of individuals that the study seeks to investigate and draw conclusions from (Barnsbee, Barnett, Halton and Nghiem, 2018). Similarly, Makapela (2015) defines a population as the group of individuals upon whom the researcher focuses on, with the results obtained representing the overall views of this group. For this study, the target population was SCFs in Mbombela Local Municipality. According to the database obtained from the Department of Agriculture, Rural Development, Land and Environmental Affairs (DARDLEA), there are 1 343 SCFs registered with the department in the municipality. These farmers cultivate a variety of crops, including vegetables, grains, and fruits. Each smallholder crop farmer was treated as a unit of analysis, and the complete database obtained from DARDLEA served as the sampling frame for the study.

3.4.2 Sample size

Sample size of any population is a subset or a smaller unit of the main population on which a research is to be carried out (Majid, 2018). For the outcome of any research about a population to be generalised, the sample size must be able to explain the characteristics of the main population under study (Singh and Masuku, 2014). To determine the sample size of the study, formula developed by Robert Slovin in 1960 was used (Slovin, 1960). A 5% margin of error with 95% confidence interval was applied. Considering the target population of 1 343 SCFs, the above set values were used to obtain a suitable sample size for the study. The formula below was used:

$$\mathbf{n} = \frac{\boldsymbol{N}}{(\mathbf{1} + \boldsymbol{Ne}^{\mathbf{2}})}$$

Where:

n = the sample size

N = the known population size of 1 343

e = the acceptable margin of error value (5% margin of error) which was 0.05 when divided by 100%.

Therefore:

$$\mathbf{n} = \frac{\mathbf{1343}}{(\mathbf{1} + \mathbf{1343}(\mathbf{0.05})^{\mathbf{2}})}$$

Using this formula, a sample size of 308 SCFs was obtained and considered adequate for the study.

3.4.3 Sampling technique

Sampling refers to the process of selecting units from the target population for analysis (Mujere 2016). This study employed a systematic sampling technique to select participants. Systematic sampling, while similar to simple random sampling, is often more straightforward to conduct as it uses a pre-existing list of participants (McCombes, 2023). To draw the systematic sample, the researcher utilised a complete list of 1 343 SCFs obtained from DARDLEA, assigning each farmer a unique number. The selection interval (K) was calculated using the following formula (Mostafa and Ahmad, 2018):

$$\mathbf{K} = \frac{\boldsymbol{Population\ size}\ (\boldsymbol{N})}{\boldsymbol{Sample\ size}\ (\boldsymbol{n})}$$

Substituting the values:

$$\mathbf{K\ (selection\ interval)} = \frac{\mathbf{1343}}{\mathbf{308}}$$

$$= \mathbf{4}$$

Thus, K (the selection interval) was 4. According to Makwana, Engineer, Dabhi, and Chudasama (2023), a researcher must randomly select a starting point within the range of 1 to K. In this study, the randomly chosen starting point was 3. The first participant selected was the 7th smallholder crop farmer, and every 4th smallholder crop farmer on the list was subsequently chosen, resulting in a sample of 308 SCFs.

3.5 Data collection

The study utilised both primary and secondary data collection methods. Sample survey techniques were employed, with trained enumerators administering questionnaires to the research participants. Extension officers for each village facilitated the process by organising the SCFs and communicating with farmers about the study. Their efforts ensured that farmers were well prepared for their interviews and helped minimise logistical challenges in reaching the target participants.

3.5.1 Primary data collection

Primary data was collected from SCFs in Mbombela Local Municipality between August 2024 and September 2024 using pre-tested structured questionnaires with closed-ended questions. The questionnaires were administered as hard copies through face-to-face interviews with the assistance of three trained enumerators under the researcher's supervision. This method ensured high response rates and clarified any misunderstandings during data collection. Mkandawire (2019) described a questionnaire as a pre-determined set of questions designed to record respondents' answers systematically. The questionnaire was divided into sections according to the study objectives and included an additional section for socio-economic characteristics.

Section A focused on the socio-economic characteristics of the participants, including gender, age group, marital status, level of education, household size, main source of off-farm income, and others relevant factors. The second section examined the agricultural support services received by farmers, including financial, technical advisory, infrastructure, input, and training support, as well as their main providers, such as DARDLEA, ARC, Timbali, Standard Bank, and others. The third section evaluated the impact of agricultural innovations (such as improve seeds, chemical fertiliser, chemical pesticides, and irrigation system) on crop yields during the farmers' last cropping season (2023/2024). The fourth section identified constraints to the use of agricultural innovations, including limited access to credit, high input costs, inadequate knowledge of inputs, and other constraints.

To enhance response accuracy, some questions included an "Other, specify" options. This allowed participants to provide responses beyond the predefined categories where necessary. This approach ensured that the questionnaire remained structured while also capturing additional insights that may not have been initially considered. Responses under "Other" were later grouped and categorised during data analysis where applicable.

A pilot study was conducted with 30 farmers to identify possible errors, improve the questionnaire, and ensure that it is clear, reliable, and relevant. Baker (1994) recommends that pilot studies include 10–20% of the intended main sample size, making this approach suitable. The pilot study assessed essential aspects such as the time required to complete the questionnaire, the appropriateness of the questions, and whether additional response categories needed to be added based on the "Other, specify" responses. Importantly, farmers who participated in the pilot study were not part of the main sample and were excluded from the main study to avoid biasness in the data collection process. The final respondent group in the field consisted of 308 farmers who participated in the main study.

3.5.2 Secondary data collection

Secondary data, both published and unpublished, were obtained from the DARDLEA smallholder farmers' database, Stats SA census data, and the Mbombela Municipality Integrated Development Plan (IDP) for 2022–2027. These sources provided demographic, agricultural, and economic profiles of the study area, informing the sampling framework and enhancing the contextual understanding of the research.

3.6 Data analysis

Data analysis is the process of transforming, inspecting, and modeling data to extract meaningful insights and draw conclusions (Bihani and Patil, 2014). It is a critical step in the research process, utilising statistical and analytical tools to analyse the data collected during the data collection phase (Bergin, 2018). The data gathered from participants was coded and captured into the Statistical Package for Social Sciences (SPSS) version 29.0 software and also transferred to STATA version 14.0 for further analysis. Both descriptive statistics and inferential statistics were employed to analyse the data using SPSS and STATA.

3.6.1 Objective 1: To investigate the agricultural support received by smallholder crop farmers through AIS

This objective was analysed the agricultural support services received by the participants, focusing on the types of agricultural support services, the main supporting institutions, and the specific services provided under each category. Data on this objective was analysed using descriptive statistics, including frequencies, percentages, and cross-tabulations, were used to analyse the data, with the results presented in tables and graphs.

3.6.2 Objective 2: To assess the impact of agricultural innovations on productivity of smallholder crop farmers

Cross-sectional data on this objective was collected to assess the impact of agricultural innovations (yield-increasing innovations) on the productivity of SCFs in the study area. The data pertained to the last cropping season (2023/2024) of the SCFs. The yield-increasing innovations considered in this study included improved seeds, chemical fertilisers, chemical pesticides, and irrigation systems, while crop yield served as a proxy for productivity measurement. The crops analysed included vegetables (tomatoes, cabbage, and chillies) and an agronomic crop (maize). Propensity Score Matching (PSM) was employed to analyse the data and estimate the impact of these yield-increasing innovations on the yield of each crop. The results from PSM were used to test the hypothesis.

PSM allows researchers to estimate propensity scores in the first step using either a logistic or probit model. In the second step, the impact is assessed by estimating the "before and after" effects (Pan and Bai, 2015). According to Fadare, Akerele, and Toritseju (2014), using either a probit or logit model yields similar results when estimating propensity scores for individuals, whether they are adopters or non-adopters. Since the dependent variable in this study is binary (taking a value of 1 if the farmer uses one or more agricultural innovations and 0 otherwise), a probit regression model was applied to estimate the propensity scores of the sampled farmers.

3.6.2.1 Probit model

The probit regression model was used to estimate the likelihood (propensity score) of SCFs using one or more agricultural innovations (improved seeds, chemical fertilisers, chemical pesticides, irrigation systems). The probit model was selected due to the binary nature of the dependent variable, which takes a value of 1 if the farmer uses one or more agricultural innovations and 0 otherwise. The general form of the probit model used in this study is as follows:

$$\mathbf{P\ (Yi = 1|\ Xi) = \Phi\ (Xi\beta)\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..\ (1)}$$

Where:

P (Yi = 1| Xi) is the probability that an individual smallholder crop farmer i uses one or more agricultural innovations, Φ represents the cumulative distribution function (CDF) of the standard normal distribution, ensuring probabilities fall within the [0,1] range. Xi is a vector of explanatory variables, which include socio-economic characteristics of the individual and β is the vector of coefficients to be estimated.

The probit model assumes that there is an underlying latent (unobserved) variable Y*, which represents the utility or benefit a farmer derives from using agricultural innovations:

$$\mathbf{Yi^* = Xi\beta + \varepsilon i\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (2)}$$

Where:

Yi* is the latent variable representing the utility or benefit derived from using one or more agricultural innovations and εi is the random error term, assumed to follow a standard normal distribution.

The relationship between the latent variable and the observed binary outcome Yi is defined as:

$$\mathbf{Yi = 1 \text{ if } Yi^* > 0,\ 0 \text{ if } Yi^* = \leq 0\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (3)}$$

The empirical model is specified as:

$$\mathbf{Y = \alpha + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \beta_5X_5 + \beta_6X_6 + \beta_7X_7 + \beta_8X_8 + \beta_9X_9 + \varepsilon i \ldots\ldots\ldots\ldots\ldots (4)}$$

Where:

Y = Binary dependent variable (1 = use one or more agricultural innovations, 0 = non-user)

α = Constant

β_1 - β_9 = Coefficient of independent variable

X_1= Gender

X_2 = Age group (years)

X_3 = Level of education

X_4 = Main source of off-farm income

X_5 = Farm size (hectares)

X_6 = Years of farming experience

X_7 = Cooperative membership (1 if yes, 0 if otherwise)

X_8 = Water access (1 if yes, 0 if otherwise)

X_9 = Main source of water for irrigation

ε_i = Random error term

3.6.2.2 Propensity score matching (PSM)

PSM was used to assess the impact of agricultural innovations on productivity of SCFs. A primary challenge when using observational data is selection-bias, which occurs when the responses of individuals who receive a certain treatment differ from those who do not, in a way that are not accounted for, leading to biased estimates. To address this, PSM introduced by Rosenbaum and Rubin (1983), minimises the potential bias arising from the selection problem by utilising non-experimental data. PSM involves pairing treatment and control units with similar propensity scores, and potentially other covariates, while discarding all unmatched units (Rubin, 2001).

The PSM can be expressed as follows:

$$\mathbf{P(X) = Pr}\ (D\mathbf{i} = 1|X) = \mathbf{E}\ (D\mathbf{i}|X) \ldots\ldots\ldots\ldots\ldots\ldots.\ (5)$$

where:

Di = (0,1) is the dummy for agricultural innovation use as the treatment and:

Di = 1 if the farmers use treatment

Di = 0 if the farmers do not use treatment

X is the vector of farmers' socio-economic characteristics (gender, age group, marital status, level of education, other certificates, household size, main source of off-farm income, main source of on-farm income, farming experience, farm size, land ownership, main reason for farming, cooperative membership).

The conditional distribution of X, given the propensity score P(X), is similar in both groups, namely, of those farmers using one or more agricultural innovations and those that do not use any agricultural innovation.

After estimating the propensity scores, the Average Treatment Effect on the Treated (ATT) can then be estimated as:

$$\mathbf{ATT = E}\ (Y1\mathbf{i} - Y2\mathbf{i}|D\mathbf{i} = 1) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots...\ (6)$$

$$\mathbf{ATT = E}\ [E\ (Y1\mathbf{i} - Y2\mathbf{i}|D\mathbf{i} = 1, \mathbf{P}\ (X))] \ldots\ldots\ldots\ldots\ldots...\ (7)$$

$$\mathbf{ATT = E}\ [Y1\mathbf{i}\ |D\mathbf{i} = 1, P\ (X)) - E\ (Y2\mathbf{i}|D\mathbf{i} = 0, P\ (X))] \ldots\ldots\ldots\ldots\ldots.\ (8)$$

Where:

$Y1$i is the expected farmer crop yield if a farmer i is using one or more agricultural innovations;

$Y2$i is the expected farmer crop yield of a farmers i not using agricultural innovations;

Di = (0,1) is the dummy for agricultural innovation use and

X = is the vector of the farmer's socioeconomic characteristics.

3.6.6.3 Hypothesis testing

Hypothesis testing was conducted to evaluate the impact of agricultural innovations (improved seeds, chemical fertilisers, chemical pesticides, and irrigation systems) on the productivity of SCFs in Mbombela Local Municipality. The hypotheses were formulated as follows:

- **Null Hypothesis (H_0):** The Agricultural Innovation System (AIS) does not significantly impact the productivity (crop yields) of smallholder crop farmers in Mbombela Local Municipality through the use of yield-increasing innovations, such as improved seeds, chemical fertilisers, chemical pesticides, and irrigation systems.
- **Alternative Hypothesis (H_1):** The Agricultural Innovation System (AIS) significantly impacts the productivity (crop yields) of smallholder crop farmers in Mbombela Local Municipality through the use of yield-increasing innovations, such as improved seeds, chemical fertilisers, chemical pesticides, and irrigation systems.

To test the hypotheses, the t-statistic obtained from the ATT results from PSM was used. Statistical significance was assessed at three levels: 1% ($p < 0.01$), 5% ($p < 0.05$), and 10% ($p < 0.10$). The decision rule was as follows (Wooldridge, 2010):

- If the p-value is less than the chosen significance level, null hypothesis (H_0) is rejected, and alternative hypothesis (H_1) is accepted.
- If the p-value is greater than the chosen significance level, null hypothesis (H_0) is not rejected.

3.6.3 Objective 3: To examine the factors constraining smallholder crop farmers use of agricultural innovations for productivity improvement.

This objective focused on the constraints faced by SCFs in using agricultural innovations to enhance productivity. A binary logistic regression model was employed to analyse this objective, with tables used to present the results for each agricultural innovation. This model was chosen because it allows the research to determine whether there is an association between a set of independent variables and an outcome.

Binary logistic regression is used to classify respondents into either one or two groups in cases where only one set of independent variables is known. Importantly, no assumptions are made about the distribution of the independent variables represented by X. This allows X variable to take a discreet or continuous form. Therefore, Ri represents the dichotomous variable, where Ri equals to 1 if SCFs are constrained and 0 if they are not. To determine whether there is a significant relationship between the independent variables (the farmer's socio-economic characteristics) and constraints in using agricultural innovations, the following model was used (Hosmer, Lemeshow, and Sturdivant, 2000):

$$\textbf{Log}\left(\frac{P}{1-P}\right) = \beta o + \beta_1 X_1 + \beta_2 X_2 + \ldots\ldots\ldots\ldots\ldots\ldots\ldots + \beta k X k + \mu \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{(1)}$$

Where:

P = the probability of the event occurring. In this case, it is the probability that SCFs constrained to use agricultural innovations (coded as 1 if constrained, 0 if not).

$\left(\frac{P}{1-P}\right)$ = the odds ratio, which represents the odds of the event occurring versus not occurring. It transforms the probability P into unbounded scale.

$\beta 0$ = the intercept or constant term in the model, which is the log-odds of being constrained when all the independent variables are zero.

$\beta_1 - \beta k$ = the coefficients of the independent variables. These represents the change in the log-odds of being constrained for one-unit change in the respective independent variable.

$X_1 - Xn$ = the independent variables, which included both socio-economic characteristics (such as gender, age group, marital status, level of education, other certificates, household size, main source of off-farm income, main source of on-farm income, farming experience, farm size, land ownership, main reason for farming, cooperative membership) and factors related to farming constraints (such as inadequate knowledge, high perceived risk, limited access to credit, dependence on input subsidies, high input costs, lack of access to reliable power, poor farm roads, lack of market access, lack of access to land, unfavourable climatic conditions, insufficient water supply, limited social connections, lack of trust).

μ = the error term, capturing the unobserved factors that might affect the outcome.

3.7 Ethical considerations

Ethical considerations are essential in research to protect participants and ensure responsible conduct of the study (Barrow, Brannan, and Khandhar, 2017). Ethical clearance for this study was obtained from the University of Mpumalanga's Faculty of Agriculture and Natural Sciences Research and Innovation Committee, under the reference number UMP/Monamodi/201995670/MAGR/2024 (see appendix 2). This study adhered to the following ethical principles throughout its implementation.

3.7.1 Informed consent

Participants were given detailed information about the study, including its purpose, objectives, and expected outcomes. They were informed of the nature of their participation, including any potential risks or benefits. Written consent was obtained from each participant, who signed a consent form. Participants were assured that their participation was entirely voluntary, and they had the right to withdraw participation at any time without any negative consequences.

3.7.2 Right to withdraw

This principle ensures that research participants have the right to withdraw from the study at any point if they feel uncomfortable continuing (Ross, Iguchi and Panicker, 2018). Participants were informed that they could withdraw from the study at any stage, without needing to provide a reason or facing any negative consequences. This principle guaranteed that participation was voluntary and that participants maintained control over their involvement.

3.7.3 Confidentiality and anonymity

This principle requires researchers to uphold the confidentiality of any information provided by participants, particularly sensitive or private details (Pietila, Nurmi, Halkoaho and Kyngas, 2020). All personal information provided by participants was treated with the highest level of confidentiality. Participant identities were anonymised during data collection and analysis to prevent the disclosure of identifying details. Unique identification codes were used instead of personal identifiers, and data were securely stored, with access restricted to the researcher and authorised personnel only.

3.7.4 Avoiding deceptive practices

This principle emphasises that participants should be fully aware of their involvement in a study and the requirements placed upon them (Ross et al., 2018). Participants should also be made aware of the study's objectives, the methods of data collection, potential outcomes, and any associated demands, discomforts, inconveniences, or risks (Pietila et al., 2020). The questionnaire was designed to avoid deception, ensuring honesty and transparency throughout the process. Participants were clearly informed about the study's purpose and the reasons for their selection. The researcher and the enumerators ensured that all questions remained within the study's scope and did not request information beyond this. Participants were also informed of the importance of signing informed consent, with the researcher and enumerators explaining the necessity of this step when obtaining consent.

3.8 Validity and reliability

Validity ensures that the research tool measures what it was intended to measure (Thatcher, 2010). According to Creswell (2014), reliability refers to the processes an investigator uses to ensure the accuracy and consistency of the research findings.

3.8.1 Validity

The validity of this study was ensured through multiple layers of review and expert input. Face validity of the survey instrument was established by the study supervisors, who critically examined the questionnaire to ensure it accurately captured the study's key variables, such as socio-economic factors, support services received, use of agricultural innovations, and crop yields. Furthermore, feedback was obtained from a group of postgraduate students, including master's and PhD candidates, who reviewed the clarity, relevance, and appropriateness of the questions.

Further validation was achieved by submitting the questionnaire to the research ethics committee within the university's School of Agricultural Sciences. The committee reviewed the instrument for ethical compliance, ensuring that the questions were clear, culturally appropriate, and sensitive to the context of SCFs in Mbombela Local Municipality. These steps collectively enhanced the content and construct validity of the survey, ensuring it accurately measured the intended concepts. The use of PSM improved internal validity by mitigating selection bias, ensuring that comparisons between users and non-users of one or more agricultural innovations were robust and reliable. External validity was addressed by ensuring that the sample was representative of the broader population of SCFs in the area, thereby allowing for the generalisability of the findings to similar contexts.

3.8.2 Reliability

To ensure the reliability of the study, the questionnaire as the primary data collection instrument, was pre-tested with a small group of SCFs to identify potential ambiguities and inconsistencies in the questions. Adjustments were made based on the feedback received to improve clarity and consistency. The final questionnaire was administered by trained enumerators with assistance from the researcher, ensuring uniformity in data collection procedures. Statistical analyses, including binary logistic regression and PSM, were conducted using robust software (SPSS and STATA), minimising computational errors. Additionally, the use of standardised thresholds for significance (1%, 5%, and 10%) ensured consistent interpretation of results across all analyses. To further enhance reliability, data entry was cross-checked for accuracy, and any discrepancies were resolved through verification with original survey responses.

