FARMER-LED AGRICULTURAL PRODUCTION INTERVENTIONS THROUGH SUSTAINABLE FARMING PRACTICES FOR UNDERUTILIZED INDIGENOUS CROPS BY RURAL COMMUNITIES IN MPUMALANGA

Report to the
Water Research Commission of South Africa

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EXECUTIVE SUMMARY

Farmer-led agricultural production interventions using sustainable farming practices for underutilized crops are essential for rural communities facing the impacts of climate change. These approaches enhance food security, biodiversity, and climate resilience by promoting drought-tolerant and nutrient-rich crops. Additionally, sustainable practices such as crop diversification, conservation agriculture, and organic farming reduce environmental degradation while improving soil health and productivity. By empowering smallholder farmers with local knowledge, adaptive techniques, and market access, these interventions contribute to economic stability, environmental sustainability, and long-term agricultural resilience.

The Water Research Commission (WRC) has identified sustainable agricultural practices as a key strategy to mitigate the impacts of climate change. These practices focus on efficient water management, soil conservation, and climate-resilient farming techniques to enhance agricultural productivity while reducing environmental degradation. The report by the University of Mpumalanga (UMP), supported by the Water Research Commission (WRC), highlights significant efforts in promoting sustainable agricultural practices through underutilized indigenous crops in Mpumalanga. This comprehensive document underscores the importance of sustainable agricultural practices, participatory approaches, capacity-building, and technology transfer in empowering smallholder farmers in the Mbombela Municipality. The project was achieved in collaboration with stakeholders such as the Mpumalanga Department of Agriculture, Rural Development, Land and Environmental Affairs (DARDLEA), the Agricultural Research Council (Vegetable Industrial Medicinal Plants) and the National Agricultural Marketing Council (NAMAC) which necessitated the promotion of underutilized crops and sustainable cultivation practices. The study evaluated the smallholder farmers' adoption of sustainable agricultural practices through the following objectives:

- To assess the extent and knowledge towards sustainable agricultural practices by legume smallholder farmers.
- To determine challenges influencing the adoption of sustainable agricultural practices by legume smallholder farmers.
- To evaluate water requirements, yield and nutritional water productivity of selected underutilized crops in response to sustainable agricultural practices (mulching).
- To evaluate the nutritional composition of selected underutilized crops in response to sustainable agricultural practices (mulching).

A qualitative technique for exploring the existing literature review was established to address the study's aims. The literature evaluation focused on conducting a situational analysis of the past, present, and ongoing development of sustainable agricultural practices. This approach enabled a comprehensive understanding of the evolution of these practices, their effectiveness, and their role in addressing climate change, food security, and rural development. By systematically analysing scholarly articles, policy documents, and case studies, the study identified key trends, challenges, and opportunities in the adoption of sustainable farming interventions. Lastly, the sustainable agricultural practices were discussed as interventions and support systems for smallholder farmers.

The integrated approaches employing qualitative and quantitative methods were used to collect data on identifying sustainable agricultural practices adoption by smallholder farmers. For the quantitative research method, the questionnaires were administered by individual smallholder farmers to provide information on their perceptions towards the adoption of sustainable agricultural practices. The population that participated in this study was smallholder farmers residing in Mbombela Local Municipality (LM). The smallholder farmers in the Mbombela municipality were selected based on their ability to adopt sustainable agricultural practices.

Approximately 308 smallholder farmers were selected from the Mbombela LM using the Mpumalanga Department of Agriculture, Rural Development, Land and Environmental Affairs (DARDLEA) database for assessment based on their experience in sustainable agricultural practices. The selection criteria for participants included the following: actively practicing underutilized crops production, high dependency on irrigation for farming and owning irrigated land ranging between 1 to 5 hectares. The project was carried out in collaboration with local extension officers to ensure effective engagement and knowledge-sharing. To gather insights, group discussions were held in each municipality, involving both smallholder farmers and extension officers to assess challenges, opportunities, and best practices in irrigated underutilized crops.

The key findings of the report included the adoption of sustainable practices through probit regression analysis, which revealed a higher likelihood of farmers adopting sustainable practices in households with more members, showing the importance of labour availability. Gender dynamics showed that female farmers (62.30%) are the majority, highlighting their critical role in smallholder farming and sustainable practices for improving household livelihoods. Legume smallholder farmers in this study were less likely to embrace sustainable agricultural practices, as 33.06% of the participants were practicing crop rotation on their farms, 23.0% of the participants were practicing soil mulching, and 27.27% of the participants were practicing intercropping. However, 23.05% of participants were practicing organic manure, 10.39% did not practice sustainable agricultural practices and 4.22% practiced soil mulching on the farm. The results also revealed that financial constraints were the principal challenge affecting the adoption of sustainable agricultural practices. The key findings in this study are that the extent of adoption is not convincing, with the majority of 140 legume smallholder farmers utilising sustainable agricultural practices but not optimally at the rate of (25-50%), whereas a few of them (18 legume smallholder farmers) fully adopt sustainable agricultural practices at the rate of (75-100%). This study calls on the government to provide agricultural extension with the required skill and knowledge to ensure that legume smallholder farmers are exposed to other sustainable agricultural practices through training and workshops. The study also recommends that researchers, government policymakers and other private sectors involve smallholder farmers during the decision-making process, supporting and encouraging them to maintain sustainable agriculture.

The project identified on-farm participatory demonstration trials as a solution to demonstrate different sustainable agricultural practices. Two smallholder farmers' cooperatives in the Mbombela LM (Luphisi and Sulubindza) were selected based on their willingness to adopt sustainable agricultural practices. The selected two cooperatives of smallholder farmers showed the potential to be more advanced in the adoption of sustainable agricultural practices to improve the production of the underutilised crops.

Based on the evaluation, the necessary infrastructure, gardening tools, inputs, and suitable crops for summer and winter production were identified. The assessment also highlighted critical factors influencing smallholder farmers' productivity, including: the primary water source and its availability for irrigation, soil and water quality for sustainable crop production, existence and functionality of irrigation systems, field size and its capacity for diverse crop cultivation, training requirements for smallholder farmer beneficiaries, adoption of sustainable agricultural practices, such as: mulching to conserve soil moisture, intercropping for biodiversity and soil fertility, and efficient irrigation systems.

The implementation of on-farm trials demonstrated the hand on the involvement of smallholder farmers in the project and covered activities such as land preparation and application of organic fertilizer and mulching to improve soil water holding capacity. The study included the use of simple irrigation scheduling equipment, including how to install them and how to use them for monitoring (including chameleon soil water sensor and wetting front detectors), underutilized crops cultivation (based on their seasonal requirements), water balance, in the smallholder farmer's field. The results showed that the biomass of the underutilized crops, including cowpea (*Vigna unguiculata*), bambara groundnut (*Vigna subterranean*), common bean (*Phaseolus vulgaris*), okra (*Abelmoschus esculentus),* Swiss chard (*Beta vulgaris*) and beetroot (*Beta vulgaris* subsp. vulgaris) increased when integrated with sustainable agricultural practices. For example, the study on mulch treatments and three underutilized crops yielded the following results: The ash content varied across the crops, with the lowest recorded at 6.36% for Bambara groundnut treated with pine bark mulch, and the highest at 13.11% for cowpeas that received no mulching treatment. The potassium (K) content was highest in cowpeas with no mulch treatment. Essential minerals such as sodium (Na), iron (Fe), molybdenum (Mo), and zinc (Zn) responded differently to various mulching treatments. The high Fe content reported in this study has significant nutritional benefits, contributing to human nutrition and dietary iron intake. Cowpeas were found to be a rich source of essential minerals, including calcium (Ca), phosphorus (P), and iron (Fe), which play a crucial role in maintaining normal homeostasis at the cellular level. The high zinc (Zn) content observed in common beans treated with pine bark mulch is particularly noteworthy, as Zn enhances plant enzyme performance, supporting growth and development. These findings highlight the importance of mulch treatments in improving the nutritional quality of underutilized crops, making them a valuable option for enhancing food security and soil health.

The study monitored various vegetable crops using chameleon irrigation sensors, but this section focuses on Swiss chard and mustard spinach at the Luphisi site. In contrast, smallholder farmers at Sulubindza primarily relied on wetting front detectors for irrigation management. The key findings at the Luphisi site showed that dry conditions (red light) were observed at the beginning of the crop monitoring phase in June for both crops. Variations in water use, as indicated by sensor colours (red, green, and blue), were influenced by the hot environmental conditions of Luphisi. Wet and moist conditions (blue and green lights) correlated with scheduled irrigation by the smallholder farmers. No rainfall was recorded during the winter months of 2024 at the site. The red light (dry conditions) was expected due to high winter temperatures reaching up to 33°C, which increased crop water demand.

These findings emphasize the importance of precise irrigation scheduling in high-temperature environments to prevent moisture stress and optimize crop productivity.

The on-farm trials provided valuable insights that were extended to smallholder farmers through stakeholder engagement and training on underutilized crops production. The key training concepts included basic cultivation practices (planting, fertilization, irrigation, harvesting, storage and nutritional value of underutilized crops). The training also included efficient water use and irrigation scheduling. The on-farm practical approaches included the hands-on training to enhance sustainable agricultural practices, strengthening smallholder farmers' understanding of crop management and planning and promoting sustainable agricultural practices. This interactive and practical training helped farmers adopt new technologies, improve their knowledge of vegetable benefits and develop sustainable crop production strategies.

This project successfully identified on-farm participatory research approaches that create valuable opportunities for smallholder farmers. Smallholder farmers enhanced productivity through sustainable agricultural practices such as mulching and drip irrigation. Continuous stakeholder engagement played a crucial role in facilitating technology adoption and ensuring that farmers benefit from their efforts in crop production.

The study highlighted several key areas for future research and policy considerations:

- Sustainable agricultural practices: Gender disparities significantly influenced the adoption of sustainable agricultural practices. Efforts should be made to increase women's participation and break male dominance in sustainable agricultural practices through awareness programs and policy support.
- Youth empowerment: The study found low youth participation in sustainable agricultural practices. To attract young farmers, the smallholder farming sector must be more accessible in empowering the youth to adopt sustainable agricultural practices.

- Capacity building for extension officers: Strengthening extension officers and research stations by providing them with the necessary training, support, and physical resources will improve sustainable agricultural practices.

The project has demonstrated great potential for smallholder farmers to adopt sustainable agricultural practices and its success suggests that similar initiatives could be scaled within South Africa. The continued investment in sustainable agricultural farming is essential to maximize local resources and contribute to long-term agricultural development.

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LIST OF ACRONYMS AND ABBREVIATIONS

ARC	Agricultural Research Council
DARDLEA	Department of Agriculture, Rural Development, Land and Environmental Affairs
IKS	Indigenous Knowledge Systems
LM	Local Municipality
NAMAC	National Agricultural Marketing Council
SAPs	Sustainable Agricultural Practices
SDGs	Sustainable Development Goals
UMP	University of Mpumalanga
VIMP	Vegetable Industrial Medicinal Plants
WRC	Water Research Commission

CHAPTER ONE

INTRODUCTION AND BACKGROUND

1.1 INTRODUCTION

For decades, domesticated plant species known for their food, fiber, fodder, oil, or medicinal characteristics have been underutilized and neglected (Mudau *et al.,* 2022). Indigenous crops are increasingly recognized for their high nutritional content and their critical role in ensuring food security. These crops provide essential food sources that diversify traditional food systems and promote biodiversity. Often available at no cost, underutilized crops offer a viable source of revenue for rural populations, particularly in areas unsuitable for cultivating staple cereal crops. Their cultivation addresses food insufficiency by supporting sustainable livelihoods, enriching diets, and boosting rural incomes.

Some of the key underutilized vegetable crops in the Ehlanzeni district include Bambara groundnuts (*Vigna subterranea* [L.] Verdc.), chickpeas (*Cicer arietinum*), cowpeas (*Vigna unguiculata*), pigeon peas (*Cajanus cajan*), and mung beans (*Vigna radiata* L.). These crops are well-suited to addressing food and nutrition security challenges through a more diverse agricultural system. They contribute to food security by providing essential nutrients and supporting sustainable livelihoods, especially in resource-constrained rural areas (Mabhaudhi *et al.,* 2017).

To unlock the potential of underutilized crops, coordinated efforts involving multi-stakeholder participation are crucial. These efforts require integrating sustainable farming practices and addressing the gaps in knowledge, resources, and support available to smallholder farmers. This project seeks to study and promote the use of underutilized and neglected plant species within sustainable production systems and to assess their role in enhancing food security in rural communities. Additionally, the role of stakeholder engagement is emphasized as a strategy to develop neglected crops and ensure their integration into food security initiatives.

The introduction of sustainable agriculture aims to generate sufficient food while conserving natural resources and minimizing environmental harm. Sustainable agricultural practices (SAPs) enable smallholder farmers to build resilient, productive food systems while reducing poverty and improving food security (FAO, 2019). SAPs incorporate a combination of external inputs and local resources, fostering agricultural sustainability for current and future generations. Sustainable practices also contribute to water conservation, a critical aspect of addressing global water scarcity. Agriculture accounts for approximately 70% of global water withdrawals, surpassing industrial (22%) and domestic (8%) sectors (FAO, 2019).

Efficient water management practices also contribute to sustainable practices by conserving water while ensuring sufficient water availability for agricultural productivity. Efficient water use is integral to achieving the Sustainable Development Goal (SDG), which emphasizes establishing sustainable food production systems by 2030. Water conservation practices enhance agricultural productivity by balancing water demand with availability, enabling rural households to cultivate nutritionally rich crops.

Analyzing the relationships between crop production, water use, and nutrition security is critical to addressing food and water scarcity. Nutritional Water Productivity (NWP) is an emerging metric that assesses the relationship between a crop's nutritional value, yield, and water consumption (Mabhaudhi *et al.,* 2016). This metric highlights the potential of underutilized crops, such as cowpeas and common beans, which are nutrient-rich and highly beneficial in addressing daily dietary requirements. These crops contribute essential minerals like calcium (Ca), iron (Fe), copper (Cu), phosphorus (P), zinc (Zn), chlorine (Cl), and sodium (Na), which are vital for growth and metabolism (Marles, 2017).

Despite the importance of NWP, gaps remain in understanding how water use impacts the nutritional quality of underutilized crops. Additionally, irrigation water quality must be considered to ensure optimal yield and nutritional content (Raza *et al.,* 2019). Research into these interconnections provides a pathway to aligning agricultural practices with the broader food-water-health-nutrition nexus.

The adoption of sustainable farming practices is crucial for improving agricultural productivity, addressing food and nutrition security, and conserving vital water resources. Underutilized crops such as Bambara groundnuts, cowpeas, and common beans hold significant potential to enhance the livelihoods of smallholder farmers while fostering environmental sustainability. This project emphasizes the need for stakeholder engagement, technology transfer, and coordinated action to support smallholder farmers in adopting sustainable practices and integrating underutilized crops into local food systems. Through these efforts, smallholder farmers can achieve greater resilience, productivity, and long-term sustainability.

1.2 Rationale

Smallholder farmers are integral to agricultural production and food security in many rural and developing areas. They produce a significant portion of the world's food supply while relying on limited resources such as land, water, and capital. However, they often face challenges such as erratic climate conditions, lack of access to inputs, and limited access to markets and technologies. Addressing these challenges is crucial to improving their productivity and resilience. Adopting sustainable agricultural practices (SAPs) enables smallholder farmers to mitigate resource constraints, enhance productivity, and reduce vulnerability to external shocks. Additionally, integrating underutilized crops into local food systems allows for diversification, improved nutrition, and better adaptation to local environmental conditions. Sustainable agricultural practices ensure long-term agricultural productivity while preserving the environment. Many underutilized crops, such as Bambara groundnuts, cowpeas, and common beans, are nutrient-dense and provide essential vitamins, minerals, and proteins that are often lacking in conventional diets. Their inclusion addresses malnutrition and improves community health. These crops are typically well-suited to local agro-climatic conditions, requiring minimal inputs and thriving in marginal environments where staple crops may fail. Cultivating underutilized crops promotes agrobiodiversity, reducing reliance on a narrow range of staple crops. Integrating these crops into local food systems creates opportunities for income generation through niche markets. Value-added products derived from underutilized crops can further enhance smallholder farmers' earnings. Smallholder farmers are pivotal to achieving food security and sustainable development. Adopting sustainable agricultural practices and integrating underutilized crops into local food systems offer viable solutions to address the pressing challenges of resource scarcity, malnutrition, and environmental degradation. By empowering smallholder farmers with knowledge, resources, and market access, they can transition to more resilient and productive agricultural systems that support long-term sustainability.

1.3 Aims and objectives of the study

1.3.1 Aim of the study

The primary aim of this study was to promote the adoption of sustainable agricultural practices (SAPs) among smallholder farmers to enhance food security, optimize water use in agriculture, and improve the nutritional value of underutilized crops. The study also integrated participatory research, technology transfer, and capacity building to empower farmers with the knowledge and skills necessary for sustainable crop production and resource management.

1.3.2 Specific objectives

Identify and document sustainable agricultural practices suitable for smallholder farmers

- Promote practices such as intercropping, crop rotation, mulching, and the use of organic amendments to improve soil health and productivity.
- Develop strategies to address barriers to adopting SAPs and create awareness among smallholder farmers.

To investigate water relations in underutilized crops

- Assess the water productivity of underutilized crops such as Bambara groundnut, cowpea, and common bean under different irrigation systems and mulching treatments.
- Understand the impact of water use efficiency on crop yield and quality in resource-constrained environments.

To analyze the nutritional composition of underutilized crops

- Conduct laboratory analyses to evaluate the macro- and micronutrient profiles of underutilized crops.
- Identify key nutritional benefits and their contributions to addressing malnutrition and food security challenges.

To implement participatory research approaches, technology transfer and capacity-building

- Engage smallholder farmers, researchers, and extension officers in co-designing and co-implementing sustainable farming interventions.
- Facilitate knowledge sharing through focus groups, workshops, and community discussions to ensure inclusivity and relevance.
- Provide training on using advanced tools such as chameleon sensors for soil moisture monitoring, irrigation systems, and sustainable cultivation techniques.

1.4 Report structure

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- Policy recommendations for integrating underutilized crops into local food systems.
- Further research needs.

References

- List all cited sources in appropriate referencing format.

Appendices

- Questionnaire samples and survey instruments.
- Additional supporting materials.

1.5 References

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CHAPTER TWO

LITERATURE ON SUSTAINABLE PRODUCTION PRACTICES

2.1. Introduction

This chapter reviews relevant literature to understand the low adoption of sustainable agricultural practices (SAPs) among legume smallholder farmers. The chapter starts by defining the terms and impact of sustainable agricultural practices on food security, environment and social activities. For this study, SAPs are discussed in detail, including the types of SAPs, factors to consider when adopting SAPs, benefits associated with adopting this technique, socio-economic factors influencing the adoption of SAPs, and challenges of adopting SAPs. Lastly, monitoring and evaluating SAPs conclude the chapter.

2.2. Sustainable Agriculture: Definition and Concepts:

The word “sustain’ is derived from the Latin word *sustinere* (sus-from below and tenere-to hold) to hold on from generation to generation without any disturbance, to keep it alive (Zaharia, 2010). SAPs are designed to preserve natural resources by maintaining farm productivity without using synthetic inputs that might harm the environment. SAPs are essential for improving agricultural products and food security (Roxana *et al.,* 2018). To increase crop production using only natural resources and avoid the use of agrochemical inputs, which affects agriculture's sustainability and, at the same time, enhances community life, sustainable agricultural techniques present a successful strategy. Sustainable agriculture is foundational to farm management, rural development, and water conservation. This includes sustainable practices such as crop rotation, intercropping, and mulching, which contribute to productivity in smallholder cropping systems (Mutyasira *et al.,* 2018). Sustainable farming methods aim to maintain farm output while avoiding artificial inputs that could harm the environment (Mishra *et al.,* 2018).

Sustainable agricultural production will help farmers preserve their natural resources without causing any harm to the environment or the people in that area. Preserving natural resources is suitable for sustainable agriculture, which will improve the livelihood of farmers due to food security, poverty reduction, and farm productivity. It is essential to encourage local farmers to adopt agricultural practices to foster sustainability in agriculture for the current and future generations. SAPs do not exclude external inputs but encourage incorporating them to complement local resources (FAO, 2018). However, adopting sustainable agricultural practices to help smallholder farmers achieve more resilient, productive food systems and foster sustainable agricultural production would reduce poverty and advance food security. Sustainable practices usually require concrete incentives, significant effort from farmers, and the support of governments and public-private partnerships at national and local levels (Teklewold *et al*., 2013).

Adopting SAPs brings stability to the environment and ecosystems, where food production does not harm the people and animal welfare. According to Zaharia (2010), agricultural production is in the safe hands of sustainable agriculture, which protects natural resources, preserves biodiversity and increases farm productivity. In addition, food production in sustainable agriculture will meet the needs and demands of the growing population. Sustainable agriculture will address the issue of food insecurity and yield the expected products in terms of market and volume, resulting in income generation to improve the standard of living in that area (Kornegay *et al*., 2010).

2.2.1. Rogers' five stages of adoption process

Adoption refers to the degree to which smallholder farmers or cooperatives select and utilise a particular innovation or technology to better their livelihoods. Adopting SAPs is influenced by various factors such as financial constraints, limited information or knowledge, insecure land tenure, risk reduction, and not being difficult to apply. The adoption process differs from the "transfer of technology" as it occurs within the farmer(s) thinking to improve their livelihoods. The adoption process is when an individual wants to embrace and try new ways of farming to improve their farming operations (Ahmed *et al*., 2015).

