Exploring the Adoption of Precision Farming in the Maize Triangle of South Africa

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ABSTRACT

Recovering after COVID-19 and struggling to compensate for the cost-plier squeeze in agriculture, the struggle of farmers has been immense to aid in food security in South Africa. As the population increases and yields are ailing because of climate change, farmers are encouraged to seek management strategies that not only increase yield but also take the environment into account.

Preserving the environment and feeding the world has become challenging as food wastage continues and ineffective farming practices remain the norm. Alternative farming methods, such as precision farming, have been proven to increase yield, lower input costs, and better farm management practices. Precision farming allows farmers to collect data and make informed decisions, optimizing weak farm areas and reducing input costs.

This study shows that farmers have conquered precision farming technology but struggle to overcome the cost of adopting precision farming. After conducting interviews with farmers in the maize triangle, conclusions were drawn that after one season, farmers experienced a yield increase and profit, and even though they struggled with no support systems, they managed to overcome the significant barriers and enjoy the benefits of precision farming. This management practice is sustainable and is still somehow not utilized. Implementation of precision farming is usually sequential, which makes calculating the adoption costs difficult. This study recommends how farmers could overcome the significant barriers, independently or with the help of agricultural companies, to increase the adoption of precision farming.

Key terms

Population, Food Security, Precision farming, Costs, Profit, Interviews, Barriers, Sustainable, Sequential Adoption.

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1 NATURE AND SCOPE OF STUDY

1.1 INTRODUCTION

Maize is a major food staple in South Africa, and 57% of the commercial area is used for its production (Greyling & Pardey, 2019:21). While the importance of maize production does not go unnoticed, farmers are abandoning the growing of field crops for a multitude of reasons. According to Shackleton (2019), high input costs, environmental changes, and higher profitability in other sectors are the reasons for the abandonment and underperformance.

Precision agriculture, a managerial and technological tool, lowers input costs and increases profitability (van Zyl, 2010:iv). The adoption of precision agriculture could aid in higher production yield, ultimately affecting the Gross Value of Protection (GVP) and the Gross Domestic Product (GDP). Only 9% of the agricultural revenue that South Africa generates comes from field crops (Campbell, 2023) and experienced a decline from 2022 to June 2023.

This study will, therefore, focus on maize farmers in the maize triangle of South Africa who have adopted precision farming management techniques to diminish the negative factors mentioned before. Focusing on maize production is crucial, as it is not only a food staple but also a popular export crop, exporting about 25% of what is grown (Greyling & Pardey, 2019:21), contributing to the economic improvement of many sectors. Precision farming, as the literature will note, is a sustainable method of farming, proven to increase yield, lower input costs, and lessen the environmental impacts that the agricultural sector has proven to contribute. This study will focus on farmers who have conquered the barriers of implementing precision farming in the maize triangle, their opinions and perspectives, the cost of implementation, and how they experienced the benefits.

1.2 THE SOUTH AFRICAN AGRICULTURAL SECTOR

South Africa has 122 million hectares of land area, 14 million of which is arable (Sihloo & Kirsten, 2021:196), providing a large scale of economic possibilities for the agricultural sector. Environmental constraints and globalisation are putting increased pressure on the farming industry, mitigating its vital roles in increasing food supplies, foreign exchange gain, and creating labour opportunities (Sihlobo & Kirsten, 2021:200). Figure 1.1 illustrates the distribution of the eight prevalent soil classes in South Africa. Class I, II, and III are considered arable; Class IV has poor adaptive cultivation properties, Classes V – VII are used for grazing, and Class VIII is used for wildlife (Scotney *et al*., 1987, as cited in Mzila, 2018:8). The arable land (Class I – III) is calculated at about 12% of South Africa (Daniell & van Tonder, 2021:5) emphasising the need to curb practices that degrade these areas. Competing activities are reducing arable land, and the continuous loss of agricultural land due to industrialisation, mining, and urbanisation is reducing food security (Lidzhegu & Kabanda, 2022:1-2). Fertile and uncultivated arable land is underutilised as climate change worsens (Deen-Swarray *et al*., 2020:2), and sustainable management practices are lacking. Further land degradation and increased population growth, especially in areas dependent on rainfall for crop production (Henrietta *et al.,* 2020:14), will be severely impacted as temperatures rise globally due to global warming. Greenhouse gas emissions (GHG) are a leading contributor to global warming, and the agricultural sector is responsible for a large portion of this as Nitrogen as fertiliser is used to increase crop production (Kim *et al*., 2022:1).

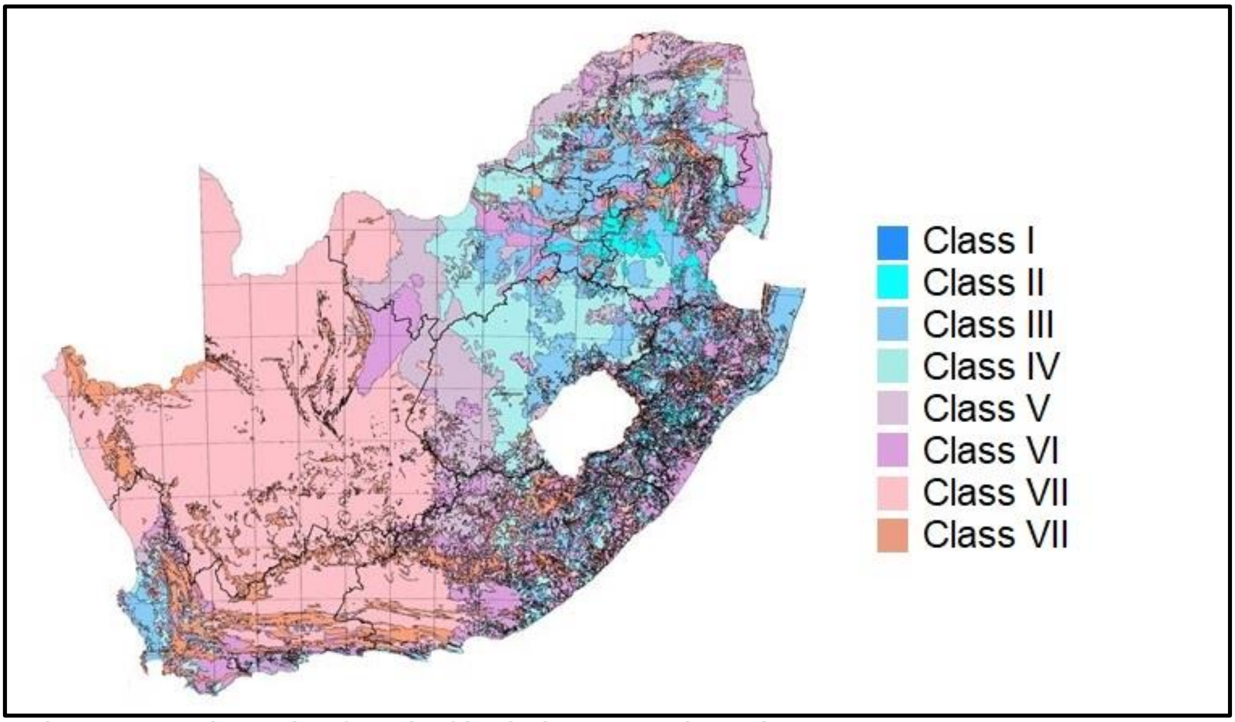

Figure 1-1: Land capacity of South Africa (Schoeman *et al*., 2002)

The agricultural sector needs cost-effective management techniques to increase production (Srinivasan, 2006:7) as the UN and FAO predict that the population could reach almost 10 billion people by 2050 (Quy *et al.,* 2022:2). By 2050, it is also expected that South Africa's crop growing periods could be shorted by 20% (Henrietta *et al.,* 2020:14), demonstrating that a solution is desperately needed to increase crop yields in such a way that is sustainable, cost-effective, and not environmentally harmful. As arable land decreases and food insecurity increases, advanced agricultural technology is needed to meet these productivity requirements (Meena *et al*., 2019:3) while reducing input costs for the farmer.

The "cost-income plier effect" of agriculture (the rising costs of inputs) has put a strain on the industry (Mergos & Papanastassiou, 2016:9), and sustainable solutions, such as precision farming, reduce these high input costs after initial investment (Srinivasan, 2006:4). Abokyi *et al.* (2020:1) deduces that input costs, especially on smallholder farms, are furthered by uncertainty about weather changes, market failures, and price variations. Lowering input costs by reducing unnecessary chemical fertiliser application is achieved with precision farming, which also lessens its harmful environmental impact. Studies show a reduction in the risk of leaching chemicals into groundwater (Lal & Stewart, 2016:20), and managing variability and various dimensions gives precision agriculture a holistic and environmentally friendly strategy to achieve sustainability (Srinivasan, 2006:3).

The demand for agricultural commodities is rising as the world population grows, and increasing food requirements and efficient agricultural production have become necessary (Wells & Stock, 2020:2). Efficiency is achieved through technology adoption. Even though technology has advanced slowly into the farming sector (Krishna, 2013:3), its GPS- and GIS technology advancements have been a breakthrough (Quy *et al*., 2022:10). Recently, agriculture has been influenced highly by technological innovation (Mergo & Papanastassiou, 2016:24), and precision farming has grown to be defined as a management approach, not just a prescriptive technology (Srinivasan, 2006:5). The technology of precision farming utilises an immense range of technology that improves the efficiency of crop production (Naidoo *et al*., 2022:28). This technology requires thorough management of spatial variability on farm fields (Han *et al*., 2016:134). The modernisation of technology has significantly changed the mechanisms of agriculture (Li & Sun, 2016:232), and it can potentially be a tool for rebuilding sustainable food production systems for the future (Dayioğlu & Tűrker, 2021:379), ultimately increasing food security for a growing global population.

Farmers in South Africa must adapt to sustainable farming methods and utilise the data-rich technology that precision agriculture offers to increase yield and lower input costs. Sequential adoption due to high input costs (Schimmelpfenning & Ebel, 2016:97) have become a trend, creating a slow transition process. This study focuses on how farmers in the maize triangle overcame the cost barrier and other obstacles associated with precision farming adoption.

1.3 PROBLEM STATEMENT

The increased population of the world requires an increase in food production. The population projections postulate that the world's population will be 8.2 billion in 2030 and 9.2 billion in 2050 (Silva, 2018). Although current agricultural practices still succeed in feeding the world, sustainable food access and availability are necessary to maintain as the population grows. One possible solution that may contribute to sustainable food production practices in developing countries is to diminish the digital divide between underdeveloped and developed countries (Zhang, 2016:viii). Low digital literacy and access to technology remain a problem in rural communities, minimising their ability to convert to sustainable farming methods. Data science and agricultural technology can help address global food security challenges (McLennon *et al.,* 2021:4543). Still, the knowledge required to implement these technologies is unavailable to all farmers (Erickson & Fausti, 2021:4458). The seriousness of the increase in the world population is underplayed (Zhang, 2016:24), and sustainable farming practices, such as precision farming, are needed to increase crop yields to ensure that food production levels keep up with population growth.

Precision farming gathers and processes data and information to make management decisions (Erickson & Fausti, 2021:4456) and will play an intricate role in the further modernisation of strategic agricultural practices (Zhang, 2016:251). Farmers can adopt these strategic practices and technologies by investing and implementing precision farming and reaping the economic and environmental rewards. Regardless of these benefits, adoption has its obstacles, as any other technology-based management practice has. A significant barrier affecting the rate of the adoption of precision farming is not only the cost of the technology but the doubt that farmers have about their ability to interpret the data and comprehend new systems (Kendall *et al.,* 2022:341), so access to skilled people is necessary (Ahmad & Nabi, 2021:1).

Despite the numerous advantages and higher crop yields, farms are still reluctant to accept precision farming as a management practice. This study aims to determine why maize farmers in the maize triangle of South Africa implemented precision farming despite the known and accepted obstacles.

1.4 RESEARCH AIM & OBJECTIVES

1.4.1 Research Aim

This research explores why farmers adopt precision farming despite the numerous hurdles associated with this management practice. As the intense technological aspects of this management technique have been stated as one of the main reasons why precision farming is challenging to adopt, research is required on how farmers have overcome this impediment. Other known obstacles, such as higher initial financial inputs, large amounts of data, and lack of support systems, are difficult to overcome and might outweigh the advantages of adopting precision farming for some farmers. The benefits, barriers, the various reasons for choosing precision farming, and how farmers overcame then in the implementation of precision farming will be explored, aiming to assist other farmers who would like to go the precision farming way in the future. This research employs qualitative interviews with farmers who have successfully implemented precision farming.

1.4.1.1 Primary Research Objective

The primary objective of this study is to explore the process whereby farmers adopt precision farming in the maize triangle of South Africa.

1.4.1.2 Secondary Research Objectives

The following secondary objectives serve the primary objective:

- Theoretically explore precision farming, its advantages, and barriers.
- Analyse the cost of adopting precision farming.
- Establish whether a yield increase occurred after adoption.
- Identify why farmers choose precision farming over other farming methods.
- Establish the key criteria to implement precision farming fully and sustainably.

1.5 IMPORTANCE AND BENEFITS

Theoretically, this study will add value to farmers by expanding the knowledge of strategies to conquer barriers to precision farming implementation. Understanding how farmers seek assistance will add value to support systems decisions and strategic decision-making processes. The utilisation of the results will create new management techniques when adopting new technology in the agricultural industry, which can promote the adoption of sustainable and efficient precision farming practices.

This study done throughout Chapter 1 describes the problematic population growth, increased food requirements, and the problems farmers face that exacerbate food security. The study will also focus on how precision farming could be a solution to increased crop production, reduced input costs, and reduced environmental impacts that agricultural practices are responsible for. The target area is of importance, as the maize triangle covers a large portion of arable land and is responsible for 8 093 700 tons of white maize and 6 298 000 tons of yellow maize production during the previous season (Maize Crop Quality Report, 2022:4).

The literature review will demonstrate that precision farming is a sustainable solution to sustain the growing population and enhance food security. Undeterred by its many benefits, the barriers to implementing precision farming are still regarded as obstacles many are unwilling or unable to overcome, and the literature review will explore these barriers and possible elucidations.

1.6 DELIMITATIONS

Various issues are out of the scope of this study:

- Firstly, this study focuses on farmers who are regarded currently as precision farmers in the maize triangle, and the results will only apply to precision farmers in the specific areas of Gauteng, Mpumalanga, Free State, and North-West that are part of the maize triangle.
- Secondly, while other crops are possibly grown on the maize triangle farms, this study only applies to farmers who grow maize.

- Thirdly, the participating farmers have already purchased their precision farming machinery and technology, and the costs were incurred years ago. The exact cost of implementation, machinery, and technology will currently differ.
- Lastly, a combination of dryland and irrigation areas are farmed in the maize triangle. Weather conditions, such as extreme rainfall, drought, pests, and other external factors, could impact yield and profit.

1.7 ASSUMPTIONS

- The assumption is based on climate change and global warming. The climate in the future will be warmer and drier.
- If implemented correctly, it is assumed that the farmer's profit margins will increase, and their input costs will decrease, as the literature suggests.
- Despite the cost-income plier effect, farmers are assumed to continue practising precision farming and not alter their management practices.

1.8 DEFINITIONS OF KEY TOPICS

Arable land: An area covered by temporary crops and suitable for cultivation (fao.org).

GIS: A geographic information system with layers that tie data with mapped areas (Marucci, 2018:28).

GHG: Greenhouse gases, such as Carbon dioxide, Methane, Nitrous oxide, and fluorinated gases, from emissions that are trapped and heat the atmosphere (epa.gov).

GPS: Global positioning systems provide precise locations for mapping and sampling (Sharma & Angidi, 2022:202).

Precision farming/agriculture: Site-specific management practices (Wolf & Wood, 1997:180) that use field variability in crops (Omofunmi & Ogunleye, 2021:1) with data and technological support (Marucci *et al*., 2017:35).

Yield: The average yearly crop output (Agricultural Yield, 2022), usually per hectare.

1.9 CHAPTER LAYOUT

- **Chapter 1: Nature & scope of the study**

The first chapter describes the study's background, problem, research goals, and delimitations. This chapter gives the reader the needed background information to understand why the investigation is taking place, the associated definitions, why it needs to take place & how it could contribute to food security.

- **Chapter 2: Literature Review**

The second chapter is the literature review. Problems that farmers face are described, and how it worsens the issue of food security. This chapter will explain how precision farming could increase crop yield and reduce input costs, contributing to food security to feed the growing population. The theoretical benefits and barriers will be explained at the end of the chapter.

- **Chapter 3: Empirical Study**

The third chapter demonstrates the study's research design, population, and sample, and how the data was gathered. Furthermore, this chapter will cover the ethical aspects of the study and data analysis.