3.9 Chapter summary

This chapter presented and discussed the methods used to collect and analyse data. The study was conducted in 16 villages within Mbombela Local Municipality, where participants' questionnaires were administered. Both SCFs using one or more yield-increasing innovations and those not using them were interviewed. A total of 308 participants were sampled. A systematic sampling procedure was applied to select a sample from a list of SCFs obtained from DARDLEA. Data collection was carried out through face-to-face interviews, and the advantages of this method were highlighted in this chapter. For data analysis, descriptive statistics, PSM, and binary logistic regression model were employed, with their advantages also highlighted. The results of the research are presented in the next chapter.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter presents the results of the study's analysis, structured into four sections. The first section discusses the socio-economic characteristics of the smallholder crop farmers (SCFs) involved in the study. The second section examines the agricultural support received by SCFs in the study area. The third section assesses the impact of agricultural innovations on SCFs' productivity. Lastly, the fourth section explores the factors constraining the use of agricultural innovations by SCFs. Descriptive statistics of the variables, along with the estimation results from the Propensity Score Matching (PSM) and binary logistic regression analyses, are also presented in this chapter.

4.2 Socio-economic characteristics of smallholder crop farmers in the study area

Socio-economic characterisation of households is essential for understanding the factors that influence or constrain the sustainable productivity of smallholder farmers at the household level (Myeni, Moeletsi, Thavhana, Randela, and Mokoena, 2019: Mathinya, Franke, Van De Ven, and Giller, 2022). In this study, the socio-economic characteristics of the SCFs were analysed to gain contextual insights into SCFs' productivity and their use of agricultural innovations.

4.1.1 Gender of the participants

Figure 4 presents the gender distribution of participants, revealing that 59.4% of SCFs were female, while 40.6% were male. This suggests that women play a more significant role in smallholder crop production in the study area compared to men. These findings concur with previous studies indicating that women constitute the predominant workforce in crop production (Abdelali-Martini, 2011; Thamaga-Chitja, 2012; Ngema, Sibanda, and Musemwa, 2018; Mukaila, Falola, Akanbi, Egwue, Obetta, and Onah, 2022). Despite historical gender inequalities in agriculture, women are increasingly challenging traditional norms and reshaping the sector (Geotina-Garcia, 2021). Their involvement is crucial for household food security and agricultural productivity. However, structural barriers such as limited access to land, inputs, and decision-making roles persist, particularly in male-headed households. Addressing these inequalities and promoting gender inclusivity in agriculture is essential for achieving the Sustainable Development Goals (SDGs) (Warren, 2020).

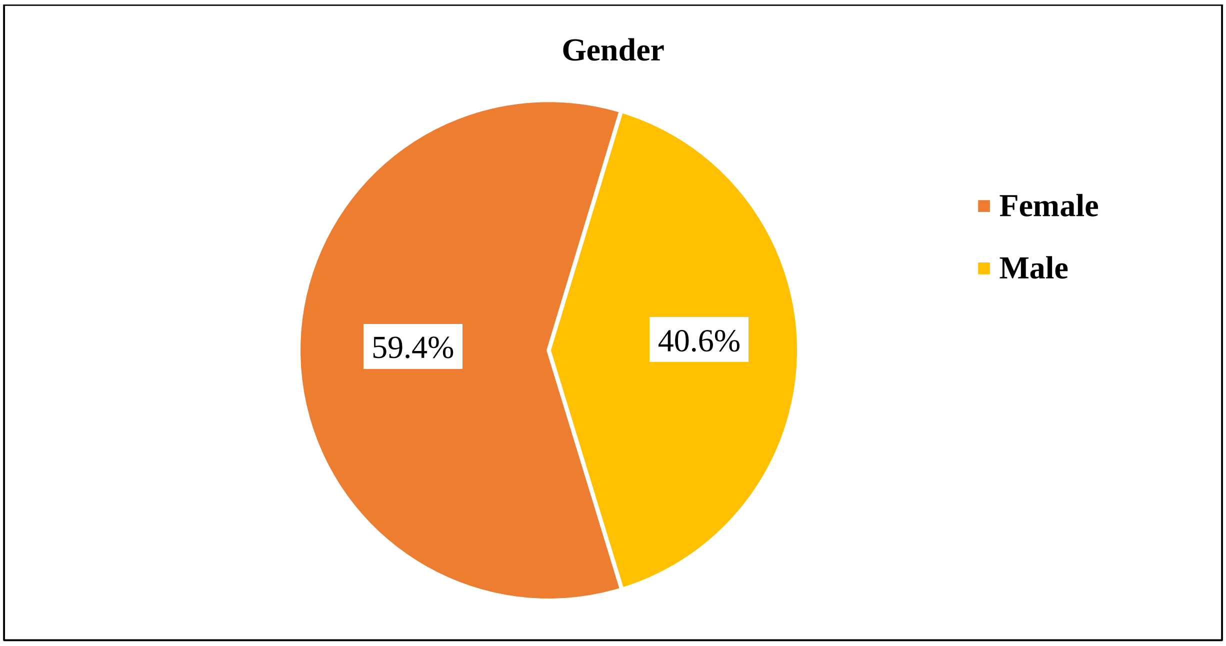


Figure 4: Gender of participants

Source: Survey data (2024)

4.1.2 Age groups of the participants

The age group distribution of the participants is shown in Figure 5. The results revealed that the largest proportion of farmers (46.4%) were 60 years and above, while 30.2% were between 35 and 59 years. Only 23.4% of the farmers fell into the youth category (18—34 years). These findings suggest that smallholder crop farming in the study area is predominantly carried out by older individuals compared to the youth. This observation coincides with Dzanku, Jirström, and Marstorp (2015), who found that older farmers tend to dominate smallholder farming due to younger generations migrating to urban areas in search of non-farming opportunities. Similarly, Geza, Ngidi, Ojo, Adetoro, Slotow, and Mabhaudhi (2021) reported that youth often have pessimistic views about agriculture's potential to improve their living standards, which contributes to their limited involvement in farming. This trend presents a critical challenge for the agricultural sector. Yeboah and Jayne (2020) highlighted that the disinterest of African youth in farming has led to a large-scale exit from agriculture, resulting in an aging farming population that may struggle to meet future food demands. Moreover, the limited interest in farming among youth is often attributed to their migration from rural to urban areas in search of better opportunities and lifestyles (Food and Agriculture Organisation, 2014).

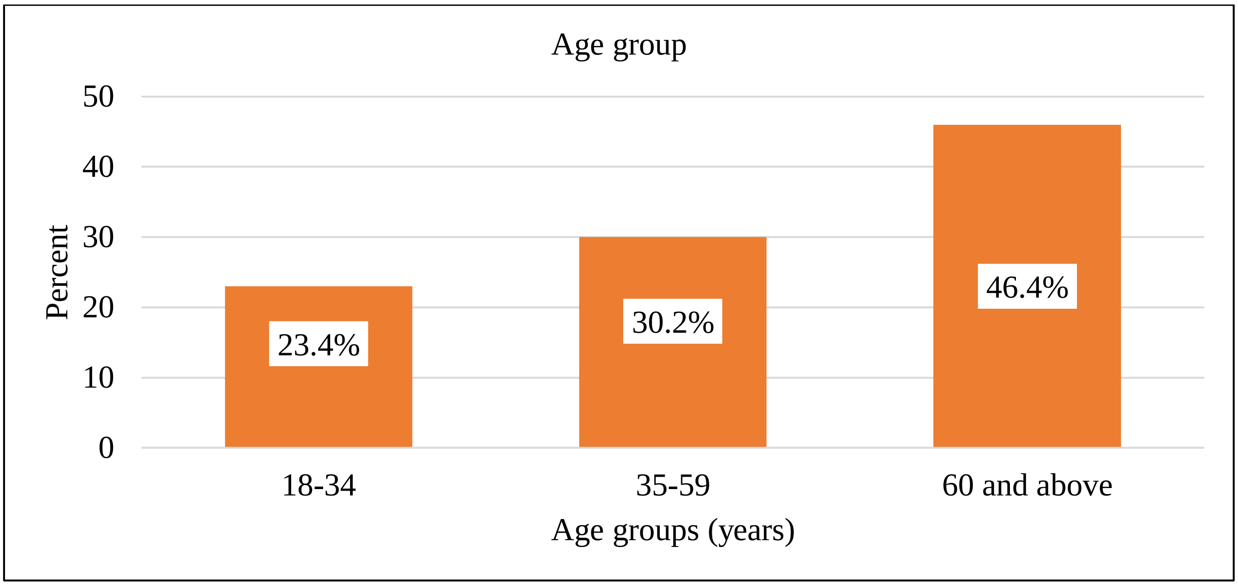


Figure 5: Age groups of participants

Source: Survey data (2024)

4.1.3 Marital status of participants

The results of the marital status of the participants are shown in Figure 6. The results revealed that 43.8% of the farmers were married, 34.7% were single, 15.6% were widowed, and only 5.8% were divorced. These results are consistent with those of Sithole and Olorunfemi (2024), who reported that the majority (75%) of SCFs were married. Marital status plays a significant role in the participation of SCFs in agricultural activities. According to Cebiso (2022), married farmers are often motivated to engage in farming to fulfill their obligation to ensure food availability as a basic need for their families. Supporting this, Hussain, Anwar, and Huang (2016) observed that married farmers tend to experience improved farm productivity and sustainability, as family members, including women and children, often contribute to farm labour, thereby reducing production costs. Similarly, Maziya (2013) highlighted that marital status can affect access to productive resources in African contexts. For instance, in some traditional systems, single women may encounter challenges in owning land, as landownership is often linked to their marital status.

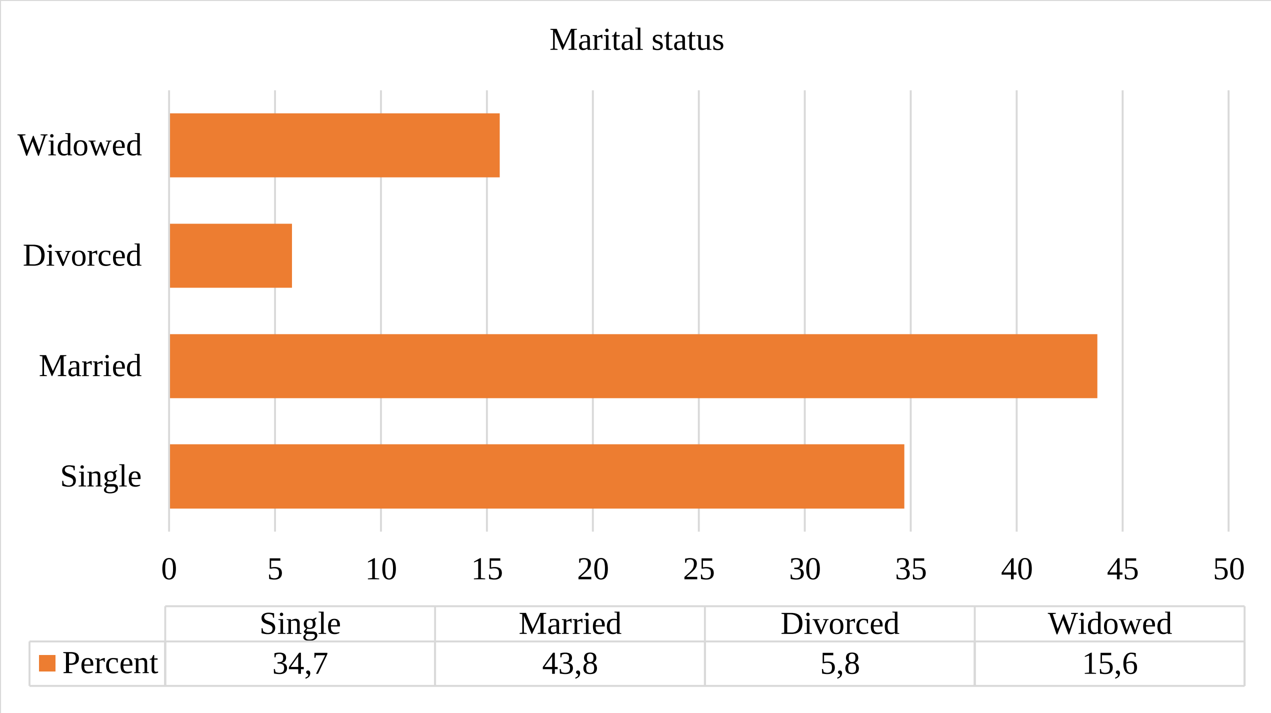


Figure 6: Marital status of participants

Source: Survey data (2024)

4.1.4 Level of education of participants

The level of education of the participants is shown in Table 1, which indicates that 26.3% of the farmers had no formal education, while 23.7% had secondary education. Those with primary school education were18.8%, while 16.9% had matriculated, and 6.5% had completed ABET. The other 3.6% of the farmers had higher certificates, and 2.6% held diplomas. Only 1.6% of the farmers had a degree or higher qualification. These findings are consistent with Leshoro and Leshoro (2013), who found that most South African smallholder farmers in rural areas have limited or no formal education. According to Mariano, Villano, and Fleming (2012) and Maziya (2013), formal education provides several benefits to farmers and their agricultural businesses. The level of education among farmers is crucial, as it determines the farmers' ability to read, write, and understand the benefits of agricultural innovations, many of which require a certain level of formal education and training.

Table 1: Level of education of participants

Variables	Frequency	Percent
No formal education	81	26.3
Primary	58	18.8
Secondary	73	23.7
Matriculated	52	16.9
ABET	20	6.5
Higher certificate	11	3.6
Diploma	8	2.6
Degree and above	5	1.6
Total	**308**	**100**

Source: Survey data (2024)

4.1.5 Household size of participants

Figure 7 shows the household size of the participants. The results revealed that 45.8% of farmers had a household size of 4—6 members, while 34.4% had a household size of 7 members or more. Only 19.8% of the farmers had a household size of 1—3 members. These results concur with Botiabane, Zhou, Oluwatayo, Oyedokun, and Oyelana (2017), who found that households with 5—7 members constituted the largest group among the farmers surveyed. Household size is often an important factor in smallholder farming, as it can enhance productivity through the availability of labour (Shemfe, 2019). Furthermore, Uhunamure, Nethengwe, and Tinarwo (2019) noted that larger families frequently provide more assistance for routine maintenance and the implementation of agricultural technology.

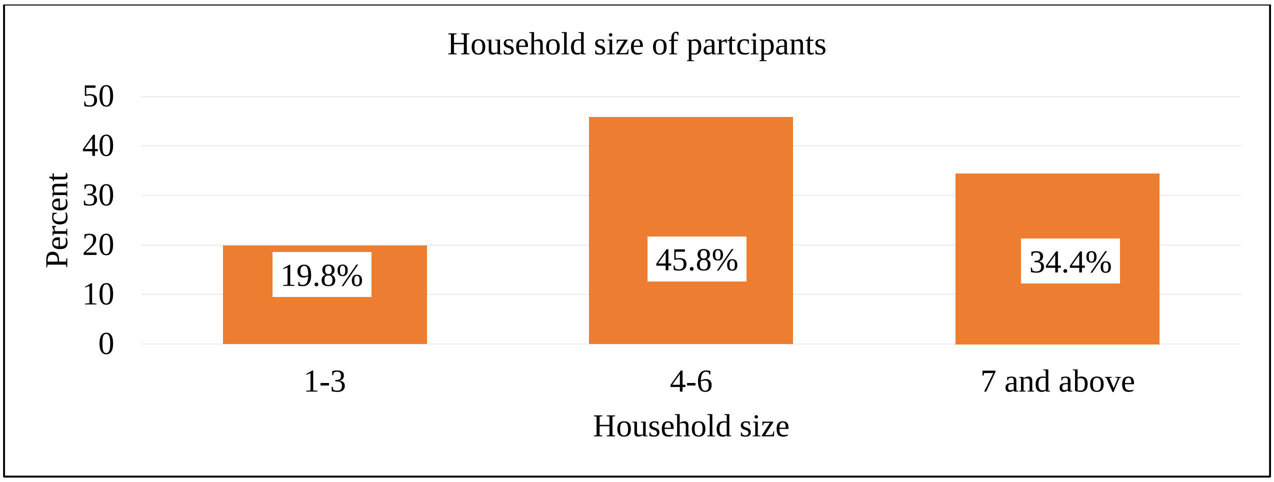


Figure 7: Household size of participants

Source: Survey data (2024)

4.1.7 Main source of off-farm income of participants

The results for the main sources of off-farm income of the participants are outlined in Figure 8. The findings show that 31.5% of farmers primarily relied on old age pension, while 30.2% depended on child support grant as their main source of off-farm income. Social relief grants supported 19.8% of farmers, while 15.9% reported having no off-farm income. Only 1.9% and 0.6% of the farmers relied on salaries and remittances, respectively. These results suggest that while farming remains the primary occupation for the rural households, most farmers in the area pursue diverse income opportunities to stabilise their livelihoods. This observation aligns with Pienaar and Traub (2015), who reported that a significant proportion of farmers depend on social grants, such as old age pensions and child support grants, as their main sources of off-farm income. Off-farm incomes provide a critical financial safety net (Jelínek, Foltyn, Spicka, and Ratinger, 2010; Zhao and Barry, 2014).

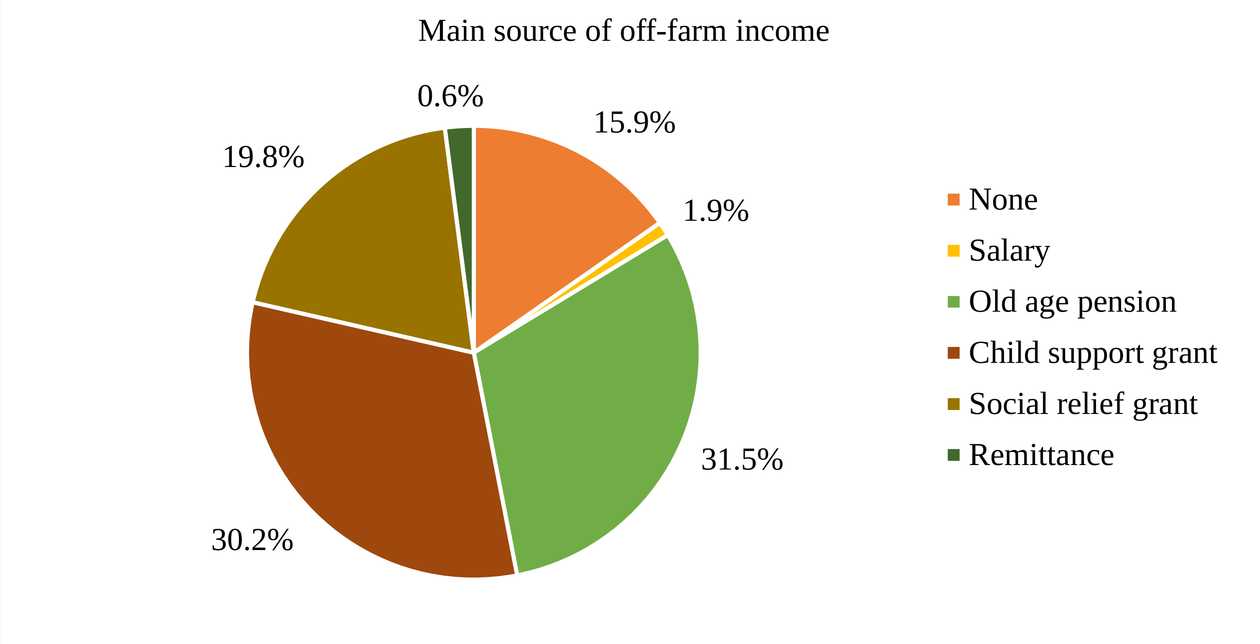


Figure 8: Main source of off-farm income of participants

Source: Survey data (2024)

4.1.8 Main source of on-farm income of participants

The results for the main source of on-farm income for the farmers are presented in Figure 9. The findings show that the majority (89.3%) of the farmers relied on the sales of vegetable crops as their primary source of on-farm income, while the remaining 10.7% indicated that they relied on the sale of agronomic crops. These results show that most farmers primarily rely on the sale of vegetable crops to sustain their livelihoods. These findings coincide with previous studies, which have shown that vegetables cultivation is crucial to rural farmers' income and plays a significant role in their households' economic status (Effiong, Aboh, and Aya, 2021; Mukaila et al, 2022). This contribution helps combat poverty, malnutrition, and food insecurity (Babatunde and Qaim, 2010). Vegetable production offers a promising economic opportunity for reducing rural poverty and unemployment in developing countries and is a key component of farm diversification strategies (Schreinemachers, Simmons, and Wopereis, 2018).