The adoption process can be categorised into five stages based on the findings of research and studies done in this field: awareness, interest, evaluation, trial, and adoption stages (Muzarii *et al*., 2012). The five stages, such as the experimentation stage, do not necessarily occur in the same scene, and some may not even exist. In response to this criticism, (Muzarii *et al*., 2012) suggested that it would be best to refer to the assessment stage as "The Innovation Decision Process," defined as the mental process by which an individual moves from the first idea until the adoption process.

- Knowledge stage: at this stage, legume smallholder farmers accept sustainable agricultural practices, which align with their demand, values and beliefs to be familiar with the information disseminated about sustainable agricultural practices (SAPs).
- Persuasion stage: at this stage, legume smallholder farmers gain enough familiarity with sustainable agricultural practices and their benefits on the farm. The smallholder farmer must start to experience a particular sustainable agricultural practice to see if it will be helpful for future use on the farm while comparing it with the existing practices. In contrast, legume smallholder farmers can reject the sustainable agricultural practices presented if they do not yield the expected results.
- Decision-making stage: at this stage, legume smallholder farmers can either accept or reject sustainable agricultural practices. Legume smallholder farmers will only accept sustainable agricultural practices that will improve agricultural productivity and be cost-effective.
- Confirmation stage: legume smallholder farmers tend to confirm their decision and determine if it is appropriate. Legume smallholder farmers must understand that this is not the end of the adoption process.

2.2.2. Legume smallholder farmers

Department of Agriculture, Rural Development, Land and Environmental Affairs (DARDLEA, 2015) states that smallholder farmers mainly produce food for consumption, and they have the potential to sell in the market and generate profit as well. In addition, smallholders are farmers in the South African context who manage an area varying from less than one hectare to 2 hectares. In this case, legume smallholder farmers focus on producing legume crops to increase farm productivity by improving soil structure and fertility. Legumes can fix their nitrogen, benefitting other crops and soil fertility. LSHF also have the potential to expand its farming operation and venture into commercial farming but needs access to comprehensive support (technical, financial, and managerial instruments).

2.3. Outcomes of sustainable agricultural practices (SAPs)

Sustainable agricultural practices ensure that farmers feed the increasing population daily with quantity and quality of foods. Farmers are encouraged to use natural resources to preserve soil status, increase farm productivity, generate enough profit and foster sustainability for the current and future generations. The status of the soil affects the quality of the products. However, improving soil fertility will enhance food security, whereby farmers can produce more products to meet the consumers' needs at the market. The adoption of sustainable agricultural practices by smallholder farmers reduces soil erosion that leads to soil degradation and, at the same time, encourages nutrient depletion (Al-Kaisi *et al*., 2020). To feed the increasing population and meet the consumers' needs, smallholder farmers must adopt sustainable agricultural practices to maintain sustainability for future generations.

Agriculture is also part of manufacturing industries contributing to greenhouse gases (GHG) by producing methane and nitrous oxide due to the inappropriate use of fertiliser, which results in the eutrophication process. According to FAO (2020), agriculture has also contributed negatively to the environment due to agrochemical inputs such as fertiliser and pesticides, which pollute surface and ground water through the leaching process from the soil. Moreover, using agrochemical inputs reduces biodiversity at the expense of the environment, which results in poor productivity and loss of income. To minimise the negative impact that comes with the use of agrochemical inputs, legume smallholder farmers must produce their food in sustainable agriculture. Doing so encourages legume smallholder farmers to expand their fields and make good quality products in terms of volume and nutritional value.

The interaction among environmental, social, and economic aspects in Mpumalanga Province, Mbombela Local Municipality, influences the production of agricultural products. Resilience and productivity are encouraged in diverse climatic conditions such as high temperatures, changes in rainfall patterns, long dry spells, and drought. Sustainable agriculture must balance environmental, social and economic aspects to improve the livelihood of legume smallholders (Allen *et al*., 2013). However, SAPs have been advocated for quite a long time to protect the environment against conventional agriculture, such as agrochemical inputs and heavy machinery. According to Allen *et al.* (2013), sustainable agricultural practices aim to foster current and future generations to produce high yields.

Adopting SAPs among legume smallholder farmers will help improve their farm productivity, minimise soil erosion, improve soil fertility and moisture content, improve soil structure, recycle nutrients, and avoid groundwater contamination. Smallholder farmers must understand that food must be produced based on sustainable agricultural practices (SAPs) to maintain farming production. Agricultural extension, policymakers, private sectors and other stakeholders must at least put the needs of farmers at the centre and try to impart knowledge and skills to farmers all the time (Zaharia, 2010). Sustainable agriculture offers better alternatives compared to conventional agriculture. Even though sustainable agriculture has no detrimental effects like conventional agriculture, smallholder farmers use limited practices (Msemo *et al*., 2018).

These farming practices play an essential role in sustainable agriculture, but some factors hinder the adoption of sustainable agricultural practices (SAPs). In addition, one of the key aspects of Sustainable Development Goals (SDGs) is to end poverty and protect the environment. To achieve those aspects, legume smallholder farmers must adopt sustainable agricultural practices (SAPs), promote sustainable agriculture worldwide, curb food insecurity, and minimise the cost of agricultural inputs (Kornegay *et al*., 2010). According to the United Nations, sustainable agriculture is critical to achieving the SDGs 2 and 3, which advocate for smallholder farmers to reduce hunger and improve their livelihood by generating enough profit.

2.4. Technology transfer of sustainable production practices

Technology transfer of sustainable agricultural practices also determines technology adoption among smallholder farmers. Smallholder farmers must learn the importance and usefulness of new technology to avoid time-consuming. Chances are higher for farmers who are used to exploring different avenues of farming practices to adopt innovations or ideas than those who do not want to learn new techniques. Information accessibility makes the lives of local people much more manageable regarding technology adoption.

The channels in which information is communicated with farmers or local people play a significant role because it might cause confusion and lead to wasteful details in front of the end-users, who are farmers. Knowledge and skill of technology transfer behind this is essential to convenience farmers about new information (Mobius *et al*., 2015). Agricultural extension officers use different channels (workshops, newsletters, WhatsApp, Farmers Day, etc.) to disseminate information about the new sustainable practices farmers must adopt to improve their farm productivity, generate enough profit, and enhance food security. Smallholder farmers, in most cases, embrace new technology that they know.

The information to farmers should be communicated appropriately, and the extension officer must use a channel of communication that will be effective and adopted by the end users. The transfer of SAPs, in the form of a top-down approach, must be revisited to improve the adoption of sustainable agricultural practices among legume smallholder farmers. The top-down approach is where researchers, policymakers, private sectors and other stakeholders develop innovations under the same umbrella and then communicate the innovation to the end users or legume smallholder farmers (Mukute, 2010). However, those at the highest level (researchers, policymakers, private sectors and other stakeholders) expect smallholder farmers to adopt SAPs, which are expensive or do not meet farmers' needs. To cater farmers' needs, it is essential to involve legume smallholder farmers and agricultural extension during innovation development. The agricultural extension works with farmers, and they understand the challenges that smallholder farmers come across daily (Christensen, 2011). In addition, technology transfer aims to address the challenges of smallholder farmers to improve farm productivity and encourage them to sell their products and generate income (Cantú-Mata *et al*., 2021). They should provide appropriate technology to solve and address smallholder farmers' problems. It should empower farmers to choose how the practices should be used, with the available information or knowledge to make decisions (Rankin, 2015).

2.5. Sustainable production practices: smallholder farmers perspective

Sustainable agricultural practices (SAPs) are designed to preserve natural resources to maintain farm productivity and minimize synthetic inputs that might harm the environment. SAP is pivotal in improving agricultural products that contribute to food security (Roxana *et al*., 2018), improving the soil status while reducing the depletion of nutrients and encouraging the soil microorganisms to diminish their reliance on harmful inorganic inputs (Samsudin *et al*., 2018). Local people are conditioned to their culture, norms, beliefs, and values, and extension agents should find a way to bring something that will solve the people's problems. Community settings vary, and practise things differently. Doing so also affects development in many rural areas. Smallholder farmers' backgrounds are a barrier to adopting agricultural practices; smallholder farmers who own plots of land (ownership) are optimistic about adopting sustainable agricultural practices. Smallholder farmers who use communal land fail to invest more in the farm since the land does not belong to that community's people (Deininger *et al*., 2011). Sustainable agricultural practices are crop rotation, organic farming, mulching, and water conservation. In addition, the extension officers need to understand the community settings of that area to adopt new methods of doing things.

2.6. The importance of policy on legume smallholder farmers regarding SAPs

The emphasis of policy measures is to guide smallholder farmers in taking good care of the environment to avoid the issue of environmental pollution, which affects the lives of people and animals. The policy measures can address all the negative impacts of conventional farming or agrochemical inputs such as fertilisers and pesticides. It is essential to raise awareness about these sustainable agricultural practices (SAPs) (Higgins *et al*., 2017). These policy measures aim to impart knowledge or information to smallholder farmers to improve their productivity, preserve natural resources and conserve biodiversity. The policy helps to guide smallholder farmers about the issue of land degradation, which slowly decreases farm productivity and results in a loss of income. Protecting the land and environment will also help farmers produce food using sustainable agriculture, which will feed the growing population daily. The main contributors to soil infertility, particularly in the commercial sector, are monoculture in cereal production, intensive tillage, and limited crop rotation. Soil degradation in communal land is caused by inappropriate land use, population density, and overgrazing. Policy measures on sustainable agriculture must be based on these five aspects: biological productivity, preservation of natural resources, economic viability, social acceptance, and minimising the level of risk (Khwidzhili and Worth, 2016).

Regarding biological productivity, it alerts us of the adverse effects caused by pesticides, fertilisers, herbicides and industrial development. At the same time, it encourages the use of organic farming, zero tillage, crop rotation and intercropping. The second aspect of preserving natural resources advocates using natural resources without any damage, reducing soil erosion, contamination of groundwater, land degradation, environmental pollution, and using machinery in farming, avoiding deforestation, and minimising industrial factories in the country. The third aspect, the lack of a market, poor infrastructure, and limited information, hinders farmers' progress in improving their livelihood and causes loss of income. The policy on sustainable farming encourages researchers to provide sustainable increases in agricultural production and improve the management of natural resources amongst poor populations, which are not supported in most cases. The fourth aspect of the minimised level of risk, in this case, encourages smallholder farmers to adopt SAPs to improve farming productivity. It allows smallholder farmers to get assistance in terms of subsidies, farmers' training, subjects expected to be agricultural extensions, and effective risk management strategies. Lastly, the fifth aspect of social acceptance focuses more on the social well-being of smallholder farmers, poverty alleviation, food insecurity, education, unemployment, a lack of opportunities and crime.

2.7. Sustainable Agricultural Practices (SAPs)

2.7.1 Intercropping system

Intercropping occurs when a farmer cultivates two or more crops simultaneously on the same plot of land, which also helps to increase crop yield and generate enough profit. The intercropping system is essential in agricultural production because it improves soil structure and reduces erosion and biodiversity (Glaze-Corcoran *et al*., 2020). Smallholder farmers are encouraged to adopt intercropping since it benefits agricultural production and minimises the cost of inputs. Intercropping is essential for resource-poor farmers, as it incorporates legume crops such as cowpea, soybeans, groundnut, and Bambara groundnut with nitrogen fixation bacteria. Legume crops improve soil fertility, increase crop yield and improve soil structure.

2.7.2 Organic manure

Organic manures are essential to sustainable agriculture since they can improve soil fertility aeration, build organic matter, and improve soil structure and water-holding capacity. Organic manure can be kraal manure, chicken manure, green manure, or any other waste product, and they improve soil fertility without harming the environment or ecosystem (Migliorini *et al*., 2017). Organic manure in the soil enhances biological activities, which helps break down crops and animals' residues and increase organic matter content, which will be accessible for crops to uptake. Organic manure is generally categorised into bulky and concentrated organic manures.

2.7.3 Crop rotation

Crop rotation occurs when farmers plant different crops yearly on a small piece of land to improve soil health, increase crop yield and profit and disrupt disease by breaking down their life cycle (Martin *et al*., 2020). Crop rotation with legumes not only increases the cropping intensity but also increases the total food availability. Legume crops help with nitrogen fixation, which will benefit the next crop on the soil. In addition, crop rotation can break down the life cycle of disease in the soil since different diseases attack different crops. Manifestation of pathogens and diseases occurs more in mono-cropping, the same crop on the same land year in and year out. It will affect the performance of the crop, which will drop production and affect the quality of the product as well (Omer *et al*., 2018).

2.7.4 Cover crops

Cover crops mainly cover the exposed soil to avoid soil erosion (wind and water erosion). The benefits of adopting cover crops in agriculture are increased soil organic matter, improved soil moisture retention, minimised soil erosion, enhanced microbial activity, and improved soil structure. Cover crops include crop residues, legumes, root crops and vegetative covers since they all improve soil fertility and cation exchange capacity (CEC) (Adetunji *et al*., 2020). However, cover crops are like dressing up the soil to avoid soil loss, incorporating Alfalfa (*Medicago sativa)* with the soil to enhance the soil with nitrogen due to their ability to fix atmospheric nitrogen. Their root system can also search for nutrients lost from the previous crops and act as a nutrient recycling agent (Mancinelli *et al*., 2019).

2.7.5 Zero tillage

Zero tillage is also known as no-tillage. It is mainly for the conservation of soil health to avoid disturbance by using machinery or other implements during the cultivation process. The adoption of zero tillage practice on the farm will also enhance microbial activity, reduce soil erosion, minimise the use of synthetic inputs, and reduce nutrient leaching. In this case, it is another solution to improve food security, be cost-effective and generate enough profit without harming the environment in which people live. Zero tillage retains the most outstanding crop residue on the soil surface and minimises evaporation since soil particles do not turn and break during soil preparation (Mäder *et al*., 2012). It is an approach whereby farmers plant crops in previously unprepared soil along with the remaining crop residue by narrow slots and trenches. However, it will minimise pests and diseases on the farm, and weeds can also be controlled.

2.7.6 Soil mulching

There are two types of mulching: organic mulching (straw, wood chips, sawdust and compost mulch) and inorganic mulching (biodegradable mulch). Organic mulch refers to applying plant and animal residues into the soil to enhance biological activity and nitrogen balancing, improve soil properties, improve water retention, and reduce soil erosion. Organic mulch also minimises nitrate leaching, and it is cost-effective mulch, which is beneficial to crops (Wang *et al*., 2014).

- Straw mulch

This type of mulch occurs after harvesting, and straw or crops remain in the soil. Straw mulches are generally light in weight and easily used. Paddy straws (*Volvariella volvacea*) are usually used as field mulch to improve the crop cultivation environment. Straw mulch should be replaced year in and year out because it is flammable and has the potential to germinate and diminish soil nitrogen levels through decomposition (Goodman *et al*., 2014).

Bark mulches are waste material from various trees and are applied to the soil to improve soil moisture content so crops can consume it. It is generally used for topography and vegetation. This mulch primarily covers the spaces between the beds (Adhikari *et al*., 2014).

- Wood chips

Recycled wood and different types of trees are used to make wood chips because wood chip mulches contain a high C: N (600:1) ratio, which hinders nitrogen availability for plant absorption while decomposing (Bantle *et al*., 2014).

- Sawdust

Sawdust is a byproduct of wood, generally found after woodworking operations, which is used as a mulch material. The material breakdown is slow due to the high C: N (400:1) ratio, and the nutritional value is poor compared to straw. The decomposition results in nitrogen deficiency in the soil, which will cause farmers to add fertilisers more often due to their acidic component. However, it helps in terms of moisture retention for quite a long time (Tan *et al.*, 2016).

- Compost

Compost comprises recycled waste materials such as leaves, grass, bark, papers, and animal faeces to improve soil structure, water holding capacity, soil fertility, and infiltration. Compost plays an essential role in agricultural production, which increases farm productivity and is cost-effective. It contains a high nitrogen content (between 0.5% and 2.5 %), which will benefit crops (Sofy *et al.*, 2021).

- Inorganic mulching

Usually, they use black plastic material to suppress weeds, improve soil moisture content, and increase temperature, and it can used all year round. It helps to increase crop productivity and product quality, improving people's livelihoods (Haapala *et al.*, 2014). It also encourages microbial activity and minimises soil evaporation. This type of mulch is also a cost-effective method that will help farmers reduce their production costs. Plastic mulch is a common practice that has been practised worldwide since it is affordable, and its benefits are impressive (Yu *et al.*, 2018).

- Biodegradable mulches

Biodegradable is a friendly environment compared to polythene mulch. It was developed to prevent the gathering of low-density polyethene and the pollution caused by environmental plastic waste (Gosar *et al.*, 2011). This form of mulch reduces the use of agrochemical inputs; however, it is essential to understand all the dynamics of selecting mulch material incorporated into the soil.

2.8. Sustainable agriculture as an alternative to conventional agriculture

Sustainable agriculture (SA) is an approach to managing agroecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment (FAO, 2019). Sustainable agriculture became an alternative to conventional agriculture to avoid the dependent use of agrochemical inputs such as fertilisers, pesticides and herbicides to increase food production at the expense of the environment. There is a serious concern globally about feeding the growing population since the demand for consumption is also increasing (Stamoulis and Hemrich, 2016). To feed the growing population, food must be produced in sustainable agriculture to accommodate the current and future generations. However, Sustainable agriculture encourages smallholder farmers to use natural resources to improve their livelihood without spending a lot of capital. Conservation agriculture, a more integrated approach, is seen as reducing land degradation and increasing food security sustainably.

Conventional agriculture (farming or tillage) is a set of farming practices that commonly focus on monoculture and consist of intensive ploughing, heavy irrigation, and chemical inputs. Land ploughing is the main operation in conventional agriculture. It reduces weeds problems and exposed soil erosion. In the long run, this operation leads to land degradation, such as soil compaction and soil infertility, which will affect the quality of crops (Adnan *et al.*, 2018). However, an alternative technology to conventional agriculture is used in conservation agriculture and integrates environmental, economic, and social benefits (Maja, 2021).

Chemical inputs (fertilizers and pesticides, etc.) almost destroy the ecosystem, where plants, animals, and organisms work together to form a symbiotic relationship (Parmentier, 2014). Agrochemical inputs have replaced organic manure, compost and leguminous crops to increase farm productivity and improve livelihoods. Conventional agriculture depends more on pesticides, which damages biodiversity and interrupts the natural control method of insects, and pests, to mention a few. Conventional agriculture would not be able to feed the growing population since the demand for food is higher than the supply (food producers), which results in food insecurity, poverty and malnutrition (McMay, 2012).

Figure 2.1 below shows the impact of conventional farming on agricultural production and the environment. Conventional farming systems have been dominant for a long time in the agricultural sector and have proven to affect the environment negatively, resulting in food insecurity, low production, and loss of income for smallholder farmers (Adnan, 2017). Land degradation is also one of the most serious issues that legume smallholder farmers face daily, as it affects their crop production and results in loss of profit/income. Legume smallholder farmers must adopt sustainable agricultural practices that will not affect human life and the environment.

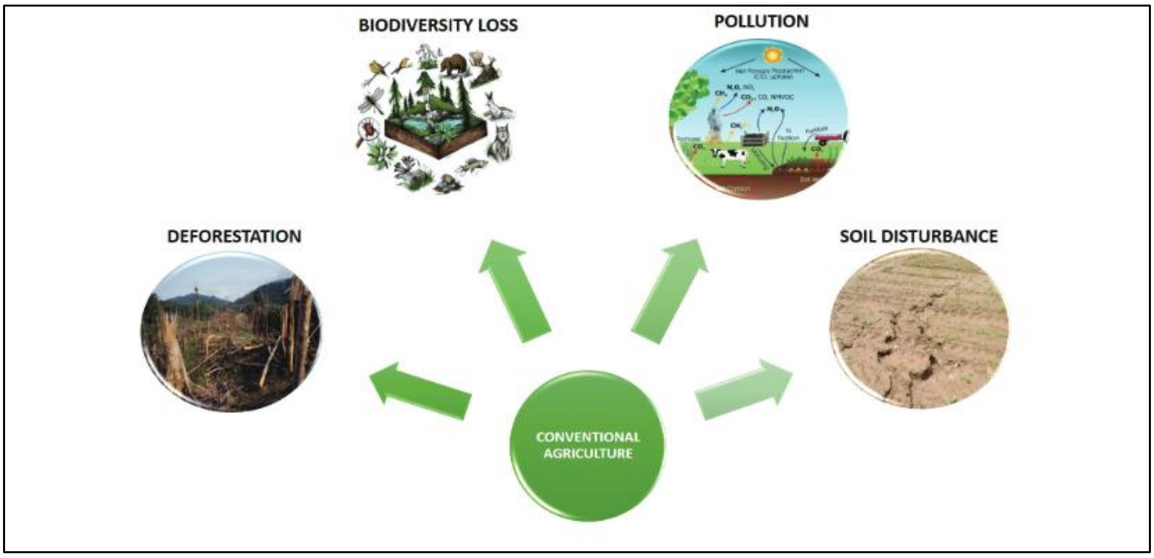

Figure 2.1: Impact of conventional agriculture (Coulibaly *et al*., 2021).