- **Chapter 4: Empirical Results**

The fourth chapter will discuss the analysis and results of the study.

- **Chapter 5: Conclusions & Recommendations**

The last chapter will discuss the data and appropriate conclusions as to why and how farmers in the maize triangle have implemented precision farming. Recommendations will also be made at the end of this chapter.

1.10 SUMMARY

Chapter 1 demonstrated that farmers in South Africa need to increase their crop yields and reduce input costs to aid in food security for the growing population. Management practices that provide these results should also curb agriculture's negative environmental impact.

The barriers that impact the rate of precision farming adoption are relatively well-known, but there are ambiguous reasons for how there are farmers who overcome these barriers. This research study explores how farmers in the maize triangle overcame the obstacles of precision farming implementation, how they experienced the benefits, and the associated implementation costs. The participant's perceptions in the maize triangle will be explored to complete a qualitative study to provide new management strategies when implementing precision farming.

CHAPTER 2

2 LITERATURE REVIEW

2.1 INTRODUCTION

This chapter will demonstrate how food security has been affected by various factors. While focusing on population growth is necessary, it is vital to highlight the effects of COVID-19, conflicts between countries, and climate change on the production and access to nutritious food.

Food wastage, economic struggles, and decreases in crop production are worsening food security in many African countries, and the residents are suffering as global food prices soar. Middle-income countries like South Africa, where input costs rise and production needs are challenging to meet, create a cost-income plier effect that farmers struggle with. This literature review will exhibit how precision farming could decrease input costs, increase profitability, and eventually contribute to food security.

2.2 CURRENT FOOD SECURITY AND POPULATION

Food security can be achieved in four ways, namely to 1) access to productive land and agricultural production, 2) physical and economic access, 3) food preparation and diversity of diet, and 4) stabilising the first three factors (Molotoks, 2021:2). Agricultural production and agrifood systems are needed to lower the cost of nutritional food (FAO, 2022:4), and as arable land decreases, advanced agricultural technology is required to meet these requirements of productivity (Meena *et al*., 2020:3).

It is estimated that by 2050, only 40% of Africa's population will be food secure (The Report: Agriculture in Africa, 2019:9). As 600 million hectares of the world's arable land is located in Africa (Bisschoff, 2019:220), one would assume that the agricultural sector would be thriving and contributing significantly to food production. Unfortunately, only 4% of global agricultural production occurs in Africa. Most of these farmers with arable land cannot acquire the necessary inputs to maintain soil fertility (The Report: Agriculture in Africa, 2019:8). Coupled with shrinking farmlands and loss of topsoil fertility (Bisschoff, 2019:220), farming to meet food requirements are worsening.

2.2.1 World Population

A theory in the 1880s by the political economist Thomas Robert Malthus constructed that the relationship between food subsistence and population growth has a geometric and arithmetic growth (Meiring, 2020:496). The projected population is growing faster than the available food supply (Walter, 2020:482), ultimately leading to food shortages and eventual famine (Meiring, 2020:496). Malthus viewed population growth as a problem (Morgan, 2021:121), and within his theory, he created two laws:

1. For the existence of humanity to continue, food is a necessity, but
2. People are passionate and need to reproduce (Morgan, 2021:123).

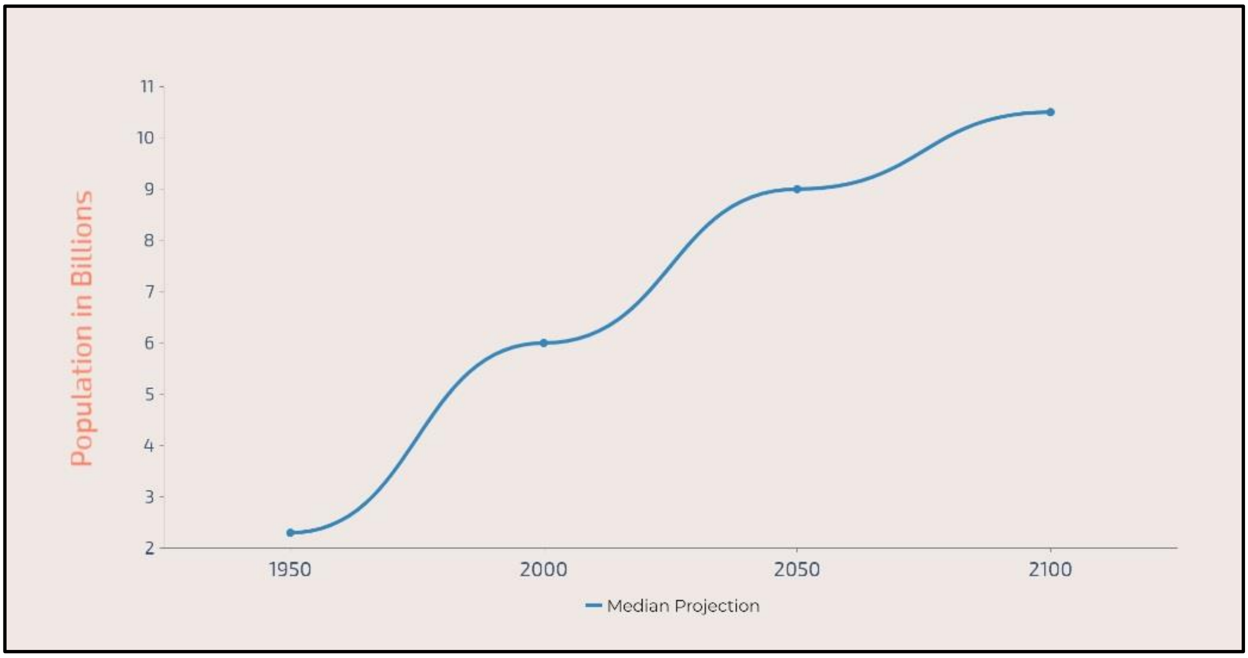

Figure 2-1: Population growth prediction: Adapted from UN (2022) & Population Explorer (2023).

The world population has surpassed 8 billion in 2023, putting pressure on food systems and risking food security. Food security is not only the shortage of food but the access to food for all (Béné & Devereux, 2023:4). Despite producing enough, 10 million tonnes of food are wasted per year in South Africa alone (FoodForward South Africa, 2022). While the data for Africa is not as prevalent, it is estimated that more than 1 ton of food is wasted per day per person in the continent (Food Waste Index Report, 2021:34). With the wastage in the millions, 21% of South Africa's population reported experience of inadequate access to food or extreme hunger in 2021 (Department of Statistics South Africa, 2021) emphasising the need for drastic change. Statistically, people's life expectancy has also increased, resulting in more food that needs to be produced

(Bisschoff, 2019:218). Food insecurity has become more pressing with the increased population and food waste. Historically, the solution to food insecurity has been seen as a combination of fortification technologies and eliminating nutrient deficiencies (Alpha *et al*., 2022:19). However, it has evolved to include safe and sufficient food access, tackle malnutrition, double agricultural productivity, and produce food sustainably (Cheo & Tapiwas, 2021:24-25).

Predictions show that the population could reach 10 billion by 2050 (Quy *et al*., 2022:2) and almost 11 billion by 2100, as shown in Figure 2.1, undermining sustainable food security (Ntiamoah *et al*., 2023:51845). Figure 2.1 also illustrates the projected increase in population through the years. The population growth will further deteriorate famine and hunger as social crises in the future.

Molotoks (2021:12) demonstrates that the rapid increase in population across the globe, specifically in Africa and Asia, has the most significant impact on food security, and swift efforts are needed to increase crop yields. Crop production can be efficiently improved using precision farming technology (Naidoo *et al.,* 2022:28) and enhancing farm yields through spatial variability management (Han *et al.,* 2016:134).

2.2.2 COVID19- pandemic

The COVID-19 pandemic further deteriorated food security globally, and the latest statistics on African food security show that one in five people (20%) are already undernourished (FAO, 2022:113). The ongoing African poverty and economic struggle have been exasperated during and directly after COVID-19~~)~~. People were held in lockdowns, limiting work abilities and travel, ultimately affecting their income. The FAO (2022:185) calculated that eating in South Africa costs approximately R78 per person daily. At a minimum wage of R25.42 per hour, it is difficult for breadwinners to feed their large families. According to the Quarterly Employment Statistics of South Africa (Department of Statistics South Africa, 2020), 648,000 jobs were lost between the first and the second quarter of 2020. The economy suffered greatly, plummeting from R1151 billion in GDP in the fourth quarter of 2019 to R592 billion in the first quarter of 2020 (Department of Statistics South Africa, 2022).

The pandemic illustrated that there are inequalities in risks and hunger in global food production (Stead & Hinkson, 2022:4), dependence on international trade (Ferrando, 2022:140), and lowered access to nutritional food (Sipple, 2022:32). The financial constraints of COVID-19 spread across all sectors. The agricultural industry was no exception (Sippel, 2022:27), but it did prove the need for agriculture investment and sustainability and furthered agricultural and food technology (Sippel, 2022:27- 31). The number of severely hungry Africans doubled during the pandemic, increasing from 135 million to 270 million (Odularu *et al*., 2020:81). COVID-19 showed the unsustainability of the import of food and agri-food systems (Deen-Swaray *et al*., 2020:2), emphasising the importance of increased crop yields locally while lowering input costs and improving nutrition. Food imports in Africa are projected to total more than $110 billion annually by 2025.

2.2.3 Ukraine-Russian conflict

These dire economic and social conditions were furthered by increasing grain prices The increase in wheat prices began rising before the Ukraine-Russia conflict, and Factors such as the price of oil, supply and demand, droughts, and poor harvests impacted the price before the conflict (Pettinger, 2022). The industry was impacted, as Russia and Ukraine produced about a third of the global grain needs (Aizenman, 2023). These factors

Figure 2-2: Global Food Prices (World Food Price Index, 2023)

increased staple food prices globally, resulting in delivery delays, food shortages, and decreased fertiliser production (Stead & Hinkson, 2022:4). Ukraine is the largest sunflower oil exporter in the world, creating a decline in supply and increasing food prices, illustrated in Figure 2.2. Countries that rely on grain and fuel imports, mainly developing countries, will be affected the most (Emediegwu, 2022). Russia exports millions of tonnes of nitrogen, potassic, and phosphorous fertiliser (Ehui *et al*., 2022), and millions of farmers were affected by the sanctions.

As supply dwindles, the price increase is directly felt domestically (Ehui *et al*., 2022). In sub-Saharan countries, 75% of income in poor households is spent on food (Emediegwu, 2022), and if the prices increase drastically, food insecurity rises too.

2.2.4 Climate change

Climate change will, and already has, affect developing countries the most, exacerbating poverty and increasing food shortages. The duration of extreme droughts will affect the livelihood of people experiencing poverty as their geographical location, natural resource dependence, and limited capacity to adapt to a changing climate put them in a compromised position (Dorland *et al.*, 2003). A projected 2.4 billion people will live in Africa by 2050. However, Africa's poor infrastructure, tribal wars, and corruption, among other factors, will probably prevent unlocking the available arable land on the continent. In addition, other factors, such as the predicted temperature increase and ailing crop yields, will accelerate African poverty (Hal *et al*., 2017:3).

South Africa has vast arid and semi-arid regions with low soil fertility (Kephe *et al*., 2021:3), threatening food security. These conditions are deteriorating because of increased greenhouse gas emissions and climate change. The agricultural sector is responsible for between 10 and 12% of GHG (Greenhouse gases) and 70% of land use emissions and deforestation (Henrietta *et al*., 2020:104).

Livestock farming produces methane emissions, while cash crop fields require large amounts of fertiliser, which releases nitrous oxide (Henrietta *et al*., 2020:104). Agricultural management practices are needed that are less intense, require less fertiliser, and are regenerative to improve food security while minimising environmental impacts.

Methane and nitrous oxide are indirect products of fertilisers (Amadau, 2022:95) that are applied to agricultural land to enhance crop growth. Improper and excessive use of fertilisers causes nitrate pollution in the area's water, both on the surface and underground. These pollutants lead to water quality impairment (Lema *et al*., 2014:338), methemoglobinemia (Mateo-Sagasta *et al*., 2017:3), acute toxicity, and cancers (Zhou, 2015:4). Soil tillage also has devastating effects on the fertility of the soil (Munyaradzi & Ngcobo, 2021:8), and adapting no-tillage management techniques can significantly minimise greenhouse gas emissions (Ghosh, 2020:10170) and nitrate pollution. Nitrate pollution from farmlands is usually over a wide area because of the overuse of fertilisers (Zhou, 2015:5). This pollution can be diminished with management strategies that practice sustainability and productivity. As manure and compost are considered low-strength fertilisers (Munyaradzi & Nombuso,2021:9), most farmers opt for nitrogen-rich fertilisers, which can cause a build-up (King, 2018:319), and these spread to wells and other water systems. Large quantities of these agrochemicals in the water are detrimental to the surrounding community and affect topsoil quality (King, 2018:284) and future economic prospects. Management strategies such as precision farming can minimise and control these implications while providing crops with enough nutrients to grow and flourish to increase food security.

2.2.5 African economics

Africa is facing a funding squeeze. As donor flows are drying up and borrowing costs are rising, the people of Africa are challenged with a high cost of living, policy struggles, and high global interest rates (IMF, 2023:2-3). Economic growth has slowed in 2023, with predictions that it would only pick up by late 2024 or 2025 (Pechel & Kenworthy, 2023). The imbalances created by COVID-19 are still rippling through the economy, with 80% of sub-Saharan Africa experiencing double-digit food inflation (IMF, 2023:3) and disrupted recovery efforts that seem inefficient in decreasing poverty (World Bank Group, 2023:1).

Countries are struggling to feed and support their poor people as prices rise (IMF, 2023:5). These financial pressures are forcing governments to delay efforts to address climate change (IMF, 2023:12). Consumer prices keep rising, hitting a record high in the last 14 years as input and output costs increase (World Bank Group, 2023:2). Farmers in Africa are struggling to keep up with the rising input costs, putting strain on their crop production abilities, resulting in a cost-income plier effect.

2.3 COST-INCOME PLIER EFFECT

The problem that farmers in South Africa face, season after season is the cost-income plier effect of agriculture. This is also referred to as the cost-price squeeze. With the fluctuating increase of input prices, the relationship between the input and output (Coleman, 2016) affects farmers' profit and, ultimately, their ability to increase production. When expenses (inputs) increase, such as fuel or fertiliser prices (Newsome, 2020:57), at a much faster rate than income (output), the cost-income plier effect occurs. The increase or decrease is recorded in the South African Producer Price Index (PPI) every year, tracking wholesale prices that are received for domestic crops (Forbes, 2022). Figure 2.3 illustrates the dramatic increase and decrease in the PPI that South Africa has experienced in the past year. A rise of 8.6% was recorded from 2022 to 2023, with a record high recorded in July 2022 at 18% (CEIC Data, 2023). Consumer prices rise as the PPI rises, transferring the added costs of inputs to consumers and affecting economic decisions, such as inflation, on various government levels (Forbes, 2022). The unpredictability and ripple effect that these price increases have roll over to the consumer, restricting some households from being able to afford nutritional food.