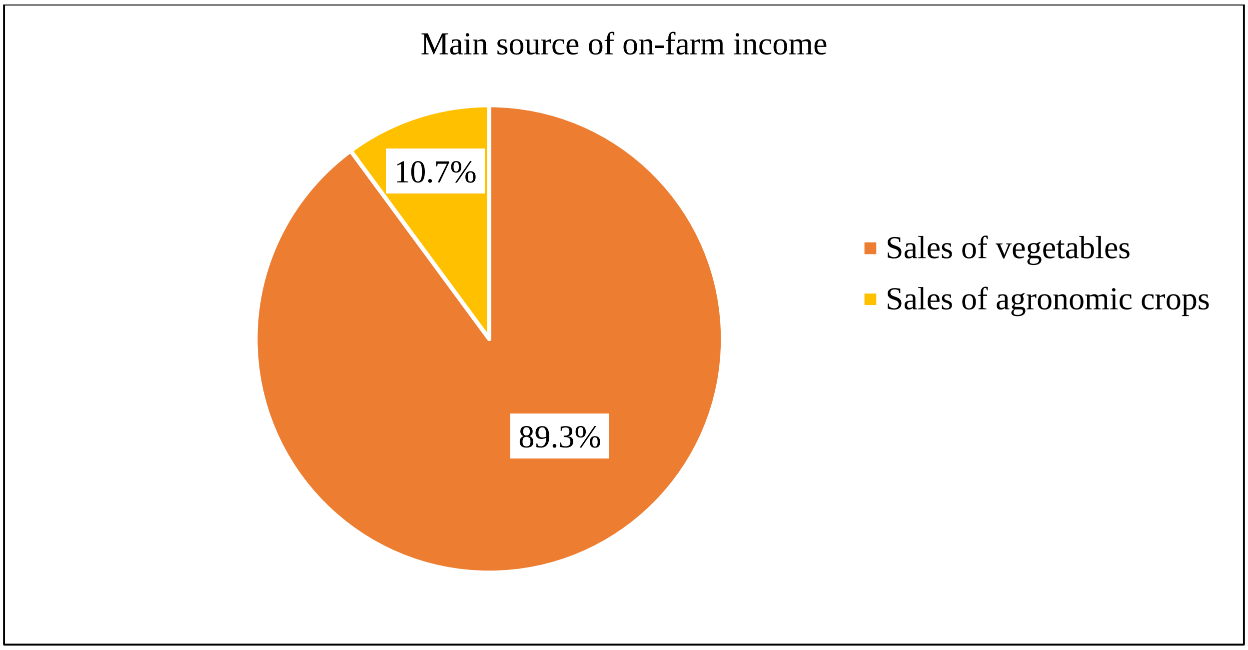


Figure 9: Main source of on-farm income of participants

Source: Survey data (2024)

4.1.9 Years of farming experience of participants

The years of farming experience of the participants are shown in Table 2. The results indicate that about 35.1% of the participants had 6—10 years of farming experience, while 30.5% had 11—20 years of farming experience. Furthermore, 25.3% of farmers had 5 years or less of farming experience, and only 9.1% of the farmers had 21 years or more of farming experience. These results align with Effiong et al (2021), who reported that the majority of SCFs had 6—10 years of farming experience. According to Mektel and Mohammed (2021), farming experience is an important factor in agricultural research, as it shapes farmers' behaviour and decision-making processes. Farmers with more farming experience are better equipped to make informed decisions, as they have greater knowledge of reliable information sources (Agholor, 2016). Moreover, Mwangi and Kariuki (2015) emphasised that experienced farmers have improved skills and are able to critically evaluate opportunities.

Table 2: Years of farming experience

Variables	Frequency	Percent
≤ 5	78	25.3
6-10	108	35.1
11-20	94	30.5
≥ 21	28	9.1
Total	**308**	**100.0**

Source: Survey data (2024)

4.1.10 Farm size

Table 3 summarises the farm sizes of the participants. The results show that 79.9% of farmers had a farm size of 5 hectares or less, while 18.8% had a farm size between 6 and 10 hectares. Only 1.3% of the farmers had a farm size between 11 and 20 hectares. This indicates that SCFs in the study area generally operate on small farm sizes. These findings agree with previous studies that reported most South African smallholder farmers have small farm sizes of less than 2 hectares, which corresponds to a limited production scale (Mwangi and Kariuki, 2015; Mutero, Munapo, and Seaketso, 2016; Von Loeper, Musango, Brent, and Drimie, 2016; Obi and Ayodeji, 2020). In addition, Phiri, Chipeta, and Chawinga (2019) stated that farm production and income are strongly impacted by farm size. Moreover, Myeni, Moeletsi, Thavhana, Randela, and Mokoena (2019) observed that larger farms are usually more profit-driven compared to smaller ones, as farmers with larger operations invest in their farms to achieve sustainable agricultural productivity.

Table 3: Farm size of the participants

Variables	Frequency	Percent
≤ 5	246	79.9
6-10	58	18.8
11-20	4	1.3
Total	308	100.0

Source: Survey data (2024)

4.1.11 Land ownership

Figure 10 illustrates the types of land ownership among SCFs in the study area. The results indicate that the majority (70.8%) of surveyed farmers owned the land they operated on, 17.2% were allocated land by the tribal authority (chief), 7.8% practiced farming on land provided through land reform (government department), and only 4.5% rented the land they used for farming. These findings differ from those of Thamaga-Chitja and Morojele (2014), who reported that most of the land available to rural communities for farming in South Africa is communally owned and managed by Traditional Authorities. The differences in findings may reflect the age group of the surveyed farmers, as older household heads tend to own land (Akinyemi and Mushunje, 2019).

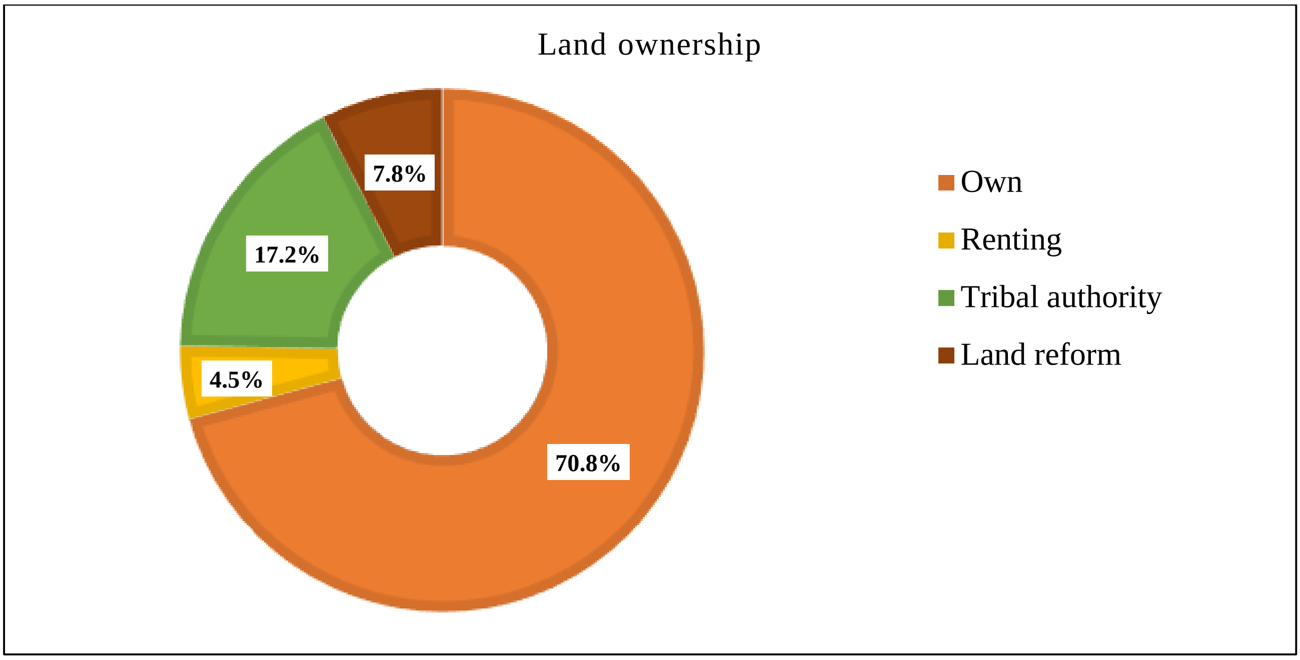


Figure 10: Land ownership of the participants

Source: Survey data (2024)

4.1.12 Main reason of farming

Figure 11 illustrates the primary reason for farming in the study area. The results show that the majority (91.6%) of farmers engage in farming for both household consumption and income generation, while 8.4% farm exclusively for income generation. These results suggest that most SCFs in the study area align with the smallholder farmer category Type 2, as defined by the

National Agricultural Extension Policy of South Africa (2016). These findings are consistent with Rapsomanikis (2015), who reported that most SCFs produce food primarily for consumption, with only a small portion being market-oriented. Ayivor (2017) and Ragie, Olivier, Hunter, Erasmus, Vogel, Collinson, and Twine (2020) support these findings, noting that SCFs often cultivate a variety of crops, including maize, peanuts, pumpkins, bambara beans, mangoes, cowpea, and spinach. While some SCFs sell their produce for cash, the income generated is typically modest.

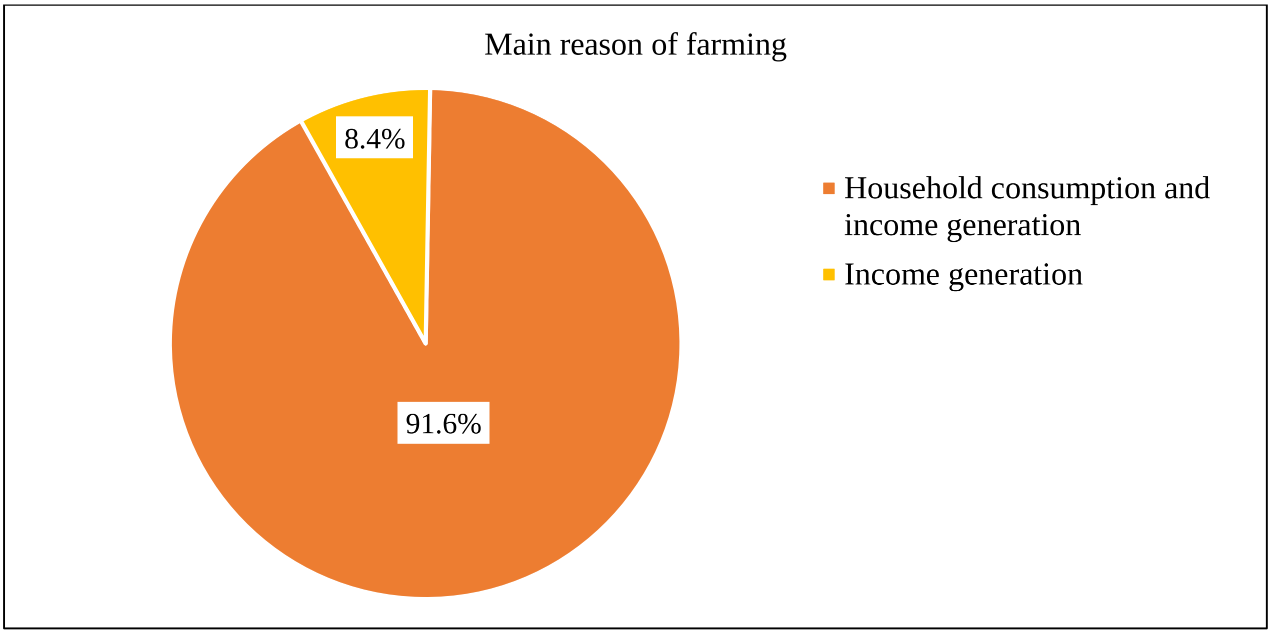


Figure 11: Main reason of farming according to the participants

Source: Survey data (2024)

4.1.13 Cooperative membership

The results in Figure 12 show that 70.2% of farmers were not members of cooperatives, while 29.8% of farmers were members. These findings suggest that the majority of SCFs in the study area do not benefit from the advantages typically associated with membership in agricultural cooperatives. This is consistent with previous studies that found most farmers in rural areas do not participate in agricultural cooperatives (Ramoroka, 2012; Msimango and Oladele, 2013; Mbanza and Thamaga-Chitja, 2014). Farmers' reluctance to join cooperatives may be attributed to the perception that these organisations fail to provide access to essential resources such as farm machinery, loans, credit, and value-added support (Mbanza, 2013; Tefera, Bijman, and Slingerland, 2017; Hun, Isoda, Amekawa, and Ito, 2017). Furthermore, agricultural cooperatives have often been ineffective in assisting members with transporting their produce to markets (Mzuyanda, 2014). The low rate of cooperative membership has been linked to food shortages and reduced household income, as measured by household welfare in terms of consumption expenditure per adult (Ahmed and Mesfin, 2017).

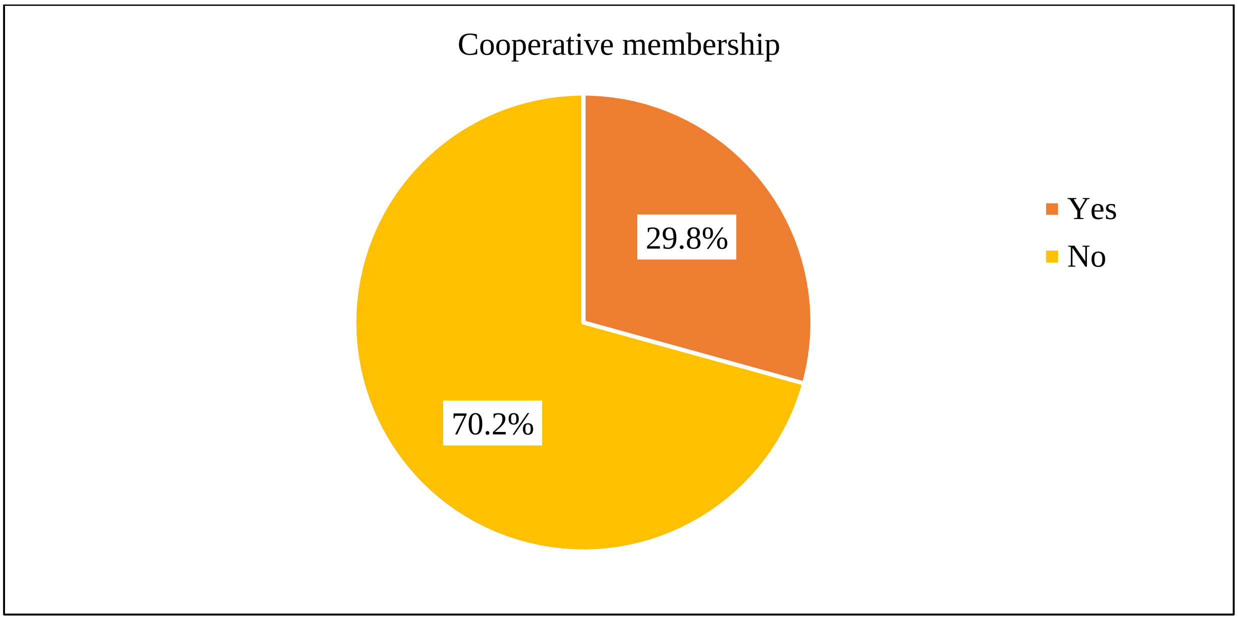


Figure 12: Cooperative membership of participants

Source: Survey data (2024)

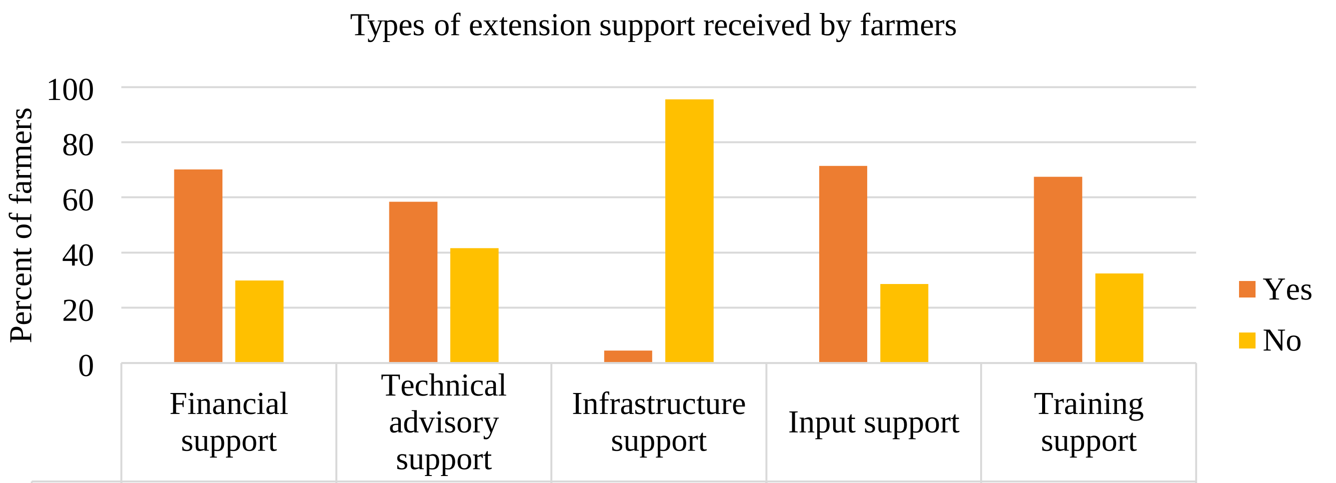
4.2 Agricultural support received by smallholder crop farmers in the study area.

4.2.1 Types of extension support received by smallholder crop farmers

The results in Figure 13 show that the majority (71.4%) of the farmers reported receiving input support, followed by financial support (70.1%), training support (67.5%), and technical advisory support (58.4%). However, 29.9% of the farmers did not receive financial support, 41.6% lacked technical advisory support, 28.6% did not receive input support, and 32.5% did not training support. Infrastructure support was the most lacking, with only 4.5% of farmers reporting access to it, leaving a notable 95.5% without any infrastructure support. This highlight a significant gap, suggesting that while financial, technical advisory, input, and training supports are relatively accessible, infrastructure support remains severely inadequate.

The levels of financial, technical advisory, and training support observed in this study align with findings from Sikwela (2013) and Mbatha (2024), who noted that rural agricultural extension services in developing countries typically focus on providing training and technical support to enhance farmers' agricultural knowledge and skills. Similarly, Nhlengethwa, Thangata, Muthini, Djido, Njiwa, and Nwafor (2023) reported high rates of input support among SCFs, often due to government subsidies on essential agricultural inputs such as seeds and fertilisers.

Moreover, the findings concur with those of Monitor (2012), who highlighted the commonality of inadequate and unreliable infrastructure services in most rural communities across Africa. Monitor (2012) argued that the absent of infrastructure support, such as transport, communication services, energy, water and irrigational facilities, and extension services, can seriously limit agricultural productivity. The low levels of infrastructure support may stem from limited funding, a lack of clear strategy, insufficient commitment, and minimal participation from national, provincial, and local initiatives (Van Heerden, Burger, Coetsee, Mahlangu, and Naudé, 2015).



	Financial support	Technical advisory support	Infrastructure support	Input support	Training support
Yes	70,1	58,4	4,5	71,4	67,5
No	29,9	41,6	95,5	28,6	32,5

Figure 13: Types of extension support received by farmers

Source: Survey data (2024)

4.2.2 Main providers of extension support types received by farmers

Figure 14 illustrates the primary institutions providing various types of extension support to SCFs in Mbombela Local Municipality. The main providers identified in the study area include the Department of Agriculture, Rural Development, Land and Environmental Affairs (DARDLEA), the Agricultural Research Council (ARC), Timbali Technology Incubator, Standard Bank, the Agricultural Sector Education Training Authority (AgriSETA), and the Small Enterprise Development Agency (SEDA).

a) Financial support

The results show that in the study area, DARDLEA and Standard Bank were the primary providers of financial support for farmers. A substantial 94.4% of farmers reported receiving financial services from DARDLEA, while 5.6% received financial services from Standard Bank. These findings indicate that the government plays a dominant role in providing financial support to rural farmers, in contrast to commercial banks. These results concur with the findings of Yang and Ou (2022), who emphasised the essential role of governments as the main sources of financial assistance for smallholder farmers, particularly in rural communities where access to private sector financing is limited. Similarly, Advisors ISF and MasterCard Foundation Rural and Agricultural Finance Learning Lab (2019) noted that commercial banks provide only about 3% of the financial services available to smallholders. This limited involvement of formal financial institutions in agricultural finance may be attributed to the lack of suitable delivery mechanisms that facilitate access to financing for smallholder farmers in South Africa (Qwabe, 2014). However, contrary evidence from Du Randt and Makina (2012) suggests that commercial banks are increasingly playing an essential role in agricultural financing. This disagreement in findings may reflect regional or temporal variations in the agricultural financing landscape for SCFs.

b) Technical advisory support

The results show that most (96.7%) of technical advisory support is provided by DARDLEA. Only 3.3% of the farmers reported receiving technical advisory support from Timbali Technology Incubator. These findings suggest that while government departments are the primary providers of technical advisory assistance to farmers, specialised agricultural organisations in the private sector also play a role, although a limited one. These results are supported by Raidimi and Kabiti (2019) and Baiyegunhi, Majokweni, and Ferrer (2019), who reported that in most developing countries, government departments are the main source of agricultural extension services available to SCFs, forming part of general public administration. FAO (2022) also corroborates these findings, noting that the provision of advisory services involves a wide range of institutions, including private sectors, NGOs, Producer Organisations (POs), and cooperatives. FAO (2022) further argues that these institutions aim to help farmers access information on technologies, markets, inputs, and finance while also upgrading their farming and managerial skills.

c) Infrastructure support

In the study area, infrastructure support is primarily provided by DARDLEA, serving only 4.5% of the farmers. These results indicate that the government is the sole provider of infrastructure support for SCFs, with minimal contribution from the private sector in infrastructure development. These results coincide with Crossley, Chamen, and Kienzle (2009) and FAO (2016) who reported that government agencies are traditionally the main providers of infrastructure in rural areas, as infrastructure is typically considered a public asset available for use by all. The low percentage of farmers receiving infrastructure support underscores the persistent challenges smallholder farmers face in accessing infrastructure services, which are critical for enhancing agricultural productivity.