2.9. Challenges influencing adoption of Sustainable Agricultural Practices

Swinton *et al*. (2015) suggested that smallholder farmers do not adopt sustainable agricultural practices (SAPs) due to unwillingness and inability to adopt them. Failure to adopt refers to a situation whereby smallholder farmers fail to adopt SAPs because of limited information, financial constraints, complicated technology, lack of labourers, a planning horizon that is too short, limited resources, and lack of managerial skills.

Unwillingness to adopt refers to a situation where smallholder farmers lack desire or are reluctant to adopt SAPs due to inconsistency, poor applicability and relevance information, conflicts between current production and the new technology, ignorance on the part of the farmers or promoter of the technology, inappropriate for the physical settings, increased risk of adverse outcomes and belief in traditional practices.

Farmers' attitudes influence the adoption of agricultural practices and technologies that are cost-effective and have the potential to adapt quickly in that area. Cost-conscious farmers and those investing in costly technologies tend to adopt practical and advantageous innovations quickly, as they provide tangible benefits. However, the overall adoption rate remains low (Swinton *et al.,* 2015). However, in contrast, large farmers adopt capital-intensive and attractive technologies more rapidly than small and resource-poor farmers. Farmers are unwilling to adopt a technology that requires high labour intensity and lower profitability. The chances of farmers adopting agricultural practices are influenced by farm size, awareness of negative agrochemicals on the environment, the number of labourers, and the lack of social capital.

The achievement of the practices relies on the selection, design and implementation of SAPs to meet the needs of smallholder farmers. It is essential to consider smallholder farmer's resources, infrastructure, market and existing practices before implementing new ideas into the farm (Mesner and Paige, 2011). Smallholder farmers are likely to adopt practices or technologies that can quickly change their lives or improve their farming productivity (Carlisle, 2016). It is suggested that females tend to have more positive attitudes towards SAPs than men, but due to a lack of knowledge, they are less likely to adopt SAPs (Druschke and Secchi, 2014).

2.10. Summary of studies on the adoption of SAPs

The information below has been classified by (a) author(s), (b) countries, (c) sustainable agricultural practices, (d) sample size, (e) method of analysis and (f) significance. The descriptive information found from these studies has been summarised in Table 2.1. Studies on adopting SAPs have been conducted locally and internationally. The logistic regression (logit) and probit model have been used to analyse the variables that affect adoption in different regions.

Table 2.1: Summary of studies on adopting sustainable agricultural practices based on review.

Author(s)	Country	Sustainable agricultural practice	Sample size	Method of analysis	Significant
Dennis sedem liakpor *et al*., (2020)	Ghana	Mixed farming	320	Multi-variate probit	Ch2=0.00
Bese *et al*., (2020)	Eastern Cape, South Africa	Agricultural practices	130	Binary model	R^2=0.914
Zeweld *et al*., (2017)	Ethiopia	Conservation Agriculture (CA)	350	Logistic regression	R^2=0.0025
Pradyot, 2019	Kenya	Minimum tillage	300	Probit	chi2=252.66
Okon & Idiong (2016)	Nigeria	Organic crops	396	Logistic regression	R^2= 0.809
Chichongue *et al*., (2020)	Mozambique	CAP (Conservation Agriculture	616	Logit model	Chi2= 53.19
Joshi *et al*., (2019)	Nepal	GAP (Good Agricultural Practices)	103	Logit model	R^2=0.363
Suneeporn *et al*., (2020)	Thailand	Organic rice production	108	Logistic regression	R^2= 0.821
Habanyati *et al*., (2018)	Zambia	Conservational agriculture	92	Logit model	Chi2=25.002
Kunzekweguta *et al*., (2017)	Zimbabwe	Conservational agriculture	237	Wald statistics	Wald statistic 53.76
Ullah *et al*., (2015)	Pakistan	Organic farming	100	Logit model	R^2= 0.45

2.11. Factors that influence the adoption of Sustainable Agricultural Practices (SAPs)

Adoption of SAPs may improve smallholder farmers' ability to minimise soil degradation and maintain agricultural productivity in a cost-effective, productive and profitable manner (Ngwenya *et al*., 2017; Aryal *et al*., 2020; Coulibaly *et al*., 2021) have demonstrated that farmers are influenced by various factors, which hinder the adoption of sustainable agricultural practices. Figure 2.2 below describes variables that affect the adoption of SAPs among smallholder farmers. These variables have been categorised into socio-economic characteristics, institutional factors, technical characteristics and management characteristics. This diagram thoroughly reviews how each variable influences the adoption process among smallholder farmers. The conceptual framework presents the main challenges that influence the adoption of SAPs with the possible outcomes that help to foster sustainable agriculture for the current and future generations. The outcomes are the results of the adoption of sustainable agricultural practices, which integrate with the environment, socially and economically.

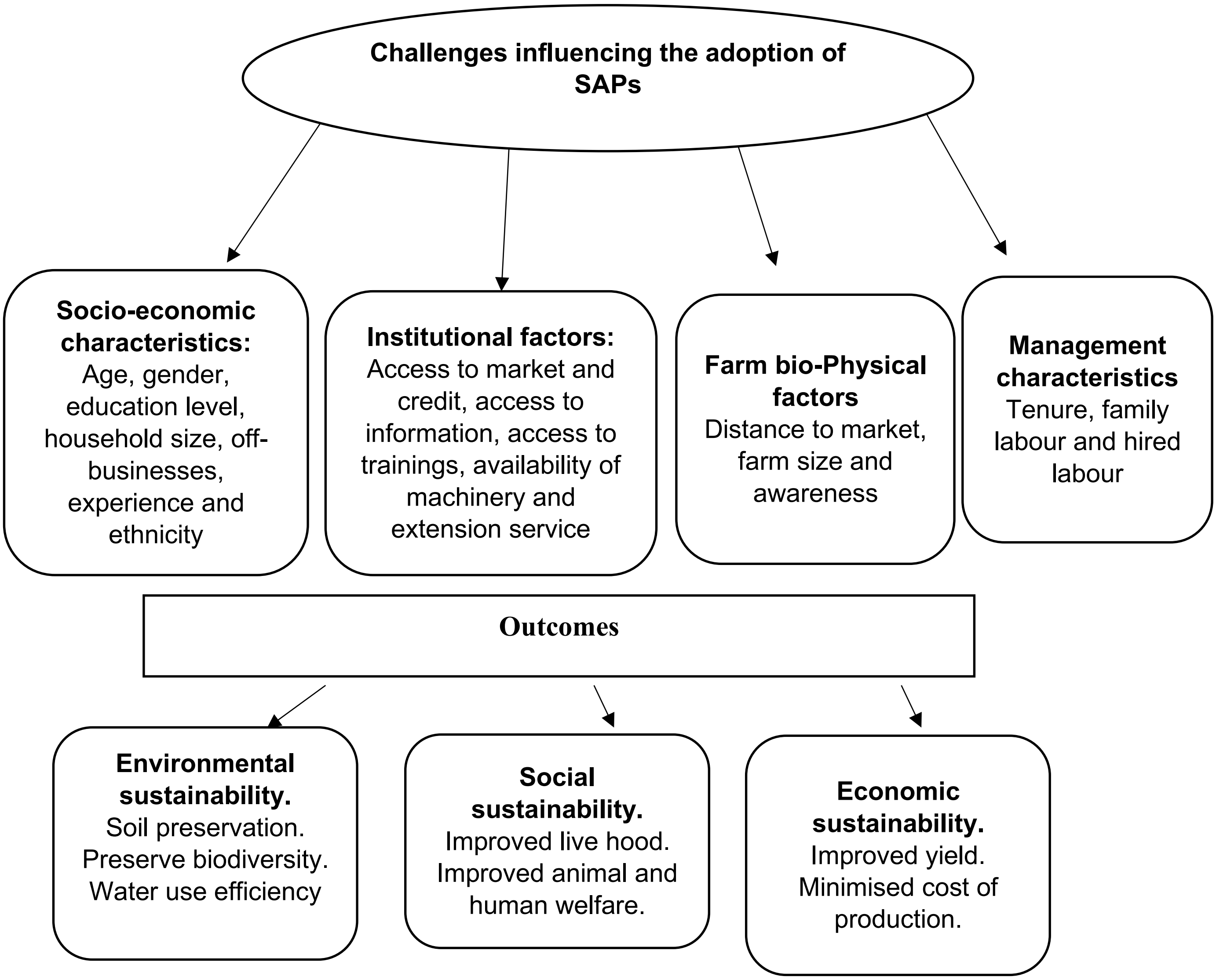

Figure 2.2: A conceptual framework of challenges influencing the adoption of SAPs (Coulibaly *et al.,* 2021).

2.11.1 Socio-economic characteristics

Kassie *et al*. (2013) state that farmers' age positively influences the adoption of SAPs. Older farmers (36-60 years) will likely adopt sustainable agricultural practices since they require much farm preparation and daily hands-on. In contrast, they could apply fertilisers and use pesticides to avoid being on the farm the whole day (Mishra *et al*., 2018). Farmers' experience in agricultural practices positively influences the adoption of new ways of farming by applying their previous knowledge and skills to improve farm productivity. The chains of practices created following the previous one (also called a "foot in the door" model) could lead to the complete transformation of farming systems (Wilson *et al*., 2014).

The level of education positively and significantly influences the adoption of sustainable agricultural practices. It was suggested that smallholder farmers with a particular formal education tend to interpret and better understand SAPs. In contrast, various studies state that the level of education negatively influences the adoption of sustainable agricultural practices (Ng'ombe *et al*., 2014; Haghjou *et al*., 2014). Women tend to adopt sustainable practices to improve farm production since many females are single parents and want to feed their children (Ball, 2020). However, the number of households tends to influence the adoption of SAPs positively. Larger households can help and assist each other with farming operations since they do not experience labour constraints in adopting sustainable agricultural practices. Labour-free will also help legume smallholder farmers minimise the cost of agricultural production, time and effort (Sinyolo, 2013). Off-farm businesses can positively or negatively influence adopting SAPs due to their involvement in farming operations or households (Abegunde *et al*., 2020). Legume smallholder farmers tend to focus much on off-farm businesses since they generate more money than agricultural production, which negatively influences adopting sustainable agricultural practices. In contrast, legume smallholder farmers who invest more in their farming operations are likely to adopt sustainable agricultural practices (Shange, 2015).

2.11.2 Institutional and technical factors

The lack of agricultural extension officers in South Africa, especially in rural areas where people depend mainly on agricultural production, affects the adoption of sustainable agricultural practices. Extension officers are essential in working with farmers to improve farm production, enhance food security, and promote sustainable agriculture. They use different channels, such as smallholder farmer's days, phone calls/WhatsApp groups, and newsletters, to mention a few, to disseminate information about the new sustainable practices that farmers must adopt daily (Mobius *et al*., 2015). Smallholder farmers' background significantly influences the adoption of sustainable agricultural practices, and smallholder farmers who own plots of land (ownership) are optimistic about adopting sustainable agricultural practices. Smallholder farmers who use communal land fail to invest more in the farm since the land does not belong to that community's people (Goldstein *et al.,* 2015).

Lack of information/social capital also affects the adoption of agricultural practices because farmers do not want to take risks on new information that is not well known or appropriate. Lack of information is one of the challenges farmers face daily, and accessible information would change their perspective at some point. Information accessibility will make the lives of local people much more manageable and make farmers likely to adopt sustainable agricultural practices. The mode of communication also plays an essential role in information accessibility, and communication channels must also be considered when trying to spread new information about sustainable agriculture (Mobius *et al*., 2015).

However, financial constraints in agriculture hinder the progress of smallholder farmers and influence the adoption of sustainable agricultural practices, which affect farm productivity and food insecurity (Omobitan *et al*., 2022). Financial constraints also affect the purchasing power of legume smallholder farmers to acquire agricultural inputs and the operational expenditure on the farm. Financial constraints influence farmers’ willingness to take on risk, which affects farmers’ choice of selection and adoption of new farming techniques to improve farm productivity (Magazzino *et al*., 2023).

2.11.3 Farm bio-physical factors

Poor infrastructure in agriculture does affect the adoption of sustainable agricultural practices since most legume smallholder farmers fail to reach the market. In this case, legume smallholder farmers are demotivated to produce more products because most of their products are perishable and have a short shelf life. Agricultural extension officers must encourage legume smallholder farmers to adopt new sustainable practices to contribute to food security (Mobius *et al*., 2015). Farmers, in most cases, embrace new technology that they know.

Regarding limited resources, access to roads or distances closest to the market and farmers' access to equipment, transport, and training are key variables that influence adopting sustainable agricultural practices (Vidanapathirana, 2019). Legume smallholder farmers can reach the market efficiently to sell their products if they can access roads or infrastructure (Kebede *et al*., 2017). If market accessibility improves, legume smallholder farmers can adopt sustainable agricultural practices to improve productivity and meet the needs of consumers at the market.

Farm size influences farmers positively regarding adopting agricultural practices and is significantly associated with adopting new technology (Nkegbe, 2014). A farmer's education level increases the ability to obtain, process, and use information relevant to adopting new technology. More educated households find a way to adjust their farm productivity by engaging in modern practices on the farm without thinking twice.

2.11.4 Management characteristics

Smallholder farmers who can employ labourers are more likely to adopt sustainable agricultural practices since they are labour-intensive than those who do not have enough cash to hire labour. The larger the number of households, the better the chances for farmers to adopt new practices on the farm compared to farmers who lack the manpower to assist in the farm.

Smallholder farmers' background significantly influences the adoption of sustainable agricultural practices, and farmers who own plots of land (ownership) are optimistic about adopting sustainable agricultural practices. Smallholder farmers who use communal land fail to invest more in the farm since the land does not belong to that community's people (Goldstein *et al.,* 2015). Sustainable agricultural practices include crop rotation, organic farming, mulching, and water conservation. Extension officers need to understand the community settings of that area to adopt new methods of doing things. Besley and Ghatak (2010) stated that having a secure land tenure or ownership is one of the crucial ways to adopt SAPs). Legume smallholder farmers tend to invest fully when they are rightful owners of the land; hence, those who do not have access to land fail to adopt sustainable agricultural practices (Deininger *et al*., 2017). Smallholder farmers who own the land have enough opportunities to access credit markets or loans by using land as collateral (Koiralaa *et al*., 2016). Previous studies suggested that most South African smallholder farmers own less than 2 ha of land (Mutters *et al*., 2016). The resource-poor black farmers mainly farm in former homeland areas and own about 13% of the total agricultural land (Mudhara, 2010).

2.11.5 Three sustainable pillars

According to Zeweld (2020), using sustainable agricultural practices has various benefits in increasing agricultural productivity to meet the needs of the consumers in the market. The following are discussed benefits/outcomes of challenges influencing the adoption of SAPs:

Environmental sustainability

- Soil preservation helps to improve soil fertility, structure and biodiversity.
- Water quality minimises water pollution through the use of agrochemical inputs such as fertilisers and pesticides. It also improves water usage.

Social sustainability

- Improved livehood adopting sustainable agricultural practices improve the lives of the people due to income generation, improved food security and betterment well-being.
- Improved animal and human welfare minimises the exposure of agrichemicals inputs in the atmosphere, which normally affects the lives of the people.

Economic sustainability

- Improved yield by adopting sustainable agricultural practices improves food productivity and the quality of products.
- Minimised the cost of production, the use of organic manure, and crop rotation, to mention a few, minimises the use of external inputs such as fertilisers and pesticides.

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CHAPTER THREE

SURVEY STUDY ON SUSTAINABLE PRACTICES

3.1 Introduction

Climate change poses a severe threat to the agricultural production and food security of developing countries. Food insecurity, financial loss, and a drop in agricultural output are significant stresses on the global food chain caused by climate change, fast urbanization, and land degradation. However, in the African continent holder, farmers, especially in rural areas, depend mainly on rainfall for agricultural production, making them vulnerable to climate change (Nyasimi *et al*., 2017). Therefore, exploring alternative sustainable farming practices (SAPs) to feed the growing population is essential. It is also important to address the daily challenges that legume smallholder farmers face to better people's livelihoods.

The more smallholder farmers produce foods on unhealthy soil, the more food production keeps declining and fails to meet the demands of the growing population. Adopting climate-smart practices has become the top priority of government policymakers, extension agents, and agricultural experts to enhance agricultural productivity, contributing to food security and generating income (Rojas *et al*., 2014).

Climate-smart agriculture (CSA) is the correct answer to climate change by adopting farming strategies that will help smallholder farmers improve production food security and minimise synthetic agro-chemical inputs (Asfaw *et al*., 2016). Smallholder farmers in Mbombela Municipality, Mpumalanga province, like any other African region, have also been affected by the issue of climate change since they are also resource-poor smallholder farmers. The impacts of climate change include shifts in rainfall patterns, extreme temperatures, poor soil status, water scarcity, and drought, which affect agricultural production negatively (Rankoana, 2016). Smallholder farmers must adopt Sustainable Agricultural Practices (SAPs) to curb climate change affecting agricultural production. Climate-smart agriculture can include crop rotation, soil mulching, conservation agriculture, intercropping, use of organic manure and new cultivars, and rainwater harvesting (Mpandeli *et al*., 2015). Researchers have been focusing more on the impact of climate change on agriculture and explored the perception of climate change by smallholder farmers. Evaluated CSA strategies and practices, explored demographic use patterns, and agronomic, economic and environmental benefits of the technologies (Baiyegunhi, 2015; Fischer *et al.,* 2015; Gandure *et al.,* 2013; Mulaudzi and Oyekale, 2015; Mutamba and Mugoya, 2014; Rankoana, 2016). In Mpumalanga, Mbombela Local Municipality, legume smallholder farmers have not utilized sustainable agriculture practices (SAPs) optimally due to several challenges they come across daily (Mutyasira *et al.,* 2018). It is essential to consider the difficulties that legume farmers face and affect the adoption of agricultural practices to improve their farm production.

3.2 Methodology

3.2.1 Description of the Study Areas

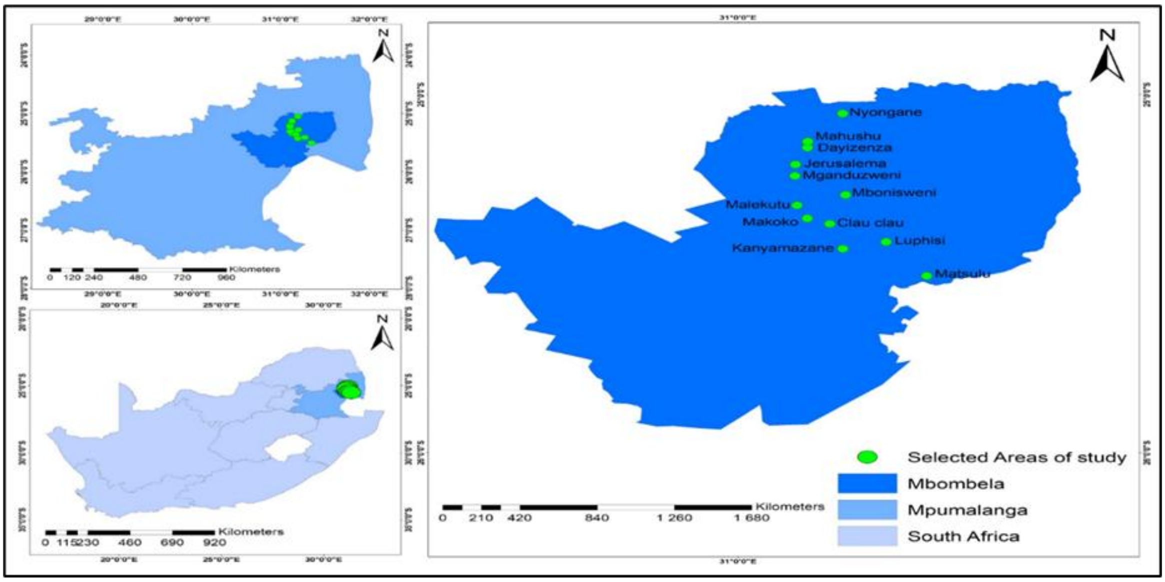

Figure 3-1: A map and location of the study areas

The study was conducted at Mbombela Municipality in Mpumalanga Province. Mbombela Municipality (25.4753° S, 30.9694° E) is located within the Ehlanzeni District of the province and covers 7,152 km². Mbombela consists of urban and peri-urban areas, and urban areas include the following: Nelspruit, White River, Malekutu, Makoko, Mpakeni, Nhlalakahle, Nyongane, Dayizenza, Clau-Clau, Bhuga, Mbonisweni, Mgaduzweni, Luphisi, Sulubindza, Dwaleni, Swalala etc. The province receives annual rainfall of 593–748 mm in the Lowveld area (Abera, 2020). The population of inhabitants in the Mbombela municipality is 818,925 (STATS, 2022). Mpumalanga contributed 8% toward total South African primary agriculture in 2020, measured in Gross Value Added (Quantec, 2021). Most smallholder farmers around Mbombela Municipality depend on agricultural produce such as spinach, common beans, ground nuts, cowpeas, maize, peanuts, cabbage, tomatoes, onions, and pumpkins. Agriculture is essential in Mpumalanga, contributing to food security and poverty alleviation.