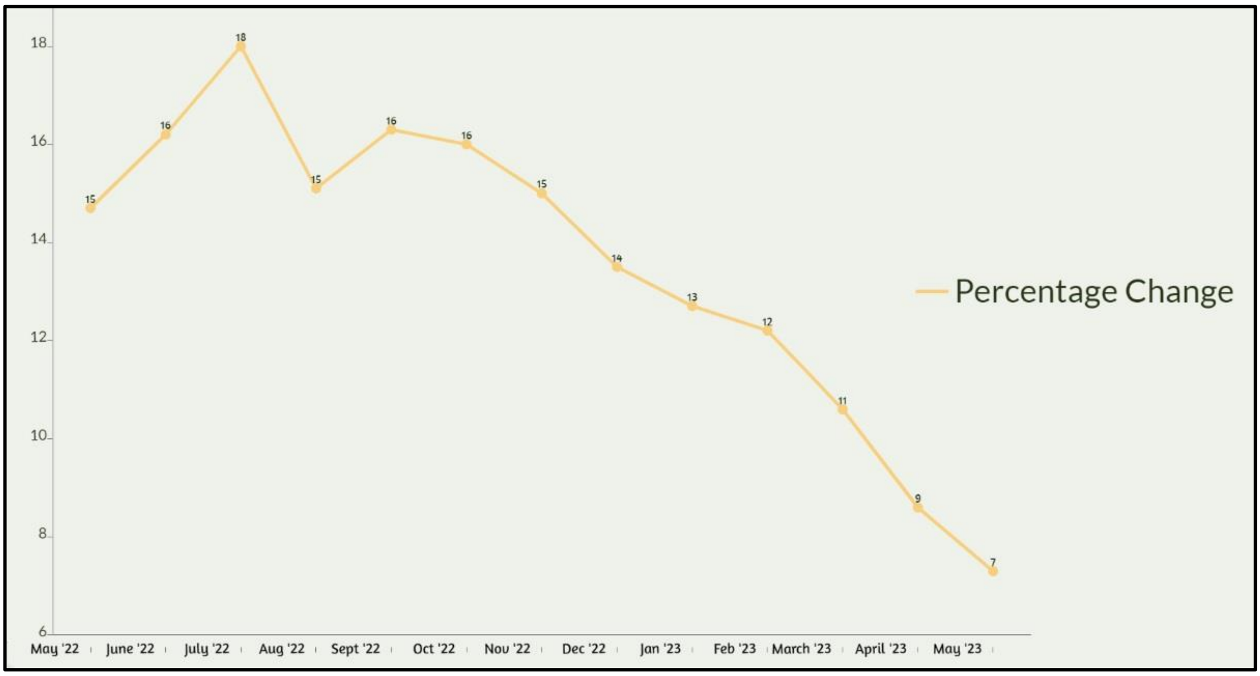

Figure 2-3: South Africa's PPI May 2022 to May 2023 (Department of Statistics South Africa, 2023)

The cost-income plier effect has been a source of affliction for decades, first noted by Moss (1992:205) as a concept with no cointegration and lacking stability. The agricultural sector's success depends on the uncertainty of the international grain scenario and environmental factors that affect financing and prevent recovery (Brits, 2019) and could severely impact the price of maize. The maize price expectancy is impacted by exchange rates, supply, and demand (Mokone, 2018). If this established price does not coincide with input costs, the cost-price squeeze could harm the farmer's profitability and expected crop production.

In 2022, the average maize yield in South Africa was 5.92 tons/ha (Adama, 2023). Considering the average input cost of R12 000 per hectare and the average selling price of white maize at R3700.31 per ton (Maize Crop Quality Report, 2022), the result of R9905.84 profit per hectare seems affordable. However, these calculations only reflect direct input costs, such as petrol, fertiliser, and lime, not considering other expenses, such as labour, professional assistance, and machinery. These numbers demonstrate that the cost-income plier effect – while already unfavourable - does not include other variables that could impact the bottom line.

With the added pressure that farmers face to increase production and reduce inputs, it is evident that alternative management strategies are needed to satisfy these needs. Precision farming and its site-specific application of inputs minimise input costs and improve soil health, increase productivity (Sharma & Angidi, 2022:201), and improve crop quality, which aids in food security and further economic development (Jacobs *et al*., 2018:108).

2.4 MAIZE & THE SOUTH AFRICAN MAIZE TRIANGLE

Maize is a commodity in South Africa that can increase food security (Naidoo *et al*., 2022:27) and is responsible for various food types. White maize is a food staple that can be consumed as grain, meal, and green mealies. In contrast, yellow maize is mainly used for livestock feed (Department of Agriculture, Land Reform, and Rural Development, 2022:4). Ten growth stages are associated with maize production, with stage zero planting the seed 25-40cm in the soil. Germination occurs between 6 and 10 days, or in drier areas, it could take up to two weeks. The ideal temperatures are between 20 and 30 degrees Celsius (du Plessis, 2019:1), and if temperatures continue to increase due to climate change, as described in the introduction, maize could potentially not germinate during this stage. Table 2.1 below depicts these stages, and stages seven and eight are when the plant needs additional nutrients such as fertiliser and lime. Precision farming would assist the farmer by recommending these additional nutrients with a site-specific method, guaranteeing that the plant will absorb the amounts applied. Figure 2.4 illustrates how the maize plant grows during the aforementioned stages.

Table 2-1: Growth stages of maize. Adapted from du Plessis (2019:8-10)

Stage	Description
One	Every third day (more or less), tussling starts.
Two	The plant's lead area increases 5 - 10 times, the stem mass increases 50 - 100 times, and the length is approximately 5 - 7.75 cm above the soil.
Three	The lateral shoot grows, and the potential number of seed buds can be determined.
Four	The tassel is almost fully developed, and the silk start to lengthen.
Five	The tassel is visible, and the leaves have all unfolded. The lateral shoot with the main ear has matured, and the need for nutrient and water increases.
Six	This stage is also known as the green mealie stage, and the ear, lateral shoots, and bracts are all fully developed.
Seven	Increased green mass occurs, and the sugars are converted into starch.
Eight	The kernel sugars disappear.
Nine	The grains are physiologically mature and have reached their maximum dry mass.
Ten	Drying of kernels must be completed to reach biological maturity.

The maize triangle of South Africa, as Figure 2.5 reflected on the next page illustrates, shows how much area is regarded as part of it. As indicated in Figure 1-1 (see Chapter 1), most Class I to Class III soils are located in the maize triangle. On this highly arable land, maize production thrives.

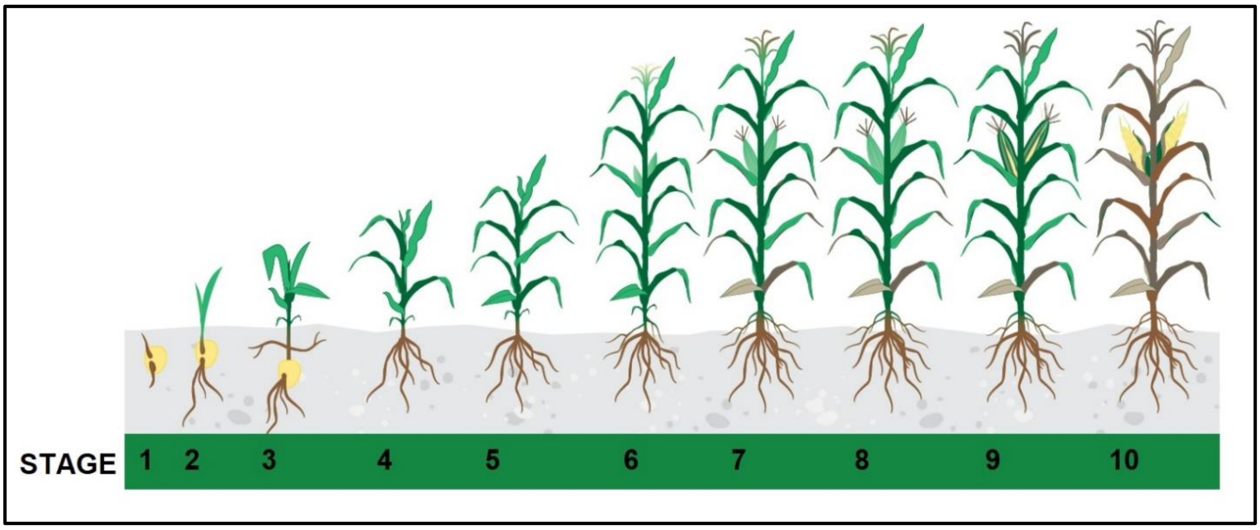

Figure 2-4 Maize Growth Stages. Adapted from Pannar (2016).

This area, which consists of mostly dryland areas, depends on rainfall for successful crops (Department of Agriculture, Land Reform, and Rural Development, 2022:1). While additional irrigation is present on some farms, it is an expensive investment.

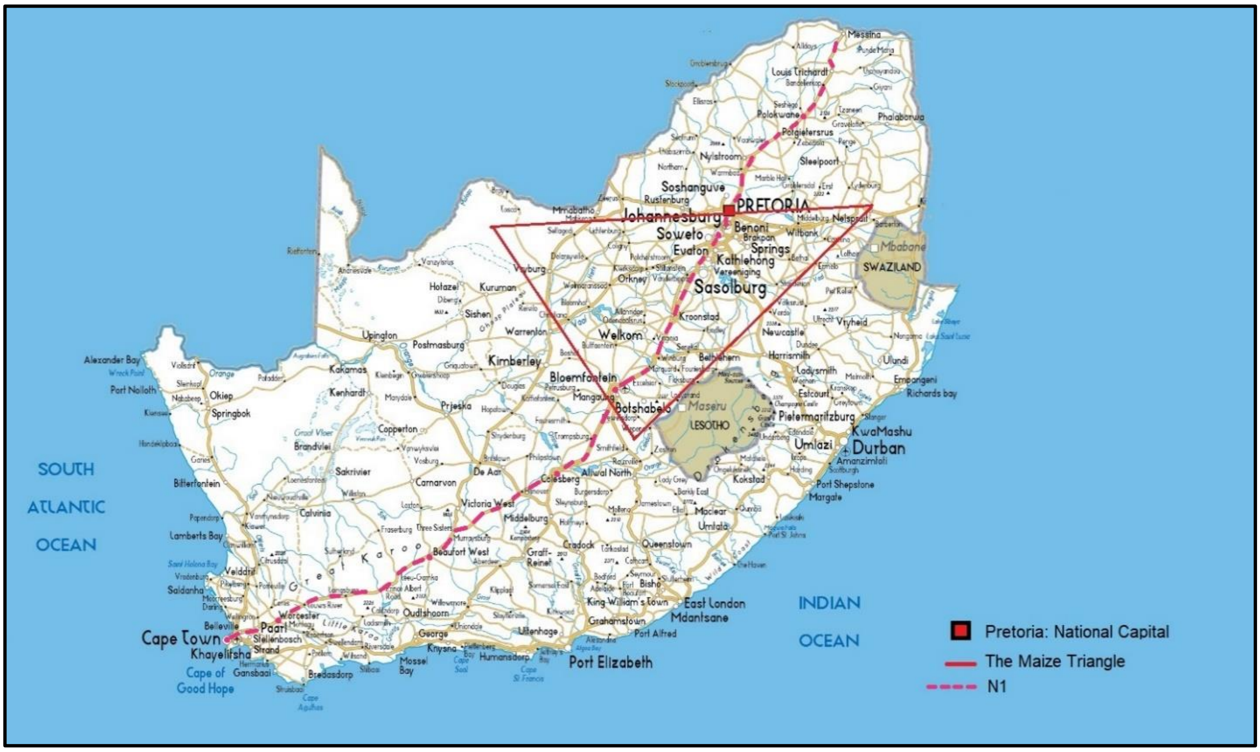

Figure 2-5: South Africa's maize triangle. Adapted from South Africa World Map (N.D) & Greyling (2019:59).

Dividing this area into east and west with the N1, as shown in Figure 2.5 one can differentiate when planting and harvesting occur. The eastern region starts planting at the beginning of October until the first week of November, while the western area starts planting in the last two weeks of November until mid-December (Department of Agriculture, Land Reform, and Rural Development, 2022:3). Harvesting in the eastern area occurs typically from mid-April to the end of June. The western area's farmers would be harvesting from mid-May to the end of July. As this area is dependent on rainfall, and 500-750mm of rain or more is required for quality crops and a stable yield (Department of Agriculture, Land Reform, and Rural Development, 2022:2), it is clear that the predicted increased temperatures could be detrimental for future crop yields in this area. Table 2.2 illustrates the possible correlation between the yield, rainfall, and temperature that the maize triangle experienced in 2022. The year Two Thousand and Twenty-Two was the fourth hottest year that South Africa had experienced since 1951, with a steady increase of 0.16° per decade (Annual state of the climate of South Africa, 2022). These statistics showcase that efforts is required to lessen the destructive environmental impacts that the growing population is contributing to.

Table 2-2: Yield per hectare, hectares planted, and average rainfall in the maize triangle in 2022. Adapted from Maize Crop Quality Report (2022:4) & Annual state of climate of South Africa (2022:6)

Maize Triangle (2022)	Yield/Tonnes	Hectares Planted	Average Rainfall	Average Temperature
Gauteng	6.40	58 000	726mm	24 ° C
Free State	4.95	907 500	820mm	28° C
North-West	4.39	485 000	727mm	23° C
Mpumalanga	6.67	165 000	950mm	22° C
Other Provinces	5.08 (average)	76 400	682mm	25° C

The 2020/2021 season of maize production saw an increase of more than 1 million metric tonnes (Gro Intelligence, 2023) from the previous season. Figure 2.6 exhibits the production tonnes per province in the maize triangle, showcasing how much of the maize produced in South Africa comes from Gauteng, Free State, North West, and Mpumalanga in correlation to the remaining five provinces. Three million tonnes of the produced maize were exported (Banya, 2023), demonstrating further that while it is a popular export commodity, more of this commodity should remain local to feed the increasing population of South Africa suffering from food insecurity.

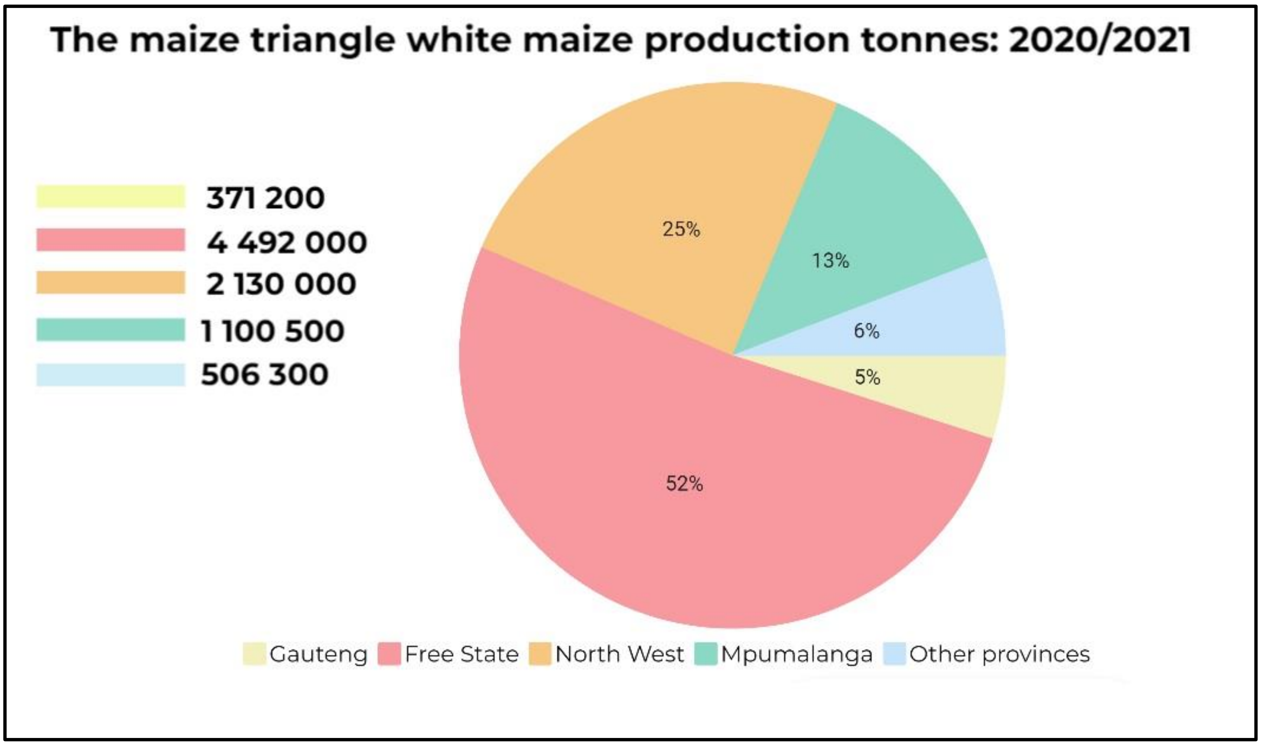

Figure 2-6: White maize production in the maize triangle 2020/2021. adapted from Maize Crop Quality Report (2022:4)

2.5 PRECISION FARMING

Farmers must explore alternative management strategies such as precision farming to curb food insecurity, the cost-income plier effect, and increased crop production. In the 1990s, Wolf and Wood (1997:180) regarded precision farming as enhancing site-specific crop production with digital data. This definition still rings true but has been expanded to include the following: It is a management technique that observes field variability in crops (Omofunmi & Ogunleye, 2021:1) through the various aspects of the soil with technological support (Marucci *et al*., 2017:35) and is also referred to as smart agriculture and satellite farming (Additcott, 2020:10). Simon Blackmore (quoted by Addicott 2020:10) says that "Precision farming is not only a type of management of spatial variability but a way of thinking."

2.5.1 Background of Precision Farming

The saying “right amount, right place, at the right time” started being used in the 1980s with the adaption of fertiliser distribution using autonomous machines, guidance systems, and software (Gebbers & Adamchuk, 2010:828). However, since the 1920s, American farmers have attempted to make wiser decisions by considering spatial variability (Franzen & Mulla, 2016:1). Robert Fisher spearheaded the development of statistical tools for spatial variability, which eventually evolved to include aspects of crop nutrient management, which it initially lacked (Franzen & Mulla, 2016:2).