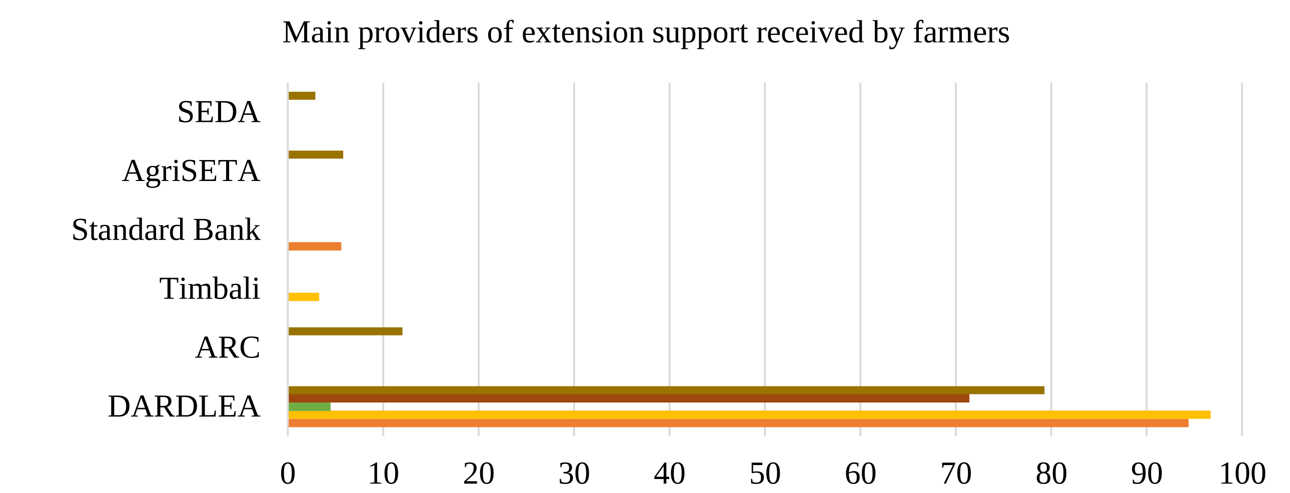
Cloete (2013) stated that poor infrastructure continues to hinder agricultural production in underdeveloped areas. Similarly, Pfunzo (2017) reported that inadequate infrastructure and a lack of investment in agricultural infrastructure have constrained agricultural growth. The willingness of farmers to use modern technology to improve agricultural productivity significantly depends on the quality of the infrastructure provided by government. In contrast, Cargani and Kherallah (2013) and Camagni, Kherallah, and Baumgartner (2016) argue that while government plays a critical role in providing foundational rural infrastructure, private sector entities also contribute to infrastructure development, especially when partnerships and collaborations are fostered.

d) Input support

The results revealed that the majority (71.4%) of the farmers received input support mainly from DARDLEA. This finding implies DARDLEA's dominant role in ensuring SCFs have access to essential production inputs on the study area. These results corroborate with Nhlengethwa et al (2023), who found that African governments are often the primary source of input subsidy programmes aimed at supporting SCFs. According to Chibwana and Fisher (2011) and Takeshima and Lee (2012), agricultural input subsidies are among the most common policy instruments employed in the agricultural sector to lower the costs that farmers pay for inputs such as fertiliser, seed, chemical pesticides, and equipment below market prices. However, Blekking, Gatti, Waldman, Evans, and Baylis (2021) noted that in Zambia, SCFs are required to join a cooperative to qualify for inputs such as seed and fertiliser through the national Farmers Input Support Program (FISP). This points to regional differences in private-sector involvement and the implementation of input support programmes.

e) Training support

Based on the results in Figure 14, the majority (79.3%) of farmers received training support from DARDLEA, followed by ARC (12%), AgriSETA (5.8%), and SEDA (2.9%). Similar findings were reported by Sikwela (2013), who noted that smallholder farmers receive training support from various organisations, including government bodies, commodity organisations, private sector, mentors from different organisations and NGOs. Sikwela (2013) further emphasised that most farmers under farmer support programmes received their training primarily from the government. Education, including training and extension services, remains a fundamental need for human development in rural areas and for the expansion and modernisation of rural economies (Wonde, Tsehay, and Lemma, 2022).



	DARDLEA	ARC	Timbali	Standard Bank	AgriSETA	SEDA
Training	79,3	12			5,8	2,9
Input	71,4					
Infrastructure	4,5					
Technical advisory	96,7		3,3			
Financial	94,4			5,6		

Figure 14: Main providers of extension support

Source: Survey data (2024)

4.2.3 Types of extension support services received by smallholder crop farmers

Tables 4 to 8 present the different types of financial, technical advisory, infrastructure, input, and training support services provided to SCFs in Mbombela Local Municipality. These tables also explore the implications of these services on agricultural development, while linking them to exiting challenges and opportunities within smallholder crop farming systems.

(a) Types of financial support services received by farmers

Table 4 presents the types of financial support services received by farmers. The majority (66.2%) of the farmers received input vouchers, while 29.9% of the farmers reported not receiving nay financial support and only 3.9% had access to short-term loans. Notably, none of the farmers (0.0%) reported receiving support in the form of microcredit loans, land redistribution grants, or crop insurance. These findings indicate the challenges commonly observed in rural smallholder farming systems, where financial support mechanisms often prioritise input provision but neglect critical aspects such as credit and crop insurance. This limitation restricts farmers' ability to invest in innovative practices, leaving them vulnerable to shocks and continuing cycles of poverty and low productivity. The results are consistent with studies by Valli, Daidone, and Sitko (2022) and the FAO (2023), which reported that in response to shocks and crises, SCFs unable to afford productive inputs are often supported with input vouchers through cash and voucher assistance programmes. These vouchers can be redeemed for goods such as seeds, fertilisers, and tools.

Similarly, Wong, Wei, Kahsay, Gebreegziabher, Gardebroek, Osgood, and Diro (2020) suggested that poor farmers in developing countries face significant credit and risk constraints, which limit their production potential and adversely affect their livelihoods. In response, many governments have established safety nets and input subsidy programs to improve farming intensity and enhance food and income security. Adjognon, Liverpool-Tasie, and Reardon (2017) also found that the use of formal bank credit for financing input purchases is extremely low among SCFs. They argued that even when farmers take loans, only a small percentage is utilised for farming purposes, with the majority being diverted to fund non-farm business start-up costs or household consumption. This emphasises the persistent challenge of ensuring financial resources are directed toward productive farming activities.

Table 4: Types of financial support services provided to farmers

Types of services provided	**Frequency**	**Percent**
None	92	29.9
Microcredit loan	0	0.0
Short-term loan	12	3.9
Input vouchers	204	66.2
Land redistribution grant	0	0.0
Crop insurance	0	0.0
Total	**308**	**100**

Source: Survey data (2024)

(b) Types of technical advisory support services provided to farmers.

The results in Table 5 present the types of technical advisory support services provided to the sampled SCFs in the study area. Among the farmers, 40.5% received advice on best crop management practices, making it the most common service. Furthermore, 6.7% were assisted with soil testing, 10% received support with funding applications, 15% were provided with recommendations on reducing farm risks, and 27.8% were linked to relevant service providers. These results imply that the predominance of advice on best crop management practices, combined with the relatively low percentages for other services, particularly soil testing assistance, farming risk reduction, and funding application assistance, indicates that technical advisory services often focus on immediate productivity improvements. However, they tend to fall short in addressing comprehensive, long-term challenges such as soil health management, farming risk mitigation, and financial accessibility. These results agree with Davis and Heemskerk (2012), who observed that agricultural advisory services in developing countries typically prioritise short-term productivity and efficiency, often overlooking broader systemic challenges like environmental sustainability and resilience. Similarly, Briggs and Eclair-Heath (2017) and McNeill, Bradley, Muro, Merriman, Pederson, Tugran, and Lukacova (2018) highlighted that advisory services frequently fail to address critical structural issues, such as soil health and risk management.

Table 5: Types of technical advisory support services provided to farmers.

Types of services provided	Frequency	Percent
None	73	23.7
Advice on best crop management practices	128	41.6
Assistance with soil testing	12	3.9
Assistance with funding application	18	5.8
Recommendations on reducing farming risks	27	8.8
Linkages on relevant service providers	50	16.2
Total	**308**	**100**

Source: Survey data (2024)

(c) Types of infrastructure support services received by farmers

Table 6 shows the types of infrastructure support services received by farmers. Among the infrastructure support provided, 35.5% of farmers received irrigation systems, 14.3% were provided with pack houses, and 50% received fencing. Notably, greenhouse tunnels and road maintenance were not provided to any farmers. These results suggest that infrastructure support in the study areas is limited and unevenly distributed among SCFs. While irrigation systems and fencing were relatively more common, other essential infrastructure services, such as pack houses and road maintenance, which are important for post-harvest handling and market access, were entirely not provided. These findings concur with Magingxa and Kamara (2003), who noted that poor infrastructure in rural areas remains a persistent issue that has not received enough attention. Similarly, Chakwizira, Nhemachena, and Mashiri (2010) identified the poor state of the basic rural infrastructures, including transport and irrigation infrastructure, as one of the key constraints to sustainable agricultural and rural development.

Table 6: Types of infrastructure support services provided to farmers

Types of services provided	Frequency	Percent
None	294	95.5
Irrigation systems	5	1.6
A pack house	2	0.6
Greenhouse tunnel	0	0.0
Fencing	7	2.3
Road maintenance	0	0.0
Total	**308**	**100**

Source: Survey data (2024)

(d) Types of input support services received by farmers

Table 7 presents the types of input support services received by SCFs in the study area. Improved seeds were the most commonly received input support service, as indicated by 36.8% of farmers, followed by chemical fertilisers, which were provided to 32.3% of the farmers. Moreover, 15.0% of farmers reported receiving chemical pesticides, while 15.9% received tractor services. Notably, hybrid vegetable seedlings were not provided to any of the sampled farmers. The results show that farmers in the study area are mostly supported with improved seeds and chemical fertilisers, which are essential for enhancing crop productivity. However, the low provision of chemical pesticides and tractors services highlights significant gaps in pest management and mechanisation support for smallholder crop farmers. These results coincide with Ricome, Barreiro-Hurle, and Fall (2024), who noted that smallholder farmers often receive packages of essential agricultural inputs, such as seeds, fertilisers, chemical pesticides, machinery, at lesser prices through the input subsidy programs (ISPs). Similarly, Hemming, Chirwa, Dorward, Ruffhead, Hill, Osborn, Langer, Harman, Asaoka, Coffey, and Phillips (2018) emphasised that agricultural input subsidy interventions aim to make inputs, most commonly fertilisers and seeds, available to SCFs at below market costs. It is well-known that a majority of countries implement agricultural input subsidies as a tool to boost agricultural productivity and output (Hemming et al., 2018).

Table 7: Types of input support services provided to farmers

Types of services	**Frequency**	**Percent**
None	81	26.3
Improved seeds	88	28.6
Hybrid vegetable seedlings	0	0.0
Chemical fertilisers	71	23.1
Chemical pesticides	33	10.7
Tractor	35	11.4
Total	**308**	**100**

Source: Survey data (2024)

(e) Types of training support services received by farmers

Table 8 outlines the types of training support services received by farmers in the study area. The results revealed that crop protection training was the most common type of training support service, provided to 43.3% of the farmers. This was followed by market access training, which 30.8% of the farmers received. About 12.0% of the farmers received training in financial planning, while 8.2% were trained in farm record-keeping and drought mitigation strategies. The least common type of training support was on the sustainable use of resources, received by only 3.8% of the farmers. These results indicate that farmers in the study area receive gricultural training, with a primary focus on crop protection and market access. This aligns with Mbatha (2024), who found that extension services often concentrate on providing rural farmers with training and support in protecting crops from insects and diseases, which can reduce productivity. Similarly, Fanadzo, Chiduza, Mnkeni, Van der Stoep, and Steven (2010) emphasised that farmers could greatly benefit from training programmes, particularly in areas such as crop and irrigation management.

Table 8: Types of training support services provided to farmers

Types of services provided	Frequency	Percent
None	64	20.8
Market access	100	32.5
Sustainable use of resources	8	2.6
Farm record keeping	17	5.5
Financial planning	27	8.8
Crop protection	90	29.2
Drought mitigation strategies	17	5.5
Total	**308**	**100**

Source: Survey data (2024)

4.3 The impact of agricultural innovations on productivity of smallholder crop farmers in the study area.

This study assessed the impact of agricultural innovations, specifically the primary yield-increasing innovations most used by SCFs in the study area. These innovations included improved seeds, chemical fertilisers, chemical pesticides, and irrigation systems. To estimate the impacts of these innovations on crop yields during the 2023/2024 cropping season, which serve as a proxy for measuring productivity, the Propensity Score Matching (PSM) method was used. The focus was on the likelihood of innovation usage among SCFs. During the analysis, it was observed that some variables in the probit regression models perfectly predicted the outcomes. Therefore, a filtering process was applied to include only variables that provided meaningful information for each specific innovation. Probit regression models were used to estimate the probabilities of agricultural innovation usage and generate propensity scores. Only those variables that significantly influenced the use of each agricultural innovation were discussed. Propensity score distribution graphs (psgraph) were created to ensure balanced covariates between farmers using one or more agricultural innovation (treated group) and non-user (control group). The Average Treatment Effects on the Treated (ATT) were then estimated using the kernel matching method. To test robustness, additional estimations were performed using the nearest neighbours and radius matching estimators, allowing a comparative analysis to assess the consistency with the kernel method results.

4.3.1 Influence of smallholder crop farmers' characteristics on the use of each agricultural innovation

(a) Effects of smallholder crop farmers' characteristics on improved seeds use

The estimated results of probit regression model are reported in Table 9. These results show the predicted probabilities of using improved seeds while controlling for participants' characteristics. To explain the differential impact of independent variables (age group, level of education, off-farm income, farming experience, cooperative membership) on the dependent variable (improved seeds usage), the coefficient estimates as well as the average marginal effect, which presents changes in the probability of usage, were used. The likelihood ratio (LR) chi-square and the probability chi-square, suggests that the overall model provides a reasonably good fit for the data at the 5% significance level. This finding aligns with Fisher's rule of thumb, which suggests that a likelihood ratio greater than 1 enhances the model's predictive power for the outcome of interest (Fisher, 1922). However, the pseudo-R-squared value shows that the model explains approximately 3.4% of the variation in the use of improved seeds, indicating relatively low explanatory power. Veall and Zimmermann (1992) noted that pseudo-R-squared values in probit models are typically lower than those in linear regression but can still signal relative improvements in model fit. Despite the low pseudo-R-squared, the probit model correctly predicted 67% of sample observations, demonstrating that the model has a moderate level of predictive accuracy in classifying improved seed usage among the sample population (Hanley and McNeil, 1982).

Table 9: Determinants of using improved seeds

Independent variables	Coefficient.	P-value	Average marginal effect
Age group(years)	0. 422	0.002***	0.155
Level of education	0.106	0.057*	0.039
Main source of off-farm income	-0.032	0.289	-0.012
Years of farming experience	-0.054	0.562	-0.010
Cooperative membership	-0.091	0.600	-0.033
Constant	-0.473	0.378	
LR chi2 (5) = 13.78	Prob > chi2 = 0.0425**	Pseudo R2 = 0.0337	
% predicted correctly = 67.92	***, **, and * = 1%, 5% and 10%		

Source: Survey data (2024)

Following the results presented in Table 9, variables such as age group and level of education are the main significant determinants of using improved seeds, with age group showing the strongest positive effect. The estimated coefficient for age group is positive and statistically significant at the 1% level, indicating that as participants belong to higher age groups, their likelihood of using improved seeds increases. Additionally, the average marginal effect of a one-unit increases in age group on conditional probability of using improved seeds is 0.155, meaning that an increase in age group is associated with a 15.5% increase probability of using improved seeds. This suggests that older farmers are more likely to use improved seeds than younger farmers as they might be more experienced, and some might have worked for commercial farmers and thus been exposed to the different types of improved seed varieties. This result is consistent with Myeni and Moeletsi (2023) who reported a positive relationship between the age of a farmer and the uptake of improved seeds. However, they differ from other studies that postulate that younger farmers were more likely to uptake improved seed varieties due to their enthusiasm for taking risks and exploring new technologies (Toenniessen, Adesina, and DeVries, 2008; Chete, 2021).

The estimated coefficient for level of education is positive and statistically significant at the 10% level for the probability of using improved seeds. This implies that a higher level of education likely influences the use of improved seeds, as more educated farmers may be better equipped to understand and apply information about seed improvement. The average marginal effect of a one-unit increases in education level on the probability of using improved seeds is 0.039, suggesting that each additional year of education increases the likelihood of improved seeds usage by 3.9%. The results concur with previous studies by Kirui (2019), Chete (2021), Siyum, Giziew, and Abebe (2022), and Baloyi (2023) who found that higher education (secondary and post-secondary level) significantly and positively increases the probability of using improved seed varieties.

(b) Effects of smallholder crop farmers' characteristics on chemical fertilisers use

Table 10 presents results for probit regression model with use of chemical fertilisers as the dependent variable. According to the model's likelihood ratio (LR Chi2) and probability chi-square (Prob > chi2), the model is statistically significant at the 1% level, meaning that the predictors collectively contribute to explaining fertiliser use (Fisher, 1922). Though, the Pseudo R-squared indicates that the model explains only about 5.7% of the variability in fertiliser use, indicating limited explanatory power. The probit model also correctly predicts 75% of the sample observations, which is a good prediction according to the Receiver Operating Characteristic-Area Under the Curve (ROC-AUC) analysis score ranges (Hanley and McNeil, 1982).

Table 10: Determinants of using chemical fertilisers

Independent variables	Coefficient	P-value	Average marginal effect
Gender	0.565	0.000***	0.171
Age group(years)	-0.013	0.933	-0.004
Level of education	-0.025	0.683	-0.007
Main source of off-farm income	-0.047	0.154	-0.014
Years of farming experience	-0.102	0.303	-0.031
Cooperative membership	-0.332	0.068*	-0.100
Constant	0.777	0.200	
LR chi2 (5) = 20.14	Prob > chi2 = 0.0026***	Pseudo R2 = 0.0574	

% predicted correctly = 74.66	*** and * = 1% and 10%

Source: Survey data (2024)

Given the female dominance of 59.4% in the total population, the results in Table 10 show that gender had a positive effect on chemical fertiliser use and was statistically significant at the 1% level. This suggests that female farmers are more likely to use chemical fertilisers than their male counterparts. The average marginal effect of 0.171 implies that female farmers are associated with 17.1% higher likelihood of chemical fertilisers use. The higher use of chemical fertilisers by females could be the results of the higher proportion of female farmers in the population and the cultivations of more fertiliser-intensive crops by female farmers. These findings concur with Anang and Zakariah (2022) who reported a positive relationship between the sex of a farmers and use of chemical fertiliser. According to Mathebula, Molokomme, Jonas, and Nhemachena (2017), females tend to participate more in agricultural activities because males migrate to the cities to look for jobs, to provide for their families. Qange and Mdoda (2020) shared similar findings.