3.2.2 Sampling Technique and Data Collection

Slovin's formula $n = N/(1+Ne^2)$

n- Sampling size (308)

e- Margin of error (0.05)

N- Total population (1343)

The sample size of 308 was determined using the formula shown above. A convenience sampling technique is used to allow smallholder farmers to participate in the study, and in this case, farmers are selected due to their availability and accessibility. The interview was in the form of questionnaires, which consisted of open- and closed-ended questions. The questions were subdivided into demographics, farm characteristics, and institutional factors to address the aim of the study. The primary language spoken in the study area is Siswati and a trained member who knows the local language administered the questionnaire. The study adopted a quantitative research design and gathered information from several participants, as previously described (Leedy *et al.*, 2011). The study classified various variables and identified factors associated with adopting sustainable production practices. The study complied with the ethics to protect the participants' identity and well-being and understand the study's purpose in the area. Consent forms were signed as an agreement to be part and parcel of the study.

3.2.3 Model Specification

Model Specification

$$Y = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \beta_5X_5 + \beta_6X_6 + \beta_7X_7 + \beta_8X_8 + \beta_9X_9 + \beta_{10}X_{10}\mu.$$

Where:

Y = the choice to adopt or not to adopt sustainable agricultural practices (Farmer adopting **SAPs** = 1, and 0 = otherwise).

$\mathbf{X_1}$ **-** $\mathbf{X_{11}}$**=** Independent variables, which have been demarcated as follows:

$\mathbf{X_1}$ = Age (years a farmer lived)

$\mathbf{X_2}$ = Gender (Male = 0, Female = 1)

$\mathbf{X_3}$ = Marital status (a state of being married or not married: Married = 1, and 0= otherwise).

$\mathbf{X_4}$ = level of education (level of educational attainment: No school = 1, and 0=otherwise).

$\mathbf{X_5}$ = Farming experience (number of years in farming operations)

$\mathbf{X_6}$ = farmland size (number of hectares farmer owns)

The link between the response variable (dependent variable), which has two or more categories and one or more explanatory variables (independent variables) on a categorical or interval scale can be predicted using the statistical analysis technique known as a binary regression model. This study used the model to explore the adoption of sustainable agricultural practices by legume smallholders.

Probit model formula

$P(Y=1|X) = \phi\ (X\beta)$

X assumed to influence the outcome ***Y***. Specifically

Where ***P*** is the probability, and Φ is the cumulative distribution function of the standard normal distribution. The parameters ***β*** are typically estimated by maximum likelihood (Agresti, 2015).

3.3 Data Analysis

Data Science version 12.1 (STATA 12.1) was employed to analyse the data. Descriptive statistics such as frequency distribution and percentages were presented in graphs and tables, while the probit model results were presented in tables. A binary logistic regression model with a dependent variable (adoption of SAPs) against independent variables such as socio-economic characteristics, institutional characteristics, farm bio-physical factors and management characteristics was used to analyse the adoption of sustainable agricultural practices (SAPs) by legume smallholder farmers.

3.4 Results and Discussions

3.4.1 Age

Table 3.1 shows the continuous variables influencing adopting sustainable agricultural practices (SAPs). The results presented in the table indicate the minimum and maximum age of 19 and 93 years old, respectively. Literature believed that the age of the farmers had a significant influence in adopting sustainable agricultural practices (SAPs) and other farming practices (Cheteni *et al.,* 2014). Primarily, those who participated in the study were older than youth in agriculture.

3.4.2 Farming experience

The literature on the relationship between farming experience and adopting agricultural innovations varies. Farmers in the study area had a minimum farming experience of 1 year and a maximum of 50 years. Even though the age distribution indicates that some farmers were as old as 93 years, the length of time people had been farming among the respondents was only 50 years. This suggests that these farmers started farming long ago and have acquired experience.

3.4.3 Employed labour

The results of employed labour indicate a minimum of 0 and a maximum of 22 in the study. It also suggests that farmers who can employ labourers are more likely to adopt sustainable agricultural practices since they are labour-intensive than those who do not have enough cash to hire labour.

3.4.4 Family labour

The results indicate a minimum of 0 and a maximum of 10 in the study. It suggests that farmers with extra hands are more likely to adopt sustainable agricultural practices. The larger the number of households, the better the chances for farmers to adopt new practices on the farm compared to farmers who lack the human resources to assist in the farm.

Table 3-1: Continuous variables of parameters on the adoption of sustainable agricultural practices

Variable	Mean	Min	Max
Age	57.918	19	93
No of household	5.435	1	15
Farming experience	14.003	1	50
Total land (ha)	2.329	.2	42
No employed labour	1.259	0	22
No family members were involved	1.461	0	10
Total cultivation for household consumption (ha)	1.517	0	20

3.4.5 Gender

The graph below (Figure 3.1) shows that female farmers (63.96%) are the majority compared to males (36.04%) in this study in agricultural production to improve their livelihood. In most cases, females are in the majority in the field of agricultural production because they are taking care of their families. Previous studies note that, in general, women tend to adopt sustainable practices to improve farm production since many females are single parents and want to feed their children (Ball, 2020).

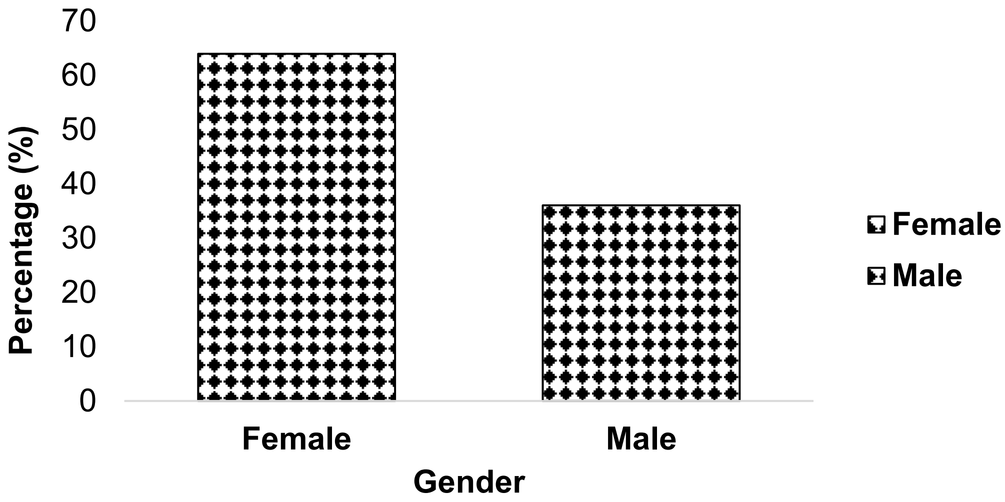

Figure 3-2: Gender of smallholder farmers from Mbombela Local Municipality

3.4.6 Level of education

The graph (Figure 3.2) shows the level of education of the participants in the study, it indicates that 47.73% have accomplished secondary school education, 25% of the participants completed primary education, and 22.4% stated that they did not go to school. Lastly, 4.87% of the participants have undergraduate certificates/ college certificates. Most farmers with higher levels of formal education and training can understand these new SAPs, which require a certain level of formal education and training (Siulemba and Moodley, 2014).

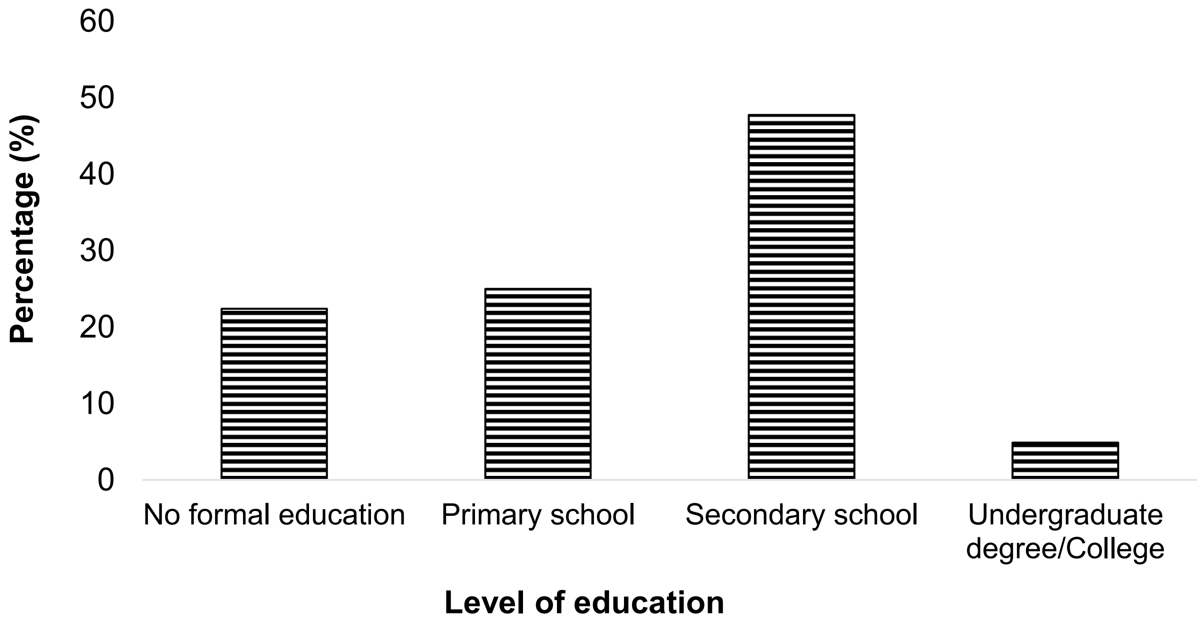

Figure 3-3: Level of education of smallholder farmers from Mbombela Local Municipality

3.4.7 Land acquisition

Most participants (51.62%) indicated that they had acquired land from tribal authority since many farmers are from villages where chiefs have the authority to give land, and 42.21% stated that they had inherited the land from their grandparents and parents; however, 4.22% acquired their land through land restitution after apartheid they had an opportunity to get their land back. In addition, 0.97% of the participants acquired their land through the Department of Agriculture, Rural Development, Land and Environmental Affairs. Lastly, only 0.97% of the participants borrowed land to utilize it, depending on their agreement. The results suggest that farmers having access to land are more likely to adopt sustainable agricultural practices. Land ownership provides collateral, enabling farmers to acquire loans that they could use to invest in their farms. It helps farmers to improve their farming production since they invest in their farms for future generations.

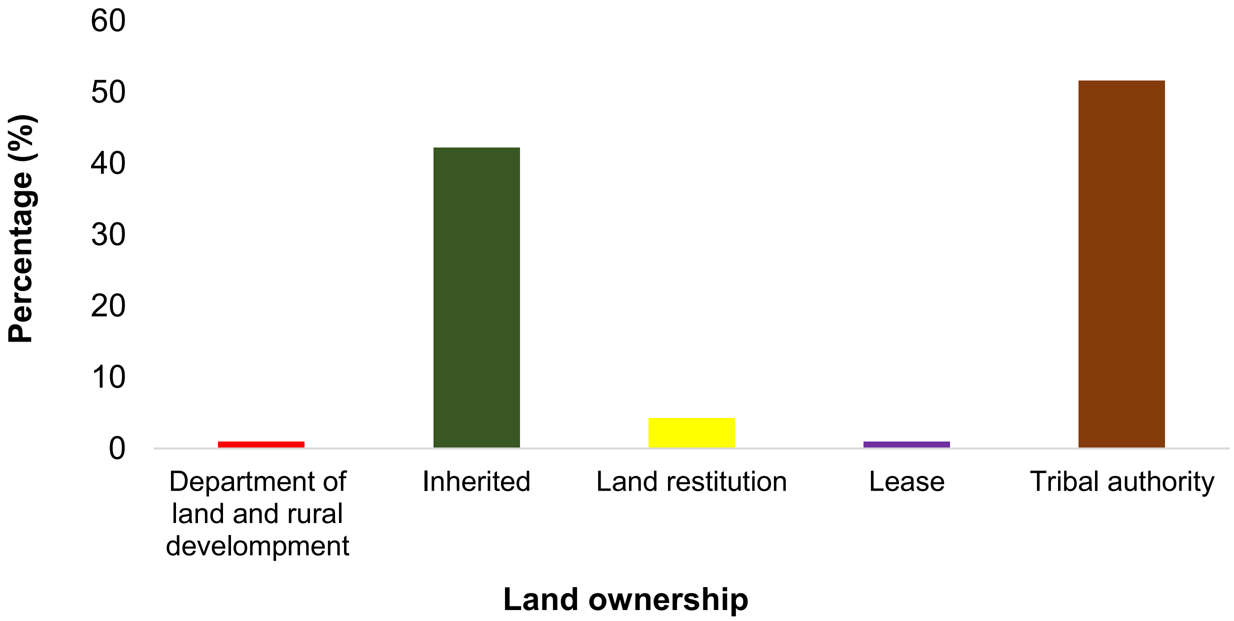

Figure 3-4: Land acquisition of smallholder farmers from Mbombela Local Municipality

3.4.8 Source of income

The study results revealed that 46.43% receive pensions, 10.06% receive government grants, 20.13% depend on selling agricultural products and 8.77% own businesses outside agrarian production. However, 8.12% have part-time jobs, 2.60% have full-time paying jobs, and 3.90

do not have any other income. These findings also confirmed that most of the older South African smallholder farmers (>60 years) supplement their pension income on their farms (Maponya and Mpandeli, 2013). It also shows that most smallholder farmers have limited income, which has a negative impact on adopting sustainable agricultural practices that require labour intensive (Marenya *et al*., 2017). Moreover, limited income could hinder smallholder farmers from adopting SAPs, such as growing new varieties.

3.4.9 Marketing channels

The study results show that 43.83% of the participant sell their agricultural products in their various communities, 34.74% do not sell their agricultural products, and 14.29% of their customers come and buy at the farm. However, 3.25% of the participants sell their agricultural products at the market. Smallholder farmers are encouraged to adopt sustainable practices to improve their farm productivity and food security and generate enough profit since most farmers depend on selling agricultural products.

3.4.10 Sustainable agricultural practices (SAPs) utilised

The graph (Figure 3.4) shows that farmers in the study are aware of sustainable farming practices and are willing to adopt them since they help them maintain their soil fertility, improving farm productivity. The study results revealed that 33.06% of the participants were practising crop rotation, and 27.27% were practising intercropping. However, 23.05% of the participants were practising green manure on their farm, 10.39% of participants did not practice any agricultural practices, and 4.22% practice soil mulching on the farm. These findings confirmed that legume smallholder farmers use crop rotation, intercropping, and organic manure as the most common practices to improve the area's productivity while sustaining the environment.

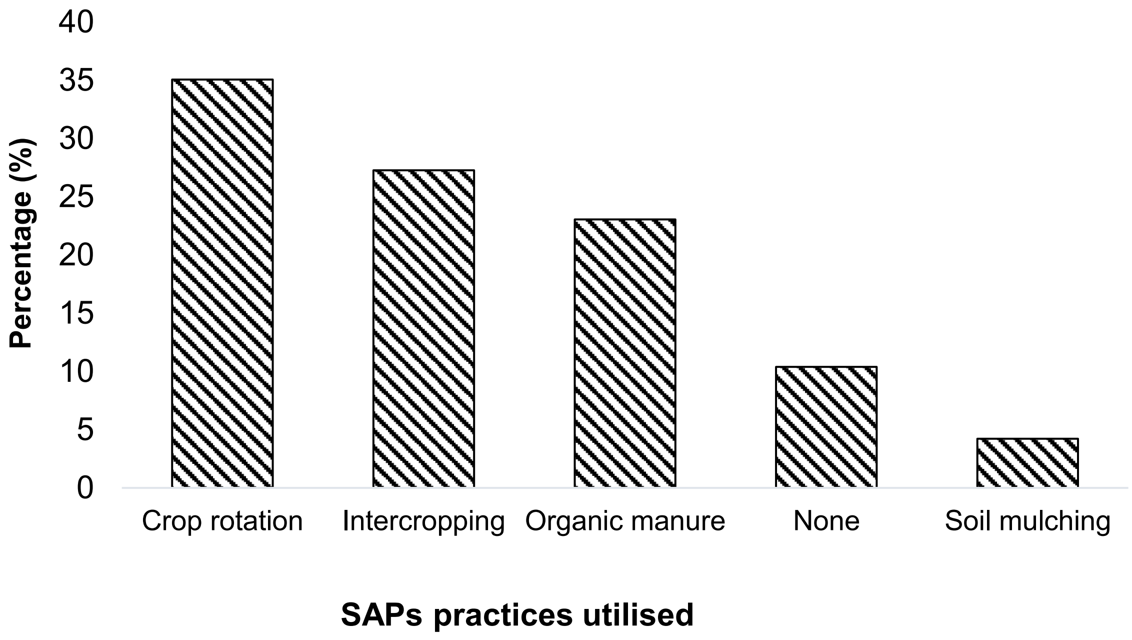

Figure 3-5: Sustainable agricultural practices (SAPs) utilized by smallholder farmers in the Mbombela Municipality.

3.4.11 Challenges of sustainable agricultural practices adoption by smallholder farmers

Adopting sustainable agricultural practices (SAPs) is critical for improving productivity, resource conservation, and resilience to climate change among smallholder farmers. However, several challenges hinder the widespread adoption of SAPs. These challenges can be categorized into technical, economic, social, and policy-related barriers. In this study (Figure 3.6), the biggest challenge for smallholder farmers in Mbombela Municipality is the financial constraints which are associated with high initial costs to implement sustainable farming practices and often require upfront investments in equipment, seeds, fertilizers, or irrigation systems, which smallholder farmers may not afford. The financial implications also make it difficult for smallholder farmers to access essential infrastructure such as irrigation systems, soil testing facilities, and storage facilities making it challenging to adopt SAPs. Other challenges include the agricultural extension services that are often understaffed, underfunded, or lack the expertise to promote SAPs effectively. In other instances, the climate-related issues and policies supporting sustainable agriculture may be poorly implemented or nonexistent in some regions.

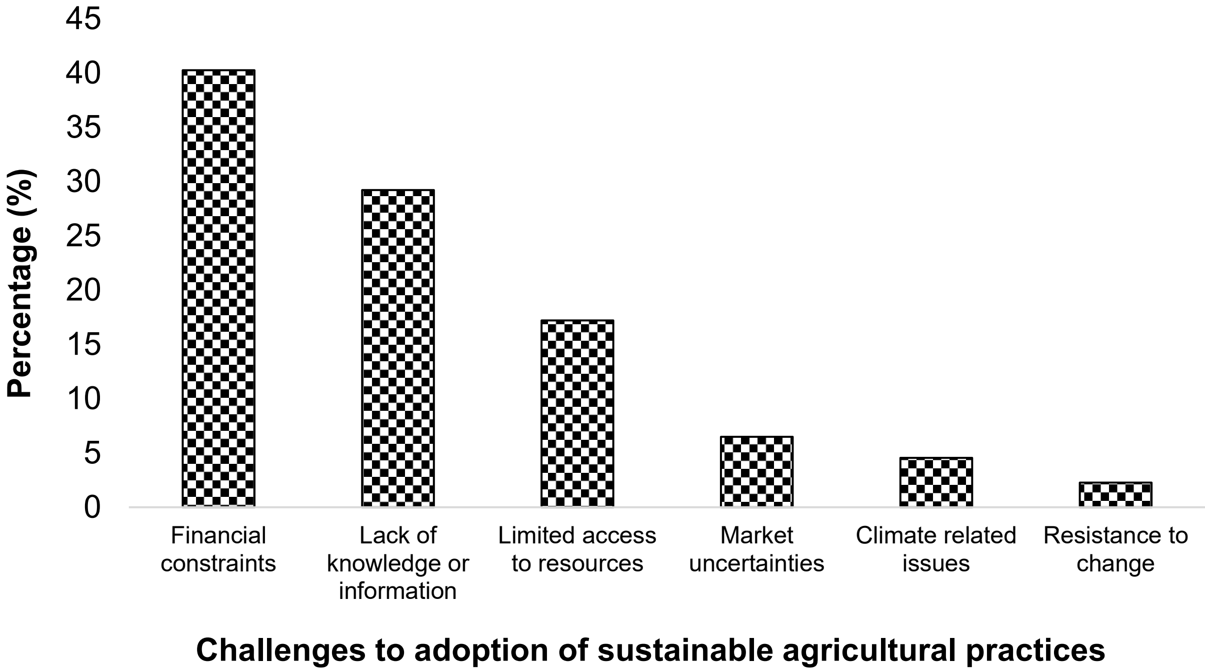

Figure 3-6: The challenges faced by smallholder farmers in the adoption of sustainable agricultural practices

3.4.12 Probit regression analysis

Results from a binary logistic regression model revealed that age, level of education, title deed and farming experience were the main factors that had a significant effect ($p \leq 0.05$) on the adoption of SAPs by smallholder farmers. Although variables such as gender, head of household, number of households, land acquisition, no employed labour were hypothesized to have an influence, they had no significant effect on adopting traditional SAPs in the study.

The regression results revealed that age was significant at 5% and negatively influenced adopting sustainable agricultural practices. It was necessary at 10%, and the positive coefficient indicates that farmers with farming experience are more likely to adopt sustainable agricultural practices in their farms compared to those who have just arrived in agricultural production. Title deeds as an independent variable showed negative influence and significance at 10%, and the negative coefficient indicates that title deeds of farmers are less likely to adopt sustainable agricultural practices on their farms. In contrast, the level of education revealed a negative and significant influence on adopting sustainable agricultural practices at 5%.