As Agriculture 1.0 with manual labour and animal power moved to Agriculture 2.0, the Green Revolution erupted through the agricultural sector. New management practices were developed to increase yields and utilise new machinery (Dayioğiu & Tűrker, 2021:875). In the following years, soil was tested at various depths on different grids. In the 1960s, a 0.4 ha grid was used to divide the farm areas and collect soil samples. In comparison, a 2.5 ha grid is currently the norm (Franzen & Mulla, 2016:2-4) as it still supports the three primary goals of precision farming: optimisation of resources to enhance sustainability and increase profits, curtail negative environmental impacts, and improve the quality of overall farming (Gebbers & Adamchuk, 2016:829).

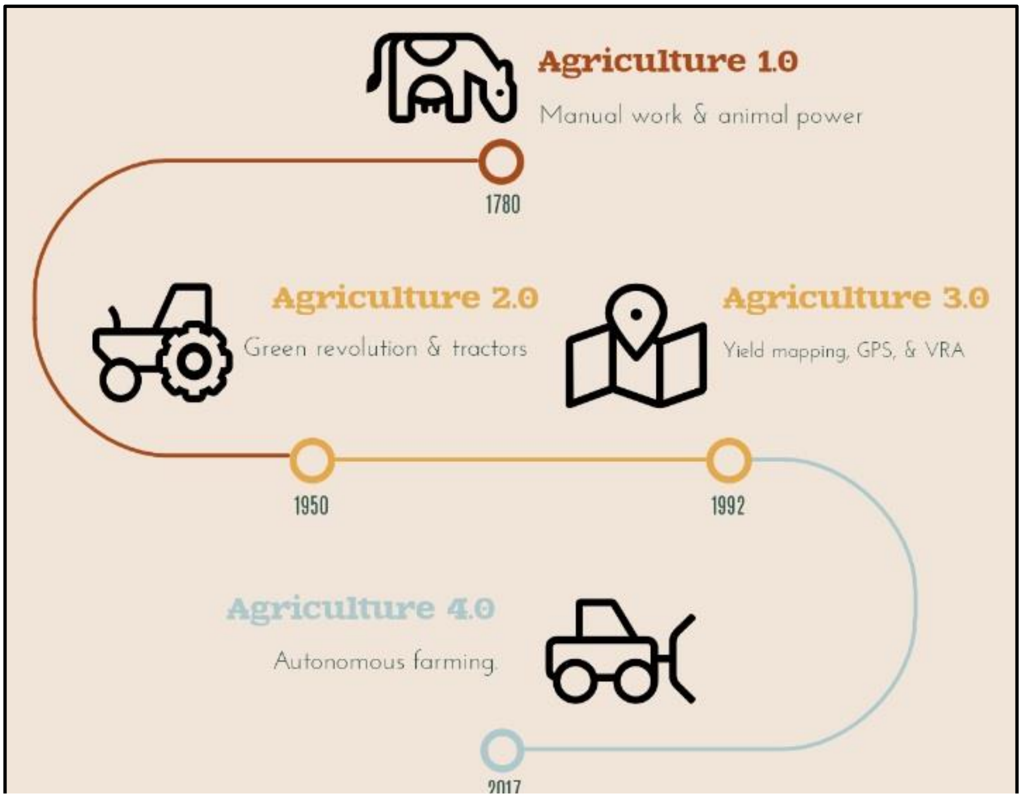

Figure 2-7: Timeline of farming technology advancement. Adapted from Lui et al., 2020:4324)

Precision farming led the movement into Agriculture 3.0, using GPS technology in the late 1980s to make soil sampling and variable-rate fertiliser application easier (Franzen & Mulla, 2016:4). Data analysis and site-specific management in the 1980s, and active-optical sensors, NVDIs, typography tools, and satellite imagery in the 1990s (Franzen & Mulla, 2016:8-11) resulted in higher productivity and reduced chemical usage (Dayioğiu & Tűrker, 2021:875) which established precision farming as a vital cornerstone of Agriculture 3.0.

In 2017, the journey to Agriculture 4.0 began as the rapid development of specialised machines progressed, producing GPS sprayer booms and advanced sensor and guidance system technology (Franzen & Mulla, 2016:11) that enables autonomous farming. Figure 2.7 shows the changes from Agriculture 1.0 to 4.0.

2.5.2 Aspects, stages, & the cycle of Precision Farming

2.5.2.1 Aspects of Precision Farming

Precision farming has three significant aspects: technology, information, and management.

Technological advancements have increased production and profitability (Sharma & Angidi, 2022:201), relying on GPS, GIS, sensor technology, remote technology and VRTs.

- **GPS**: Global positioning systems guarantee accurate yield mapping, grid sampling and precise locations for VRA's (Sharma & Angidi, 2022:202). Additional progress has been made with Global Navigation Satellite Systems (GNSS) due to the advancements in GPS technology (Marucci, 2017:27)
- **GIS**: Geographic information systems is a layered-based system (Marucci, 2017:28) that ties data with mapped areas, establishing typography, soil types, drainage, and crop yields (Sharma & Angidi, 2022:202). Agro-technological assessments are made by the refined GPS data during the GIS process (Marucci, 2017:27) that identify constraints that precision farming could address.
- **Sensor technology**: Soil quality and information on plant fertility are gathered via photo electricity and ultrasound, measuring vegetation, humidity, and temperatures to identify species and monitor droughts (Sharma & Angidi,

2022:202). Sensor technology includes sensor networks (Yazdinejad, 2021:2) that effectively communicate in real-time to farmers (Addicott, 2020:31). As one of the goals of precision farming is to decrease input costs, sensor networks successfully contribute to this by identifying critical target areas (Stone & Raun, 2016:23).

- **Remote sensing**: Information about surface reflections or emissions is recorded from a distance (Sharma & Angidi, 2022:202). Decisions about spatial information (Zhao *et al*., 2016:56) can be made with Chlorophyll assessment in plant canopies (Stone & Raun, 2016:34). Remote sensing is used to measure nitrogen and water content – which can limit photosynthesis and plant productivity, leaf N-distribution, and the growth status of crops (Zhao *et al*., 2016:57-59). Prescription maps are created after analysis and managed with satellite imagery (Sharma & Angidi, 2022:202).
- **VRT**: Variable-rate technology allows the farmer to change the rate of inputs in specific areas of their field, improving input application and creating sustainability (Sharma & Angidi, 2022:202). These applications could be fertilisers, herbicides, or pesticides in specific areas with integrated sensors and rate controllers (Zhang, 2016:123). The automatic delivery of inputs strengthens the precision farming slogan "the right time amount, in the right place, at the right time" (Sharma & Angidi, 2022:202).

The second aspect of precision farming is gathering information on crop characteristics and soil properties that assist the farmer in decision-making (Sharma & Angidi, 2022:201). Implementing the technology and acquired information to manage crop production (Sharma & Angidi, 2022:201) and evaluating decisions will result in effective management, the third aspect of precision farming.

2.5.2.2 Stages & Cycle of Precision Farming

Data collection, interpretation, and application are regarded as the three stages of precision farming (Comparetti, 2011:2). Figure 2.8 depicts the cycle with the appropriate stage after considering Rüsch's (2005:2) visual representation of the precision farming cycle and Comparetti's (2011:2) illustration of the stages (see Figure 2-8).

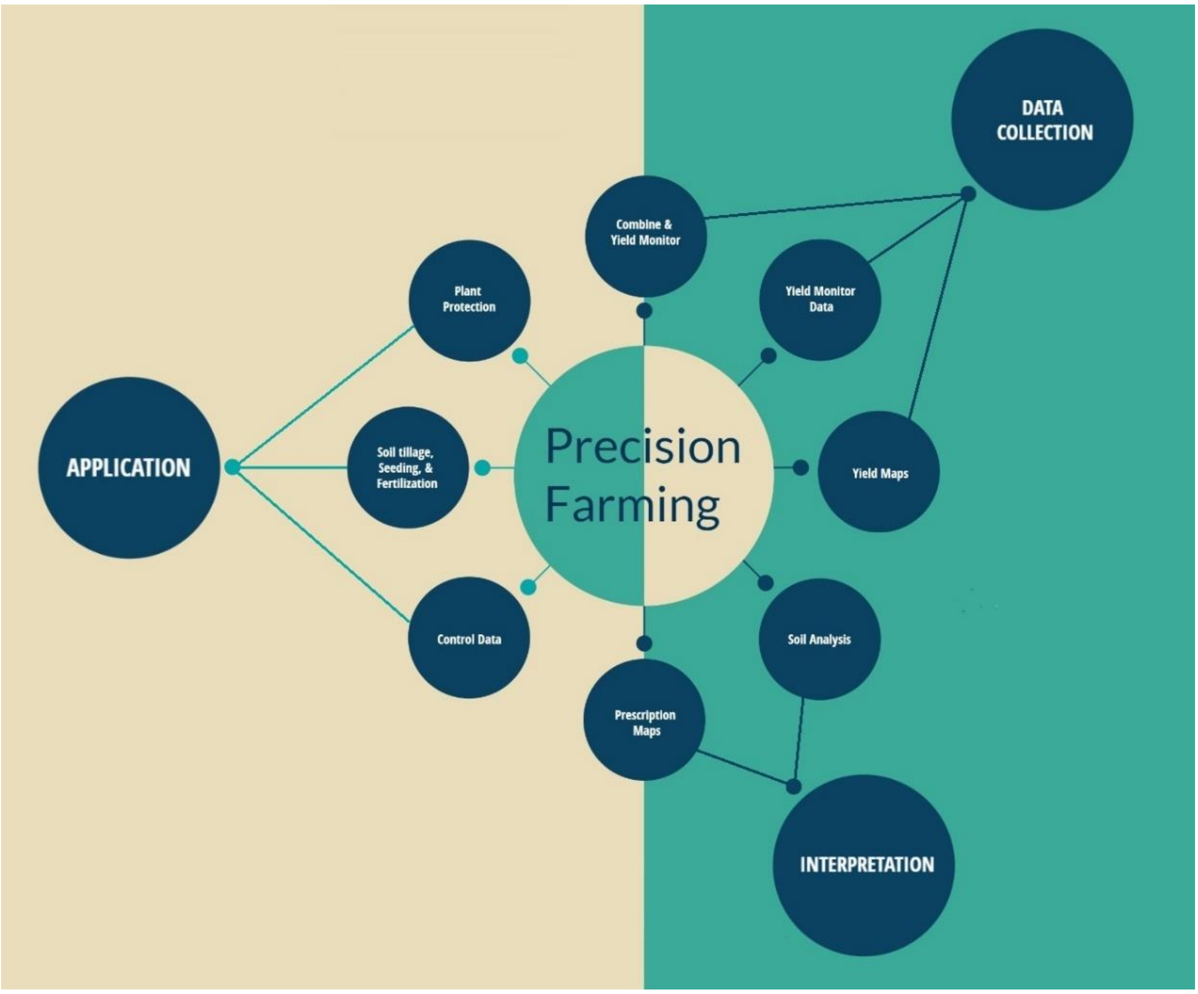

Figure 2-8: Stages & cycles of precision farming. Adapted from Rusch (2005:2) & Comparetti (2011:2)

Precision farming data collection includes data from combines, yield monitoring, and information displayed on yield maps. Combines employ GPS technology to capture the rate of grain harvesting and map yields (Addicott, 2020:7). During harvesting, yield-mapping visually showcases the yields of the areas in the field; farmers can quickly identify areas performing sub- or above par (Addicott, 2020:29-30). The measurement of spatially variable soil and crop parameters is interpreted to implement optimal production decisions befitting each specific area (Comparetti, 2011:2). Therefore, data collection optimises inputs and assists management decisions throughout the production season.

Prescription maps are based on the data interpretations after the soil analyses. A soil sample is coordinated with GPS mapping (Zhao *et al*., 2016:61) to determine the soil nutritional levels of the samples at a specific field position. Fertiliser requirements are based on the results (De Baerdemaeker & Saeys, 2016:285) and prescription maps (Zhao *et al*., 2016:56). As such, a Geographical Information System (GIS) is created for each field (or area in the field) of the farm. Based on demand calculations, the GIS tasks determine the yield potential (Zhao *et al*., 2016:84-85). Mapping of input applications occurs, crop management programs can be created (Comparetti, 2011:2-3), and resultantly, informed decisions can be made on seeds, fertiliser, and other inputs.

Considering the data and recommendations, soil tillage can be avoided or increased. Tillage optimisation with GNSS-based guided tractors avoids gaps and overlapping (Auernhammer & Demmel, 2016:314). The application of seeds, fertiliser, and plant protection are applied according to the prescription maps at a spatially variable rate (Comparetti, 2011:2) in the areas that have been identified. Seeding and planting require immense precision, and GNSS improves plant growth and equal distribution while reducing costs (Aurenhammer & Demmel, 2016:315-316). Fertilisation can be managed in three ways, namely to 1) balance, 2) growth, or 3) sustainability.

Fertilising by balance – also known as prescription fertilisation - takes historical data into account and deals with the essential nutrients of N, P, and K (Aurenhammer & Demmel, 2016:316). Growth fertilisation avoids over-fertilisation and manages nitrogen fertilisation, especially in humid areas with unpredictable rainfall (Aurenhammer & Demmel, 2016:317). Fertilisation, as a sustainable measure, requires the farmer's knowledge and long-term spatial field data (Aurenhammer & Demmel, 2016:319). Lastly, using plant protection products will reduce residues on food crops (De Baerdemaeker & Saeys, 2016:283) and require monitoring throughout (Aurenhammer & Demmel, 2016:321).

2.5.3 Barriers to Implementing Precision Farming

Michau (2019:28) demonstrates that farmers are hesitant to implement precision farming for various reasons, mainly the amount of data that needs to be used and understood. The data is perceived to be overwhelming, and farmers experience data overload. A lack of support systems and the immense financial input at the start of the precision farming implementation (Michau, 2019:29) are also barriers. Hendriks (2011:31) reiterates these reasons for slower adoption, adding that the lack of perceived benefit and an overall conservative view towards farming amplifies the unwillingness to adopt precision farming.

2.5.3.1 Information factors

Given these reasons, Zhang *et al*. (2016:122) focus on an inability to use the gathered data to improve management decisions. This ties in with the notion of data overload, which farmers experience, making it difficult to know what to do with the information. Having no or few support systems or trained professionals to assist with the feedback given and apply it during the growing season makes farmers weary of precision farming technology.

2.5.3.2 Socio-economic factors

Farmers older than 45 are less likely to adopt precision farming (Jacobs *et al*., 2018:110) because of the technology associated with the adoption. Some younger farmers are in partnerships with farmers in this age group. As older farmers are more likely to make management and financial decisions, precision farming is not implemented (Jacobs *et al*., 2018:110). Farmer education and the farm size in question play a role (Schimmelpfenning & Ebel, 2016:98). Farmers with farms smaller than 500ha are less likely to implement precision farming (Jacobs *et al*., 2016:111), and farmers with farms larger than 2000ha are more likely to adopt it (Boehlje & Langemeier, 2021).

2.5.3.3 Cost factors

Regarding the initial costs of implementing precision farming, especially the machinery, there is uncertainty (Schimmelpfenning & Ebel, 2016:97). Additional costs, such as storage and insurance, should be considered (Bruce, 2017:40) after the initial investment, and many farmers opt to invest and implement because of these factors gradually. Sequential adoption results from this (Schimmelpfenning & Ebel, 2016:97) and is sometimes considered inefficient. Although acquiring the machinery and technology is a substantial financial commitment, precision farming also has annual operating costs, such as outsourced services. Typical outsourced services include soil sampling and soil analysis. Multiple samples may be required to cover several areas of the field; hence, depending on the chosen grid and size of the farm, it can be expensive.

2.5.4 Advantages of Precision Farming

The most significant advantage of precision farming, which expands into various other benefits, begins with lowered inputs on the farm. Decreased inputs increase productivity (Jacobs *et al*., 2018:108) and lead to profitability, which is the primary motive for adopting precision farming (Mizik, 2023:386). Lower inputs benefit the environment because the plants absorb the needed nutrients, and less leaching is likely.

2.5.4.1 The four perspectives

Dayioğiu & Tűrker (2021:379) claim that the four perspectives of precision farming that illustrate its benefits are agronomic, technical, environmental, and economic.

2.5.4.1.1 Agronomic perspective

The actual nutrient needs of the crops are matched from a site-specific agronomic perspective. Hyper-spectral imaging maps the soil characteristics and nutrient content that guarantees a uniform soil study; this enables accurate prescriptions and predictions (Ahmad & Dar, 2020:126). Agronomic advantages following the implementation of precision farming are soil stability, better crop production (Erickson & Fausti, 2021:4461), and quality improvements of the soil and water (Ahmad & Dar, 2020:123).