Being on cooperative membership also revealed a notable impact, with a negative effect on farmer use of chemical fertilisers and was statistically significant at 10% level. This implies that being a member of a cooperative decreased the probability of smallholder crop farmers' use of chemical fertiliser. This further reflected in the marginal effect of -0.100, suggesting that cooperative membership is linked to a 10% decrease likelihood of chemical fertiliser use. A reason could be that cooperatives are ineffective with providing relevant information concerning chemical fertilisers to the farmers. Farmer cooperatives constitute platforms where members can share information. However, in most cases, the group meetings are not held often, thus disadvantaging farmers in knowing about different types of chemical fertilisers available for specific crops due to lack of information sharing. Wei, Kong, and Wang (2022) and Wu, Liu, Chen, Wang, Huang, Cai, Zhang, and Jia (2022) reported similar findings. However, they contrast with the finds of Blekking, Gatti, Waldman, Evans, and Baylis (2021) and Geffersa (2024) who revealed that cooperative membership increased inorganic fertilisers use intensity, as well as the probability of it being used in the first place.

(c) Effects of smallholder crop farmers' characteristics on chemical pesticides use

The variables affecting the probability of smallholder crop farmers' chemical pesticides use are summarised in Table 11. The likelihood ratio and probability chi-square at the bottom of the table, specify that the overall model is marginally significant at the 10% level, suggesting that the identified variables collectively provide some explanatory power to the model (Fisher, 1922). Even thou the pseudo-R-squared shows that the model explains only about 2.7% of the variation in chemical pesticides use, the model correctly classifies 70% of the sample observations, which proves a moderate capacity to predict chemical pesticides use (Hanley and McNeil, 1982).

Table 11: Determinants of using chemical pesticides

Independent variables	Coefficient	P-value	Average marginal effect
Gender	0.115	0.454	0.042
Age group(years)	-0.069	0.606	-0.025
Level of education	0.052	0.356	0.019
Main source of off-farm income	-0.076	0.019**	-0.027
Farm size	-0.180	0.278	-0.064
Cooperative membership	0.179	0.315	0.065
Constant	0.586	0.334	
LR chi2 (6) = 10.72 Prob > chi2 = 0.0976* Pseudo R2 = 0.0267			
% predicted correctly = 70.34 ** and * = 5% and 10%			

Source: Survey data (2024)

Main source of off-farm income had a negative effect on chemical pesticide use and was statistically significant at the 5% level. The negative coefficient implies that farmers who rely on off-farm income sources are associated with decreasing probability of using chemical pesticides. Specifically, for an increase in the amount of salary, old age pension, child support grant, or remittances decreases the likelihood of chemical pesticides use by 2.7%. A reason for this finding could be that SCFs with off-farm income may priorities these funds for other investments or household needs instead of purchasing chemical pesticides, leading to less reliance on these inputs. These findings concur with those of Migheli (2017), who highlighted a negative effect of off-farm income and the use of chemical pesticides, potentially implying lower probability of pesticide use for higher off-farm income due to the substitution effect. On the contrary, Huang, Luo, Tang, and Yu (2020) suggested that higher income households can afford to buy more chemical pesticides (quantity and type), leading to higher probability of pesticide overuse.

(d) Effects of smallholder crop farmers' characteristics on irrigation systems use

A probit regression model was used to examine the effects of identified variables on smallholder crop farmers use of irrigation system. Table 12 shows the results from the probit model. The probit model summary suggests that the model is not statistically significant hence the p-value from the Chi-squared test is greater than 0.05. However, the model is moderately a good fit when reading the percent correctly predicted which is about 69% of the sample observations.

Table 12: Determinants of using irrigation system

Independent variables	**Coefficient**	**P-value**	**Average marginal effect**
Gender	-0.153	0.325	-0.059
Age group(years)	0.287	0.031**	0.111
Level of education	0.059	0.284	0.023
Main source of off-farm income	-0.000	1.000	-0.000
Cooperative membership	0.154	0.370	0.059
Water access	-0.030	0.916	-0.012
Main source of water for irrigation	-0.094	0.340	-0.036
Constant	-0.667	0.304	
LR chi2 (7) = 6.09	Prob > chi2 = 0.5290	Pseudo R2 = 0.0145	
% predicted correctly = 68.90	** = 5%		

Source: Survey data (2024)

The age group variable had a positive effect on irrigation system use and was statistically significant at the 5% level. The positive coefficient implies that farmers belonging to older age groups are more likely to use irrigation systems with an 11.1% more likelihood as opposed to younger age group farmers. This may be because age group is associated with the years of farming experience. Therefore, older farmers may have accumulated experience over time, and they may have recognised and understand the benefits of irrigation for crop yield improvements, which makes it more likely for them to use irrigation systems. These results closely mirror Daniel (2011) and Salome and Rotimi (2013) who established that age was significant in the household head decision to adopt new technologies. Recent study by Jiba, Obi, Mdoda, and Mzuyanda (2024) revealed similar findings in a study that looked on the impact of smallholder irrigation scheme on household welfare in farm-managed irrigation scheme communities in Eastern Cape. On the contrary, a study by Mattee and Gebreyes (2013) indicated that younger household heads are more innovative in terms of technology participation and are more likely to take risks than older household heads.

4.3.2 Estimated propensity scores

Table 13 present the summarised statistics of the propensity scores for the different treatment variables (improved seeds, chemical fertilisers, chemical pesticides, irrigation systems) among the 308 observations generated from the Probit regression models for impact estimations. Propensity scores, as noted by Lee (2013), are useful for balancing the distribution of observed covariates across the treated and the untreated groups. The propensity scores are probabilities (Inacio, Chen, Paxton, Namba, Kurtz, and Cafri, 2015), so the average probabilities in the treatments reveal high use probabilities for improved seeds and chemical pesticides, moderate probabilities for chemical fertiliser, and lower probabilities for irrigation systems among the SCFs.

Table 13: Average propensity to use agricultural innovations

Variables	Observation	Mean	Std. Dev.	Min	Max
Improved seeds	308	0.877	0.052	0.702	0.973
Chemical fertiliser	308	0.760	0.120	0.604	0.944
Chemical pesticides	308	0.942	0.035	0.846	0.999
Irrigation system	308	0.422	0.083	0.237	0.604

Source: Survey data (2024)

Following Table 13, the mean for improved seed use is 0.877, indicating a high average probability that a farmer will use improved seeds (treatment assignment) is 87% with scores ranging from 0.702 to 0.973. Chemical fertilisers use had a mean value of 0.760, indicating 76% moderate probability of use with scores spanning from 0.406 to 0.944. With a mean of 0.942, the likelihood of using chemical pesticides is 94% higher than the other innovations across observations with scores of 0.846 and 0.999. The mean value for irrigation system use is 0.422 and lower compared to other innovations, reflecting a 42% probability of use among farmers with scores ranging from 0.237 to 0.604.

4.3.3 Propensity score distribution graphs (psgraph)

To further test for balancing i.e. quality of matching, density plots of propensity scores were drawn as shown by Figure 15. These tests are effective because they aid to visualise the balance or overlap between treatment and control groups for each agricultural innovation. Overlap or common support is a region where the two groups share some similarities (Gates, Wood, Hetrick, and Ahn, 2019). A larger proportion of overlap implies a good match of treated and control cases (Dehejia and Wahba, 2002). From the graphs below there are observable overlaps in the propensity scores distributions between farmers who use specific agricultural innovations (treatment group) and the non-users (control group).

(a) Propensity score graph for improved seeds

Based on the visual observations, the distributions of the estimated propensity scores for the farmers who are using improved seeds and those who do not show that there is some overlap, but there are some notable differences in certain areas, particularly where the blue line (treatment) has higher density than the red line (control group). This indicates that while there is some balance, the overlap is adequate between 0.8 and 0.9, which is essential for effective matching between users and non-users. Beyond 0.9, farmers using improved seeds dominate and may have distinct characteristics, while below 0.8, non-users are more prevalent.

(b) Propensity score graph for chemical fertilisers

The blue line represents a group of farmers who are using chemical fertilisers and are concentrated between 0.7 and 0.9, where the density curve peaks. This shows that this group of farmers is more likely to use chemical fertilisers based on their observed characteristics.

Furthermore, red line which represents non-users have higher densities at lower propensity scores, primarily between 0.4 and 0.7, where the likelihood of using is lower. The is a good amount of overlap between the group of smallholder crop farmers who use chemical fertilisers and non-users, especially in the central range of the propensity scores (between 0.6 and 0.8), ensuring compatibility for matching between users and non-users across a wider range of propensity scores.

(c) Propensity score graph for chemical pesticides

The graph below represented the density distribution of propensity scores for a group of farmers who are using chemical pesticides (treatment group, shown in blue line) and a group that do not use chemical pesticides (control group, shown in red line). The blue line shows a higher density of propensity scores peaking around 0.96, indicating a larger proportion of users had high probabilities of suing chemical pesticides. It is observed that the red line peaks slightly earlier, around 0.94 but declined more steeply, indicating fewer non-users with high probabilities of using chemical pesticides. The blue and red curves overlap significantly in the range of propensity score from approximately 0.87 to 0.98. This indicates that there is strong balance or similar probabilities between the treatment and control groups for chemical pesticides usage, suggesting a well-matched distribution. Observations below 0.87 and above 0.98 region were excluded in the analysis, as they lack comparable counterparts with the opposite group.

(d) Propensity score graph for irrigation systems

The provided density plot graph represents the density of propensity scores for the treatment group (farmers using irrigations systems) as shown in blue colour and the control group (farmers not using irrigation systems) as indicated in red colour before matching. From the graph, there is an observable overlap between the two groups of farmers in the middle range of propensity scores from 0.3 to 0.5. This indicates the presence of comparable characteristics between the group of farmers who use irrigation systems and those farmers who do not use irrigation systems, making it possible to perfume matching. The overlap between the propensity score distributions of the treatment and control groups appears to be moderate. However, there are regions where the blue line (treatment group) had higher propensity scores at the range of 0.4 to 0.5 than the red line (control group). The lack of perfect overlap was seen below 0.3 and above 0.5, which implied that some of the observations were discarded during matching because they fall outside of the common support region.

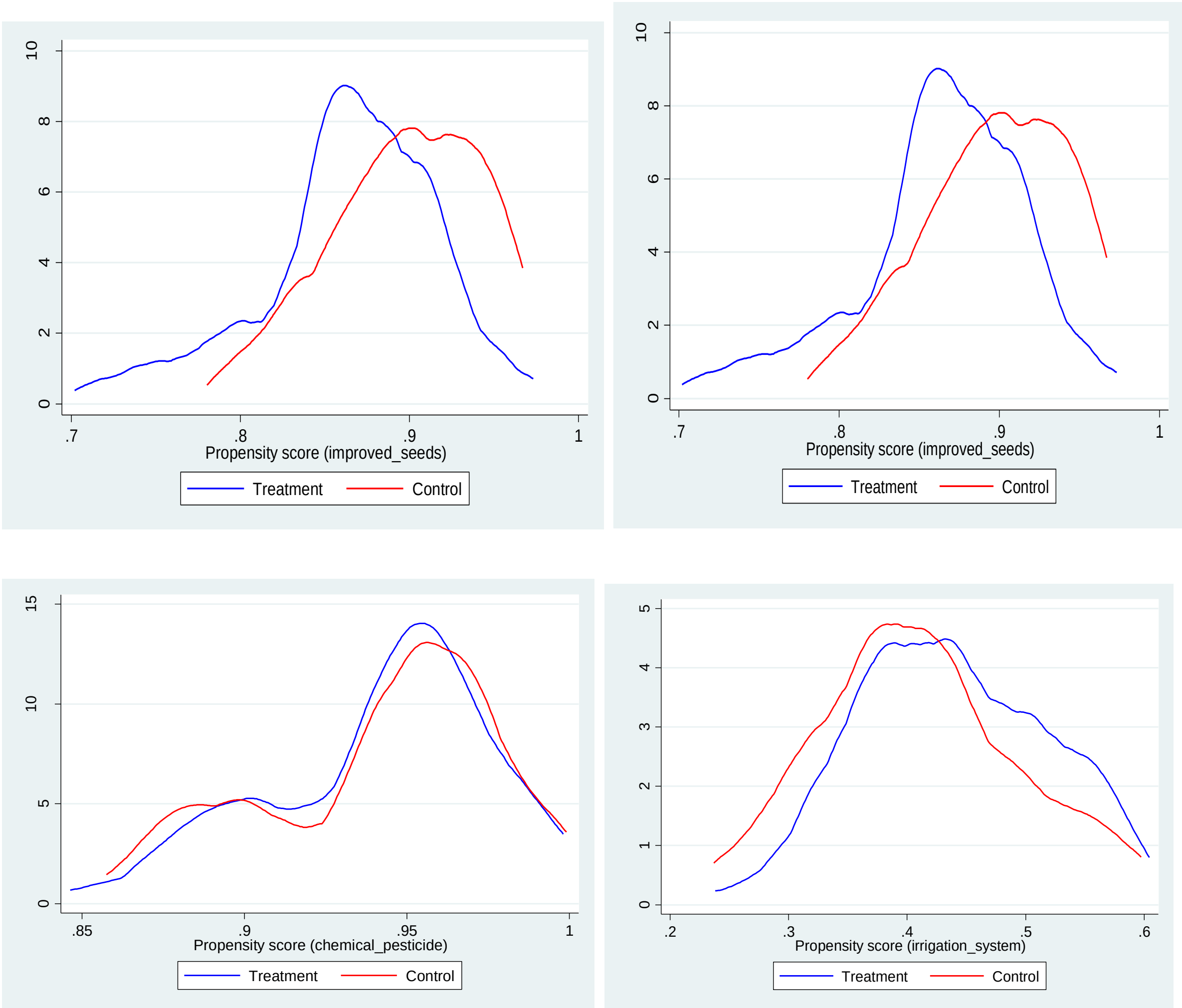


Figure 15: Densities of the estimated Propensity Scores over treatment assignments

Source: Survey data (2024)

4.3.4 Estimated average impact of agricultural innovations on crop yield

In this study, the impact of the agricultural innovations on crop productivity was assessed using crop yield as a proxy for measuring productivity for selected vegetable and agronomic crops cultivated during the last cropping season (2023/2024). Although nine vegetable crops and four agronomic crops were initially identified in the study area, the analysis focused on three vegetable crops (tomatoes, cabbage, chilies) and one agronomic crop (maize). This selection was based on the availability of sufficient number of comparable farmers (users and non-users of agricultural innovations) to generate meaningful matches for statistical analysis, as well as high cultivation percentages of these crops.

The findings showed significant positive impacts of agricultural innovations on crop yields, emphasising their role in enhancing productivity. To validate these results, various propensity scores matching estimators, including kernel, nearest neighbour, and radius methods were applied to ensure consistency and reliability of the treatment effects. Tables 14 to 17 summarise the ATT for each selected crop, comparing yields of farmers using one or more innovations (treated group) and those not using innovations (control group). SCFs in the study area quantify output gains as follows:

- One ton of tomatoes or chilies is equivalent to 143 crates (7kg each),
- One ton of cabbages is equivalent to 500 heads (2kg each)
- One ton of maize is measured as one load of a bakkie (pickup truck).

(a) Impact of improved seeds on crop yields

The impact of improved seeds on the yields of tomato, cabbage, chilies, and maize farmers was estimated using propensity score matching. Results presented in Table 14 show that the use of improved seeds had a positive and statistically significant effect on crop yields for all four crops. The impact was notably higher among tomato, cabbage, and maize farmers, while chilies farmers experienced the lowest impact.

Specifically, the ATT values show that using improved seeds increased crop yields (measured in tons per hectare) by 6.941 tons/ha for tomato farmers, 8.905 tons/ha for cabbage farmers, 2.197 tons/ha for chilies farmers, and 3.854 tons/ha for maize farmers. These results suggest that SCFs using improved seeds achieve higher crop yields compared to their counterparts who do not use this innovation. These findings concur with those of Hemming et al (2018), who reported that the adequate use of agricultural inputs, such as improved seeds, significantly increase productivity in low yielding areas. However, as highlighted by Wiggins and Brooks (2012), the affordability and accessibility of these inputs remain significant challenges for many poor SCFs in developing countries.

Table 14: Average impact estimates of propensity score matching of improved seeds on crop yield

Crop Yield (tons/ha)	Sample	Treated	Control	Difference	t-stats
Vegetable crops					
Tomato farmers					
Kernel	ATT	19.145	12.205	6.941	7.71***
Nearest neighbours	ATT	19.145	12.458	6.687	6.93
Radius	ATT	19.145	14.042	5.104	12.56
Cabbage farmers					
Kernel	ATT	32.829	23.924	8.905	3.60***
Nearest neighbours	ATT	32.829	24.286	8.543	3.86
Radius	ATT	32.333	24.286	8.048	6.07
Chilies farmers					
Kernel	ATT	8.326	6.129	2.197	4.34***
Nearest neighbours	ATT	8.326	5.711	2.622	4.07
Radius	ATT	8.333	6.111	2.222	4.59
Agronomic crop					
Maize farmers					
Kernel	ATT	9.947	6.094	3.854	2.27**
Nearest neighbours	ATT	9.9	6.4	3.5	2.49
Radius	ATT	9.9	5.333	4.567	4.19
Note that ***, **, and * = 1%, 5% and 10%					

Source: Survey data (2024)

To evaluate the reliability of the above results, the consistency of the estimated ATT for each crop across all the three matching methods (kernel, nearest neighbour, and radius) was compared. The results across the different matching methods generally show consistency, particularly for the vegetable crops. Therefore, the use of improved seeds has a robust positive impact on crop yields for SCFs, regardless of the choice of matching method.

(b) Impact of chemical fertiliser usage on crop yield

The impact of chemical fertiliser usage on tomato, cabbage, chilies, and maize farmers was estimated through propensity score matching. The estimated impact shows that there were significant positive differences between farmers who used chemical fertiliser and counterfactual farmers for tomato, chilies, and maize at the 1% level, while chemical fertiliser usage was found not to have any statistical significance on the crop yields of cabbage farmers. For tomato, chilies, and maize farmers, treated farmers experienced increases in yields of 7.541 tons/ha, 3.318 tons/ha, and 5.022 tons/ha, respectively, compared to farmers in the counterfactual group. These findings align with those of Nguyen, Russ, and Triyana (2023), who found that subsidized fertilisers are associated with average yield increases of 18%. According to Heisse and Morimoto (2024), chemical fertilisers can significantly improve agricultural productivity, but their environmental sustainability is much debated. Atafar et al. (2010) and Ying et al. (2017) highlighted that, despite chemical fertilisers' positive contribution to agricultural production, farmers often apply high dosages, which has led to many ecological issues, particularly in developing countries.

Table 15: Average impact estimate of propensity score matching of chemical fertiliser on crop yield

Crop yield (ton/ha)	Sample	Treated	Control	Difference	t-stats
Vegetable crops					
Tomato farmers					
Kernel	ATT	21.438	13.897	7.541	4.05***
Nearest neighbours	ATT	20.75	13.65	7.1	4.42
Radius	ATT	20.75	13.867	6.883	5.59
Cabbage farmers					
Kernel	ATT	28.5	21.751	6.749	1.07
Nearest neighbours	ATT	28.5	21.667	6.833	1.12
Radius	ATT	28.5	25.781	2.719	0.64
Chilies farmers					
Kernel	ATT	8.833	5.515	3.318	4.41***
Nearest neighbours	ATT	8.938	5.875	3.063	4.18

Radius	ATT	8.938	6.290	2.647	5.22
Agronomic crop					
Maize farmers					
Kernel	ATT	7.941	2.919	5.022	7.14***
Nearest neighbours	ATT	8.4	2.85	5.55	6.72
Radius	ATT	8.4	3.265	5.135	6.79
***, *, and ** = 1%, 5% and 10%					

Source: Survey data (2024)

The reliability of the results was evaluated by comparing the consistency of impact estimates across multiple matching methods (kernel, nearest neighbour, and radius). The results indicated a general consistency in the positive impact of chemical fertilisers on crop yields for tomatoes, chilies, and maize. However, the lack of significant impact on cabbage yield suggests that further exploration is needed to understand the factors affecting its productivity.

(c) Impact of chemical pesticides on crop yield

Chemical pesticide usage was found to positively impact the crop yield of farmers in the study area. However, statistically significant differences were observed to be high for tomato farmers and marginal for chilies farmers, while no significant effects were found for cabbage and maize farmers. The use of chemical pesticides increased the crop yield (measured in tons per hectare) of farmers by 6.703 tons/ha and 1.294 tons/ha for tomato and chilies farmers, respectively. Cabbage farmers had higher crop yields than tomato, chilies, and maize farmers, but unfortunately, this difference was not statistically significant. These findings concur with those of Sheahan, Barrett, and Goldvale (2017), who noted that modern agricultural inputs, such as chemical pesticides, potentially help SCFs boost productivity significantly, particularly in regions like sub-Saharan Africa (SSA). McArthur and McCord (2017) argue that there is a strong, causal relationship between the use of modern agricultural inputs and crop yields, and subsequently, economic growth. However, the continuous use of chemical inputs, such as chemical pesticides, has resulted in environmental damage, caused human health issues, negatively impacted agricultural production, and reduced agricultural sustainability (Wilson and Tisdell, 2001).