Table 3-2: Logistic regression

Logistic regression	Number of obs	= 308
	LR chi2(13)	= 206.34
	Prob > chi2	= 0.0000
Log-likelihood = -13.84413	Pseudo R2	= 0.8817

Do you know saps	Coef.	Std. Err. z	P>z [95% Conf.	Interval]
Gender	.8744072	1.612541 0.54	0.588	4.034929
Age	-.4612392	.1883343 -2.45	0.014 **	-.0921107
Head of household	-.5186288	1.36803 -0.38	0.705	2.162661
Marital status	.6167351	1.199045 0.51	0.607	2.96682
Highest level of education	-13.892	5.820396 -2.39	0.017**	-2.484234
Farming experience	.225139	.1327669 1.70	0.090**	.4853573
How did land acquire	-.3609479	.7463528 -0.48	0.629	1.101877
Title deeds	-2.548518	1.532149 -1.66	0.096**	.4544386
No employed labour	-.1259561	.4007321 -0.31	0.753	.6594644
No family members	.6801358	.8096516 0.84	0.401	2.267024
Any support service	.2282656	.5024417 0.45	0.650	1.213033
Additional support in adopting saps	3.44952	79.90767 0.04	0.966	160.0657
Part of farmers group	14.96421	16.6565 0.90	0.369	47.61035
_cons	21.19502	19.3872 1.09	0.274	59.19324

3.5 Conclusion

The results also indicate that most farmers who participated in this study were older than 35 years old, the study recommends that the national and local governments and other stakeholders find ways to work as a team to encourage youth involvement in farming activities since they are the country's future. In addition, 22.4% indicated that they did not go to school or complete formal education, so the government and other stakeholders must find a way to teach or train farmers so that they can take advantage of natural resources. The study recommends that the government give farmers incentives for adopting and implementing SAPs. This may result in improved adoption of SAPs. Regarding the challenges faced by smallholders interviewed concerning sustainable farming practices, the study found that farmers face various challenges in terms of lack of information, lack of access to the market, lack of access to loans/financial constraints and adequate land.

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CHAPTER FOUR

NUTRITIONAL COMPOSITION AND WATER RELATIONS OF UNDERUTILIZED CROPS

4.1 Introduction

South Africa is among the region's most severely impacted by the significant challenges that climate change poses to agricultural systems worldwide. The anticipated increase in global population growth is expected to drive higher food demand, which will, in turn, place greater pressure on agricultural water use. Previous studies have shown that crop yields, particularly in lower latitude regions, have been adversely affected by climate change, leading to a productivity challenge (Olabanji *et al.,* 2021). By 2050, water demand is projected to surpass availability, with climate change exacerbating drought and water scarcity, especially in regions already experiencing water stress.

One strategy to mitigate yield losses in a changing climate is to diversify crops beyond staples like maize (*Zea mays*), wheat (*Triticum spp*.), and rice (*Oryza spp*.) by incorporating species that are better adapted and more tolerant to environmental stress, such as minor and underutilized crops (Mango *et al.,* 2018). These underutilized crops and innovative crop-growing techniques are crucial for increasing food production, reducing irrigation water consumption, and enhancing agricultural water efficiency.

Underutilized crops are increasingly recognized for their potential to thrive on marginal lands and improve food security due to their adaptability to various environmental conditions (Mabhaudhi *et al.,* 2018). They are also a rich source of essential nutrients, including pro-vitamin A, vitamin C, folic acid, riboflavin, and minerals such as iron, zinc, calcium, and magnesium, all of which are vital for a balanced human diet (Mabhaudhi *et al.,* 2018). In sub–Saharan Africa, deficiencies in micro and macronutrients pose a severe health risk, particularly for women and children (Galani *et al.,* 2020).

Although the nutritional value of underutilized crops is well-documented, it is also essential to evaluate the impact of water on food and nutrition security. Improving water productivity for underutilized leafy vegetable crops is a valuable agricultural strategy, as it can help reduce competition for scarce water resources. Mitigation strategies that address adverse effects, such as water scarcity, will also enhance food security by increasing production with reduced water availability (Hadebe *et al.,* 2021).

Adopting drought-tolerant cultivars and improved crop management strategies can further enhance water productivity. Research on Nutritional Water Productivity (NWP) and the nutritional value of underutilized crops provides insights into how NWP is influenced by water scarcity. Adopting sustainable practices, such as mulching, can significantly contribute to moisture conservation, which is crucial in retaining soil moisture and enhancing crop resilience under water-limited conditions. This report documented the nutritional composition of underutilized legume crops through elemental analysis, assessing their response to different mulching treatments.

4.2 Description of Study Sites

4.2.1 Study location and soil sampling

The smallholder farmers' fields are located in Sulubindza (25.1441° S, 31.1575° E) and Luphisi (25.3925° S, 31.2953° E). Luphisi is a village of Ehlanzeni, Mpumalanga, situated 36 kilometres north-northeast of Mbombela. The area has a population of approximately 2,900, with most of the inhabitants women (Statistics, 2012). Sulubindza is a village in the Mbombela Local Municipality, Ehlanzeni District, Mpumalanga, home to about 4,700 residents. Sulubindza is located near the small towns of Bojwana and Numbi Park.

The trial experiment was conducted at the University of Mpumalanga farm at 25.4371° S, 30.9818° E, Mbombela, South Africa. The trial experiment was conducted at the University of Mpumalanga farm at 25.4371° S, 30.9818° E, Mbombela, South Africa. The soil samples were taken from both topsoil (0-30 cm) and subsoil (30-60 cm) using a soil auger (Volume ≈ 703.72 cm3) for analysis of the physical and chemical properties of the study area. The samples were analysed at the Agricultural Research Council’s Soil, Climate and Water (ARC-SCW, South Africa) using atomic absorption spectroscopy and ammonium acetate extraction (1N

NH40Ac). The soil analysis results from the trial experiment at the University of Mpumalanga are presented in Table 4.1.

Table 4-1: Physical and chemical properties of the soil at the University of Mpumalanga.

Soil nutrients	Topsoil (0-30 cm)	Subsoil (30-60 cm)
	Macronutrients (mg/kg)	
Ca	428	217
K	156	18.18
Mg	83.42	53.92
Na	12.34	8.22
P	36.50	16.86

Soil samples were collected from Luphisi and Sulubindza, focusing on the topsoil layer (0-30 cm) using a soil auger (Volume ≈ 703.72 cm^3) to analyze the physical and chemical properties of the study areas (Table 4.2). The samples were analyzed at the Agricultural Research Council's Soil, Climate, and Water (ARC-SCW) facility in South Africa, using atomic absorption spectroscopy and ammonium acetate extraction (1N NH_4OAc). The smallholder farmers in Luphisi utilize compost as a soil amendment, while those in Sulubindza use cow dung. Accordingly, the samples were categorized as "compost" and "cow dung" based on the soil amendments used.

Table 4-2: Physical and chemical properties of the soil from Sulubindza and Luphisi

Soil nutrients	Compost	Cow dung
	Nutrients	
Total Carbon	15.50%	9.90%
Total Nitrogen	1.24%	1.16%
Cu	75.5 mg/kg	15.4 mg/kg
Mn	417 mg/kg	317 mg/kg
B	24.6 mg/kg	17.4 mg/kg

Compost represents the sample collected from Luphisi and cow dung represents the sample collected from Sulubindza

4.2.2 Soil characterization

The analysis of soil macronutrient levels from samples collected at the University of Mpumalanga is presented in Table 4.1. The results indicate that macronutrients such as calcium, potassium, magnesium, sodium, and phosphorus vary between the topsoil and subsoil. The highest concentrations were recorded in the top-soil layer, with calcium at 428 mg/kg, potassium at 36.50 mg/kg, phosphorus at 156 mg/kg, and sodium (Table 4.1). According to Nguyen *et al.* (2017), the uptake of plant nutrients depends on the soil's nutrient concentration and ratio. To improve productivity, the concentration of these macronutrients can be enhanced by incorporating organic matter, including organic fertilizers and manure. The slightly acidic condition observed in the subsoil (30-60 cm) and deficient calcium levels suggest that liming may be necessary before planting to correct these imbalances.

Analysis of data collected from smallholder farmers' fields revealed an increase in total carbon (15.50%) in the compost prepared by farmers in Luphisi. The study showed that all soil nutrients were higher in the compost than the cow dung used as a soil amendment in Sulubindza (Table 4.2). The high carbon percentage in the compost is likely due to its ability to sequester carbon into the "fast" carbon cycle, making it nutritionally available for plants, insects, and microbial life.

Furthermore, the benefits of compost, such as improved nutrient supply, reduced erosion, and enhanced soil parameters, have been well documented (Martínez-Blanco *et al.,* 2013). Compared to cow dung, the higher nutrient content in compost suggests that compost could be a more effective sustainable practice for smallholder farmers.

4.2.3 Treatments and Design: University of Mpumalanga

A randomized complete block design (RCBD) with four replications was used in the study. The treatments included three underutilized legume crops (Cowpea, Bambara groundnut and Common bean) and three mulches (plastic mulch, pine bark mulch and no mulch). The treatment plots were fitted with watermark irrigation sensors (A900M-8) to assess soil water content in response to the mulching treatments.

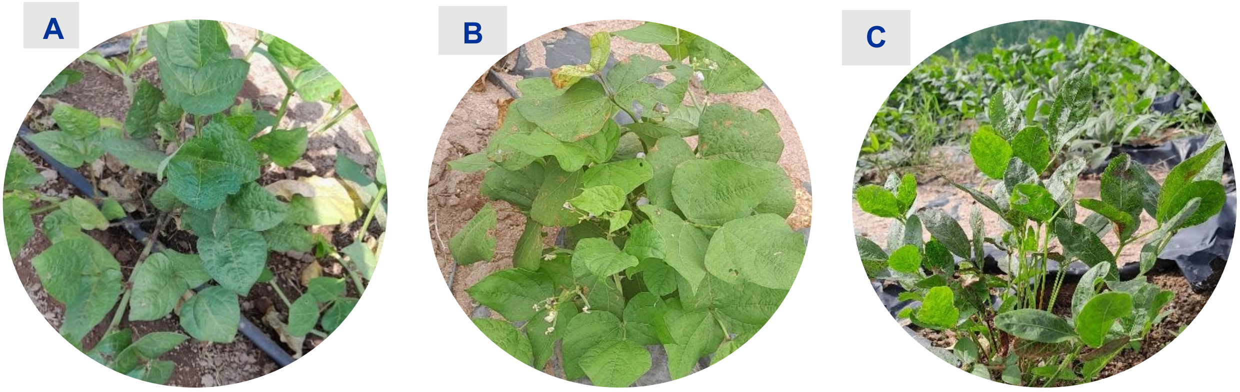

Figure 4-1: Underutilized legume crops (A: Common bean, B: Bambara groundnut and C: Cowpea).

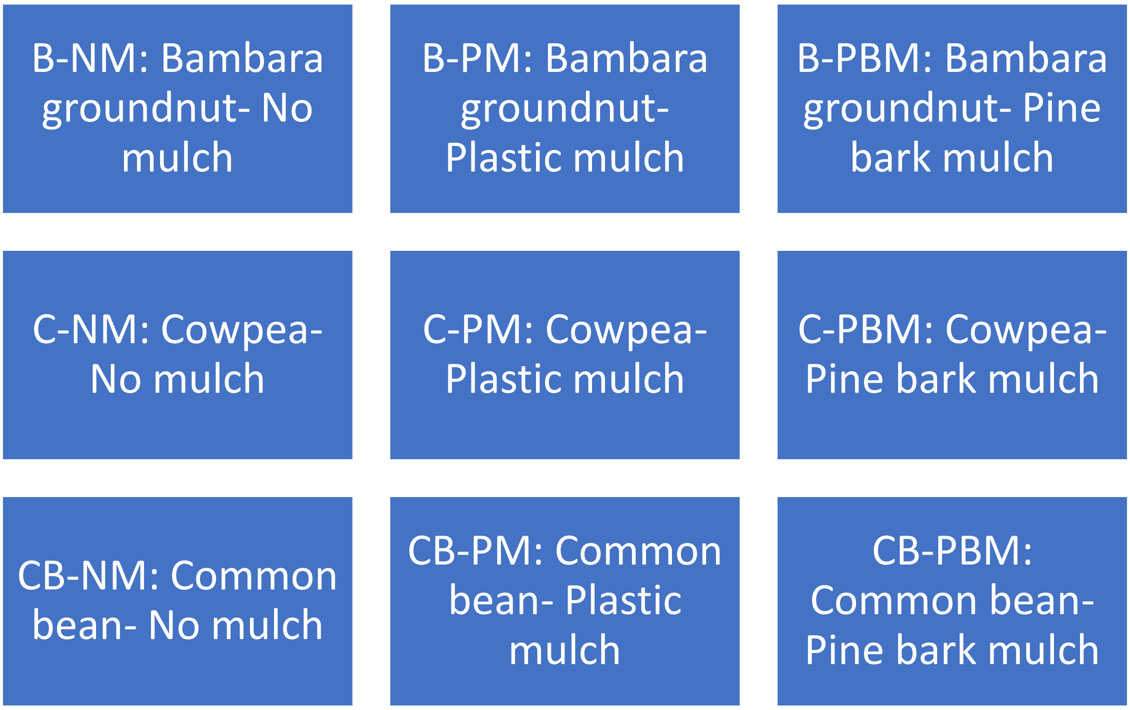

Figure 4-2: Experimental plots: Treatments that were used in the study

4.2.4 Treatments and Design: Smallholder farmer's fields (Luphisi and Sulubindza)

The on-farm plots at smallholder farmers' fields (Luphisi and Sulubindza) composed of three blocks measuring 5 m × 4 m (20 m^2) were replicated three times. The blocks were cropped with winter crops (Swiss chard and mustard spinach). Each experimental plot per treatment was divided into five rows; the three centre rows were used for data collection, while the two rows on either side were represented as border rows. The planting and selection of the winter crops by smallholder's fields were based on the utilization by the farmers, considering the market availability for income generation purposes. The trial plots were fitted with watermark irrigation sensors (A900M-8) at 0-30 cm to monitor soil moisture content and water requirements. The smallholder farmers were trained in the utilization of the chameleon. The smallholder farmers reported the chameleon colours every week. The colours include blue, which indicates the wet surface, green (moist) and red (dry), as presented in Figure 4.3.

Wetting Front Detectors (WFDs) were installed in various blocks to help smallholder farmers understand what occurs in the plant's root zone during irrigation. The WFD is a funnel-shaped device buried in the soil, with an indicator visible above the soil surface. In this study, the WFDs were buried at depths of 30 and 60 cm within the root zone. The indicator pops up when infiltrating water passes through the funnel, signalling that the water has reached that depth. As water moves down the funnel, the soil water content increases as the cross-sectional area narrows, eventually leading to saturation. The WFDs were used to determine whether the amount of irrigation applied was too little or too much.

Figure 4-3: Chameleon card system (Source: https://via.farm/card/)

4.2.4 Data collection

University of Mpumalanga experimental trial: **nutritional composition analysis**

The leaves of cowpea, common bean, and Bambara groundnut and the fractions were freeze-dried, ground, and stored until the nutritional composition was determined. The plant samples from the University of Mpumalanga were collected and processed for analysis. The nutritional composition included mineral element analysis determination using inductively coupled plasma optical emission spectrometry (ICP-OES).

Smallholder farmer's fields (Luphisi and Sulubindza): Water analysis

The water was collected from the borehole from the smallholder farmer's field, and they were analyzed for several parameters, including electrical conductivity, ash, organic matter, moisture, total C and total N (etc.).

4.2.5 Water relations (Chameleon irrigation and watermark sensors)

The trial plots cultivated at the University of Mpumalanga were fitted with watermark irrigation sensors (A900M-8) at 0-30 cm to monitor soil moisture content and water requirements. The smallholder farmers were trained in the utilization of the chameleon. The smallholder farmers reported the chameleon colours every week. The colours include blue, which indicates the wet surface, green (moist) and red (dry), as presented in Figure 3.3.

4.2.6 Statistical analysis

All data were subjected to analysis of variance using GenStat software 17.1 edition (VSN International, Hemel Hempstead, UK). The treatment means were separated using ($p \leq 0.05$) Duncan’s multiple range test (DMRT).

4.3 Results and Discussion

4.3.1 Soil characterization

The analysis of soil macronutrient levels from samples collected at the University of Mpumalanga is presented in Table 4.1. The results indicate that macronutrients such as calcium, potassium, magnesium, sodium, and phosphorus vary between the topsoil and subsoil. The highest concentrations were recorded in the top-soil layer, with calcium at 428 mg/kg, potassium at 36.50 mg/kg, phosphorus at 156 mg/kg, and sodium (Table 4.1). According to Nguyen *et al.* (2017), the uptake of plant nutrients depends on the soil's nutrient concentration and ratio. To improve productivity, the concentration of these macronutrients can be enhanced by incorporating organic matter, including organic fertilizers and manure.

The slightly acidic condition observed in the subsoil (30-60 cm), along with very low calcium levels, suggests that liming may be necessary before planting to correct these imbalances. Analysis of data collected from smallholder farmers' fields revealed an increase in total carbon (15.50%) in the compost prepared by farmers in Luphisi. The analysis showed that all soil nutrients were higher in the compost than the cow dung used as a soil amendment in Sulubindza (Table 4.2). The high carbon percentage in the compost is likely due to its ability to sequester carbon into the "fast" carbon cycle, making it nutritionally available for plants, insects, and microbial life.

Furthermore, the benefits of compost, such as improved nutrient supply, reduced erosion, and enhanced soil parameters, have been well documented (Martínez-Blanco *et al.,* 2013). Compared to cow dung, the higher nutrient content in compost suggests that compost could be a more effective sustainable practice for smallholder farmers.

4.3.2 Water analysis: Smallholder farmers' fields (Luphisi and Sulubindza)

The water samples collected from the two smallholder farmers' fields showed no significant differences in pH levels, with Luphisi recording a pH of 6.88 and Sulubindza having a pH of 6.93 (Table 4.2). However, the electrical conductivity was higher in the water sample from Luphisi compared to Sulubindza. This difference in electrical conductivity may be attributed to discharge or other disturbances that have compromised the condition and health of the water body and its associated biota. Additionally, concentrations of sulphate, sodium, calcium, magnesium, and alkalinity were significantly higher in Luphisi than in Sulubindza. Notably, the sodium level in Luphisi exceeded 20 mg/L, which can contribute to health issues such as high blood pressure.

The water samples collected from the two smallholder farmer's fields did not show significant differences in the pH amounts. Luphisi recorded a pH of 6.88 while Sulubindza recorded a pH of 6.93. The electrical conductivity was higher for the water sample collected from Luphisi than for the sample from Sulubindza. The differences in electrical conductivity can be attributed to a discharge or some other source of disturbance that has decreased the relative condition or health of the water body and its associated biota. The sulphate, sodium, calcium, magnesium and alkalinity were extremely high for Luphisi compared to Sulubindza. The attributed increase in sodium in Luphisi was measured to be higher than the above 20 mg/L level. High blood pressure or common chronic medication can also be attributed to high amounts of sodium.

Table 4-3: Water analysis from smallholder farmer's fields (Luphisi and Sulubindza)

Parameters	**Luphisi**	**Sulubindza**
pH	6.88	6.93
EC	278 mS/m	24.0 mS/m
	mg/l	
NO_3^- (Nitrate)	7.53	5.63
Cl^- (Chloride)	607	18.1
F^- (Fluoride)	0.67	0.11
SO_4^{2-} (Sulphate)	100	19.5
Na	398	21.0
K	8.71	2.7
Ca	93.4	10.5
Mg	62.6	10.5
Alkalinity	314	54.0

4.3.3 Plant height and chlorophyll content of three crops in response to mulching

The results showed higher plant growth for the underutilized cowpea legume irrespective of the mulching treatment. The findings were followed by Bambara groundnut and Common bean in terms of growth under the plastic and pine bark mulch, respectively. The beneficial outcomes of mulching the underutilized legume crops in this study suggest that modifying the green environment to control soil temperature and moisture, inhibit weed growth, and increase crop production is a successful strategy. To determine the effects of mulching on the various underutilized legume crops, the report suggests conducting additional research on the validation of the obtained data.

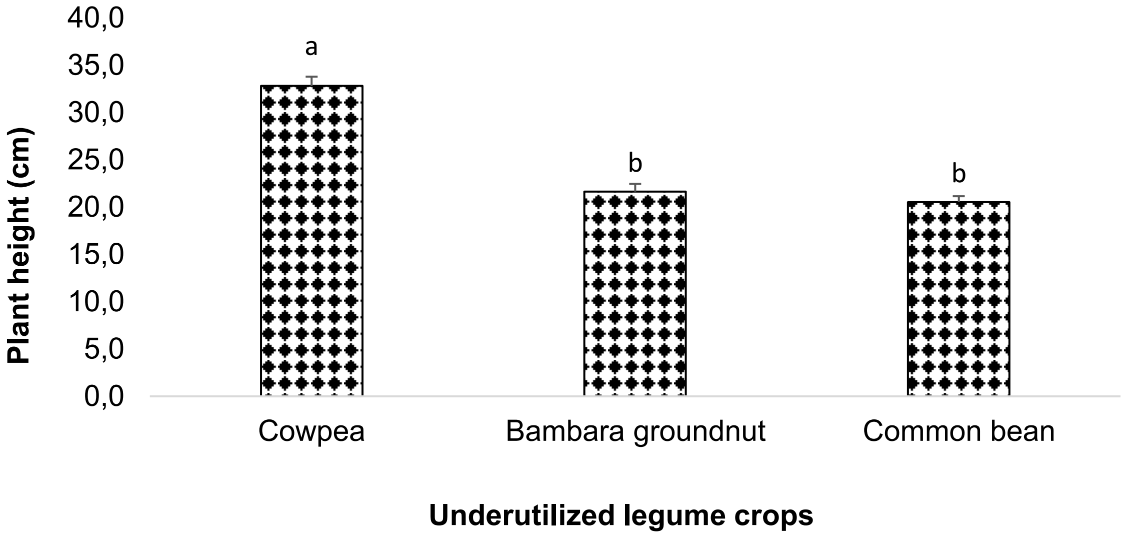

Figure 4-4: Plant height of three underutilized legume crops in response to mulch treatments. Mean values are of five replicates for plant height and error bars show one standard error. Columns with different letters are significantly different at $p \leq 0.05$.