2.5.4.1.2 Technical perspective

Precision farming's technical perspective results in better time management (Dayioğiu & Tűrker, 2021:379) as the various types of intricate technology implement site-specific management. The farmer focuses on areas that can be improved, and areas that are not profitable are treated accordingly by reducing inputs. Overlapped areas are reduced (Bruce, 2017:34) as the preciseness of the equipment is GNSS-based because there is no room for errors. These technical investments are often recouped as the input costs decline (Ahmad & Dar, 2020:122), lowering production costs (Erickson & Fausti, 2021:4456) and operator fatigue with automation is minimised (Bruce, 2021:37). The variety of data gathered by the technology measure inputs and outputs (Bruce, 2017:34) and enables the farmer to make informed decisions.

2.5.4.1.3 Environmental perspective

Tying in with the goals of precision farming, as mentioned before, curtailing negative environmental impacts is a known advantage. Site-specific inputs result in minimised herbicide application (Ahmad & Dar, 2020:123) could reduce pesticides by as much as 25%, and a study by Kempenaar *et al*. in 2017 showed that insecticide use reduced by 13% (Ahmad & Dar, 2020:124) with the adoption of precision farming. When the appropriate amount of input is delivered, the plant can absorb all the nutrients, and there is little or none left that could contribute to leaching (Ahmad & Dar, 2020:126) and groundwater contamination.

2.5.4.1.4 Economic perspective

The main goal of precision farming is profitability. Investing in precision farming technology can be considered a financial risk (Bruce, 2017:40), but increased productivity leads to eventual profitability. Increasing yields and reducing inputs are well-known benefits (Bruce, 2017:41). As production costs decrease, the cost-benefit ratio improves (Ahmad & Dar, 2020:124).

2.6 SUMMARY

The literature review demonstrates that increased crop production is necessary to feed the increased population. Food security requires access to productive land and agricultural production while considering the effects of political instability and pandemics. Achieving food security must not negate the importance of sustainability or at the cost of the environment. Precision farming is a possible solution, as the implementation increases crop production, improves the quality and quantity of yields (Admad & Dar, 2020:122), and could increase food stability on a global scale (Erickson & Fausti, 2021:4461). The technology and machinery that precision farmers utilise apply inputs on site-specific areas to reduce costs and save time, which ultimately increases yields and is less harmful to the environment.

The literature shows that precision farming could aid in curbing food insecurity, but it is not without barriers. Apprehension of new technology and how it could benefit them is among the main reasons for the lack of implementation. Data overload and the application of gathered data generate concern among the farmers – especially the older generation.

Financial obligations, which do not end after the purchase of the precision farming technology, also add to the doubts about implementation.

Taking these aspects into consideration and focusing this study on the maize triangle of South Africa is two-fold.

- Firstly, 14.7 million tons of maize (white and yellow) were produced during the 2021/2022 season in South Africa. The importance of this crop as a staple food crop in South Africa on most smallholder farms (Musokwa *et al*., 2019:65) is evident in these figures.
- Secondly, of the 2.6 million hectares of maize planted in South Africa, more than 2.2 million were located in the maize triangle (Crops & Markets, 2022:1). Referring back to Figure 1 in Chapter 1 again, most of the arable land (Class I to III) is in the maize triangle.

The maize triangle of South Africa is the area that includes Sedibeng District Municipality, Metsweding District Municipality, and the West Rand District Municipality (Government of South Africa, 2011). The triangle comprises 46.7% of South Africa's maize production and stretches across parts of Mpumalanga, North West, Free State and Gauteng, with Free State being the largest producer (Crops & Markets, 2022:1). The next chapter will explore the study's research methodology in depth.

CHAPTER 3

3 EMPIRICAL STUDY

3.1 INTRODUCTION

The literature review demonstrated that the world is headed towards severe food insecurity, and environmental, socio-economic, and financial constraints contribute to the fact. Increased crop production is needed as the population is growing, and a possible solution could be precision farming.

Precision farming, while a growing management strategy, is technology-intensive and requires vast amounts of data to implement successfully. Besides the necessary technology and data, it is also expensive to implement in phases to ease the financial implications.

The main objective of this study is to investigate the implementation of precision farming in the maize triangle of South Africa. This area is essential, as the maize triangle accounts for millions of tonnes of annual maize production. It is a rainfed area with fertile, arable land stretching across four provinces. The personal experiences and perspectives of the farmers need to be empirically analysed to achieve this objective. The empirical research and literature review will assist in addressing the secondary objectives.

In this chapter, the research process and research design are discussed. The chapter will conclude with how the data will be collected, the study population, sampling, and data analysis.

3.2 RESEARCH DESIGN

According to Saunders *et al*. (2019:130), the research approach is the approach to theory development and can be either deductive, abductive, or inductive. A deductive approach can be seen as a tendency (Bryman *et al.* 2019:12) that can control functions and direct the researcher's knowledge (Melnikovas, 2018:38). By applying deductive knowledge to research, observations and predictions can result from the hypothesis (Pruzan, 2016:78).

For this study, a deductive approach was chosen as an existing observation was picked, a question was raised, and data was collected to either prove or reject the hypothesis (Melnikovas, 2018:34). The theory for this study is the possible methods used for overcoming the obstacles when implementing precision agriculture technology, thus resulting in the research question of: “How and why do farmers in the maize triangle of South Africa adopt precision farming?” The data that was collected and the study was done to confirm the hypothesis. The deduction approach is a linear process (Bryman *et al*., 2019:10) and is regarded as preserving truth (Pruzan, 2016:99).

Qualitative research methods are used for the primary and secondary objectives, such as the definition of precision farming, which will be applied differently from farmer to farmer, interviewing the farmers about their input and output costs and identifying the possible methods to overcome obstacles in implementing precision farming technology. The descriptive data (Melnikovas, 2018:39) that will be collected with the qualitative research methods will unveil considerations that numerical data may not be able to (Pruzan, 2016:188).

Considering the qualitative approach, the subjective assessment of the chosen participants in terms of their opinions is focused on (Sahu, 2013:4). Methods used by one farmer could be a possible option for another that has not been considered before. The natural setting the participants will be in will provide more accurate answers and observations (Kuada, 2012:93). This first-hand look, combined with the critical incident technique (Kuada, 2012:99), will provide rich, qualitative data.

According to Adams *et al*. (2007:64), the research strategy entails how the research will be conducted. When examining the research onion (Saunders *et al*., 2019:130), the process involves how the study’s data will be collected. For this study, the data that will investigate how the farmers within the maize triangle have successfully adopted, implemented, and understood the technology associated with precision farming. Determining the strategy depends on the research question (Adams *et al*. 2007:64), and this study is, therefore, investigatory.

3.3 RESEARCH POPULATION

The study population was reached within the maize triangle area of South Africa. The participants of this study are maize farmers in the North West, Free State, Gauteng, and Mpumalanga who are actively practising precision farming. Over 85% of South Africa's maize production happens in Mpumalanga, North West, Free State, and Gauteng.

The inclusion criteria for the population are as follows:

- Actively practising precision farming
- Practising precision farming for at least two years
- Maize farmers (additional crops are accepted)
- Located in Gauteng, Mpumalanga, North West, and Free State
- Willing to disclose some yield data from before and after adoption.
- Willing to disclose input and output costs before precision farming adoption.
- Commercial farmers
- Has successfully implemented precision technology on their farm(s)

The exclusion criteria for the population for this study are as follows:

- Not actively practising farming as of 2021 or 2022
- Other crops but do not include maize.
- Started applying precision farming management principles after 2021.
- The farm is located outside of the designated areas within Gauteng, Mpumalanga, North West, or Free State

3.4 SAMPLING

The sampling strategy is convenient and non-probability, as possible participants have been identified through an employer. There is no randomisation in this study, and the representativeness will hopefully correlate with other data gathered throughout the study. To complete the survey on time, not all farmers in the sample area can be contacted to participate.

In collaboration with the abovementioned employer, maize farmers were identified in the given area. The director contacted the possible participants to adhere to the POPI Act, and the farmers were permitted to be contacted by the researcher.

Combining the different perspectives of the farmers and utilizing the appropriate questions, the researcher will be able to make appropriate conclusions on the implementation of precision farming in the maize triangle of South Africa. The sample size that fit the criteria was 28, 18 of which responded when asked to participate. 14 participants sent back consent forms, and the remaining four did not continue the conversation. Data saturation usually happens after 12 interviews (Guest *et al*., 2007:74), but all willing participants were interviewed, nonetheless. During the conduction of the interviews, data saturation became evident in the 12th interview.

3.5 DATA COLLECTION

Taking the inclusion and exclusion criteria into consideration, the following steps were taken after the participant had agreed to be part of the study:

- Step 1:

The researcher discussed the criteria with their employer. It was established that approximately fifty farmers are maize farmers from their client database. Some 28 of these farmers are located within the maize triangle. The employer contacted these and asked if they were interested in participating in the study. The population at this stage was 28 participants.

- Step 2:

Over WhatsApp, all possible participants were sent a message reiterating the aspects of the study and inquiring again if they would be willing to be interviewed. The sample size at this stage was 18 farmers who replied to the initial message from the researcher. Participant numbers were assigned to the farmers, and consent forms were sent to them to be signed.

- Step 3:

Western farmers were scheduled first because the western farmers harvest before the eastern ones. The participant determined a date and time for the interview over WhatsApp. Before the interview began, a recap was given about the study and the consent form. It was repeated that the conversation will be recorded.

- Step 4:

The interviews commenced over two and a half weeks. Of the 18 participants who received consent forms, 14 signed and set a date and time for an interview.

3.5.1 Interviews

The interviews ranged from 6 to 52 minutes. The questions were semi-structured, and the researcher hoped the farmers would expand and explain their answers. These questions aimed to investigate how the farmers overcame the barriers to adoption and their perceived experience of the advantages of precision farming.

In this context, the implementation of precision farming is divided into the successful understanding of the technology and data, the costs spent, and the experience of the benefits. These assumptions are justified in the literature review in Chapter 2.

The ten questions are as follows:

1. What was the main reason for implementing precision farming?

2. What was the biggest obstacle when implementing precision farming?

3. What were the initial costs to implement precision farming?

4. What training did you receive to comprehend the technology, machinery and data?

5. What support systems were used to understand the technology, machinery and data?

6. As a precision farmer, how difficult was it to overcome the intensity of the technology?

7. As a precision farmer, how complex was the data management to surmount?

8. Do you feel precision farming, not traditional or other farming methods, has made your farm more profitable?

9. How long was it before you saw an increase in yield? How much was the increase?

10. How significant are the environmental effects of using precision farming management to you?

After the interviews were recorded, it was transcribed by the researcher. It was determined that transcribing the interviews herself and not using a third party would strengthen her familiarity with the data, themes, and patterns.

3.6 DATA ANALYSIS

Guest *et al.* (2006:65) stipulate that data saturation is the point in data collection where new information is no longer added to the codebook. Various factors could contribute to data saturation, such as the topic and aim of the study, the participants, and the chosen methods of collecting and analysing the data (Tran *et al*., 2016:88).

A study by Guest *et al.* (2006:74) concluded that data saturation happens after 12 interviews which would indicate the final sample size and more than 90% of the codes will have been developed. Interviews are one of the most common forms of data collection within qualitative research (Guest *et al*., 2012:3), and the descriptive accounts allow for interpretation. Transcription for coding will enable the researcher to enhance the data quality (Guest *et al*., 2012:3) to answer the research question.

According to Adeoye-Olatunde (2021:1360), data analysis starts with transcription. Checking and re-checking transcriptions for accuracy and transcribing the interviews verbatim will aid in the analysis. Braun and Clarke (2006), as illustrated by Sendeze (2019:148), include the following steps to analyse data:

- ***Get acquainted with the data:***

Transcribing the interviews, re-reading the collected data, and capturing initial ideas will result in familiarisation of the data.

- ***Generating initial coding:***

Creating a codebook manually with words and phrases crucial to the study. The initial coding of the features of the data that are relevant to the research.

- ***Identifying themes***

The coding and categories will enable the researcher to identify themes regarding their perceptions and experiences. These themes will also identify sub-themes, requiring revision to generate a map of themes. As this study is deductive, the researcher expects to find specific themes the literature establishes. Figure 3.1 below illustrates how coding leads to sub-themes and themes.

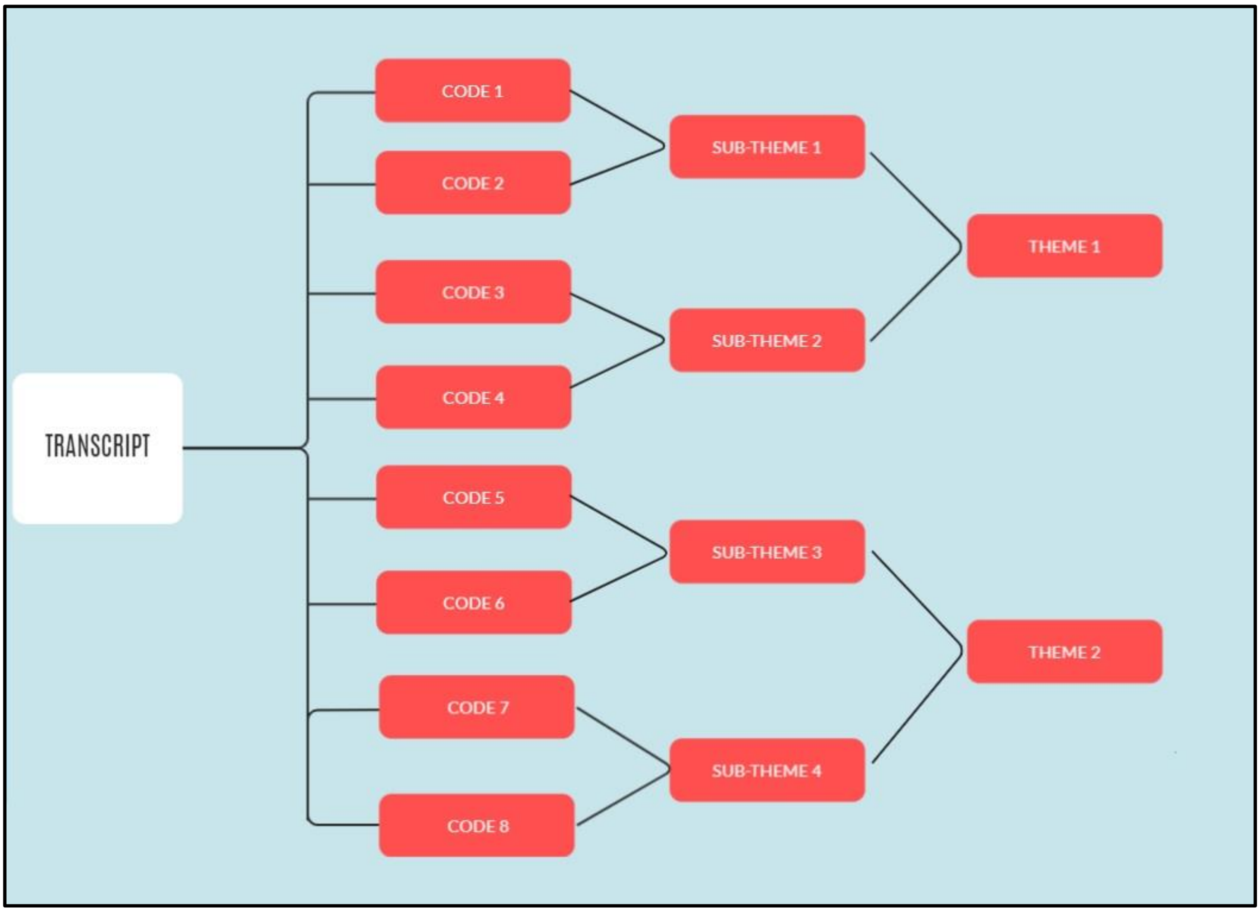

Figure 3-1: The thematic analysis. Adapted from Talebi et al. (2020:9)

- ***Reviewing themes***

The validity and reliability of the themes relevant to the research will allow the researcher to add to the thematic map.

- ***Defining themes***

Each theme will need to be analysed, defined, and named accordingly.

- ***Making a report***

A report will be written using the guidelines of the Consolidated criteria for reporting qualitative research (2017), and the findings will be interpreted and displayed using quotes, tables, figures, and explanations.