Table 16: Average impact estimate of propensity score matching of chemical pesticide on crop yield

Crop yield (ton/ha)	Sample	Treated	Control	Difference	t-stats
Vegetable crops					
Tomato farmers					
Kernel	ATT	18	11.297	6.703	41.54***
Nearest neighbours	ATT	18	11.114	6.886	56.69
Radius	ATT	18	13.848	4.152	45.70
Cabbage farmers					
Kernel	ATT	23.75	15	8.75	1.84
Nearest neighbours	ATT	26.6	18	8.6	1.70
Radius	ATT	26.6	24.625	1.975	0.42
Chilies farmers					
Kernel	ATT	8.556	7.262	1.294	1.01*
Nearest neighbours	ATT	8.385	6.154	2.231	3.28
Radius	ATT	8.896	6.1	2.796	11.45
Agronomic crop					
Maize farmers					
Kernel	ATT	7.5	5.428	2.072	1.54
Nearest neighbours	ATT	8.333	4.267	4.067	3.70
Radius	ATT	8.333	3.5	4.833	4.88
***, *, and ** = 1%, 5% and 10%					

Source: Survey data (2024)

The results in Table 16 highlight a strong consistency in the positive impact of chemical pesticides on tomato yields. However, there is variability in the results for cabbage and chilies, indicating the need for further investigation into the specific conditions affecting the productivity of these crops. The consistency of results across the different matching methods for maize suggests that chemical pesticides can enhance yields, but the variability observed in the results indicates that the effectiveness may depend on other contextual factors.

(d) Impact of irrigation system on crop yield

The impact of irrigation systems on tomato, cabbage, chilies, and maize farmers was estimated through propensity score matching. Results presented in Table 17 show that the use of irrigation systems had a positive and significant effect on the crop yield of all four groups of farmers considered in the study. However, the impact was higher among tomato, cabbage, and chilies farmers, while maize farmers experienced the lowest impact of irrigation systems on their crop yields. The use of irrigation systems increased the crop yield (measured in tons per hectare) of farmers. Therefore, the ATT for the entire sub-population of farmers was 7.273 tons/ha, 8.851 tons/ha, 3.196 tons/ha, and 2.471 tons/ha for tomato, cabbage, chilies, and maize farmers, respectively. More specifically, the results imply that farmers using irrigation systems tend to have higher crop yields than those not using irrigation systems. These findings corroborate those of Nakawuka, Langan, Schmitter, and Barron (2018), who stated that smallholder farmers' engagement in small-scale irrigation systems is vital for boosting agricultural productivity, ensuring food security, and fostering sustainable rural development worldwide. Furthermore, Yang et al. (2023) concluded that drip irrigation technology is effective in improving crop yields by 28.92% compared to other irrigation systems. Although irrigation in Africa has the potential to boost agricultural productivity by at least 50%, food production on the continent is almost entirely rainfed (You, Ringler, Wood-Sichra, Robertson, Wood, Zhu, Nelson, Guo, and Sun, 2011).

Table 17: Average impact estimate of propensity score matching of irrigation system on crop yield

Crop yield (ton/ha)	Sample	Treated	Control	Difference	t-stat
Vegetable crops					
Tomato farmers					
Kernel	ATT	18.273	11	7.273	51.64***
Nearest neighbours	ATT	19.074	11	8.074	14.49
Radius	ATT	19.074	11	8.074	14.49
Cabbage farmers					
Kernel	ATT	33	24.149	8.851	4.10***
Nearest neighbours	ATT	33	24.437	8.563	3.35

Radius	ATT	32.855	24.149	8.706	5.79
Chilies farmers					
Kernel	ATT	8.965	5.769	3.196	8.41***
Nearest neighbours	ATT	8.965	5.877	3.088	7.77
Radius	ATT	8.965	5.833	3.132	11.69
Agronomic crop					
Maize farmers					
Kernel matching	ATT	7.190	4.710	2.471	2.86***
Nearest neighbours	ATT	7.190	4.757	2.433	2.68
Radius matching	ATT	7.190	4.25	2.940	3.77
***, *, and ** = 1%, 5% and 10%					

Source: Survey data (2024)

Following the results in Table 17, a strong consistency in the positive impact of irrigation systems on crop yields for tomatoes, cabbages, and chilies is demonstrated, with robust statistical support across various matching methods. Maize also shows a positive effect, but with comparatively lower consistency and robustness. This suggests that irrigation systems are an effective agricultural innovation for enhancing productivity SCFs, particularly for vegetable crops.

(e) Hypothesis testing

The study tested the hypothesis that agricultural innovations significantly increase the productivity (crop yield) of SCFs. The null hypothesis (H_0) stated that AIS does not significantly impact the productivity (crop yields), while the alternative hypothesis (H_1) posited that AIS significantly impacts the productivity (crop yields).

Table 14 presents the impact of improved seeds on crop yields. For tomatoes, significant differences in crop yield were observed across all matching methods, with t-statistics consistently above the 1% significance level (e.g., t=7.71 for kernel matching). The null hypothesis was rejected, indicating that improved seeds significantly increase tomato yields. Similarly, cabbage yields showed significant increases, with t-statistics exceeding the 1% significance level (t=3.60 for kernel matching), leading to the rejection of the null hypothesis. For chilies, yield increases were significant at the 1% level across all methods (t=4.34 for kernel matching), resulting in the rejection of the null hypothesis. Maize yields also increased significantly at the 5% and 1% levels (t=2.27 for kernel matching), leading to the rejection of the null hypothesis.

Table 15 evaluates the effect of chemical fertilisers on crop yields. Significant yield increases were observed for tomatoes (t=4.05), chilies (t=4.41), and maize (t=7.14) at the 1% level, prompting the rejection of the null hypothesis for these crops. However, cabbage showed no significant yield increases across all methods (t=1.07 for kernel matching), so the null hypothesis was not rejected for cabbage. The results confirm that chemical fertilisers significantly improve yields for tomatoes, chilies, and maize but not for cabbage.

Table 16 explores the impact of chemical pesticides. For tomatoes, significant yield increases were observed at the 1% level (t=41.54 for kernel matching), resulting in the rejection of the null hypothesis. Maize yields also showed significant increases at the 1% level for some methods (t=4.88 for radius matching), leading to the rejection of the null hypothesis. Chilies displayed significant yield increases at the 10% level (t=1.01 for kernel matching), resulting in the rejection of the null hypothesis with weaker confidence. However, no significant yield increase was observed for cabbage across all methods (t=1.84 for kernel matching), so the null hypothesis was not rejected. Overall, chemical pesticides significantly increased yields for tomatoes and maize, while effects on chilies and cabbage were less consistent.

Table 17 highlights the effect of irrigation systems on crop yields. Significant yield increases at the 1% level were observed for tomatoes (t=51.64), cabbage (t=4.10), chilies (t=8.41), and maize (t=2.86) across all methods. Consequently, the null hypothesis was rejected for all crops, confirming that irrigation systems significantly enhance crop yields.

The findings demonstrate that AIS significantly impacts the productivity (crop yields) of SCFs in the study area through the use of yield-increasing innovations such as improved seeds, chemical fertilisers, chemical pesticides, and irrigation systems. However, there are exceptions, such as cabbage yields with chemical fertilisers and chemical pesticides, where no significant impact was observed.

4.4. Binary logistic regression analysis of factors constraining smallholder crop farmers use of agricultural innovations.

This study employed a binary logistic regression model to examine factors constraining SCFs' use of agricultural innovations in Mbombela Local Municipality. Agricultural innovation use was treated as a binary variable, where zero (0) denotes farmers using one or more innovations and one (1) if farmers do not use any. A filtering process was applied to include only theoretically relevant or statistically significant factors for each innovation. This approach acknowledges that different innovations (improved seeds, chemical fertilisers, chemical pesticides, and irrigation systems) are influenced by distinct factors.

To interpret the results, coefficients and odds ratios of identified variables were used. A positive coefficient indicated that the factor increases the likelihood of farmers not using agricultural innovation, while a negative coefficient indicated it decreases the likelihood. Odds ratios measured the magnitude at which each significant variable constrained innovation use. Tables 18 to 21 present estimated results from binary logistic regression analyses and explain model fits. This section discusses only variables that significantly constrained agricultural innovation use.

4.4.1 Factors constraining smallholder crop farmers use of improved seeds

Table 18 shows the binary logistic regression results illustrating the association between explanatory variables that constrain the use of improved seeds. The goodness-of-fit test, demonstrated by the logit regression model, confirmed that the model's predictors align well with observed outcomes. The H-L test showed a Chi-square value of 4.332 with a p-value of 0.826. Since the p-value exceeded significance thresholds ($p<0.05$ and $p<0.10$), the model was a good fit. The rule of thumb for accepting a logit model is that the H-L statistic must be greater than 0.05 and non-significant (Hosmer, Jovanovic, and Lemeshow, 1989). The explanatory variables in Table 18 were measured for their relevance in improved seed usage. However, only four variables significantly constrained improved seed use. These variables are age group, education level, limited access to credit, and inadequate knowledge of inputs. The other eight variables were not significant. All four significant variables had negative signs, implying that an increase may decrease the likelihood of improved seed use.

Table 18: Binary logistic regression results illustrating the association between the selected explanatory variables that constraints the use of improved seeds

Independent Variables	B	S.E.	Wald	Df	Sig.	Exp(B)	95% Confidence Interval Exp(B)	
							Lower	Upper
Gender	.387	.412	.885	1	.347	1.473	.657	3.301
Age group(years)	-.690	.325	4.518	1	.034**	.502	.265	.948
Level of education	-.323	.151	4.601	1	.032**	.724	.539	.973
Household size	-.062	.254	.060	1	.807	.940	.571	1.547
Main source of off-farm income	.041	.073	.310	1	.578	.960	.832	1.108
Cooperative membership	.064	.426	.023	1	.881	1.066	.463	2.457
Inadequate knowledge on inputs	-.638	.371	2.957	1	.086*	.529	.256	1.093
Limited access to credit	-.616	.362	2.892	1	.089*	.540	.266	1.099
High input costs	.563	.370	2.317	1	.128	1.755	.851	3.623
Unfavorable climatic conditions	.429	.385	1.245	1	.264	1.536	.723	3.266
Lack of water access	.058	.358	.027	1	.871	1.060	.526	2.138
Lack of social connections	.013	.371	.001	1	.972	1.013	.490	2.094
Constant	.308	1.859	.027	1	.868	1.361		

Hosmer-Lemeshow chi-square = 4.332 (p=.826) ***Number or observation = 308***

**** and * = 5% and 10%**

Source: Survey data (2024)

(a) Age group (years)

The variable age group had a negative coefficient (-0.690) and was statistically significant at the 5% level. This suggests that for every unit increase in age group, the likelihood of SCFs using improved seeds decreases. The estimated odds ratio (0.502) indicates that with an increase in age group, the probability of older farmers using improved seeds is reduced by approximately 49.8%. Older farmers may rely on traditional knowledge passed down through generations, making them hesitant to use improved seeds due to familiarity with traditional seeds. The findings align with studies by Zavale, Mabaya, and Christy (2005), Baumgart-Getz, Prokopy, and Floress (2012), and Ndiritu, Kassie, and Shiferaw (2014), who reported a negative relationship between age and improved seed use, revealing that older farmers are less likely to use improved maize seed and often rely on indigenous knowledge. However, this knowledge is becoming unreliable due to climate change and variability (Kolawole, Wolski, Ngwenya, and Mmopelwa, 2014; Jiri, Mafongoya, Mubaya, and Mafongoya, 2016). In contrast, Ademiluyi (2014) and Kaliba, Mazvimavi, Gregory, Mgonja, and Mgonja (2018) found a positive relationship between age and improved seed use.

(b) Level of education

Level of education had a negative coefficient (-0.323) and was statistically significant at the 5% level. This implies that a unit increase in education level decreases the likelihood of using improved seeds. The odds of farmers using improved seeds are 0.724, indicating that as education increases, the likelihood of using improved seeds decreases by 27.6%, as farming in the study area is dominated by people with no formal education. Low literacy levels indirectly impact productivity since technological advancements require a certain level of formal education (DAFF, 2012; Kolawole et al., 2014). According to Maziya (2013), farmers with low education levels are less likely to adopt new technologies geared toward improving productivity. Lower education levels among targeted farmers imply that written agricultural information is of minimal benefit.

(c) Inadequate knowledge on inputs

Knowledge on inputs had a negative influence on the use of improved seeds, with a coefficient of (-0.638) and statistically significant at the 10% level. This indicates that a greater lack of knowledge on inputs, specifically improved seeds, lowers the probability of improved seed usage among farmers. The odds ratio (0.529) shows that lack of knowledge decreases the chances of using improved seeds by 47.1%. This might be because inadequate knowledge increases uncertainty, making it difficult for farmers to understand the benefits of improved seeds. Since farming is knowledge-intensive, many farmers lack a single channel serving as a comprehensive source for their information needs (Giller et al., 2011; Mutyasira, Hoag, and Pendell, 2018). Consequently, most rely on indigenous knowledge, which they believe is more accurate and easier to understand than agricultural innovations requiring formal education

(DAFF, 2012). These findings align with Myeni and Moeletsi (2023), who emphasized that lack of awareness and inadequate information are key constraints limiting the use of improved seeds.

(d) Limited access to credit

The variable access to credit had a negative coefficient of (-0.616) and was statistically significant at the 10% level. This suggests that greater lack of access to credit lowers the likelihood of farmers using improved seeds. The odds of farmers using improved seeds are 0.540, suggesting that limited access to credit decreases usage by 46%, as they are expensive to purchase. Most farmers in the study area have very limited access to credit due to low income, old age, and low education levels. Those meeting credit requirements are more likely to invest in other businesses, such as tuckshops, than agriculture. These findings align with previous studies, which reported that limited access to credit is the main obstacle to using agricultural technologies, including improved seeds (Abate et al., 2016; Khandker and Koolwal, 2016; Balana and Oyeyemi, 2022).

4.4.2 Factors constraining smallholder crop farmers use of chemical fertilisers

Table 19 shows the binary logistic regression results illustrating the association between explanatory variables that constrain the use of chemical fertilisers. The results of the goodness-of-fit test, as demonstrated by the logit regression model, confirmed that the model's predictors align well with observed outcomes. The H-L goodness-of-fit test showed a Chi-square value of 3.957 with a p-value of 0.861. Since the p-value exceeded common significance thresholds ($p<0.05$, $p<0.01$, and $p<0.10$), the model was a good fit, as the rule of thumb for accepting a logit model is that the H-L statistic must be greater than 0.05 and show non-significance (Hosmer, Jovanovic, and Lemeshow, 1989).

The explanatory variables interpreted in Table 19 were measured for relevance in chemical fertiliser usage. However, only five (5) variables significantly constrained the use of chemical fertilisers. These variables are gender, main source of off-farm income, high perceived risk, lack of access to credit, and unfavourable climatic conditions. The other six (6) variables were not significant. Three (3) of the significant variables had negative signs (gender, high perceived risk, limited access to credit), implying an increase in these variables may be associated with a decreased likelihood of using chemical fertilisers. The other two significant variables had positive signs (main source of off-farm income, unfavourable climatic conditions), implying an increase in these variables may be associated with an increasing likelihood of not using chemical fertilisers.

Table 19: Binary logistic regression results illustrating the association between the selected explanatory variables that constraint the use of chemical fertilisers

Independent Variables	B	S.E.	Wald	df	Sig.	Exp(B)	95% Confidence Interval for Exp(B)	
							Lower	Upper
Gender	-1.650	.660	6.249	1	.012**	.192	.053	.700
Age group(years)	-.409	.509	.646	1	.422	.664	.245	1.801
Level of education	-.266	.208	1.629	1	.202	.767	.510	1.153
Main source of off-farm income	1.601	.742	4.659	1	.031**	4.960	1.159	21.231
Farm size(ha)	-1.769	1.095	2.609	1	.106	.171	.020	1.459
Main reason for farming	.823	.835	.973	1	.324	2.278	.444	11.705
Cooperative membership	.169	.629	.072	1	.789	1.184	.345	4.058
Inadequate knowledge on inputs	-.482	.561	.739	1	.390	.618	.206	1.853
High perceived risk	-1.240	.656	3.574	1	.059*	.289	.080	1.047
Limited access to credit	-1.558	.612	6.484	1	.011**	.211	.064	.699
High input costs	.495	.559	.782	1	.376	1.640	.548	4.905
Lack of input storage facilities	.229	.549	.173	1	.677	1.257	.428	3.690
Unfavourable climatic conditions	2.012	.682	8.692	1	.003***	7.476	1.963	28.475
Lack of social connections	-.121	.563	.046	1	.829	.886	.294	2.671
Constant	.937	3.330	.079	1	.778	2.553		

Hosmere-Lemeshow chi-square = 3.957 (p=.861) Number of observations =308

***, **, and * = 1%, 5% and 10%

Source: Survey data (2024)

(a) Gender

In the study, gender was found to negatively influence the use of chemical fertilisers with a coefficient of (-1.650) and statistically significant at the 5% level. This indicates that female farmers (dominant group) are less likely to use chemical fertilisers compared to their counterpart, with the odds of 0.192 which indicates 80.8% less likely to use. This imply that female farmers face more constraints, and male farmers have greater access to resources, support, or information needed to use chemical fertilisers. These results corroborate with Diiro, Ker, and San (2015) who found that male heads of household were between 49 % and 70 % more likely to use inorganic fertiliser than female heads of household. Similarly, Mensah, Villamor, and Vlek (2018) and Wossen (2018) highlighted that fertiliser which is known to increase soil fertility is not widely used especially by female headed households. However, these results do not coincide with those of Okoboi and Barungi (2012), who reported that there are more male farmers than female farmers who are using chemical fertilisers.

(b) Main source of off-farm income

The variable main source of off-farm income as shown in Table 19 was found to have a positive coefficient of (1.601) and was statistically significant at the 5% level. This result suggests that the more the income coming from off-farm activities, the more the likelihood of farmers not to use chemical fertilisers, the odds of a farmer not to use chemical fertilisers are 4.960 times. These results concur with Chang and Mishra (2008) and Feng, Heerink, Ruben, and Qu (2010) who stated that off-farm employment promotes a decrease in the usage of chemical fertilisers. On the other hand, previous studies found that off-farm income increases the probability of use of chemical fertilisers, suggesting that non-farm activities are an important source of liquid capital for investing in fertilisers (De Janvry and Sadoulet 2001; Reardon et al. 2007; Diiro and Sam, 2015).

(c) Higher perceived risk

The variable perceived risk was also found with a negative coefficient of (-1.240) and statistically significant at the 10% level. The results imply that higher perceived risk reduces the likelihood of a farmers using chemical fertilisers, with the odds of a farmer reduced to 0.289 times, which is 71.1% less likelihood. These results suggest that higher risk perceptions lower farmers' intensions to use or invest in chemical fertilisers, as also found by Dessart, Barreiro-Hurlé, and Van Bavel (2019), Savari, and Gharechaee, (2020) and Xiang, Tian, and Li (2021).

(d) Limited access to credit

Access to credit had a negative coefficient of (-1.558) and statistically significant at the 5% level. This indicate that farmers without access to credit are much less likely to use chemical fertilisers, with the odds being about 0.211 times which is 78.9% than those with access to credit. This suggests that credit constrains are a major barrier. These findings coincide with previous studies, which reported that limited access to credit is the main constrain to fertiliser use (Okoboi and Barungi, 2012; Balana and Oyeyemi, 2022). This suggests that limited access to credit worsen the cash constraints and as such make it impossible for farmers to afford fertilisers. However, Mensah, Villamor, and Vlek (2018) reported that access to credit was not statistically significant to fertiliser usage among the group of farmers.

(e) Unfavourable climatic conditions

The variable unfavourable climatic conditions also had a positive coefficient of (2.012) and statistically significant at the 1% level. This indicate that an increase in unfavourable climatic conditions greatly increase the likelihood of farmers' inability to use chemical fertilisers, with the odds being about (7.476) times higher. Environmental conditions pose an inherent risk to agriculture, and environmental conditions determine, in part, the type and amount of inputs chosen for production. Farmers' decisions to use chemical fertilisers are highly influenced by climate variability (Heisse and Morimoto, 2024). These findings concur with findings from Dercon and Christiaensen (2011) and Arslan, Belotti, and Lipper (2017) who reported that higher rainfall and temperatures variability reduces the probability that farmers will apply chemical fertiliser on their crops in any given year.