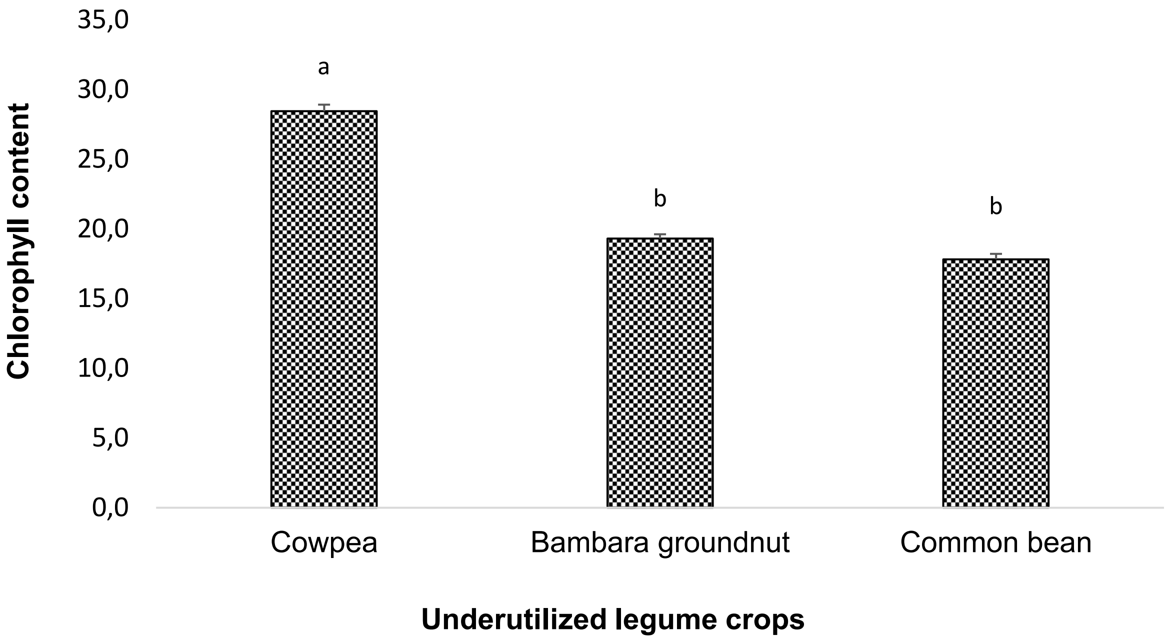

Figure 4-5: Chlorophyll content of three underutilized legume crops in response to mulch treatments. Mean values are of five replicates for chlorophyll content and error bars show one standard error. Columns with different letters are significantly different at $p \leq 0.05$.

4.3.4 Nutritional composition of underutilized crops

The nutritional composition of three underutilized crops (cowpea, common bean and Bambara groundnut) in response to different mulching treatments are presented in Tables 4.4 and 4.5.

Ash and mineral nutrients of underutilized crops

The ash content of the three underutilized crops ranged from a low 6.36% for Bambara groundnut (pine bark) to 13.11% for cowpeas that did not receive any mulching treatment. The potassium, phosphorus, calcium and magnesium reported in percentages are reported in Table 4.4. The highest content was observed for K for cowpea that was treated with no mulch and the one that was treated with pine bark mulching. In Table 4.5, sodium, iron, molybdenum and zinc are presented in response to different mulching treatments. The reported high Fe content can greatly contribute to human nutrition. Cowpea provides a rich supply of minerals required for maintaining normal homeostasis at the cellular level. Sharma *et al.* (2020) have reported on the edible parts of cowpeas, which have been documented to possess calcium

(Ca), phosphorus (P), and iron (Fe) in different amounts which align with the values that are presented in this report.

The iron content differed significantly between the three crops in response to mulching treatments. The highest iron content was reported for common beans treated with pine bark mulch at 708 mg/kg (Table 4.5). The reported high Fe content can greatly contribute to human nutrition. The results of the study showed that cowpea high potassium content. Zinc is a micronutrient that greatly influences the growth, yield, and quality of leafy vegetable crops. The high zinc content reported in this study for common bean that were treated with pine bark mulch which can accelerate many plants enzymes' performance (Table 4.5).

Table 4-4: Elemental analysis of three underutilized crops in response to mulching

Treatments	Ash	K	Ca	Mg	P
		%			
B-NM	7.22	0.645	1.37	0.425	0.380
B-PBM	6.36	0.506	1.31	0.433	0.332
B-PM	7.58	0.785	1.55	0.452	0.339
C-NM	8.18	2.09	1.16	0.486	0.632
C-PBM	8.07	2.13	1.23	0.497	0.593
C-PM	8.65	1.87	1.42	0.484	0.539
CB-NM	13.1	0.875	1.94	0.701	0.652
CB-PM	11.7	1.27	1.76	0.687	0.455
CB-PBM	12.4	1.17	1.86	0.736	0.555

B-NM: Bambara groundnut- No mulch; B-PM: Bambara groundnut- Plastic mulch; B-PBM: Bambara groundnut- Pine bark mulch; C-NM: Cowpea- No mulch; C-PM: Cowpea- Plastic mulch; C-PBM: Cowpea- Pine bark mulch; CB-NM: Common bean- No mulch; CB-PM: Common bean- Plastic mulch; CB-PBM: Common bean- Pine bark mulch.

Table 4-5: Elemental analysis of three underutilized crops in response to mulching

Treatments	Na	Fe	Mn	Zn	**Cu**
		mg/kg			
B-NM	82.4	303	136	74.7	38.2
B-PBM	73.2	361	129	80.9	39.8
B-PM	85.0	289	108	84.2	39.2
C-NM	163	198	93.1	83.1.	43.3
C-PBM	98.1	184	96.8	75.0	43.4
C-PM	87.2	170	127	93.5	47.0
CB-NM	94.8	527	66.1	125	53.6
CB-PM	78.7	384	30.9	169	46.5
CB-PBM	87.2	708	86.5	98.5	51.7

B-NM: Bambara groundnut- No mulch; B-PM: Bambara groundnut- Plastic mulch; B-PBM: Bambara groundnut-Pine bark mulch; C-NM: Cowpea- No mulch; C-PM: Cowpea- Plastic mulch; C-PBM: Cowpea- Pine bark mulch; CB-NM: Common bean- No mulch; CB-PM: Common bean- Plastic mulch; CB-PBM: Common bean- Pine bark mulch.

4.3.5 Water relations of underutilized crops

Water use: Chameleon soil moisture sensor profiles smallholder farmer's fields (Luphisi)

Smallholder farmers reported the chameleon sensor readings weekly (Table 4.4), using the blue, green, and red lights to gain a high-level overview of soil moisture conditions in their fields. In Luphisi, the chameleon sensors predominantly showed red (dry soil), followed by green (moist soil) and blue (wet soil). This site is characterized by very hot and often dry summers, with an average annual rainfall of about 190 mm, typically occurring between November and March. The training provided to the smallholder farmers has equipped them with the skills to adjust irrigation amounts or frequencies based on the sensor readings, enabling them to schedule irrigation effectively and determine when the soil requires water to reach field capacity.

Table 4.6 details the data collected on different days of the week over three months (June to August 2024). Although various vegetable crops were monitored using chameleon irrigation sensors, this section focuses on the findings for two specific crops: Swiss chard and mustard spinach. The data presented relates to the Luphisi site, as the smallholder farmers in Sulubindza relied more on wetting front detectors.

At the Luphisi site, dry conditions (indicated by the red light) were reported at the beginning of the crop monitoring phase in June for both mustard spinach and Swiss chard (Table 4.6). The variations in water use, as indicated by the different sensor colours, can be attributed to the hot environment of Luphisi. The wet and moist conditions reported (depicted by blue and green lights) reflect the farmers' scheduled irrigation. The site did not receive rain during the winter months of 2024. The red light, indicating dry conditions, is not surprising given that temperatures in Luphisi can reach up to 33°C even in winter.

Table 4-6: Chameleon soil moisture sensor patterns measured during the growing season under the supplementary irrigation treatment in Luphisi: the blue (wet), green (moist) and red (dry) colours based on the reading at different dates.

Depth (cm)	***Crop***	***10 Jun***	***19 Jun***	***28 Jun***	***5 Jul***	***12 Jul***	***22 Jul***	***30 Jul***	***3 Aug***	***6 Aug***	***9 Aug***	***13 Aug***	***15 Aug***
0-30	***Swiss Chard***												
	Mustard spinach												

Watermark irrigation sensors (*UMP experimental trial)*

Figure 4.7 presents the preliminary results on soil water content, temperature, and relative humidity for Bambara groundnuts in response to mulching treatment. The data indicate that relative humidity fluctuates throughout the day. For example, it was recorded at 70% early in the morning but dropped significantly between 3:00 and 4:00 p.m., before increasing again after 5:00 p.m. Relative humidity is closely tied to temperature, rising or falling accordingly. In this study, the relative humidity dropped around 3:00 p.m., a time when temperatures are typically higher in Mbombela. Warm air, such as that experienced in the afternoon on a sunny day, has a lower relative humidity because it can hold more moisture. Figure 4.8 presents the preliminary results on soil water content, temperature, and relative humidity for Common beans in response to mulching treatment. The data indicate that relative humidity fluctuates throughout the day. The data showed high temperatures in the afternoon from 2:00 pm until 4:00 pm. The data ranges of the relative humidity for the common bean are not significantly different to the data reported in Figure 4.6 of the Bambara groundnut. Figure 4.8 presents data on temperature, soil water content, and relative humidity for cowpeas in response to mulching treatments. The temperature and soil water content were relatively high, averaging around 30°C. While the trends in temperature and soil water content are similar to those observed in Figures 4.6 and 4.7, it is evident that the values in Figure 4.8 were the highest among the compared datasets.

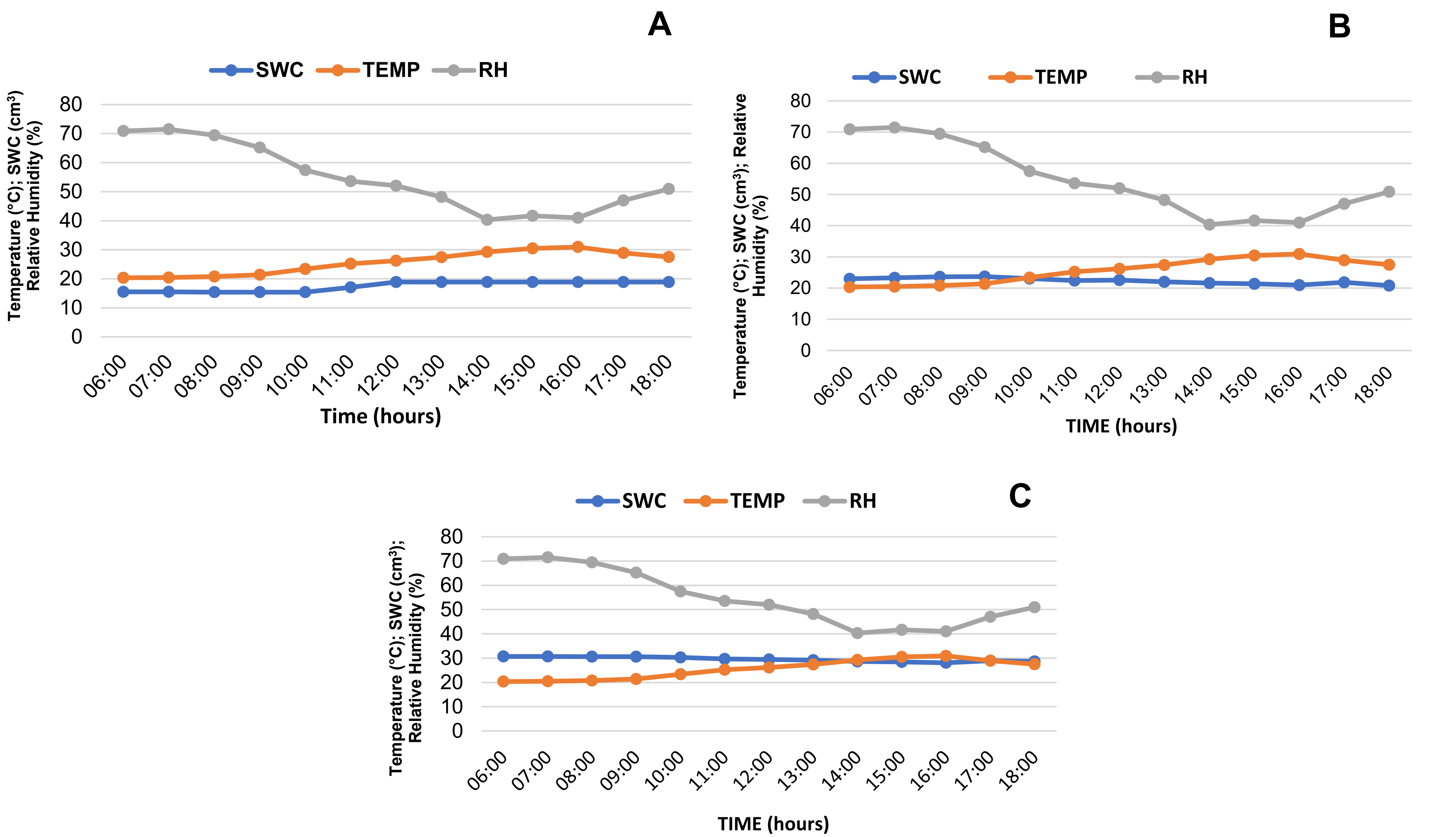

Figure 4-6: Temperature, soil water content and relative humidity of Bambara groundnut (A), Common bean (B) and Cowpea (C) in response to mulching treatments.

4.4 Conclusion

Smallholder farmers were engaged in various activities utilizing an on-farm practical approach to achieve sustainable agricultural practices. Some of the practices adopted by the farmers include crop rotation, mulching, intercropping, and the use of chameleon irrigation sensors for soil moisture monitoring. The data from the experimental plots at the University of Mpumalanga present preliminary results, which will be further validated during the September 2024 to February 2025 cropping season. The results will form part of the final report. This study revealed that cowpea legume crops exhibited the highest plant height and chlorophyll content, highlighting the need for further research to identify additional plant parameters that may contribute to this growth. While the current data is preliminary, it suggests that underutilized crops like cowpeas have significant potential as drought-tolerant crops with a rich nutritional profile, making them valuable for dietary diversification. Enhancing smallholder farmers' adoption of new technologies requires training grounded in practical, on-farm activities. The involvement of multiple stakeholders has shown how training and education can transform the lives of smallholder farmers. By equipping them with the necessary tools and knowledge, we empower them to take control of their livelihoods and build successful, sustainable enterprises that benefit their families and communities.

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CHAPTER FIVE

PARTICIPATORY RESEARCH AND KNOWLEDGE DISSEMINATION

5.1 Introduction

Participatory research is a research-to-action approach that promotes direct engagement with local communities and ensures that priorities and perspectives are achieved. It serves as a term that consists of research methods, research designs, and frameworks that utilize direct collaboration with those affected by the issue being investigated, such as food security and climate change's impact on smallholder farmers (Vaughn and Jacquez, 2020). Participatory research prioritizes co-constructing research by collaborating with several stakeholders, including the researchers, community members, government departments and the private sector (industry) (Montreal and Bogossian, 2021; Jacquet *et al.,* 2022). Participatory research approaches involve various stakeholders that, in most cases, assist farmers (smallholder farmers) in mitigating agricultural challenges like climate change and promoting sustainable agricultural practices. Sustainable agricultural practices can be described as eco-friendly methods of production that do not harm the environment (Parr *et al.,* 2020). This approach is aimed at neutralizing the effects of conventional agriculture, such as using synthetic chemicals that degrade land productivity. Adopting sustainable agricultural practices through participatory research involves integrating indigenous knowledge with modern agricultural production systems (Ulian *et al.,* 2020). This includes sharing indigenous knowledge of farming underutilized crops amongst communities, researchers and other stakeholders. Participatory research promotes the working together between the people and their communities, including the ecosystem of which they form part. There are numerous benefits of participatory research, which informs the translation of information into the community and non-academic settings and the integration of the researcher's theoretical and methodological expertise with the participant's real-world knowledge and experiences into a mutually reinforced partnership (Vaughn and Jacquez, 2020, Van De Gevel *et al.,* 2020).

Additionally, participatory research is crucial across different disciplines to solve complex, varying problems. Agricultural demonstrations through participatory research consist of instructions to smallholder farmers, allowing them to observe different farming methods and technologies that can be used in their practices, resulting in positive changes on the farm (Adamsone-Fiskovica and Grivins, 2022). Demonstrations have existed as a way of facilitating learning and knowledge sharing amongst individuals for a very long time, hence, they are currently regaining momentum in different regions to promote research-based farming solutions (Burton, 2020). Commonly, demonstrations are pursued to encourage the uptake of environmentally and economically sustainable production methods or systems. Smallholder farmers across different regions face diverse challenges related to climate change, degradation of natural resources and poor yield production (Richardson *et al.,* 2022). The promotion of smallholder farmers to access and be adaptable to agroecological innovations can improve issues such as food insecurity and poor yield production of crops. Research and outreach aim to support smallholder farmers in promoting and advancing sustainable agricultural practices (Van den Berg *et al.,* 2020; Richardson *et al.,* 2022). Integrating sustainable agricultural practices principles can improve on-farm and sustainable practices (Canwat *et al.,* 2021; Nicolétis *et al.,* 2019). To achieve participatory research, activities can be coordinated through collaboration between the stakeholders, including smallholder farmers, researchers from the University of Mpumalanga, and extension officers from the local department of agriculture, to strengthen the use of sustainable agricultural practices.

5.2 Methodology

5.2.1 Stakeholder Identification and Engagement

The criteria used to identify stakeholders included targeting participants who engaged in agriculture as a livelihood activity and had the influence on shaping policies and disseminating information to farmers. Smallholder farmers were recognized as key stakeholders because they actively participated in farming activities and would directly benefit from the workshops. Engagement strategies included surveys, on-farm training workshops, feedback sessions, peer-to-peer learning, and farmer-led innovations. Additionally, community leaders were engaged as they played a crucial role in fostering trust and facilitating the adoption of outreach, workshops, and projects among the local community. Other vital stakeholders included researchers, agricultural extension services, and agencies that generated information and shared findings with farmers. The stakeholders were engaged through various strategies, including participatory consultation, capacity building, conflict resolution, monitoring and evaluation, communication, and transparency. Firstly, surveys and focus group discussions were conducted to identify opportunities and challenges. After each meeting, stakeholders were regularly updated on the progress and outcomes of the previous engagements. Secondly, various working and training sessions, such as on-field demonstrations, were conducted to enhance and build the capacity of the local people to sustain the initiatives beyond the project's lifespan. Thirdly, a platform was created where farmers could express their grievances and maintain a harmonious working environment. Accountability criteria were established in collaboration to track the progress of the local people and ensure accountability. During the engagements, stakeholders were polled with open-ended questions, and their responses were recorded during focus group discussions.

5.2.2 On-farm participatory research

The on-farm participatory implementation approach encourages all the stakeholders (smallholder farmers, researchers, community leaders, government policymakers, agricultural extension and other private sectors) to participate in the decision-making process to ensure a successful action plan. However, the participatory approach aims to impart knowledge and skills among each other to improve agricultural productivity (Vogl *et al.,* 2015). The whole plan is to empower smallholder farmers to take ownership of their farming operations, doing all the work with or without agricultural extension since agricultural extension works with farmers do not work for them. According to Small and Raizada (2017), participatory research aims to enable communities to identify and decide on their innovation that will be entirely accepted in their various communities. It strengthens communities' abilities to address and solve problems independently and encourages communities to preserve their Indigenous Knowledge Systems (IKS) and integrate them with modern innovation (Mapfumo *et al.,* 2016). It is essential to use farmers as a source of information due to their experience and indigenous knowledge system to build innovation that will foster sustainable agriculture for current and future generations. It is essential to listen and learn from various farmers and to promote sustainable development based on the priorities of families as determined by them. It is a process that enhances the community's capacity to help them and utilize their resources and external providers more effectively to improve their livelihoods (Lobry de Bruyn *et al.,* 2017).

Participatory Research Approaches

The smallholder farmers in Luphisi and Sulubindza were part of the participatory research approach workshop that was hosted by the University of Mpumalanga researchers and the extension officers from the Department of Agriculture, Land Reform and Rural Development (DALRRD). As delineated below, the following technologies and activities were practised with the smallholder farmers.

Participatory training

Participatory training on seedling production and chameleon sensors focused on practical, hands-on learning to equip smallholder farmers and community members with the skills and knowledge needed for sustainable agriculture. This approach encourages active involvement, empowering participants to learn, share, and implement techniques to boost productivity and resource management.