3.7 TRUSTWORTHINESS OF THE DATA

Qualitative research relies on descriptions and aims to understand the meaning of perceptions (Adler, 2022:598). As there is no quantitative data to rely on, the data of a qualitative study requires trustworthiness. Connelly (2016:435) reiterates the findings of Lincoln & Cuba (1985) that there are four criteria that a study must meet to have trustworthiness.

- ***Credibility:*** A qualitative study must display confidence in the truth of the findings.
- ***Dependability:*** The data of the study must have stability.
- ***Confirmability:*** The data collected must be consistent and repeatable.
- ***Transferability:*** The study's findings must be helpful in other settings.

Lincoln and Denzin (1994) later added another criterion: authenticity. This dictates that the research should showcase different realities (Connelly, 2016:436).

Adler (2022:599) adds that transparency is crucial in qualitative research which should be apparent through the researcher's techniques, epistemological, and theoretical bases (Adler, 2022:600). Transparency can successfully be achieved by focusing on displaying the methods used in the research (Adler, 2022:600-601):

- ***Reflexibility***

Showing their social position compared to the participant as biases can influence objectivity.

- ***Triangulation***

Cross-checking data and research are necessary to ensure credibility. This can be methodological or with other research members.

- ***Raw data availability***

Making data available contributes to transparency and reliability. Transcripts with participation numbers (to ensure anonymity) and data tables will provide a better understanding. Cloutier and Ravasi (2020:114) conclude that tables reflect useful ontology and analytical data and could back up conclusions.

Considering these elements, the interviews were transcribed and analysed to generate codes and themes. These themes will be triangulated with the assistance of the research supervisor to strengthen the trustworthiness and reliability.

3.8 RESEARCH ETHICS

This research is considered low risk as the participants are adults, covers a non-controversial topic and is anonymous.

This study has been registered with the Economic and Management Sciences Research Ethics Committee (EMS-REC) with the ethics number **NWU-00587-23-A-4**. Per the NWU Institutional Research Ethics Regulatory Committee (IRERC), this research was conducted with honesty, accountability, professional courtesy and fairness, and good stewardship on behalf of others.

The following ethical considerations were adhered to during the research:

- **Risks**

There are no expected risks when participating. Personal information, such as financial inputs and profits on the participant's farm, will be gathered to establish the validity of the disadvantages and advantages of implementing precision farming.

- **Confidentiality**

This study is anonymous. The participant's identity or the information they provide will not be known to anyone except for the researcher and the research supervisor. After the study, the recordings will be deleted.

- **Right to withdraw**

As voluntary participants, they can withdraw at any time with no consequences. You will have the right to request that none of the data obtained be used if you so wish.

- **Questions and doubts**

Participants have the right to ask for clarification on the research, research questions or any questions about the procedure. Contact information was given to each in the consent form to reach the researcher via phone or email.

The consent form is attached as Annexure A.

3.9 ACCUMULATION OF THE DATA

As the researcher did the transcription, the audio recordings and transcriptions will be stored on a password-protected personal computer electronically, and the codebook will be kept if questions arise in the future.

3.10 PUBLICATION OF FINDINGS

This research and its findings will be submitted as a partial requirement for an MBA degree at NWU Business School as a mini dissertation. After finalisation, it will be made available on the mini dissertation database of the NWU.

3.11 ASSESSMENT AND DEMONSTRATION OF THE QUALITY AND SIZE OF THE PROPOSED RESEARCH DESIGN

This study is a qualitative study on precision farmers in the maize triangle of South Africa. It is an investigative study of how precision farming is implemented, considering the barriers and discussing the perceived advantages. Semi-structured interviews were used to collect the data to understand how precision farming was implemented in the maize triangle.

This study could provide strategic ways for farmers to adopt precision farming more effectively and manage the barriers. The increase in precision farming adoption in South Africa could benefit the agricultural sector, the country's economy, and the farmers.

3.12 SUMMARY

This chapter deduced why a deductive approach was chosen for this qualitative research study and how the data will be collected and analysed. The farmers are participants chosen with convenience sampling and adhere to the inclusion criteria as explained.

Ethical considerations are essential in conducting research, and this chapter describes how this study will comply with the guidelines and requirements.

CHAPTER 4

4 EMPIRICAL RESULTS

4.1 INTRODUCTION

The previous chapter discussed the research methodology and the analysis method. The importance of this chapter is to showcase how this methodology and analysis were applied. The interview results will be discussed, and a thematic analysis will be used to explore the gathered data. The participants' demographics, the established themes, and subthemes will be focussed on, and the chapter will end with the results based on the identified themes.

4.2 RESULTS

4.2.1 Demographic Profiles

Hammer (2011:261) illustrates the importance of participants' demographic profiles: it moves researchers towards universalism, could assist in interpretation, and is helpful for secondary data analysis. The participants' demographic profiles will focus on the geographical area, their additional crops besides maize, their ages, and their educational backgrounds.

4.2.1.1 Location

Figure 4.1 below shows the participants' location, labelled with their participation numbers. The study investigated the perceptions of precision farmers in the maize triangle of South Africa, which was a convenience sampling. The farmers the researcher had access to were narrowed down solely to maize farmers and eventually reduced to maize farmers in the specified area of the maize triangle. As seen in Figure 4.1, the participants are pretty spread out across the maize triangle, resulting in various perceptions.

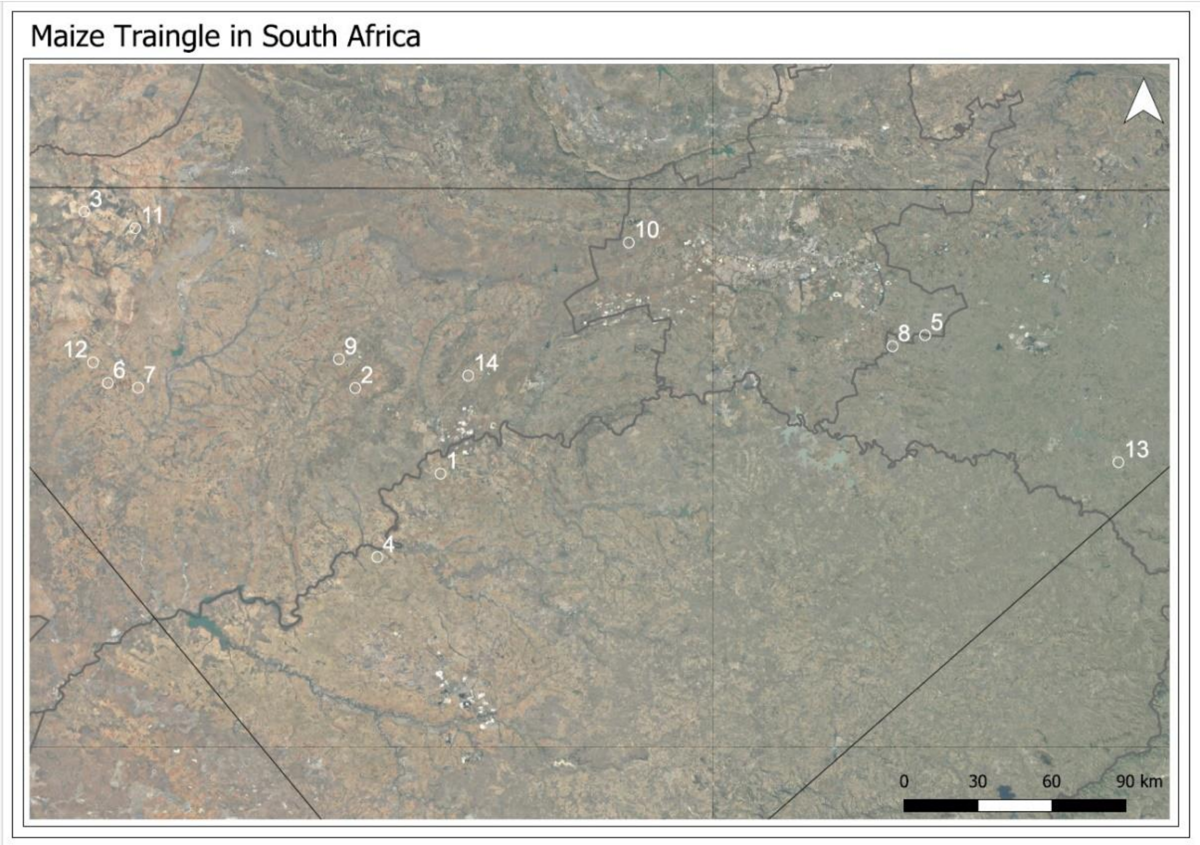

Figure 4-1: Geographic Representation of Participants

4.2.1.2 Age

Figure 4.2 illustrates the range of ages of the participants. The youngest participant was 29, and the oldest was 65. Majority of the participants (43%) were between 35 and 44.

4.2.1.3 Educational Background

As discussed in Chapter 2, farmers older than 45 are less likely to adopt precision farming because of the intense technology (Jacobs *et al.*, 2018:110). Participants in this age group and their experienced barriers will be discussed later in this chapter. Masi *et al*. (2022:4) demonstrate that older farmers compensate for their lack of education with experience, while younger farmers are more motivated to be innovative. Twenty-eight point fifty-six per cent of the participants only completed grade 12, while the remaining participants furthered their education on some level after high school. Figure 4.3 shows the diverse academic qualifications.

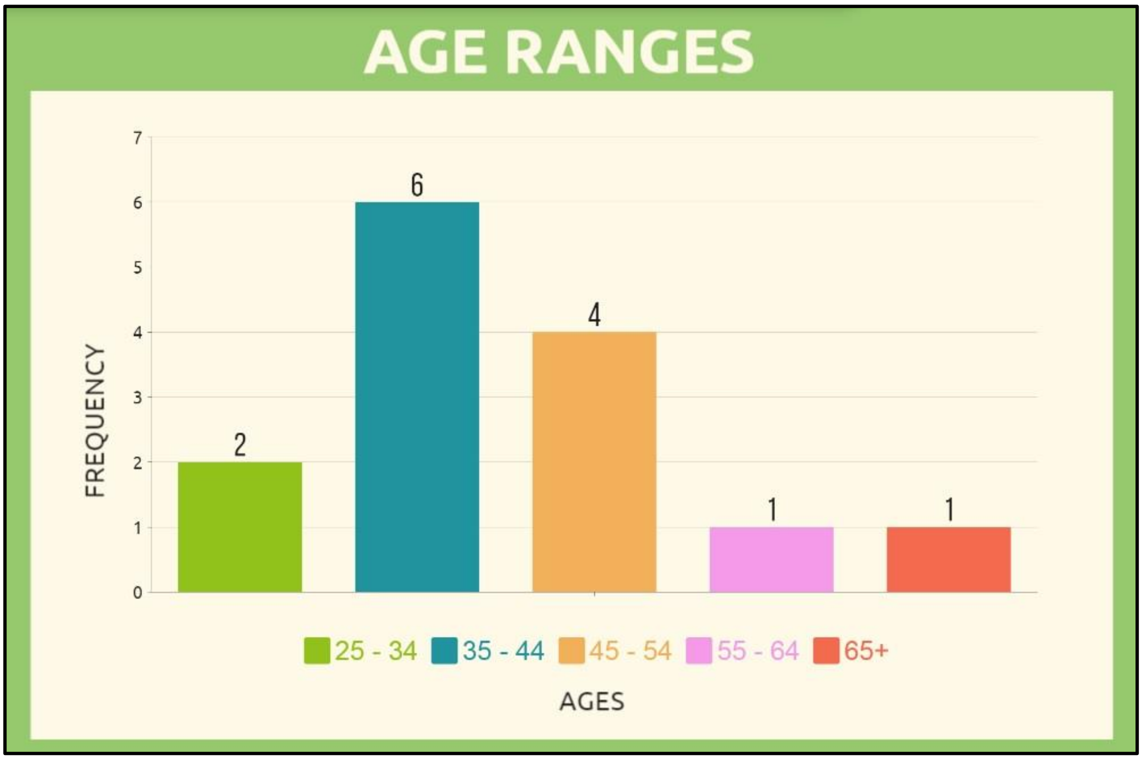

Figure 4-2: Age Ranges of Participants

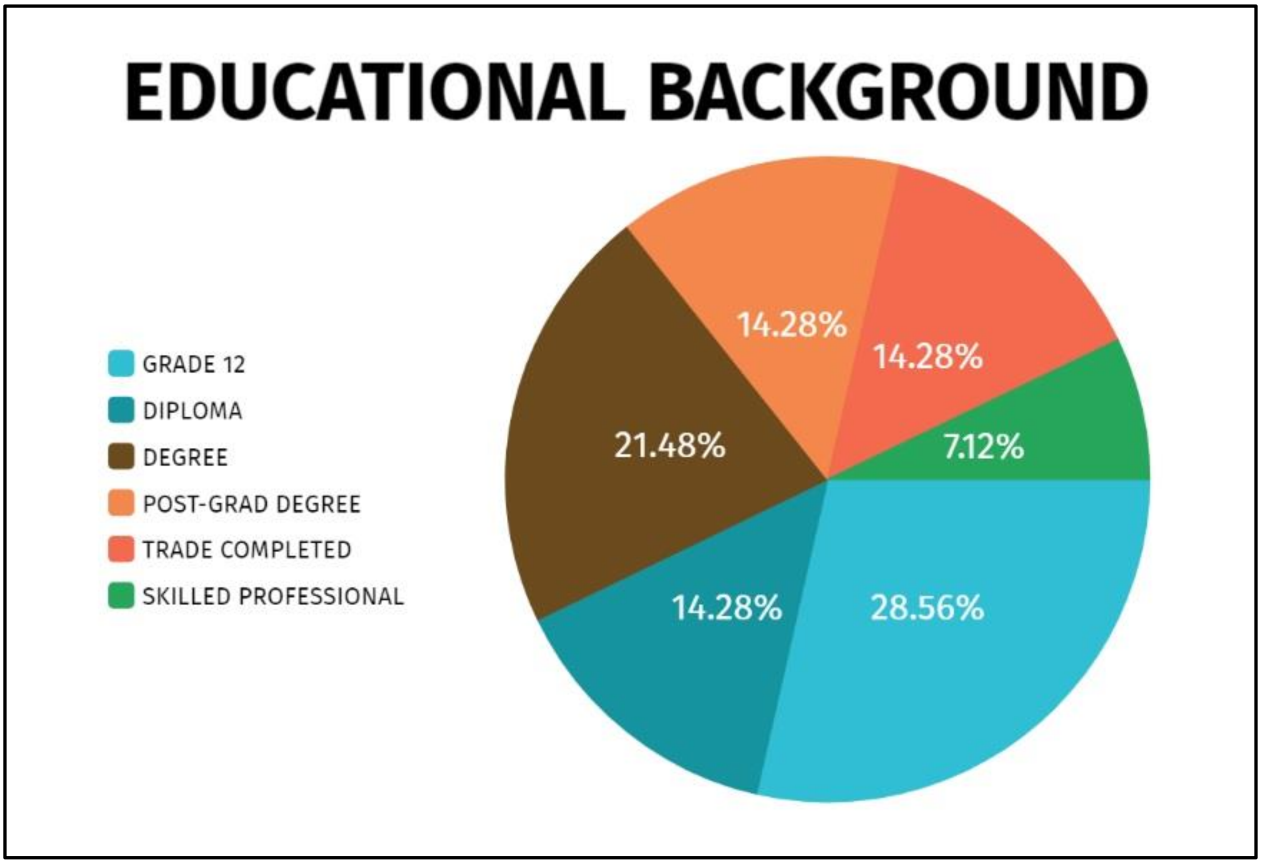

Figure 4-3: Educational Background of Participants

4.2.1.4 *Additional Crops*

The inclusion criteria of this study state that participants must grow maize. However, planting a supplementary crop is allowed. Each participant had supplementary crops, with 11 of the 14 interviewed farmers also growing sunflowers. Matthews (2015) reported for Grain SA that sunflowers are planted on maize farms for drought tolerance, as a crop cover, and are incorporated in crop rotation with maize. This diversification can be seen in Figure 4.4.

4.2.1.5 *Experience*

Most of the interviewed participants adopted precision farming between 3 and 5 years ago, with the rest varying in years, as seen in Figure 4.5 below. One of the participants, who has been a precision farmer between 11 and 20 years, acknowledges that he began using the technology 11 years ago but began implementing the thought process of precision farming 19 years ago by using satellite imagery, considering the environment, and doing grid work.