4.4.3 Factors constraining smallholder crop farmers use of chemical pesticides

Table 20 shows the binary logistic regression results illustrating the association between the selected explanatory variables that constrain the use of chemical pesticides. The results of the goodness-of-fit test as demonstrated by the logit regression model, a Hosmere and Lemeshow (H-L) statistic test confirmed that the model's predictors align well with the observed outcomes. The H-L goodness-of-fit test showed a Chi-square value of 5.199 with a p-value of

0.736. Since the p-value exceeded common significance thresholds ($p<0.05$ and $p< 0.01$) indicating that the model was a good fit as the rule of the thumb for accepting a logit model is that the H-L static must be greater than 0.05 and it should show non-significance (Hosmer, Jovanovic, and Lemeshow, 1989).

The explanatory variables selected and interpreted in Table 20 were measured for their relevance in chemical pesticides usage of the participants. However, only four (4) variables were found to be significant in constraining the use of chemical pesticides. These variables are gender, main source of off-farm income, cooperative membership, and lack of social connection. The other ten (10) variables were not significant. One (1) of the significant variables had a negative sign (gender), implying that an increase in these variables may be associated with a decrease likelihood of chemical pesticides usage. The other three (3) of the significant variables had positive signs (main source of off-farm income, cooperative membership, and lack of social connection), implying that an increase in these variables may be associated with an increasing likelihood of not using chemical pesticides.

Table 20: Binary logistic regression results illustrating the association between the selected explanatory variables that constrain the use of chemical pesticides

Independent Variables	B	S.E.	Wald	df	Sig.	Exp(B)	95% Confidence Interval for Exp(B)	
							Lower	Upper
Gender	-1.143	.308	13.763	1	<.001***	.319	.174	.583
Age group(years)	.270	.270	1.000	1	.317	1.309	.772	2.221
Level of education	.018	.107	.027	1	.870	1.018	.824	1.256
Main source of off-farm income	.0863	.435	3.937	1	.047**	2.371	1.011	5.564
Main source of on-farm income	.068	.059	1.313	1	.252	1.070	.953	1.201
Main reason of farming	.127	.135	.885	1	.347	1.136	.871	1.481
Farm size(ha)	-.120	.338	.125	1	.723	.887	.457	1.722
Land ownership	.081	.140	.337	1	.561	1.085	.824	1.428
Cooperative membership	.671	.337	3.974	1	.046**	1.957	1.011	3.785
Inadequate knowledge on inputs	.116	.291	.159	1	.690	1.123	.635	1.985
High perceived risk	-.417	.307	1.841	1	.175	.659	.361	1.204
Limited access to credit	-.458	.297	2.380	1	.123	.633	.354	1.132
High input costs	.343	.299	1.314	1	.252	1.409	.784	2.534
Lack of social connections	.582	.298	3.818	1	.051**	1.789	.998	3.206
Constant	-2.700	1.819	2.203	1	.138	.067		

Hosmere-Lemeshow chi-square = 5.199 (p=.736) *Number of observations*= 308

and * = 5% and 1%

Source: Survey data (2024)

(a) Gender

In the study, gender was found to negatively influence the use of chemical pesticides with a coefficient of (-1.143) and statistically significant at the 1% level. This indicates that female farmers (dominant group) are less likely to use chemical pesticides compared to their counterpart, with the odds being (0.319) which is 68.1% less likely to use. This may be due to the traditional belief that chemical pesticide spraying is a male dominated activity. These findings corroborate with Ochago (2018) who found that most men (52%) compared to women (36%) were reported to apply chemical pesticides and noted that pesticide application was generally considered a man's role in the community. Furthermore, Alem, Bezabih, Kassie, and Zikhali (2010), Wossen (2018), and Doss (2018) argues that women in Sub-Saharan Africa tend to be poor and face discrimination in accessing complementary productive inputs.

(b) Main source of off-farm income

Main source of off-farm income had a positive coefficient of (0.863) and statistically significant at the 5% level. This indicate that an increase in off-farm income increases the likelihood of SCFs not using chemical pesticides, with the odds (2.371) of a farmers being 137.1% times more likely. This might be because the higher the off-farm income the more farmers want to explore and use practices that minimise or eliminate the use of chemical pesticides, prioritising sustainability and market trends over chemical interventions. These results concur with Caulfield, Bouniol, Fonte, and Kessler (2019) and Zhang et al (2020) who noted that the diversification of income sources through off-farm employment enhances farmers' capacity to manage and mitigate risks in household income and agricultural production, thereby facilitating the use of eco-friendly farming techniques. In contrary, off-farm employment increases the farmers' exposure to information and knowledge, which enhances their receptivity to new technologies and thus their demand for a variety of different technologies (Shi, Heerink, and Futian, 2011; Chang and Mishra, 2012).

(c) Cooperative membership

Based on Table 20, co-operative membership had a positive coefficient of (0.671) and was statistically significant at the 5% level. This suggest that an increase in the decision of farmers joining cooperatives the more likely their inability to use chemical pesticides with an odd ratio of (1.957) times which means about 95.7% likelihood. This might be because of that cooperatives can promote sustainable farming practices and reduce reliance on chemical pesticides by fostering information sharing, providing alternative resources, and priorities market preferences for environmentally friendly products. According to Zhu and Wang (2024), through cooperative there is an increased probability of reducing the use of chemical pesticides among farmers. Similarly, Ma, Zheng, and Nnaji (2023) found that t cooperative membership significantly increases the probability of adopting physical pest control practices (e.g., pest-killing lamps or sticky plate traps) and biological pest control practices (e.g., bio chemical pesticides) by 6% and 19%, respectively. Furthermore, noted that cooperative membership significantly reduces chemical pesticide expenditures through its mediation effect on improving the probability of using biological pest control practices.

(d) Lack of social connections

Lack of social connections had a positive coefficient of (0.582) and was statistically significant at the 5% level. This shows that an increase in lack of social connections increases the likelihood of farmers not to use chemical pesticides with an odd ratio of (1.789) times more likely which give about 78.9% chances of not using. This indicates that social connections may have a role in overcoming constraints. A reason for this might be that lack of social connections can limit access to information, support, and collaboration, which may result in farmers not being aware of the available chemical pesticides to use for their specific crops. Sponsler, Grozinger, Hitaj, Rundlöf, Botías, Code, Lonsdorf, Melathopoulos, Smith, Suryanarayanan, and Thogmartin (2019) and Hu (2020) noted that farmers apply chemical pesticides based on associated information; therefore, information provision regarding chemical pesticides are of particular importance to pesticide usage.

4.4.4 Factors constraining smallholder crop farmers use of irrigation system

Table 21 shows the binary logistic regression results illustrating the association between explanatory variables that constrain the use of irrigation system. The results of the goodness-of-fit test as demonstrated by the logit regression model, a Hosmere and Lemeshow (H-L) statistic test confirmed that the model's predictors align well with the observed outcomes. The H-L goodness-of-fit test showed a Chi-square value of 5.153 with a p-value of 0.741. Since the p-value exceeded common significance thresholds ($p<0.05$, $p<0.001$, and $p< 0.10$) indicating that the model was a good fit as the rule of the thumb for accepting a logit model is that the H-

L static must be greater than 0.05 and it should show non-significance (Hosmer, Jovanovic, and Lemeshow, 1989).

The explanatory variables selected and interpreted in Table 21 were measured for their relevance in irrigation system usage of the participants. However, only three (3) variables were found to be significant in constraining the use of irrigation systems. These variables are age group, main source of off-farm income, and high input costs. The other eleven (11) variables were not significant. All three (3) of the significant variables had negative signs, implying that an increase in these variables may be associated with a decrease in the likelihood of using irrigation system.

Table 21: Binary logistic regression results illustrating the association between the selected explanatory variables that constrain the use of irrigation system

Independent Variables	B	S.E.	Wald	Df	Sig.	Exp(B)	95% Confidence Interval for Exp(B)	
							Lower	Upper
Gender	.044	.258	.029	1	.865	1.045	.630	1.732
Age group(years)	-.412	.220	3.491	1	.062*	.663	.430	1.020
Level of education	-.089	.090	.966	1	.326	.915	.766	1.092
Main source of off-farm income	-.788	.406	3.765	1	.052**	.455	.205	1.008
Farm size(ha)	-.174	.277	.392	1	.531	.841	.488	1.448
Land ownership	-.145	.125	1.337	1	.248	.865	.677	1.106
Cooperative membership	-.305	.287	1.130	1	.288	.737	.420	1.294
Inadequate knowledge on inputs	-.054	.247	.048	1	.826	.947	.584	1.536
Limited access to credit	-.223	.247	.815	1	.367	.800	.493	1.299
High input costs	-.645	.247	6.786	1	.009***	.525	.323	.853
Lack of social connections	.170	.247	.475	1	.491	1.186	.730	1.925
Lack of access to water	.079	.244	.104	1	.747	1.082	.671	1.745
Lack of access to power	-.007	.252	.001	1	.977	.993	.606	1.627
Constant	4.113	1.420	8.387	1	.004	61.113		

Hosmere-Lemeshow chi-square = 5.153 (p=.741)   *Number of observation* = 308
***, **, and * = 1%, 5%, and 10%

Source: Survey data (2024)

(a) Age group (years)

The variable age group had a negative coefficient of (-0.412) and was statistically significant at the 10% level. This suggest that for every unit increase in age group, the lesser the likelihood of older farmers use of irrigation system, meaning that older farmers are less likely to use irrigation systems compared to younger farmers. The estimated odds ratio (0.663) indicates that an increase in age group, the likelihood of using irrigation system decrease by 33.7% among older farmers. The reason might be that older farmers prefer their traditional farming practices as they are familiar with and resistant to use new technologies, including irrigation systems. Ekepu and Tirivanhu (2016) indicated that the older the farmer, the more experience had been gained, which makes it even easier for them to implement innovations than the young farmers. On the other hand, Serote, Mokgehle, Du Plooy, Mpandeli, Nhamo, and Senyolo (2021) and Yazdanpanah, Zobeidi, Mirzaei, Löhr, Warner, Lamm, Rouzaneh, and Sieber (2023) found similar results, which reported that the effect of age on the probability of using modern irrigation technologies was positive and significant

(b) Main source of off-farm income

The variable main source of off-farm income as shown in Table 21 was found to have a negative coefficient of (-0.788) and was statistically significant at the 10% level. This indicate that an increase in off-farm income the lesser the likelihood of farmers using irrigation systems, with estimated odds of (0.455) 54.5% times less likely. This might be because an increase in off-farm income can lead farmers to rely on existing practices, prioritize other investments, and perceive less need for irrigation systems. Similar findings were obtained by Abdulai and Huffman (2014) and Hussen and Hussen (2024). However, Hadush (2014) and Astatike (2016) discovered that off-farm activities positively increase the amount of irrigation involvement.

(c) High input costs

The variable high input costs had a coefficient of (-0.645) and was statistically significant at the 1% level. The negative coefficient value indicates that the higher the cost of inputs such as irrigation system, the lesser the likelihood of farmers use of irrigation system as they are considered expensive to purchase. The estimated odds ratio of (0.525) suggests that farmers are 47.5% less likely to use irrigation systems. These results concur with Hards and Du Plessis (2013) and Mkuna and Wale (2023) who highlighted that high initial costs as well as high fuel costs for the operation of the pressure pumps have been the major constraints in relation to wide spread utilisation of a certain irrigation system by SCFs.

4.5 Chapter Summary

This chapter presented and discussed the results of the descriptive analysis, PSM, and binary logistic regression analysis of SCFs in the study area.

Demographic characteristics of smallholder crop farmers

The demographic characteristics of the SCFs included variables such as gender, age group, marital status, level of education, household size, off-farm and on-farm income sources, years of farming experience, farm size, land ownership, primary reasons for farming, and cooperative membership. Descriptive statistics such as frequencies and percentages, were used to analyse the characteristic of the surveyed farmers, with results presented in tables and graphs.

The study results indicated that 59.4% of the SCFs in the study area were females. The study also found that there are older farmers (46.4%) that are farming than younger farmers and that most of the SCFs are married (43.8%). In terms of education attainment, the results revealed that the farmers had no formal education (26.3%). Household sizes from the surveyed farmers were found to have 4 to 6 members (45.8%). The results showed that old age pension (31.5%) was the main source of off-farm income for the farmers and majority (89.3%) depend on the sales of vegetables as a main source of on-farm income.

The results indicated that the years of farming experience the SCFs have is 6 to 10 years (35.1%) with the majority (79.9%) holding farm sizes of 5 hectares or less and 70.8% owning the land they are farming on. The results also showed that the majority (91.6%) of the farmers in the study area fall in the category of farming for household consumption and income generation as their main reason of farming. This shows that the majority (91.6%) of farmers in the study area are smallholder farmers Type 2 as categorised by the National Policy on

Extension and Advisory Services. It was revealed that even though the farmers in the area are SCFs' type 2, majority of the farmers are not members of the cooperatives.

First objective: To investigate the agricultural support received by smallholder crop farmers through agricultural innovation system

This objective analysed the agricultural support services received by the surveyed farmers, focusing on the types of support, their main providers, and the specific services received. The types of extension support assessed included financial support, technical advisory support, infrastructure support, input support, and training support. Descriptive statistics such as frequencies, percentages, and cross-tabulations were used, with results presented in tables and graphs.

The study results revealed that input support (71.4%) was the most frequently received, followed by financial support (70.1%) and training support (67.5%). However, it was found that technical advisory support was provided the lowest and infrastructure support was found to be the most lacking. The farmers indicated that their main providers of extension support were DARDLEA, Timbali Technology Incubators, ARC, Standard Bank, AgriSETA, and SEDA. Among the main providers, it can be observed that DARDLEA is the most prominent, providing all types of extension support to the significant majority of the farmers.

The farmers indicated that they received input vouchers (94.4%) and short-term loans (5.6%), as a form of financial support services. Based on the technical advisory support offered, farmers indicated that they received advice on best crop management practices as the most common service, assistance with soil testing, assistance with funding applications, recommendations on how to reduce risks associated with farming and linkages to relevant service provide. Irrigation systems, pack houses and fencing were one of the infrastructure support services received by farmer. However, greenhouse tunnels and road maintenance services were not provided to any of the farmers. Improved seeds were the most common type of input support services received by farmers followed by chemical fertilisers, chemical pesticides and tractor, respectively. Hybrid vegetable seedlings were not provided to any of the sampled farmers. The results generally showed that farmers in the study area received training in market access, sustainable use of resource, farm record-keeping, financial planning and crop protections as the most

(43.3%), common type of training support service received. Training in drought mitigation strategies was received by few farmers (8.2%).

Second objective: To assess the impact of agricultural innovations on crop productivity of smallholder crop farmers

This objective assessed the impact of specific agricultural innovations namely, improved seeds, chemical fertilisers, chemical pesticides, and irrigation systems on crop yields as a proxy of productivity. The main vegetable and agronomic crops with the highest cultivation percentages were identified including tomatoes, cabbage, chillies and maize. PSM was used to estimate the impact of these agricultural innovations on crop yields. According to the results presented in all the probit regression models, all the independent variables that determines farmers use of each innovation were gender, age group, level of education, main source of off-farm income and cooperative membership. Only those variables that had a significant effect on the use of each innovation were discussed. From the probit regression models, propensity scores for each type of innovation were generated.

The results from the ATT indicated that improved seeds have a positive and significant effect on crop yield of all the four crops and increases tomatoes yield by 6.941 tons/ha, cabbage by 8.905 tons/ha, chillies by 2.197 tons/ha and maize by 3.859 tons/ha. It was found that chemical fertilisers have a positive and significant impact on tomatoes, chillies, and maize and it increases their yield by 7.541 tons/ha, 3.318 tons/ha and 5.055 tons/ha respectively. However, the results indicated that chemical fertiliser have no significant impact on cabbage. The results showed that chemical pesticides have a positive and significant impact on tomatoes and chillies with the increase in yields by 6.703 tons/ha and 1.294 ton/ha. Cabbage and maize were not significantly impacted by chemical pesticides even though cabbage had the highest yield among the four crops. The study found out that irrigation systems have a positive and significant impact in all the four crops. The results indicated that irrigations systems increases tomatoes yield by 7.273 tons/ha, cabbage by 8.851 tons/ha, chillies by 3.196 tons/ha and maize by 2.471 tons/ha

Based on the results, the use of improved seeds, chemical fertilisers, chemical pesticides and irrigation systems was associated with improved productivity, emphasising their importance in enhancing smallholder crop farmer outputs. However, the insignificant impact of the use of chemical fertilisers and chemical pesticides in cabbage and maize among farmers were pointed out, suggesting that further exploration is needed to understand the factors affecting their outputs.

Third objective: To examine the factors constraining smallholder crop farmers use of agricultural innovations for crop productivity enhancement

This objective analysed the constraints faced by SCFs in using agricultural innovations to enhance productivity. The results were categorized by innovation type, highlighting significant variables and their influence. Binary logistic regression model was used to analyse this objective and tables were used to present the results.

The study results showed that variables such as farmers gender (p=0.012**),** age group (p=0.034), lower education levels (p=0.032), limited access to credit (p=0.011) and inadequate knowledge (p=0.086), constrained farmers use of improved seeds. The study also revealed that gender, high perceived risk, and lack of access to credit reduced farmers' willingness to use chemical fertilisers. Variables such as off-farm income and unfavourable climatic conditions also increases the likelihood of farmers not using chemical fertilisers. The study did show that variable with a negative sign such as gender reduced the likelihood of farmers using chemical pesticides and variables with positive signs such as off-farm income, cooperative membership, and lack of social connection increased the likelihood of farmers not using chemical pesticides. In terms of using irrigation systems, the study revealed that age group, main source of off-farm income and high input cost reduces the likelihood of farmers using irrigation systems.

This shows that there are constraints that influences farmers' willingness to use agricultural innovations and across all the innovations, gender, age group, lack of credit, and main source of off-farm income were recurring constraints.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

This chapter presents the conclusions drawn from the study's findings. Finally, it provides recommendations aimed at advancing the Agricultural Innovation System (AIS) and supporting the development of the smallholder crop farming community, with a particular focus on fostering rural agricultural development and alleviating poverty. Additionally, it offers suggestions for future research to further explore and address the challenges and opportunities identified in this study.

5.2 Conclusion

It has been mentioned that in the modern history of developing countries including South Africa the role played by the AIS in facilitating collaboration between multiple actors including farmers to bring innovation into agricultural use through conducive policies cannot be ignored. The importance of AIS in providing agricultural research-based knowledge, providing agricultural support, and introducing innovations aim to improve productivity, sustain livelihoods, create jobs, mobilise resources efficiently, enhance food security, and promote sustainable agricultural development. This study aims to investigating the impact of AIS on the productivity of SCFs in Mbombela Local Municipality.

The study revealed that most of SCFs in the study area are females, with a significant proportion of older farmers actively involved in farming compared to young farmers. However, a notable concern is the low education attainment among the SCFs, as the majority lacked formal education. Economically, the SCFs mostly depend on old age pensions as a primary source of off-farm income, while vegetable sales found to be the main source of on-farm income. In terms of farming experiences, most SCFs had been involved in farming for 6 to 10 years primarily on small plots of 5 hectares or less. SCFs in the area, mainly engaged in farming for household consumption and income generation, classifying them as Type 2 smallholder farmers according to the National Policy on Extension and Advisory Services. Despite the potential benefits of cooperative membership, most SCFs are not members of cooperatives. These findings highlight the reliance on smallholder farming for livelihoods.

The study shows that input support was the most received type of extension support among smallholder crop farmers in the study area, followed by training support, while technical advisory support was less common, and infrastructure support was the most lacking. The main providers of agricultural support included DARDLEA, Timbali Technology Incubators, ARC, Standard Bank, AgriSETA, and SEDA, with DARDLEA being the most prominent. Financial services received by SCFs mainly consisted of short-term loans and input vouchers, while technical advisory services included advice on best crop management practices, assistance on soil testing and funding application, recommendations on farming risk reduction, and linkages to relevant service provide. Infrastructure services such as irrigation systems and fencing was provided, whereas greenhouse tunnels and road maintenance services were not provided. Input support services provided were improved seeds, chemical fertilisers, chemical pesticides, and tractors. Training focused on market access, sustainable resource use, and financial planning, with limited emphasis on drought mitigation strategies. Overall, these results give emphasis to the importance of government and development agencies in providing agricultural extension services to farmers while highlighting critical gaps, especially in infrastructure support.

The Average Treatment on the Treated (ATT) results demonstrated that agricultural innovations, such as improved seeds, chemical fertilisers, chemical pesticides, and irrigation systems significantly impact the crop yield of smallholder farmers in Mbombela Local Municipality. Improved seeds and irrigation systems positively impacted yields of tomatoes, cabbage, chillies, and maize, while chemical fertilisers significantly increased yields of tomatoes, chillies, and maize but had no significant effect on cabbage yields. Chemical pesticides significantly increased the yields of tomatoes and chillies but did not significantly influence cabbage and maize yields. These findings emphasise the critical role of using agricultural innovations, particularly improved seeds and irrigation systems, in enhancing productivity, while also highlighting gaps in the effective use of chemical fertilisers and chemical pesticides.