Seedling Production

Training is encouraged to teach the participants the techniques for growing high-quality seedlings to improve crop yields and resilience. Some important vital factors include seed selection and preparation and learning about selecting healthy seeds and preparing them for optimal germination. The smallholder farmers were engaged in soil preparation and potting, and the training involved creating the right soil mix and using pots or seed trays to promote strong root systems. The transplanting techniques were also part of the training, which showed hands-on practice in transplanting seedlings to the field, ensuring minimal root damage and better establishment. The Chameleon sensor training allowed the smallholder farmers to understand the monitoring of soil moisture levels effectively, using Chameleon sensors to improve water efficiency in crop production. Demonstrations on installing chameleon sensors at various soil depths to measure moisture at different root levels. Teaching participants to read sensor colour indicators (typically blue for wet, green for moist, and red for dry) to make informed irrigation decisions. Practical guidance on adjusting watering based on the sensor data to avoid water wastage and support crop health. The training also emphasized the importance of tracking moisture levels over time and sharing insights with the community to support collective learning. The benefits of the participatory research were observed directly in training, and participants gained the confidence to apply and replicate these practices on their farms. The training on learning to grow healthy seedlings and manage water resources efficiently supports long-term, sustainable agriculture. The workshop also contributed to community knowledge sharing as the participants acquired valuable knowledge resources for their communities, fostering collective resilience and food security.

5.2.3 Adoption of sustainable practices

The project incorporated sustainable practices and principles, emphasizing environmental conservation, efficient resource utilization, and economic viability. Smallholder farmers were taught essential agronomic practices through on-farm training sessions, including crop rotation, water-saving irrigation methods, soil health management, rainwater harvesting, and organic pest control. By integrating environmentally friendly agronomic practices into the workshops, farmers were empowered to adopt these practices, leading to long-term agricultural success while preserving the environment. This pilot project involved using local manure as fertilizers in the cultivated fields and establishing drip irrigation systems.

5.3 Feedback from stakeholders

The stakeholders were satisfied with the participatory research approach as it improves agricultural productivity. Most of the local farmers expressed satisfaction with the activities because they received hands-on training, which enabled them to gain valuable skills. This contrasts with previous findings, which demonstrated that most initiatives and extensions did not provide farmers with hands-on training. Therefore, this approach would eradicate food and nutrition insecurities by improving the farmers' agricultural productivity. One community leader, commenting on the impact of the on-farm demonstration, remarked, “These trainings will reduce food and nutrition insecurities and improve the yield of each farmer's crops.” The researchers have emphasized the significance of collaborating and working closely with farmers. This partnership has deepened their understanding of the unique challenges faced by farmers in rural areas. They can formulate subsequent projects to address these gaps effectively by identifying them. One researcher highlighted the benefits of the participatory research approach, stating, “Engaging with the farmers in these communities has truly opened my eyes to the specific challenges they encounter.” Another researcher remarked, “Interacting with the farmers has sparked new research ideas.” These on-farm demonstrations and engagements will foster a bridge between researchers and farmers. This collaboration will enhance the productivity and climate resilience of rural subsistence and smallholder farming systems.

5.4 Conclusion and Recommendation

The participatory research approach has proven invaluable for enhancing smallholder farmers' understanding and adoption of sustainable agricultural practices. By directly involving farmers in seedling production training and using chameleon irrigation sensors, this approach has bridged the gap between research and practical implementation, empowering participants to make informed decisions and improve productivity on their farms. This participatory approach fosters a culture of continuous learning and shared knowledge, enabling farmers to manage resources and adopt climate-smart practices independently. The success of this project highlights the potential for similar initiatives to build resilient agricultural systems within rural communities, ensuring food security and sustainable development for smallholder farmers. The knowledge gained through this research can serve as a foundation for future programs to expand these practices to more communities.

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CHAPTER SIX: GENERAL SUMMARY, CONCLUSION AND RECOMMENDATIONS

6.1 General Summary

Sustainable agricultural practices (SAPs) are vital for addressing food security challenges while ensuring environmental conservation and resource efficiency. These practices, such as crop rotation, intercropping, mulching, and water conservation techniques, have been demonstrated to improve productivity, enhance soil health, and reduce dependency on synthetic inputs. Engaging stakeholders, particularly smallholder farmers, through participatory research, capacity building, and technology transfer is crucial for successful implementation.

This report highlights the importance of SAPs in enhancing the livelihoods of smallholder farmers, focusing on underutilized crops that contribute to nutritional security. The integration of SAPs with modern technology, such as chameleon irrigation sensors, facilitates precision agriculture and optimizes resource use. Despite their benefits, the adoption of SAPs faces several challenges, including socio-economic constraints, limited access to resources, and knowledge gaps.

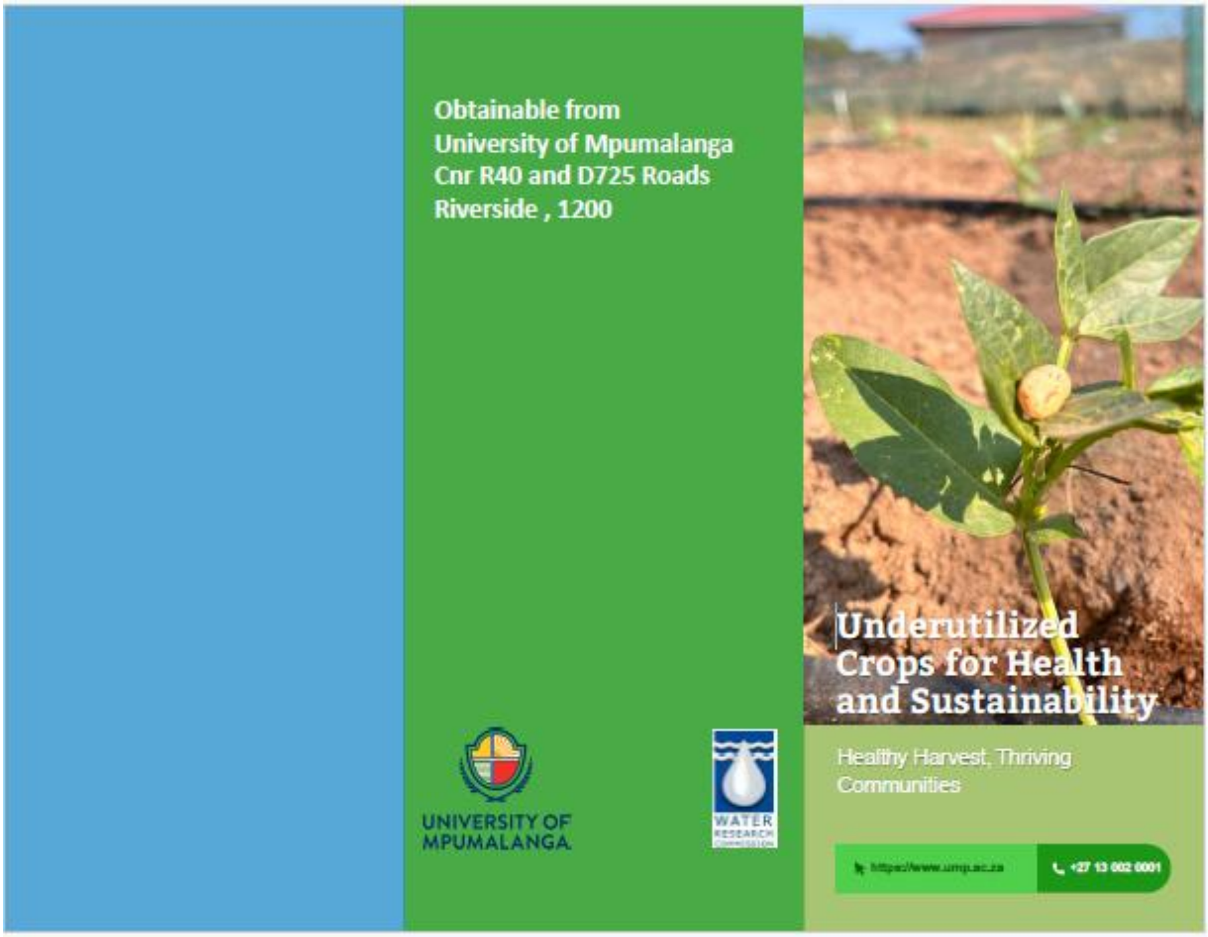
6.2 Conclusions

SAPs, such as mulching, crop diversification, and water-use optimization, have demonstrated the potential to significantly increase yield for underutilized crops such as cowpea, common beans and Bambara groundnut. Participatory approaches, including workshops, training, and feedback sessions, build trust and encourage the adoption of sustainable practices among smallholder farmers. Legumes like cowpea, Bambara groundnut, and common beans offer high nutritional value and adapt well to marginal environments, making them crucial for food security and sustainable livelihoods. The socio-economic factors, knowledge gaps, and limited access to modern technologies hinder the widespread adoption of SAPs. Tools like chameleon sensors for soil moisture monitoring bridge the gap between traditional and modern practices, improving decision-making at the farm level.

6.3 Recommendations

The scaling up and training awareness programs to conduct extensive workshops and field demonstrations to educate smallholder farmers on the benefits and implementation of SAPs. The investment in research and development of underutilized crops to harness their nutritional and environmental benefits, coupled with market development to encourage their production and consumption. The project recommends collaboration, fostering partnerships between governments, research institutions, NGOs, and local communities to align efforts and resources toward promoting SAPs. The project recommends advocating for policies that support smallholder farmers, including access to markets, credit facilities, and infrastructure development for sustainable farming. The implementation of robust systems to measure the adoption and impact of SAPs, using the data to refine strategies and ensure sustainability is crucial. By adopting these recommendations, stakeholders can drive the transition toward more sustainable agricultural systems, ensuring enhanced productivity, resilience to climate change, and improved livelihoods for smallholder farmers.

APPENDIX I: PRODUCTION GUIDELINE OF COWPEA, BAMBARA GROUNDNUT AND COMMON BEAN



Cowpea (*Vigna unguiculata L.*)

Origin and distribution

Cowpea is native to Central Africa. It is widespread throughout the tropics and most tropical areas between 40°N to 30°S and below an altitude of 2000 m

Growing areas in South Africa

Cowpeas are grown in the following provinces of South Africa: Limpopo, Mpumalanga, North-West, KwaZulu-Natal, and Gauteng.

Uses

Food, animal feed, hay production , soil improvement, weed competition, silage

Climatic requirements

350-500mm rainfall, 15-23°C temperature, 4-9 pH, 300-4300m elevation

Origin and distribution

Phaseolus vulgaris originated from Central and South America, It is now widespread and cultivated as a major food crop in many tropical, subtropical and temperate areas of the Americas, Europe, Africa and Asia

Growing areas in South Africa

Common bean is grown in the following provinces of South Africa: Limpopo, Mpumalanga, North-West, Northern Cape, Free State, KwaZulu-Natal, and Gauteng.

Uses

Food, animal feed, soil improvement, indigenous medicine, cosmetics.

Climatic requirements

350-500mm rainfall, 15-27°C temperature, 5.5-76.5 pH soil, 2200-3000m elevation

Common Bean (*Phaseolus vulgaris*)

Bambara Groundnut (*Vigna subterranea L.*)

Origin and distribution

Vigna subterranea originated from West Africa (Nigeria, Cameroon, Central African Republic and Chad) and has been cultivated throughout drier tropical Africa.

Growing areas in South Africa

Bambara groundnut is grown in the following provinces of South Africa: Limpopo, Mpumalanga and KwaZulu-Natal.

Uses

Food, indigenous medicine, industrial applications

Climatic requirements

750-1400mm rainfall, 19-30°C temperature, 4.3-7 pH soil, 200-1400m elevation

APPENDIX II: QUESTIONNAIRE

QUESTIONNAIRE:

This questionnaire aims to evaluate the challenges affecting the adoption of sustainable agricultural practices by legume smallholder farmers in Mbombela municipality, Mpumalanga province. The information of each participant will be managed privately. Please use an X next to the code to answer the questions where appropriate.

Should you feel uncomfortable answering any question, please leave the item blank and answer the following question.

INTERVIEWER DECLARATION:
I, ……………………………………………………………………………………………
Declare that I will ask this questionnaire as it will be laid out. I declare that all responses recorded will be the true responses of the respondent and that I have thoroughly checked the questionnaire.
Signature: ……………………………………………………………………….
Date: ………………………………………………………………………………

Section A: Demographic Information

A1. Gender A2. Age [ ]

1. Male	2. Female

A3. Are you the head of the household?

1. Yes	2.No

A4. Marital status

1. Married	2. Single	3. Divorced	4. Widowed	5. Other (specify) ___________

A5. What is your highest level of education completed?

1.No formal education	2. Primary school	3. Secondary school	4. Undergraduate degree	5. Postgraduate degree	6. Other (specify) ___________

A6. How many people currently reside in your [ ] household?

A7. Other than farming, do you have another income-paying job?

1. Yes	2.No

If yes, what is your occupational status?

1. Labourer	2. Sales/marketing	3. Administration	4. Businessperson	5. Professional	6. Other (specify) ___________

A8. What are the main sources of income in your household?

Government grant	Pension	Sale of agricultural products	Full-time paid job	Part-time job	Own business	Other (specify) ___________

Section B: Farm Characteristics

B1. How long have you been a farmer (Number of [ ] years)?

B2. How much total land do you own (in hectares)? [ ]

B3. How did you acquire your land?

Inherited	Tribal authority	Applied to the Department of	Land restitution	Other (specify) ___________

		Land and Rural Development		

B4. Do you have title deeds for your land?

1. Yes	2.No

B5. Do you employ people for labour or use family members on your farm?

- Employed labour: How many individuals are used on your farm? [ ]
- Family members: How many family members are involved in farming activities on your farm? [ ]

Section C: Legume Cultivation

C1. Which legumes do you primarily cultivate?

1. Chickpeas	2. Lentils	3. Peas	4. Soybeans	5. Other (please specify): ___________

C2. What influenced your decision to cultivate the specific legumes mentioned earlier? (Select all that apply or provide other reasons.)

1. Economic factors	2. Market demand	3. Soil suitability	4. Climate conditions	5. Tradition or cultural preferences	6. Previous success with the crop	7. Government incentives	8. Other (specify): ___________

Section D: Sustainable Agricultural Practices (SAPs): Adoption and Impact of SAPs

D1. Do you have knowledge about sustainable agricultural practices?

1. Yes	2.No

D2. If yes, which sustainable agricultural practices are you aware of? (Select all that apply)

1. Crop rotation	2. Intercropping	3. Soil mulching	4. Organic manure	5. Minimum tillage	6. Other (specify): ___________

D3. Among the practices you are aware of, please specify which ones you have adopted on your farm. ___________

D4. How many hectares of your total cultivated land are dedicated to sustainable agricultural practices [ ] (SAPs)?

D5. What factors influenced your decision to adopt sustainable agricultural practices? (Select all that apply)

1. Economic benefits	2. Environmental Conservation	3. Increased crop yield	4. Soil health improvement	5. Access to government incentives	6. Knowledge gained through training	7. Peer influence	8. Other (specify): ____________

D6. What benefits have you observed since adopting sustainable agricultural practices? (Select all that apply)

1. Improved crop yield	2. Soil fertility enhancement	3. Cost savings	4. Reduced environmental impact	5. Access to government incentives	6. Improved resilience to climate change	7. Enhanced biodiversity on the farm	8. Other (specify): ____________

D7. What challenges have you encountered in implementing sustainable agricultural practices on your farm? ________________________________

D8. How have these challenges affected your agricultural activities and overall farm productivity?

____

D9. What strategies or measures do you employ to overcome the challenges you face in adopting sustainable agricultural practices? ___________________________

Section E: Challenges in Adopting SAPs

E1. What challenges have prevented you from adopting sustainable agricultural practices? (Select all that apply)

1. Lack of knowledge or information	2. Financial constraints	3. Limited access to resources	4. Climate-related issues	5. Resistance to change	6. Market uncertainties	7. Other (specify): __________

E2. How do these challenges impact your willingness to adopt sustainable practices?

____

Section F: Support Services

F1. Are there any support services or programs available for adopting sustainable practices? (Check all that apply)

1. Government extension services	2. Non-governmental organization (NGO) assistance	3. Local agricultural cooperatives	4. Training and workshops	5. Access to sustainable farming technologies	6. Financial support or subsidies	7. Other (specify): __________

F2. Are you satisfied with the existing support services?

1.Yes	2.No

If you are not satisfied, can you please explain why?_________________________

F3. What additional support services would be beneficial for you in adopting sustainable agricultural practices?

1. Tailored training programs	2. Financial assistance or grants	3. Access to modern farming equipment	4. Networking opportunities with other farmers	5. Market linkages for sustainable products	6. Other (specify): ___________

Section G: Community Engagement

G1. Are you part of any local or regional farmer groups or cooperatives?

1. Yes	2.No

G2. How does community engagement contribute to the adoption of sustainable practices in your farming community?

1. Knowledge sharing	2. Group purchasing power	3. Collective bargaining	4. Mutual support in implementing practices	5. Other (specify): ___________

Section H: Marketing Practices

H1. Do you primarily cultivate legumes for household consumption or sale in the market?

1. Household consumption	2. Sale in the market	3. Both

H2. Have the sustainable agricultural practices you adopted influenced the market quality and quantity of your legume produce?

1. Yes	2.No

If yes, please specify: _____________

H3. Where do you sell your legume produce?

1. Sell at the market	2. Sell in the community	3. Sell to local supermarket	4. Customers buy at the farm	5. Other (specify): ______________

H4. Have marketing-related challenges impacted your ability to adopt sustainable agricultural practices for legumes?

1. Yes	2.No

If yes, please specify: _____________

H5. Are there any support services or programs related to marketing that you have utilized for your legume farming?

1. Yes	2.No

If yes, please specify: _____________

H6. Considering your plans for sustainable agriculture, do you expect to make any changes in how you sell your legume produce in the future?

1. Yes	2.No

If yes, please specify: _____________

Section I: Food Security

I1. Is promoting food security for your household a primary goal in your legume farming practices?

1. Yes	2.No

I2. If yes, how have sustainable agricultural practices contributed to improving food security for your household? _________________________________

I3. How much legumes you cultivate is allocated for your family's consumption?

1. Small portion (0-1 hectare)	2. Moderate portion (1.1-3 hectares)	3. Substantial portion (3.1-5 hectares)	4. Almost all (5.1 hectares and above)

I4. Have you faced challenges in achieving food security through legume farming in the past 12 months?

1. Yes	2.No

If yes, please specify: _____________

I5. Do you believe that adopting sustainable agricultural practices has positively impacted the food security of your household?

1. Yes	2.No

I6. Have you received any support or assistance related to food security in the context of your legume farming?

1. Yes	2.No

If yes, please specify: ____________

I7. In your opinion, how can sustainable agriculture contribute to improved food security in your community? ______________________________

Section J: Future Perspectives

J1. Are you planning further to increase the adoption of sustainable practices?

1. Yes	2.No	3. Unsure

J2. In your opinion, what role can government policies play in promoting sustainable agricultural practices among legume farmers?

1. Providing financial support	2. Offering educational programs	3. Implementing supportive regulations	4. Facilitating market access	5. Other (specify): __________

APPENDIX III: SMALLHOLDER FARMERS WORKSHOP IN MBOMBELA

PRODUCTION GUIDELINE FOR LEAFY VEGETABLE USING SUSTAINABLE PRACTICES IN LUPHISI AND SALUBINDZA IN MPUMALANGA PROVINCE

PRODUCTION GUIDELINE FOR AFRICAN LEAFY VEGETABLE USING SUSTAINBLE PRACTICES IN LUPHISI AND SULUBINDZA IN MPUMALANGA PROVINCE

Report to the Water Research Commission of South Africa edited by

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EXECUTIVE SUMMARY

This guideline was made possible by the University of Mpumalanga's project, funded by the Water Research (WRC) under project number C2023/2024-01368, on farmer-led agricultural production interventions through sustainable farming practices by rural communities in Mpumalanga. This guideline focuses on the sustainable practices and serves as a roadmap to help farmers achieve a balance between productivity, environmental stewardship, and economic growth, ensuring a sustainable agricultural future.

This included on-farm activities in participatory training talks on land preparation, seedling production, utilization of chameleon irrigation sensors and application of mulch and organic manure. This included discussions and demonstrations on the principles, processes and methods, and other aspects of manure. During the regular monitoring visits, smallholder farmers were assisted in planting and applying manure on their farm plots.

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We sincerely acknowledge the Luphisi Farmers' Cooperative, a remarkable group of 36 farmers represented by the visionary Ms. Thandi Mlombo, for their unwavering dedication and contributions to the project. Their willingness to embrace innovative technologies, such as chameleon sensors, has set a commendable example of modernizing agricultural practices for improved efficiency and productivity.

INTRODUCTION

The agricultural sector is the basis for developing economies and an important tool through which rural economic development can be achieved in communal areas of developing countries (DAFF, 2012). According to Senyolo *et al.* (2009), sustained farm production has become an ideal goal of agricultural development in South Africa. This view is integrated in SA's rural development framework in the National Development Plan (NDP), which pointed out the prospect of agriculture as the main driver in developing the country's rural areas to improve the livelihoods of approximately 2.6 million smallholder farmers who are faced with several production constraints in smallholder agriculture (Parr *et al*., 2020). However, smallholder agriculture is considered a low agricultural production activity in South Africa, because of its simple, outdated farming technologies and low-return production systems (DAFF, 2012).