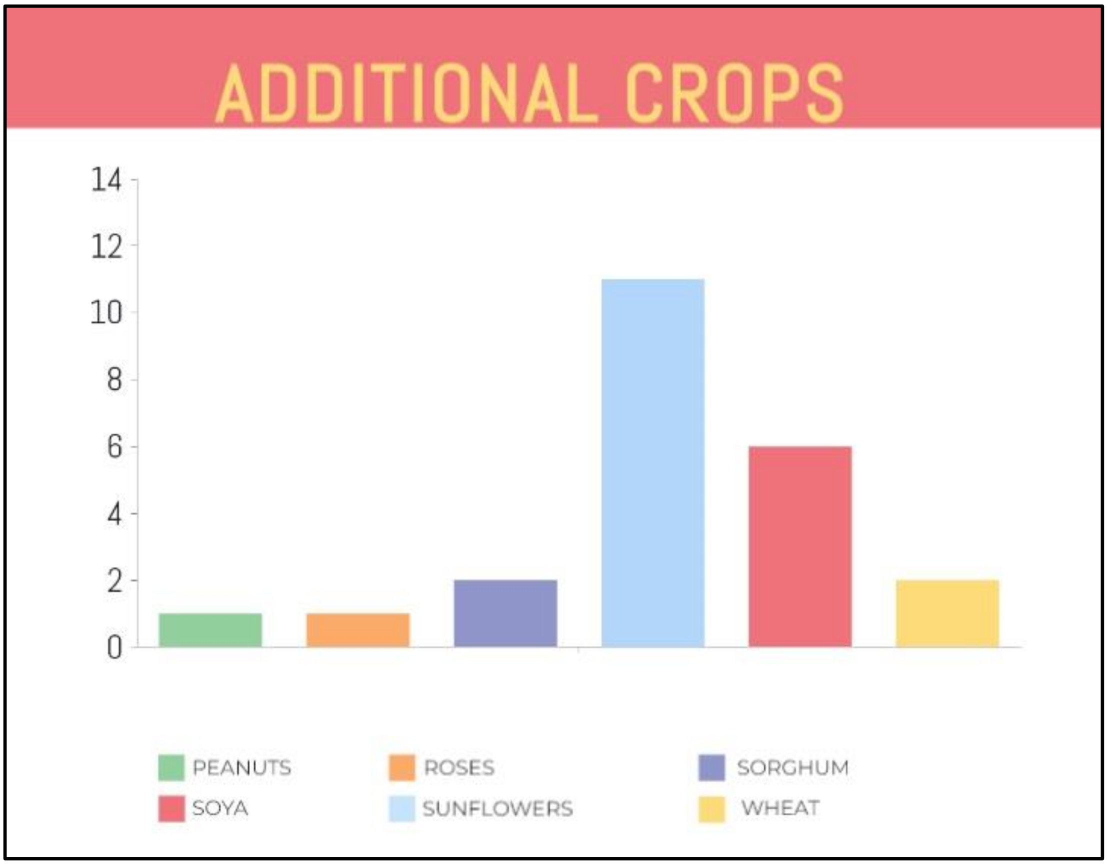

Figure 4-4: Additional Crops of Participants

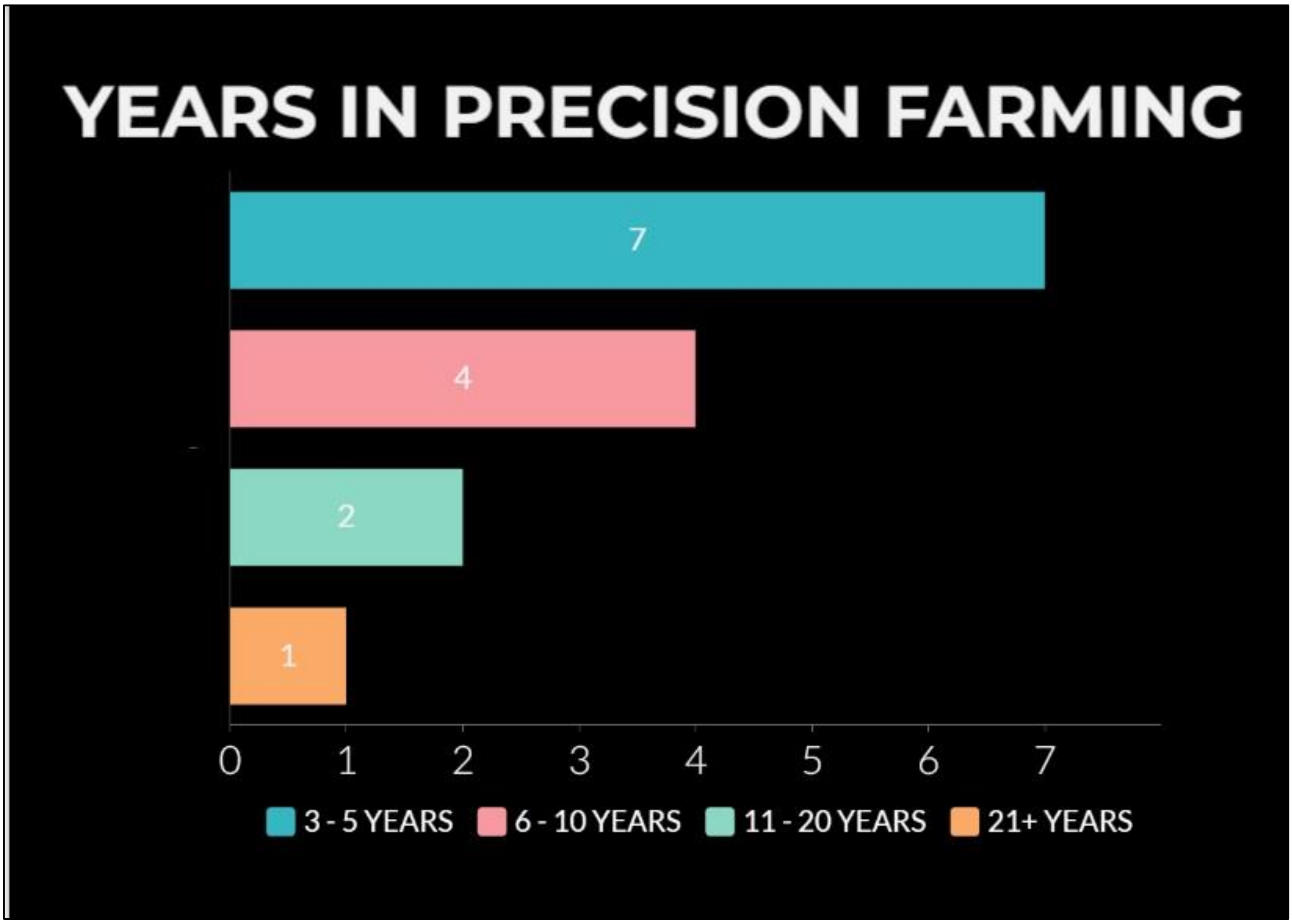

Figure 4-5: Years in Precision Farming

4.2.2 Background of Participants

Table 4.1 below summarises the participants' background information to highlight the diversity of their profiles. Their areas, age, and the number of years they have actively been practising precision farming were recorded.

Table 4-1: Background of Participants

Participant	Area	Age	Years PF
1	Bothaville	35	7
2	Hartbeesfontein	32	10
3	Mareetsane	65	19
4	Bothaville	53	5
5	Balfour/Nigel	47	18
6	Delareyville	37	10
7	Delareyville	29	3
8	Balfour	37	5
9	Hartbeesfontein	49	21
10	Carletonville	56	5
11	Mareetsane	40	3
12	Delareyville	47	10
13	Standerton	36	4
14	Potchefstroom	38	3

The participants' perceptions are discussed per the research question in the next section.

4.2.3 Perceptions of Participants

A summary of the participants' perceptions is discussed to enable the reader to grasp the information obtained during the interviews.

Participant 1:

The participant supported his reason for precision adoption with one word: "*efficiency*". Being in his 30s, this participant found the technology relatively easy to adopt and understand. He relied on agents and agriculturalists to assist him when needed and found the most challenging aspect of precision adoption was the financial weight of purchasing the machinery. The initial purchase of the required machinery and technology amounted to more than R450,000. The adoption of this technology was systematic, and after the first year, he saw an increase of 0.5 tonnes yield per hectare.

He acknowledges precision farming's impact on how he manages his farm but emphasises that other factors have also impacted his profit and yield, such as rain and changing other practices. Knowing his soil is being sculpted according to its maximum potential and that his yield continues to increase demonstrates that his return on investment is sufficient.

The participant agrees with the environmental benefits, stating he has experienced first-hand how chemicals have altered the soil and their water as he and his family can no longer drink the borehole water on his farm.

Participant 2:

This participant adopted precision farming to save on input costs and to build a growing business. Learning and grasping the technology came easy for this participant in his early thirties, and he emphasises that the support given by the agents who sold him the machinery and technology was the main reason he did not experience this aspect as a barrier. The biggest challenge for this participant was the financial implications, and he thoroughly planned every step and every cent he spent. The initial cost of adoption was R3,700,000.00 and was also implemented in stages, and he saw an increase of 2 tonnes per hectare with his yield.

Talking about his perceived benefits, the participant says his yield and profit have increased, and he has years of data that he can refer back to when managing his decisions. He refers to his decision to adopt precision farming as an "i*nvestment*."

The environmental benefits this participant acknowledges are that the soil is healthier and is needed to sustain future generations. His experience with precision farming accumulates with successfully restoring sub-par soil to an exceptional level and attributes conservation practices and soil health to these milestones.

Participant 3:

Participant 3 had doubts as to when he adopted farming. According to him, he changed his mindset and some practices 19 years ago, managing his decisions to optimise his soil potential and actively altering his lime applications – but without the machinery and technology. 11 years ago, this participant began investing in precision farming machinery and technology and spent approximately R200,000.00 when implementation began in stages. At age 65, the most significant barrier he overcame was the technical support he needed with the machinery and technology, adding that he had to learn everything independently. He eventually received support from agriculturalists, and his yield increased, specifically on weak spots on his farm, as much as 3 tonnes per hectare.

Besides the yield increase, the participant saw a dramatic change in his soil health after the first season and argues this is an excellent aspect that he attributes to precision farming.

The environmental benefits of precision farming are not unnoticed by the participant, who states he tries to be as "*organic as possible*".

Participant 4:

When discussing the reason for adopting precision farming, the 53-year-old participant said he wanted to decrease his expensive input costs to become more profitable. Addressing the extensive technology and amounts of data, the participant acknowledges that it was his biggest challenge. The support he received from professionals was of help and was something he counted on throughout the process. The financial implications were also mentioned, as he spent R800,000.00 on his initial implementation, which was also done systematically.

Explaining his perceived benefits, the participant has increased his profit and fertilised his fields less. Focussing on areas with more potential, money is spent more wisely and has raised his yield by 2 tonnes per hectare after the second year.

The environmental benefits and implications of precision farming have been significant to the participant, as he thinks every farmer should "strive towards making an environmental difference."

Participant 5:

The participant states that he adopted precision farming to lower input costs and increase yield. In his 18 years of utilising precision farming, the 47-year-old participant has taught himself how to navigate technology and data management. He says he had pushback from his father when making the switch. Initially, the financial implications were around R300 000, but it has "*paid off*". Implementing precision on his farm was done systematically. While he used YouTube in later years to teach himself, he learned the ins and outs by himself and received support from agriculturalists.

His yield has increased by 1 tonne, and he attributes his success to "*rain makes grain*" and cost-saving management.

Reflecting on the environment and its importance, the participant explained that he has always been environmentally conscious and made responsible decisions before implementing precision farming.

Participant 6:

Explaining that his farm is in the far west of the maize triangle and experiences droughts, he adopted precision farming to focus on profitable fields and decrease the input on less profitable areas. In his late 30s, the participant stated he would seek support with the technology from other farmers and agents and experienced the costs of adopting precision farming as his biggest challenge. Implementing precision farming in small stages, the initial purchases of stands cost more than R18,000.00 each.

Acknowledging the yield differences in wet and dry years, he stated he has experienced a yield increase of 1.5 tonnes per hectare. This was because of "*a combination of many factors*" but partly due to precision farming.

As there are few rivers of natural water resources on or near his farm, the environmental benefits of less chemical runoff do not affect him personally. Still, the participant did state that it is a necessity.

Participant 7:

Managing drought and making better decisions is why this participant adopted precision farming. Aged 29, this participant utilised onsite training and videos to learn the technology and experienced it as an exciting challenge. The most significant barrier he faced was the financial obligation, which amounted to R500,000.00 to start initially.

With the help of agriculturalists, he increased his yield by 2 tonnes per hectare and stipulates that his soil is healthier and is being utilised "*just right*".

The participant has noted environmental changes such as mulching and moisture conservation but is not concerned with the ecological benefits.

Participant 8:

This participant is 37 years old and expressed his reasoning for adopting precision as a cost-saving measure to increase profit and yield. Convincing his father was the most significant barrier he experienced, implementing in "*small stages*". This amounted to more than R1,000,000.00 when purchasing three planters. He quickly learned how to manage the technology and machinery from YouTube and his neighbouring farmers. After implementation, he experienced another barrier: unskilled labour. As the technology advanced, which he understood, obtaining labourers who could understand and manage the technology, machinery, and data was challenging. He has relied on agriculturalists to manage his data.

He has experienced the benefits of an increased yield of 1 tonne per hectare after his first year and expressed that getting his soil healthier and seeing that transition took four years.

Being environmentally conscious is the "*concept of precision farming*". Actively focussing on organic practices and avoiding excess chemicals is vital to the participant and results in better yields.

Participant 9:

Transitioning to precision farming would be more financially profitable in the long run than continuing with traditional methods, which was the main reason this participant gave for adopting precision farming. He aimed to increase profit while decreasing inputs and weighed these potential benefits before deciding. The most significant barrier was convincing his father, and he expressed that the financial obligations did affect his decision. He systematically purchased the technology and machinery in 2002, initially costing R200,000.00. The support was little; he relied on other farmers and the internet to create his personal manuals. Understanding the technology was "*not easy*", and he relied on professionals to assist him with the data management.

He has "*definitely*" been making more money since the adoption, and even in dry seasons, yield increased by 0.5 tonnes per hectare.

The 49-year-old participant wishes his father and grandfather had access to precision farming technology when farming, as farming results in healthier soil. He states that if he does not look after his soil, his children will not be able to benefit from it.

Participant 10:

The participant is 56 years old and stated his reason for adopting precision farming was cost saving. His most significant barrier was the financial implications, resulting in an initial cost of R400,000.00. He learned to navigate the technology and machinery, which was "*very difficult*", and relied on agriculturalists to manage his data.

An increase of 1 tonne per hectare was achieved after the transition, which increased even further to 2 tonnes per hectare. He states that every cent is spent in the right place.

Looking after the environment for future generations is essential for the participant.

Participant 11:

The participant, who is 40 years old, implemented precision farming to cut costs and increase his yield, stating that he saw where his weak spot on the fields was and wanted to address and correct them. Convincing his father of the benefits of precision farming was his biggest challenge, and he noted the financial implications were significant, spending at least R500,000 to adopt the technology systematically. Agents supported him when he needed it, but mostly, he learned the technology and machinery himself.

He believes he is on the right track, seeing a fast yield increase of 1 tonne per hectare. Increasing potential to its optimal level is an enormous benefit; he knows which areas do not need as much input.

Not having to fertilise as much is seen as an environmental benefit for the participant.

Participant 12:

The participant is 47 years old and saw yield differentiation in his fields and wanted to address the differences with precision farming. The machinery was expensive, resulting in purchases of R1 million when he adopted precision farming initially. He learned all the aspects independently and delegated the data management to professionals.

Saving money on inputs and being profitable are the two main benefits experienced by the participant. The increase was seen across all the farm fields in terms of yield, and especially financially on the bottom line.

According to the participant, his fertilising has not diminished, but the environment is essential to him.

Participant 13:

Aged 36, this participant says his main reason for adopting precision farming is as follows: "*If you give 110% to 1 hectare, your yield will be better than giving 90% to 2 hectares*." He adds that you have to use his soil at an optimal level. Understanding the technology was a significant barrier for the participant, and he had to change his mindset to purchase the technology, accept it, and experience the return on investment. This investment was more than R1,3 million. He attended information events on precision farming technology and relied on IT professionals and agriculturalists to manage his data.

The benefits the participant experienced were a 20–25% yield increase and better overall management of his farm.

Speaking about the environment, he stated that his soil is healthier and that using the right product in the right place benefits all.

Participant 14:

The participant is 38 years old and explained that he adopted precision farming to manage the products on his farm effectively. The cost of the adoption, initially more than R580,000, was the most significant barrier he experienced, but he admits he also experienced pushback from his father. He taught himself how to use the technology with YouTube and reading manuals and received some support from the sales agents of the machinery. As an experienced computer user, it was not difficult to use the technology, and he had "*searched for the most versatile technology*" to use.

On a flat rate base, he saw he was making more money and increasing his yield and experienced the benefits of not being wasteful with products and being efficient.