Socio-economic characteristics such as gender, age group, level of educations, off-farm income, and cooperative membership, along with financial and knowledge constraints, hinder SCFs use of agricultural innovations in the study area. Addressing these challenges through targeted interventions, such as improving access to credit, providing training, and reducing input costs, is essential for enhancing productivity, promoting sustainable farming practices, and supporting the effective use of agricultural innovations in smallholder farming systems.

5.3 Recommendations

Based on the empirical findings of this study, the following recommendations are proposed for various stakeholder within the Agricultural Innovation System (AIS) to enhance the productivity of smallholder crop farmers (SCFs) in Mbombela Local Municipality. These recommendations are targeted to address the specific constraints and leverage the positive impacts identified.

5.3.1 Recommendations for the Department of Agriculture, Rural Development, Land and Environmental Affairs (DARDLEA) and provincial government

As the primary support provider, DARDLEA is central to improving AIS functionality.

- **Shift from a uniform to a differentiated support strategy:** The one-size-fits-all approach to input support is ineffective. DARDLEA should:

Develop crop-specific input packages: Discontinue the blanket distribution of chemical fertilisers and pesticides. For cabbage production, where these inputs showed no significant yield impact, support should be reallocated to integrated pest management (IPM) training and organic soil amendments. For tomatoes, chilies, and maize, where impacts were significant, continue and improve access to these inputs.

Segment extension services: Tailor programs for specific farmer cohorts. For the dominant older farmer population, use practical, hands-on demonstration plots to showcase the benefits of improved seeds and irrigation, overcoming knowledge gaps and risk aversion. Develop targeted programs for women farmers to facilitate their access to and knowledge of fertilisers and pesticides, potentially through women's cooperatives.

- **Address the critical infrastructure deficit:** The near-total lack of infrastructure support (95.5%) is a major bottleneck. Policy must pivot from solely providing consumable inputs to co-investing in productive assets.
  Prioritise the development of shared infrastructure, such as communal pack houses and improved rural access roads, to reduce post-harvest losses and improve market access.

This will increase farm profitability, making farmers less dependent on off-farm income and more willing to invest in productivity-enhancing inputs.

- **Enhance the quality and reach of financial and technical support:**

Broaden financial support: Move beyond input vouchers by facilitating partnerships with financial institutions to develop low-collateral, short-term input loans for farmers, addressing the critical constraint of limited access to credit.

Improve technical advisory: Increase the capacity for and frequency of soil testing services. Provide clear, crop-specific fertiliser and pesticide recommendation charts to farmers to combat inadequate knowledge and the perceived risks of misuse.

5.3.2 Recommendations for financial institutions (e.g., Standard Bank, Land Bank)

The findings show a severe gap in formal financial products for SCFs.

- **Develop and promote context-appropriate financial products:** Financial institutions should design products that cater to the realities of smallholders.
  Create low-collateral, short-term "input loans" specifically for the purchase of improved seeds, fertilisers, and pesticides, the innovations proven to boost yields. These loans should be disbursed timely, aligned with the planting season.
  Bundle these financial products with basic financial literacy and farm record-keeping training to improve loan utilization and repayment rates.

5.3.3 Recommendations for research and training institutions (e.g., ARC, AgriSETA)

- **Focus on context-driven research and training:**

ARC should conduct localised research to understand why chemical fertilisers and pesticides are ineffective for cabbage in this specific agro-ecology and develop alternative, effective soil and pest management strategies.

AgriSETA and other trainers should develop practical training modules focused on the operational use and maintenance of irrigation systems and the correct application of chemical inputs, directly addressing the knowledge gaps identified.

5.3.4 Recommendations for Farmer Cooperatives and Associations

- **Improve internal governance and service delivery:** For cooperatives to be effective, they must deliver tangible benefits to their members. Cooperatives should focus on improving transparency and actively facilitating bulk purchase of inputs (to lower costs) and better market linkages for their members. This would make membership more valuable and help overcome constraints related to high input costs and lack of social connections.

5.4 Implications for future research

The suggestions below aim to deepen the understanding of AIS and their broader implications for productivity, sustainability, and rural development.

- The current study concentrated on SCFs. Expanding the scope to include livestock farmers could offer a more holistic perspective on agricultural practices and their impact within the district or province.

- Further studies could compare the efficiency and impact of extension service providers, including public, private, and NGO entities. This comparison would help identify strengths and weaknesses, contributing to improved extension support for farmers.

- This study focused on four primary yield-increasing innovations. Future research could explore the full spectrum of agricultural innovations, such as mechanisation, agroforestry, or digital tools, to assess their collective and individual impacts on productivity and livelihoods.

- Future research could investigate strategies to overcome barriers to innovation use, such as socio-economic challenges, limited financial access, and knowledge gaps. Identifying and addressing these constraints could enhance the effectiveness and usage of agricultural innovations among smallholder farmers.

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APPENDIX 1

Questionnaire

INFORMATION LEAFLET

Researcher: Prayer Monamodi (201995670)

Supervisor:

Name: Dr JT Ndoro

Telephone: 013 002 0166

E-mail address: jorine.ndoro@ump.ac.za

Co-Supervisor:

Name: Dr MB Matiwane

Telephone: 013 002 0374

E-mail address: mona.matiwane@ump.ac.za

Dear Potential Research Participant,

I am, Prayer Monamodi, a Master of Agriculture in Agricultural Extension and Rural Resource Management student at the University of Mpumalanga, in the school of Agricultural Sciences and faculty of Agriculture and Natural Sciences You are invited to participate in a research project titled Impact of Agricultural Innovation System on Productivity of Smallholder Crop Farmers' in Mbombela Local Municipality.

Research objectives.

1. To investigate the agricultural support received by smallholder crop farmers through AIS.
2. To assess the impact of agricultural innovations on productivity of smallholder crop farmers.
3. To examine the factors constraining smallholder crop farmers use of agricultural innovations for productivity improvement.

If you decide to take part in the study, you will be required to do the following:

- Sign this informed consent form

Questionnaire

The questions are strictly for the purpose of this research study. Please note that your participation in answering this questionnaire is completely voluntary and you are allowed to withdraw any time should you wish to. Your name will not be recorded anywhere, and no one will be able to connect you to the answers you give. Your answers will be given a code number, or a pseudonym and you will be referred to in this way during data analysis and discussion of results in the research report. All responses will be summed together as a group with other respondents with no reference to individuals. This research is strictly for educational or academic purposes.

Your co-operation and participation in the study will be greatly appreciated. Please sign the informed consent below if you agree to participate in the study.

Kindly, answer each question honestly and accurately as your participation in this process is essential to the success of this study.

Yours faithfully

____

Prayer Monamodi

Questionnaire

CONSENT FORM

1. I __ *(name of participant)* ______________________ agree to participate and am voluntarily taking part in this research project.
2. I understand that I have the right to withdraw from the study at any time and may choose no longer to participate without having to explain myself.
3. I am aware that the information I provide on the questionnaire is for educational / academic purposes.
4. I understand that my name will not be recorded.
5. I have been provided with, have read, the information leaflet regarding this research study.
6. I have had the opportunity to ask any questions related to this study, and received satisfactory answers to my questions, and any additional details I wanted.
7. I agree to answer the questions to the best of my ability.
8. I understand that I may refuse to answer any questions that I do not feel comfortable answering.
9. By signing this letter, I give free and informed consent to participate in this research study.

DATE			
PARTICIPANT SIGNATURE			
RESEARCHER NAME	Prayer Monamodi	RESEARCHER SIGNATURE	

This research is being conducted by Prayer Monamodi.

Telephone: 079 910 0908 E-mail: 201995670@ump.ac.za

If there are any further questions about the research study or the questions itself, please contact the Supervisor (Dr. JT Ndoro) at UMP. The Supervisor's contact details are as follows:

Supervisor

Tel: 013 002 0166 E-mail: jorine.ndoro@ump.ac.za

Co-Supervisor:

Tel: 013 002 0374 E-mail: mona.matiwane@ump.ac.za

This research project has received ethical approval from the School Research Ethics Committee

UNIVERSITY OF MPUMALANGA

Questionnaire

SECTION A: DEMOGRAPHIC INFORMATION

(Tick √ or a cross X on the appropriate box ☐)

NO	QUESTIONS	OPTIONS							
1.	Gender	☐ Male	☐ Female						
2.	Age group (years)	☐ 15-34	☐ 35-59	☐ 60 and above					
3.	Marital status	☐ Single	☐ Married	☐ Divorced	☐ Widowed				
4.	Level of education	☐ No formal education	☐ Primary	☐ Secondary	☐ Matriculated	☐ ABET	☐ Higher certificate	☐ Diploma	☐ Degree and above
5.	Other certificate(s)	☐ Completion of training	☐ Completion of a short course	☐ Attendance	☐ Other, specify....				
6.	Household size	☐ 1 – 3	☐ 4 – 6	☐ 7 and above					
7.	Main source of off-farm income	☐ None	☐ Salary	☐ Wage	☐ Remittance	☐ Pension	☐ Child support grant	☐ Foster child grant	☐ Disability grant
		☐ Social relief grant	☐ Other, specify....						
8.	Main source of on-farm income	☐ Sales of vegetable crops	☐ Sales of agronomic crops						

Questionnaire

9.	Years of farming experience	☐ ≤ 5	☐ 6 – 10	☐ 11 – 20	☐ ≥ 21					
10.	Farm size (ha)	☐ ≤ 5	☐ 6 – 10	☐ 11 – 2 0	☐ 21 – 30	☐ 31 – 40	☐ ≥ 41			
11.	Land ownership	☐ Own	☐ Renting	☐ Tribal authority	☐ Land reform					
12.	Main reason for farming	☐ Household consumption	☐ Household consumption and income generation	☐ Income generation						
13.	Co-operative membership	☐ Yes	☐ No							
14	Access to water for irrigation	☐ Yes	☐ No							
15	Main source of water for irrigation	☐ River	☐ Dam	☐ Borehole	☐ Other, specify....					

Questionnaire

SECTION B: AGRICULTURAL SUPPORT SERVICES RECEIVED BY SMALLHOLDER CROP FARMERS

(Tick √ or a cross X on the appropriate box ☐)

NO	QUESTIONS		OPTIONS
16.	**Have you received financial support? Yes ☐ No ☐ If yes, who is the main provider?**		**Which one(s)?**
☐ DARDLEA		☐ Timbali	☐ Microcredit loan for purchasing production inputs
☐ Grain SA		☐ Land Bank	☐ Short-term loan for purchasing production inputs
☐ Standard Bank		☐ Nedbank	☐ Input voucher for purchasing production inputs
☐ ABSA		☐ FNB	☐ Land redistribution grant for acquiring agricultural land
☐ MADC		☐ MAFISA	☐ Crop insurance for protection against unforeseen production risks
☐ Other, specify….			☐ Other, specify….
17.	**Have you received technical advisory support? Yes ☐ No ☐ If yes, who is the main provider?**		**Which one(s)?**
☐ DARDLEA		☐ ARC	☐ Technical advice on best crop management practices
☐ LIMA		☐ Timbali	☐ Assistance with soil testing which involve the analyses of soil properties and conditions
☐ Grain SA		☐ AFRGRI	☐ Assistance with the entire process of request application for funding
☐ Co-operative			☐ Recommendation on how to reduce risks associated with farming
☐ Other, specify….			☐ Linkages with other service providers within the agricultural industry ☐ Other, specify….
18.	**Have you received infrastructure support? Yes ☐ No ☐. If yes, who is the main provider?**		**Which one(s)?**
☐ DARDLEA		☐ DPWRT	☐ Installation of irrigation system for consistent water supply to crops

☐ ARC	☐ LIMA	☐ A pack house for sorting produce for immediate sale
☐ Co-operatives	☐ Grain SA	☐ A tunnel providing a controlled environment which helps to extend growing season
☐ Other, specify....		☐ Installation of a fence to help keep animals away from the crops
		☐ Maintenance of roads for easier transportation of goods in and out of the farm
		☐ Other, specify...
19.	**Have you received input support? Yes ☐ No ☐. If yes, who is the main provider?**	**Which one(s)?**
☐ DARDLEA	☐ Grain SA	☐ Improved seeds for high-yielding potential
☐ AFGRI	☐ ARC	☐ Hybrid vegetable seedlings
☐ Alzu	☐ LIMA	☐ Chemical fertilizers for crop growth
☐ Timbali	☐ Co-operative	☐ Chemical pesticides for crop protection against pest and diseases
☐ Other, specify....		☐ Tractor with mechanized implements for cultivation
		☐ Other, specify...

20.	**Have you received training support? Yes ☐ No ☐ If yes, who is the main provider?**	**Which one(s)?**
☐ DARDLEA	☐ Grain SA	☐ Crop management
☐ AFRGRI	☐ ARC	☐ Available market access opportunities
☐ AgriSETA	☐ SEDA	☐ Sustainable use of resources
☐ LIMA	☐ Co-operative	☐ Farm record keeping

☐ Other, specify	☐ Business Financial planning
	☐ Other, specify

Questionnaire

SECTION C: IMPACT OF AGRICULTURAL INNOVATIONS ON RODUCTIVITY OF SMALLHOLDER CROP FARMERS

(Tick √ or cross X on the appropriate box ☐) the information of the last cropping season (2023/2024)

NO	QUESTION	OPTIONS
21	**Are you using yield-increasing innovation(s) to produce?**	**If yes, which one(s) are you using?**
Improved seed varieties Yes ☐ No ☐		☐ High-yielding
		☐ Disease resistant
		☐ Drought tolerant
		☐ Other, specify…
Chemical fertilizers Yes ☐ No ☐		☐ NPK
		☐ LAN
		☐ Lime
		☐ Other, specify…
Chemical pesticides Yes ☐ No ☐		☐ Insecticide
		☐ Herbicide
		☐ Fungicide
		☐ Other, specify…

Irrigation system Yes ☐ No ☐	☐ Drip
	☐ Sprinkler
	☐ Other, specify….
	☐ Other, specify…
☐ Other, specify…	

Questionnaire

22. Based on your answers in question 21, please fill the information for the last cropping season (2023/2024) in the table below indicating the crop yield(s) obtained

(Tick √ or cross X on the appropriate box ☐)

	2023/2024		
Main crop(s) grown	**No. of new cultivated grown**	**Cultivated area (ha)**	**Yield obtained (ton/ha)**
Vegetables			
☐ Tomatoes			
☐ Cabbages			
☐ Spinach			
☐ Lettuce			
☐ Other, specify….			
Agronomic crops			
☐ Maize			
☐ Groundnuts			
☐ Common beans			
☐ Cassava (Mjumbula)			
☐ Other, specify….			

Questionnaire

SECTION D: FACTORS CONSTRAINING SMALLHODER CROP FARMERS USE OF AGRICULTURAL INNOVATIONS

(Tick √ or cross X on the appropriate box ☐)

NO	QUESTION	OPTIONS	
Human capital			
23	Inadequate knowledge on the proper use of production inputs e.g. seeds, fertilizers, pesticides discourages me from utilising them	☐ Yes	☐ No
24	Lack of technical support limit my interest to invest in new production inputs	☐ Yes	☐ No
25	My fear of risks makes me hesitant to invest in new inputs due to fear of potential failure	☐ Yes	☐ No
Financial capital			
26	Limited access to credit influences my ability to acquire essential inputs such as seeds, fertilisers, pesticides for optimal crop production	☐ Yes	☐ No
27	My dependence on input subsidies discourages me from seeking out additional production inputs	☐ Yes	☐ No
28	High production input costs influence my ability to invest in farming inputs such as seeds, fertilisers, pesticides, irrigation	☐ Yes	☐ No
Physical capital			
29	Lack of access to reliable power makes it difficult for me to acquire an electric operating irrigation system	☐ Yes	☐ No
30	Poor farm roads affect my transportation of farming production inputs in the farm	☐ Yes	☐ No
31	Lack of market discourages me from investing in production inputs which will increase crop output	☐ Yes	☐ No
Natural capital			
32	Lack of access to land hinder my ability to acquire production inputs	☐ Yes	☐ No

33	Unfavourable climatic conditions make it difficult to obtain necessary inputs like seeds hence they may not perform well under adverse weather conditions	☐ Yes	☐ No
34	Insufficient water supply limit my usage of irrigation systems, affecting my ability to grow crops effectively	☐ Yes	☐ No
Social capital			
35	Limited social connections hinder my ability to acquire information about improved production inputs	☐ Yes	☐ No
36	Lack of trust among members of the group I am part of hinders our efforts to jointly purchase production inputs	☐ Yes	☐ No
37	Not being a cooperative member hinders my ability to acquire a tractor provided by the department for sharing	☐ Yes	☐ No

THANK YOU FOR YOUR TIME!

APPENDIX 2

UNIVERSITY OF MPUMALANGA

Creating Opportunities

B Maoneke (PhD)

School of Computing and Mathematical Sciences

Mbombela Campus.

Dear Prayer Monamodi

Protocol Reference Number: UMP/Monamodi/201995670/MAGR/2024

Project Title: Impact of Agricultural Innovation System (AIS) on Productivity of Smallholder Crop Farmers in Mbombela Local Municipality.

Approval Notification: In response to your application received on **15/01/2024,** The Research Ethics Committee Faculty Research Ethics Committee has considered the above mentioned application and the protocol has been granted **FULL APPROVAL.**

Any alteration/s to the approved research protocol i.e. Questionnaire/Interviews 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 stored securely in the School/ division for a period of 5 years.

The Ethical Clearance certificate is only valid for a period of 3 years from date of issue. Thereafter, Recertification must be applied for on an annual basis.

Wishing you the best with your study.

Yours faithfully,

....

B Maoneke (Chair)

Cc: Faculty Research & Innovation Committee Chair.............................. M. Barbe

DECLARATION OF INVESTIGATOR(S)

I/We fully understand the conditions under which I am/we are authorised to carry out the abovementioned research and guarantee to ensure compliance with these conditions. I agree to completion of a yearly progress report.

.... 05/03/2024

Signature Date

PLEASE QUOTE THE PROTOCOL NUMBER ON ALL ENQUIRIES

APPENDX 3

UNIVERSITY OF MPUMALANGA

FACULTY OF AGRICULTURE AND NATURAL SCIENCES

Postgraduate Studies Committee

Certificate of Approval – Research Proposal

Date of this Approval:	**27 September 2023**

Student Details

1	Student Name:	Monamodi, P
2	Student Number:	201995670
3	School	School of Agricultural Sciences
4	Degree Registered for:	MAgric
5	Date of First Registration:	2023
6	Supervisor(s):	Drs JT Ndoro & MB Matiwane

The research proposal entitled '**Impact of Agricultural Innovation System on productivity of smallholder crop farmers in Mbombela Local Municipality'** has been evaluated and approved by the Postgraduate Studies Committee of the Faculty of Agriculture and Natural Sciences.

Chairperson: Prof. Victor Mlambo

Signature:

Date & Official Stamp:

UNIVERSITY OF MPUMALANGA

28 -09- 2023

FACULTY OF AGRICULTURE AND NATURAL SCIENCES

APPENDIX 4

agriculture, rural development, land & environmental affairs
MPUMALANGA PROVINCE
REPUBLIC OF SOUTH AFRICA

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umNyango weZelimo UkuThuthukiswa kweeNdawo zemaKhaya, iNarha neeNdaba zeBhoduluko

Enq: Ms. Bester Masuku
Ext: 6728

Ms Prayer Monamodi
Stand No. 445, Elandsdoorn C
Dennilton
1030

RE: PERMISSION TO CONDUCT A STUDY IN THE DEPARTMENT OF AGRICULTURE, RURAL DEVELOPMENT, LAND AND ENVIRONMENTAL AFFAIRS

The request for Ms Prayer Monamodi to carry out a study on the **Impact of Agricultural Innovation System on productivity of smallholder crop farmers in Mbombela Local Municipality,** is hereby granted.

Take note that this authorisation is based on a mutual understanding that the Department of Agriculture, Rural Development, Land and Environmental Affairs and the departmental officials' names will not be mentioned anywhere in the study. Additionally, no information in the study will enable a third party to identify the name of the Department. The information provided by the employees or any other means (such as confidential archived documents or reports) of the Department is purely for academic purposes and cannot be used for any other purposes.

Regards

MR. C.M. CHUNDA
HEAD: AGRICULTURE, RURAL DEVELOPMENT, LAND AND ENVIRONMENTAL AFFAIRS
DATE: 24/10/22

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