Trainings through demonstration offer an opportunity for smallholder farmers to learn by doing from the agricultural extension, researchers, and private sectors. Trainings are essential to farmers to unleash their hidden potentials with the available resources in their disposal. The aim is to equip smallholder farmers with necessary knowledge and skills about the important of sustainable agricultural practices in agriculture through trainings. This guideline outlines the key element to consider when conducting on-farm training in order encourage smallholder farmers to adopt sustainable agricultural practices (SAPs) in Mbombela Municipality. Agricultural extension help smallholder

TRAINING ON UNDERUTILIZED CROPS IN MBOMBELA MUNICIPALITY

1.1 Introduction

On farm participatory implementation approach encourages all the stakeholders (farmers, researchers, community leaders, government policy makers, agricultural extension and other private sectors) to be part and parcel of the decision-making process to ensure a successful action plan. However, the participatory approach aims to impart knowledge and skill among each other to improve agricultural productivity (Vogl *et al.*, 2015). The whole plan is to empower smallholder farmers to take ownership in their farming operations, doing all the work with or without agricultural extension since agricultural extension works with farmers do not work for them. According to Small and Raizada (2017), participatory research aims at enabling communities to identify and decide on their own innovation that will be fully accepted in their various communities. The on-farm trials and trainings on smallholder farmers on sustainable agricultural practices (SAPs) has been conducted at Luphisi (25.4108^0 S, 31.2702^0 E) and Salubindza (25.1441^0 S, 31.1575^0 E) in Mbombela Municipality.

The training also included a basic understanding of sustainable agricultural practices (SAPs), incorporate both theory and practical aspects. Technology transfer and knowledge sharing in most cases is one of the primary functions of agricultural extension. However, the training provided by WRC team in collaboration with agricultural extension can improve farm productivity and foster sustainable agriculture for the current and future generations. Smallholder farmers' educational program was developed in a way that will address the challenges that farmers are facing in a daily basis. In most cases, farmers depend more on government or any other stakeholders to improve their farming productivity. therefore, this chapter will report different production guideline for sustainable agricultural practices for smallholder farmers in Mbombela Municipality.

1.2 Production guideline for SAPs

1.2.1 Land preparation

Clearing the land is also part of the training, smallholder farmers must understand the importance of land preparation and the site suitable for Swiss chards production. Figure 1.1. show step by step training that smallholder farmers in Mbombela Municipality received on land preparation. Land preparation loosen the soil to improve aeration, drainage and root penetration and it also involves the removal of weeds, debris and old plants residues.

Figure 1.1: Step-by-step of land preparation

1.2.2 Seedling production

It is important to use good quality seedlings to maximize productivity and generate enough profit at the same time. The training or demonstration of seedling production occurred step by step so that smallholder farmers can understand the requirements of seedling production. Figure 1.2. show materials used to produce good quality seedlings (seedling trays, growing medium, certified seeds and water). The smallholder farmers were trained disinfect seedlings trays before they can use it as part of the preparation. Thereafter, smallholder farmers learned how moisten growing medium and putting it on the seedling trays to prepare seed sowing.

The smallholder farmers were trained to sow the seeds in each hole of the seedling trays. The guideline presented in Figure 1.2. also guides the smallholder farmers on the removal of excess plants in the seedling trays (overcrowded).

Figure 1.2: Training smallholder farmers in seedling production and thinning process.

1.2.3 Cultivation

In this case smallholder farmers used transplanting methods into the field, the seedlings were of good quality. Swiss chard like any other vegetable normally grown around August to November, it is important for smallholder farmers to understand when to plant and when to harvest Swiss chard. Smallholder farmers in Mbombela Municipality were trained to cultivate vegetable crops.

Figure 1.3: Smallholder farmers in Mbombela Municipality transplanting vegetable crops.

1.2.4 Organic manure

Smallholder farmers received training on the adoption or the use of organic manure and their application methods in the soil. Organic manure can be kraal manure, chicken manure, green manure or any other waste product, which normally farmers use broadcasting method and mix it with soil. Figure 1.4. show organic manure Organic manure in the soil enhances biological activities which helps to break down crops and animal residues to increase organic matter content, which will be accessible for crops to uptake.

Figure 1.4: Training smallholder farmers on the use of organic manure

1.2.5 Mulching

Mulching is mainly used to cover the exposed soil to avoid soil erosion (both wind and water erosion). The benefits related to soil mulch in agriculture is to increase soil organic matter, improve soil moisture retention, minimize soil erosion, enhance microbial activity and improve soil structure. During the training, the smallholder farmers used seedless grass mulch they adopted as part of sustainable agricultural practices. Figure 1.5. show smallholder farmers using grass mulch which contributes to their improved soil fertility.

Figure 1.5: Application of grass mulch by smallholder farmers

1.2.6 Irrigation schedule

The smallholder farmers were trained to use irrigation schedule to avoid water loss through evaporation or runoff. In most cases, farmers tend to over-irrigate their field which end up causing land degradation and so forth. Smallholder farmers had an opportunity to learn the use of chameleon sensors, which helps the irrigator “how hard a plant must work” to extract water from the soil. For instance, when the soil is very wet and the tension is low, it shows blue colour and when the soil is dry and the tension is high, it shows red colour. The blue colour also means that although the soil is wet enough for plants to easily extract water.

Figure 1.6: Training smallholder farmers on the utilization of the chameleon irrigation sensors

1.3 Conclusion

This guideline has outlined several activities that smallholder farmers were trained about in their various farms, performing practical since most farmers learn by doing. The training based on the on-farm practical activities is essential in influencing smallholder farmers in adopting sustainable agricultural practices (SAPs).

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TINKHOMBANDLELA TEMKHICITO WETIBHINDVO LETINEMACEMBE TASE AFRIKA NGEKUSEBENTISA TINDLELA LETITIMELE ELUPHISA NASESALUBINDZA ESIFUNDZAVENI IMPUMALANGA

TINKHOMBANDLELA TEMKHICITO WETIBHINDVO LETINEMACEMBE TASE AFRIKA NGEKUSEBENTISA TINDLELA LETITIMELE ELUPHISA NASESALUBINDZA ESIFUNDZAVENI IMPUMALANGA

Umbiko weKhomishana lekuCwaninga ngeManti eNingizimu Afrika

Uhlelwe ngu

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SIFINYENTO SENKHOMBANDLELA

Lenkhombandlela yentiwa yaba imphumelelo ngumklamo weNyuvesi yaseMpumalanga, lechaswe ngetimali i-Water Research (WRC) ngaphansi kwenombolo yemklamo C2023/2024- 01368, mayelana nekungenelela kwekukhicita kwekulima lokuholwa balimi ngekusebentisa tindlela tekulima letisimeme emimangweni yasemakhaya eMpumalanga. Lenkhombandlela igcile emikhubeni lesimeme futsi lesebenta njengendlela yekusita balimi kutsi bakhone kulinganisa emkhatsini kwekukhicita, kugcinwa kwendzawo kanye nekukhula kwemnotfo, kucinisekisa likusasa letekulima lelisimeme.

Loku kwafaka ekhatsi imisebenti yasemapulazini ekufundziseni ngekuhlanganyela ngekulungiswa kwemhlaba, kukhicitwa kwenhlanyelo, kusetjentiswa kwetinhlayiya tekunisela kanye nekusetjentiswa kwemcuba kanye nemanyolo. Loku kwafaka ekhatsi tinkhulumiswano kanye nekukhombisa ngetimiso, tinchubo kanye netindlela, kanye naletinye tincenye temgcobo. Ngesikhatsi seluhlololuvakasho lolutayelekile, balimi labasafufusa basitwa ekuhlanyeleni nasekusebentiseni manyolo etindzaweni tabo tekulima.

EMAVI EKUBONGA

Likhomishani Lekucwaninga Ngetemanti (WRC), iNyuvesi yaseMpumalanga (UMP) kanye neSikhungo Sekucwaninga Ngemanti (WRC) Umkhandlu Wetelucwaningo Lwetekulima (ARC) ubonga kakhulu ngeluchaso letimali kanye netikhungo ngekusekela. Onkhe emalunga elicembu lemklamo ayabongwa ngelusito lwawo ekukhiciteni lomklamo loyinkhombandlela.

Emalunga Elicembu Lekomba

Dr. SN Hlophe-Ginindza (WRC): Chairman
Dr. L Nhamo (WRC)
Prof NS Mpandeli (WRC)
Ms. M Kapari (WRC)
Prof E Nesamvuni (Khanimambo Innovative Solution) Prof
M Mudhara (UKZN)
Ms. Sandra Fritz (Mabhalane weLikomidi)

Emalunga Elicembu Lemklamo we-UMP kanye Nebahlanganyeli

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Mr. Mthobisi Dhladhla (Umfundzi wase-UMP)

Emalunga emmango

Sibonga kakhulu inhlangano yebalimi baseLuphisa, licembu lelikhetsekile lebalimi laba-36 lelimelwe nguMs. Thandi Mlombo, ngekutimisela kwabo lokungapheti kanye neminikelo yabo kulomklamo. Kutimisela kwabo kwemukela tetheknoloji letinsha, letifana nelithulusi lekucapha emanti emhlabatsini, sekube sibonelo lesihle sekwenta tindlela tekulima tibe sesikhatsini lesisha kute kwentiwe ncono kusebenta kahle nekukhicita

SINGENISO

Umkhakha wetekulima usisekelo semnotfo losatfutfuka kanye nesikhali lesibalulekile lekungazuzwa ngaso kutfutfukiswa kwemnotfo wasemakhaya etindzaweni letihlangene temave lasatfutfuka (DAFF, 2012). Ngekusho kwaSenyolo nalabanye (2009), kukhicitwa kwemapulazi lokuchubekako sekube ngumgomo lomuhle wekutfutfukisa tekulima eNingizimu Afrika. Lomcondvo uhlanganiswe neluhlaka lwentfutfuko yasemaphandleni eNingizimu Afrika kuLuhlelo Lwekutfutfukisa Lwavelonkhe (i-NDP), lolwakhomba ematfuba etekulima njengentfo lehamba embili ekutfutfukiseni tindzawo tasemaphandleni kulelive kute kwentiwe ncono tindlela tekutiphilisa tebalimi labasafufusa labacishe babe tigidzi leti-2.6 labahlangabetana netinkinga tekukhicita tekulima lokuncane (Parr nalabanye, 2020). Nomakunjalo, kulima lokuncane kutsatfwa njengentfo lephansi yemkhicito wetekulima eNingizimu Afrika, ngenca yemasu ekulima laphelelwe sikhatsi, kanye netinhlelo tekukhicita letimbuyeselo lencane (DAFF, 2012).

Kuceceshwa ngekukhombisa kuniketa balimi labasafufusa litfuba lekufundza ngekwenta kusuka ekwandzisweni kwetekulima, bacwaningi kanye nemikhakha yangasese. Kuceceshwa kubalulekile kubalimi kwentela kukhulula emakhono abo langabonakali ngemitfombolusito labanayo. Inhloso kuhlomisa balimi labasafufusa ngelwati kanye nemakhono ladzingekile mayelana nekubaluleka kwekusebentisa tindlela tekulima letisimeme kutekulima ngekubacecesha. Lenchubomgomo ichaza tintfo letibalulekile lekumele ticatjangwe uma kuceceshwa emapulazini kute kugcugcutelwe balimi labasafufusa kutsi basebentise tindlela tekulima letisimeme (SAPs) kuMasipala waseMbombela. Lusito lwekwandzisa tekulima

KUCECESHWA NGETIBHIDVO LETILUHLUTA LETINEMACEMBE LAMAKHULU, LASHWABENE NETICU LETINKHULU KUMASIPALA WASEMBOMBELA

1.1 Singeniso

Kuloluhlelo lwekusebenta ngekuhlanganyela emapulazini kukhutsata bonkhe labatsintsekako (balimi, bacwaningi, baholi bemmango, bahleli bemacebo bahulumende, kutfutfukiswa kwetekulima kanye naletinye tikhungo tangasese) kutsi babe yincenye lenkhulu yeluhlelo lwekutsatsa tincumo kute kucinisekiswe luhlelo lwekusebenta lolunemphumelelo. Nanobe kunjalo, indlela yekuhlanganyela ihlose kuniketa lwati kanye nemakhono emkhatsini walabanye kute kwentiwe ncono umkhicito wetekulima (Vogl nalabanye, 2015). Lonkhe loluhlelo lwekuniketa balimi labasafufusa emandla ekutsatsa bunikati bemisebenti yabo yetekulima, benta wonkhe lomsebenti ngekuhlanganisa nobe ngaphandle kwekuhlanganisa tekulima, njengobe umsebenti wekuhlanganisa tekulima nebalimi awusebenti kubo. Ngekusho kwaSmall naRaizada (2017), lolucwaningo loluhlanganisako lufuna kwenta imimango kutsi ikhone kubona iphindze itsatse sincumo mayelana nalokuyintfo lensha letawemukelwa ngalokuphelele kumimango yabo leyehlukene. Kulingwa kwemapulazi kanye nekuceceshwa kwebalimi labasafufusa ngetindlela tekulima letisimeme (SAPs) kwentiwe eLuphisa (25.4108^{0} S, 31.2702^{0} E) naseSalubindza (25.1441^{0} S, 31.1575^{0} E) kuMasipala waseMbombela.

Lokuceceshwa kwaphindze kwafaka ekhatsi kuvisisa lokusisekelo kwetindlela tekulima letisimeme (SAPs), kufaka ekhatsi tifundvo tekusebenta kanye netintfo letentekako. Kudluliswa kwetheknoloji kanye nekwabelana ngelwati etikhatsini letinyenti kungulenye yemisebenti lebalulekile yekwandzisa tekulima. Nobe kunjalo, kuceceshwa lokuniketwe licembu le-WRC ngekubambisana nekwandzisa tekulima kungakhulisa kukhicita kwemapulazi futsi kukhutsate tekulima letichubekako kwentela titukulwane letikhona naletitako. Luhlelo lwekufundzisa balimi labasafufusa lwakhiwa ngendlela yekubukana netinsayeya balimi labahlangabetana nato onkhe malanga. Ngalokuvamile, balimi batsembele kakhulu kuhulumende nobe labanye babambilichaza kutsi batfutfukise umkhicito wabo. Ngako-ke, lenchubomgomo kulesehluko itawubika ngetindlela letehlukene letisimeme tekukhicita kutekulima kubalimi labasafufusa kuMasipala waseMbombela.

1.2. Inkhombandlela yekukhicita ye-SAPs

1.2.1 Kulungiswa kwemhlaba

Kususwa kwelikhula kumhlaba wekulima kuyincenye yekuceceshwa, balimi labasafufusa kumele bacondze kubaluleka kwekulungiswa kwemhlaba kanye nendzawo lefanele yekukhicitwa kwetibhidvo letiluhluta nemacembe lamakhulu, lashwabene neticu letinkhulu.

Umdvwebo 1.1 ukhombisa kuceceshwa lokwentiwe ngekulandzelana kwetinyatselo lokwentiwe kubalimi labasafufusa kuMasipala waseMbombela mayelana nekulungiswa kwemhlaba. Kulungiswa kwemhlabatsi kukhulula umhlabatsi kwentela kutfutfukisa umoya, kunisela kanye nekungena kwetimphandze phindze kufaka kususa lukhula, tintfo letisele kanye netitjalo letindzala letisele.

Sibonwa 1.1: Sigaba-nesigcawu sekulungiswa kwemhlaba

1.2.2 Kukhicitwa kwenhlanyelo

Kubalulekile kusebentisa inhlanyelo letisezingeni lelisetulu kute ukhulise umkhicito futsi ukhicite inzuzo leyenele ngesikhatsi lesifanako. Kuceceshwa noma kukhonjiswa kwekukhicitwa kwenhlanyelo kwenteka kancane kancane kwentela kutsi balimi labasafufusa bakhone kuvisisa tidzingo tekukhicitwa kwenhlanyelo.

Sibonwa 1.2. sikhombisa tintfo letisetjentiswako kukhicita inhlanyelo lesezingeni lelikahle (titsebe tenhlanyelo, indzawo yekukhulisa, tinhlavu letifakiwe kanye nemanti). Balimi labasafufusa bafundziswe kubulala emagciwane etitjeni tetitjalo ngaphambi kwekutsi batisebentise njengencenye yekulungiselela. Ngemuva kwaloko, balimi labasafufusa bafundza indlela yekunisela indzawo yekuhlanyela bese bayifaka etitjeni tekuhlanyela kute balungiselele kuhlanyela. Balimi labasafufusa bebaceceshelwa kuhlanyela letinhlavu kuwo onkhe emabhokisi. Lonchubomgomo lekhonjiswe kumfanekiso 1.2 iphindze ifundzise balimi labasafufusa ngekukhishwa kwenhlanyelo etitsebenti tetitjalo (uma tigcwele kakhulu)

Sibonwa 1.2: Kuceceshwa kwebalimi labasafufusa ngekukhicitwa kwetitfombo

1.2.3 Kulima

Kulendzaba balimi labasafufusa basebentise tindlela tekuhlanyela emasimini, lenhlanyelo beyisezingeni lelikahle. Tibhidvo letiluhluta nemacembe lamakhulu, lashwabene neticu letinkhulu njengaletinye tibhidvo letihlanyelwa ngenyanga yeNgci kuya kunyanga yeLweti, kubalulekile kubalimi labasafufusa kutsi bati kutsi kumele balime nini futsi bavune nini letibhidvo letiluhluta nemacembe lamakhulu, lashwabene neticu letinkhulu. Balimi labasafufusa kuMasipala waseMbombela baceceshelwa kulima tibhidvo. Sibonwa 1.3. sikhombisa balimi labasafufusa kuMasipala waseMbombela bahlanyela tibhidvo.

Sibonwa 1.3: Kuceceshwa kwebalimi labasafufusa kuMasipala waseMbombela ngekulima tibidvo

1.2.4 Umcuba wemfuyo

Balimi labasafufusa batfola kuceceshwa ngekwemukelwa noma kusetjentiswa kwemanyolo wemvelo kanye netindlela tekusebentisa lomanyolo emhlabatsini. Umcuba wemvelo ungaba ngumcuba wesibaya, umcuba wetinkhukhu, umcuba lomtfubi noma nguyiphi lenye intfo lelahlekile, levame kusetjentiswa balimi ngendlela yekusakata bese bayihlanganisa nemhlabatsi. Sibonwa 1.4. sikhombisa manyolo wemfuyo. Umanyolo wemfuyo emhlabatsini ucinisa imvundziso yetintfo letiphilako lesita kuhluma kwenhlanyelo kanye netintfo letisele tetilwane kwentela kwandzisa lokucuketfwe imvundziso, lokutawusita inhlanyelo kutsi ihlume.

Sibonwa 1.4: Kuceceshwa kwebalimi labasafufusa kuMasipala waseMbombela ngekusetjentiswa kwemanyolo wemvelo

1.2.5 Kumbonywa kwembatsi ngemvundziso

Imvundziso isetjentiswa kakhulu kwentela kuvala umhlabatsi lovulekile kute ivikela kugedvuka kwemhlabatsi (kokubili kugedvuka kwemhlaba lokwentiwa ngumoya nemanti). Tinzuzo letihambelana nekumbonywa kwemhlabatsi ngemvundziso kutekulima kungeta kuvundza kwemhlabatsi, kutfutfukisa nekugcina bumantana bemhlabatsini, kunciphisa kugedvuleka kwemhlabatsi, kutfutfukisa kusebenta kwemagciwane kanye nekutfutfukisa simo semhlabatsi. Ngesikhatsi seluhlelo lwekucecesha, balimi labasafufusa basebentis tjani lobungenambewu njengemvundziso lekungulenye yetindlela tekulima letisimeme. Sibonwa 1.5. sikhombisa balimi labasafufusa labasebentisa imvundziso yetjani.


Sibonwa 1.5: Imvundziso yetjani

1.2.6 Luhlelo lwekunisela

Balimi labasafufusa bafundziswe kusebentisa luhlelo lwekunisela kute kuvinjelwe kulahleka kwemanti ngekuhwamuka noma ngekugeleta. Esikhatsini lesinyenti, balimi bavame kunisela kakhulu emasimi abo lokugcine kubangele kutsi umhlabatsi ulahlekelwe kunotsa kwawo nalokunye. Balimi labasafufusa batfole litfuba lekufundza kusebentisa umshini wekulinganisa manti emhlabatsini, lesita umniseli kutsi “akwati kutsitjalo sitawusebentisa mandla langanani” kute sidvonse manti emhlabatsini. Kwenta sibonelo, uma umhlabatsi umanti kakhulu futsi nekucindzeteleka kuphansi, kukhombisa libala leliluhlata sasibhakabhaka kantsi uma umhlabatsi womile futsi nekucindzeteleka kusetulu, kukhombisa libala lelibovu. Lombala loluhlata sasibhakabhaka uphindze usho kutsi nanobe umhlabatsi umanti ngabe umanti ngalokwanele kutsi titjalo tikhone kumunya manti kalula.

Sibonwa 1.6: Yesilinganiso semanti emhlabatsini

1.3 Siphetfo

Lonchubomgomo ichaze ngemisebenti leminyenti lececeshelwe balimi labasafufusa emapulazini abo lahlukahlukene, kwentiwa ngekusebenta njengoba balimi labanyenti bafundza ngekwenta. Kuceceshwa lokwentiwa emapulazini kubalulekile ekutseni balimi labasafufusa bakhone kutsatsa tindlela tekulima letisimeme (SAPs).

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