The environmental benefits are not the participant's main focus, as he concentrates on his cultivation practices to conserve the soil.

4.2.4 Process of Data Reduction

Data reduction is the process of reducing quotes and answers into smaller, more comprehensible aspects to form patterns and themes. Annexure D demonstrates the data reduction of this study.

4.3 RESPONSES OF PARTICIPANTS AND THEMATIC ANALYSIS

During the data collection phase, the participants explained their motivations for adopting precision farming, how they experienced the perceived benefits, and their most significant perceived barriers. Using thematic analysis, the data was grouped into themes and subthemes to explore the implementation of precision farming in the maize triangle of South Africa. With data reduction, the thematic analysis is showed in Annexure D.

The results of the interviews and the research question, four main themes were identified:

1. Motivating factors for adoption
2. Significant barriers to implementation
3. Perceived benefits of precision farming
4. Technology and data management

Sub-themes were identified from these themes and illustrated below in Figure 4.6.

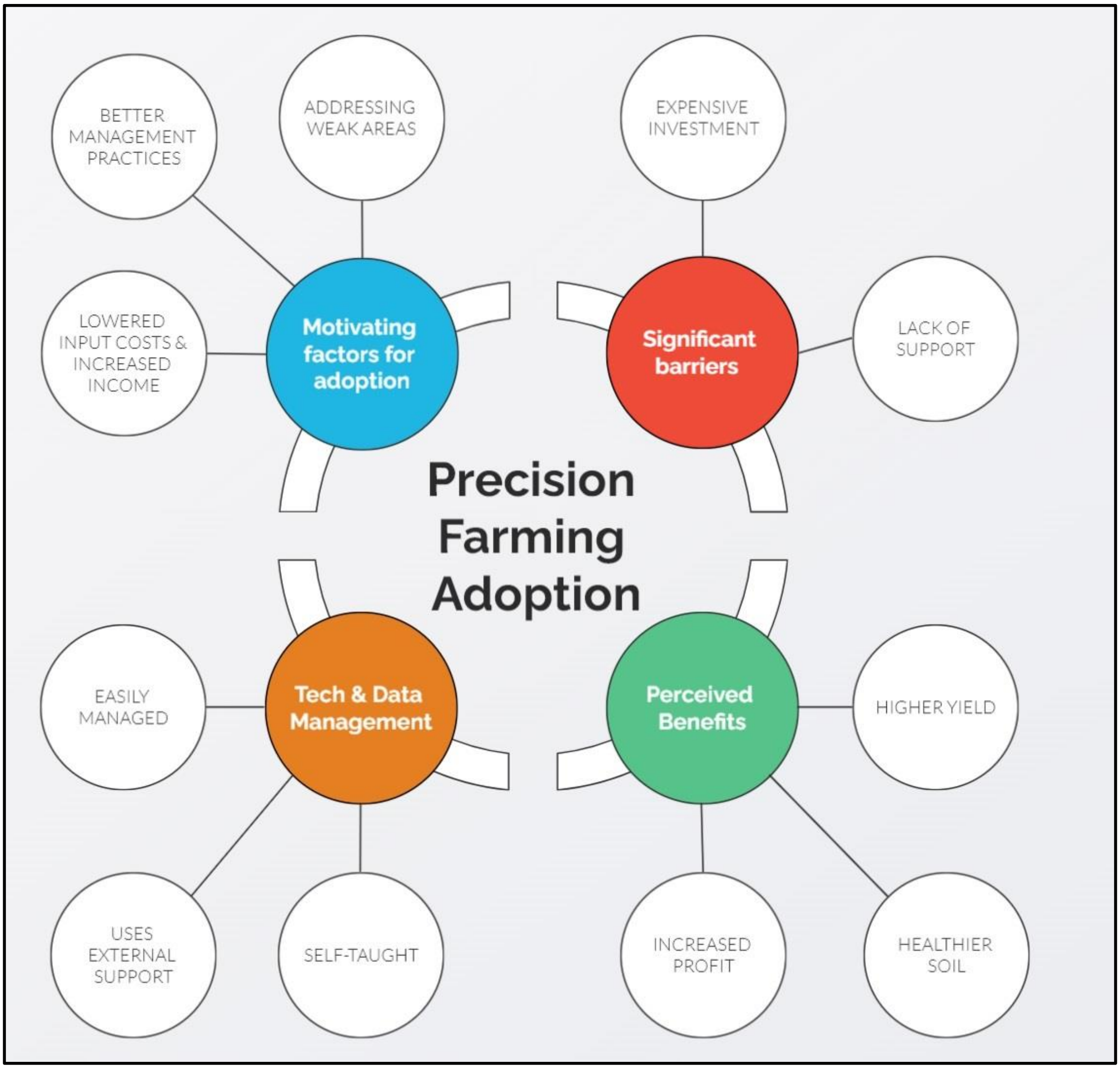

Figure 4-6: Themes & Sub-themes of the Data

4.3.1 Motivation for Adopting Precision Farming.

Considering the thematic analysis, the motivation for adopting precision analysis is mainly to lower input costs and increase their yield. Cost-saving measures to increase profit were found to be the primary motivation.

Acknowledging that better management practices are needed to make their farms more profitable is another motivation for adopting precision farming in the maize triangle. These management practices impacted how fertilisation and risk management were approached. Efficiency increased after making these changes.

Addressing weak areas on their farms, seen in yield differences, or observed by the farmer himself, is the third motivating factor for adopting precision farming. Precision farming uses grid-work to address these areas, so prescriptions and recommendations are made to address them to their optimum.

4.3.2 Significant Barriers

Ranging from R18,000.00 for simple add-on technology to existing machinery to expenses exceeding R3,000,000.00, the expensive nature of implementing precision farming is often acknowledged as the most significant barrier. Each farmer has stated that the money spent was worth it.

Resistance from older generations and lack of support from agents were also identified as a challenge for the farmers, forcing the farmers to seek assistance from neighbours and agriculturalists. As farm workers also need to understand the new technology, the farmers felt unsupported in all aspects.

4.3.3 Perceived Benefits

All the participants experienced a yield increase after the first or the second season. Figure 4.7 below shows the increased yield of 11 of the participants. Three participants acknowledged a yield increase, with percentages ranging from 20–35%.

Tying in with the increased yield, all participants experienced an increased profit, even with the added expense of grid sampling and the use of agriculturalists.

The farmers stated they now have healthier soil, experiencing the environmental benefits of precision farming. Healthier soil equates to more nutritious crops and better yields. It is essential to mention that most farmers acknowledge that they must keep the soil healthy for the well-being of future generations.

4.3.4 Technology & Data Management

Managing the technology is relatively easy for the farmers, and most of them rely on external professionals – such as agriculturalists – to collect and manage the data. Farmers managing their data are self-taught.

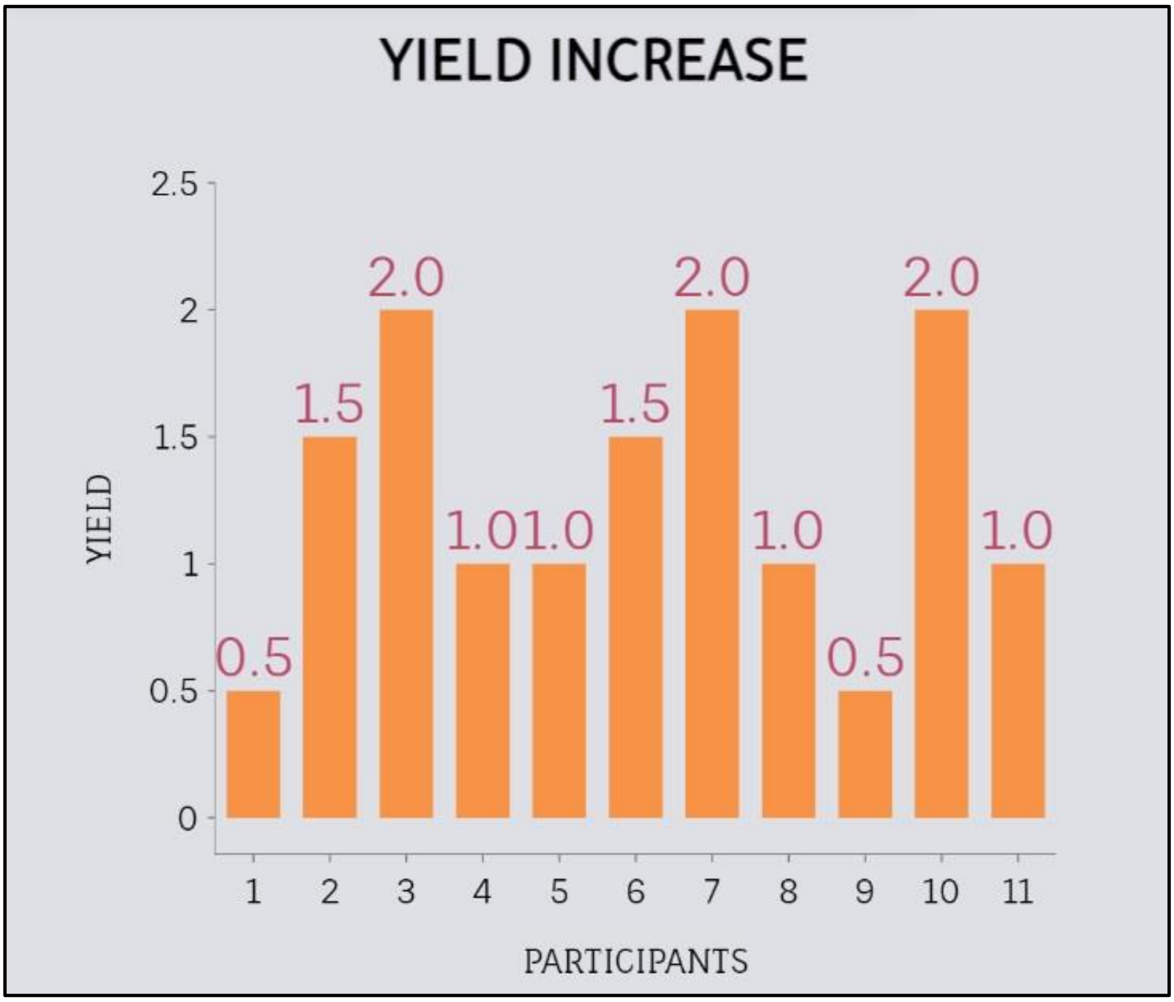

Figure 4-7: Yield Increase after Precision Farming Adoption

4.4 SUMMARY & CONCLUSION

This chapter explored the results of the data that was gathered via interviews. The participants' demographic profile demonstrated that while the literature states that educational background plays a significant role in adopting precision farming (Schimmelpfenning & Ebel, 2016:98), the farmers who adopted precision farming at a young age did not further pursue their studies. The older farmers with more education adopted precision farming at an older age. As discussed in Chapter 2, farmers older than

45 years are less likely to adopt precision farming (Jacobs *et al*., 2018:110), and this is seen as one of the significant barriers that these farmers experienced with their fathers.

The most significant barrier that the farmers experienced was the costs. The precise costs are uncertain as most precision farmers adopt precision farming sequentially (Schimmelpfenning & Ebel, 2016:97). Sequential adoption was evident throughout the information provided by the participants. Added costs of the use of agriculturalists, professionals for data management, and grid sampling estimate the costs associated with the help of precision farming problematic to calculate.

The benefits that the farmers experience coincide with the literature. Chapter 2 described the agronomic, technical, environmental, and economic benefits of precision farming. The results from the interviews demonstrate that precision farming improves soil (Ahmad & Dar, 2020:123), improves management decisions with the available data (Bruce, 2017:34), chemical input is lessened (Ahmad & Dar, 2020:124), and input costs are reduced (Bruce, 2017:4).

As farmers become more skilled in using and understanding technology, the intense technology barrier associated with precision farming has become less evident. All participants, except one, acknowledged that it was challenging but did not vocalise that the technology was a significant barrier. The “older farmers” are also being phased out, and when that generation is replaced, pushback because of the unfamiliarity of the technology will dissipate.

The following and final chapter will discuss the conclusions, recommendations, and possible future fields of study to expand on the topic.

CHAPTER 5

5. CONCLUSIONS & RECOMMENDATION

5.1 INTRODUCTION

This chapter will discuss interpretations from the results expressed in Chapter 4 and establish whether or not the objectives illustrated in Chapter 1 were achieved. Conclusions from the interpretations will be examined, and the chapter will also discuss the limitations of this study. Building from these limitations, possible future research areas will be explored.

5.2 CONCLUSIONS REGARDING RESEARCH OBJECTIVES

As discussed in Chapter 1, this study focuses on exploring the adoption of precision farming in the maize triangle. The various secondary objectives of the study that stem from the aforementioned primary objective will also be discussed below.

5.2.1 Primary Objective

The primary objective of this study is to explore the process whereby farmers adopt precision farming in the maize triangle of South Africa. As discussed in Chapter 2, research has been done on the benefits and barriers of implementing precision farming, as well as demographic factors that affect the decision to adopt precision farming.

The following aspects demonstrate to which degree the objective was met:

- The empirical research shows that adopting precision farming in the maize triangle starts with motivating factors that overwhelmingly consist of lowering input costs. With the known financial implications of the adoption, farmers are willing to risk the capital to lower input to reduce the future.
- The cost of adopting precision farming varies and is high, and due to sequential implementation and ongoing expenses, the cost grows over time.
- Farmers in the maize triangle learned the technology independently, sought assistance when needed, and relied specifically on agriculturalists to manage their data.

Farmers in the maize triangle seek solutions to lower input costs and are willing to learn and master new technology to become more profitable. Investing in technology to ease their inputs and increase outputs is a proven way to ensure a return on investment. As discussed in Chapter 2, South African farmers struggle financially due to the cost-income plier effect. Coleman (2016) stipulated that the relationship between input and output costs influences their profits and ability to increase production.

5.2.2 Secondary Objectives

Establishing the abovementioned primary objective, the researcher could determine why precision farming was implemented, the effects of the costs, and how the technology and data are managed.

The following aspects demonstrate if the objective was met:

- The benefits of precision farming experienced by the participants match what is regarded as advantages theoretically: the participants experienced increased yield and profit and healthier soil. Most of them also reported having large amounts of data from previous years to make more informed decisions. While the literature tends to focus on the intense technology, most participants stated their most significant barrier was the costs and experienced the technology as a challenge.
- The cost of precision farming adoption is sequential and rarely implemented in full.
- All participants experienced a yield increase per hectare after the initial adoption of precision farming. Many attribute this increase to precision farming while maintaining that environmental factors, such as rain and other management adjustments, also contributed to the increase.
- The motivations for adopting precision farming vary but can be grouped as decreasing input costs as the primary motivation.
- To sustainably implement precision farming, farmers need support navigating technology and professional assistance to interpret the data. Although the cost of implementation will increase, utilising these services will guide farmers to make more informed decisions on their farms.

These objectives were accomplished and were used to make recommendations that will be discussed below.

5.3 RECOMMENDATIONS

This section will focus on how agricultural companies could strategically assist farmers in adopting and implementing precision farming. These recommendations also illustrate potential management strategies the farmers could implement to overcome the significant barriers independently.

As with the delimitations discussed in Chapter 1, these recommendations could differ significantly if implemented in other areas with other crops. The following factors could be considered on management levels to contribute to the sustainable implementation of precision farming:

5.3.1 Agricultural Companies

- Strategy management for the farmers starts with the known benefits of adopting precision farming, shaping their motivation. Agricultural companies, such as risk mitigation companies or companies that sell machinery and technology, could increase awareness of the benefits. Backing their stance with data, more farmers in the maize triangle could become acquainted with the possible increased yield, reduced input costs, and healthier soil that precision farming adoption provides.
- Agricultural companies could allocate resources to specifically assist farmers with understanding the data collected with the precision farming technology. Most farmers stated they delegate the responsibility of interpreting the data to external companies and do not understand it themselves. Providing resources to guarantee farmers do not get discouraged about the amount of data or dissuade them from the continued implementation of precision farming.
- As the costs of acquiring the machinery and technology are high, many farmers are unwilling to risk the financial implications. Farmers need financial support, and agricultural companies or organisations could spearhead campaigns for additional financial support from the government. Alternatively, companies that sell the machinery and technology could provide financial assistance by allowing transitioning farmers to pay off the equipment over time or purchase it at discounted rates.
- If all types of technology could be synchronised across platforms, farmers would navigate the technology quickly, even if they are not actively struggling to

comprehend it. This synchronised aspect across various platforms would make the process smoother and improve the experience of adopting precision farming.

- Lastly, continued support, practical guidance, and consultations from knowledgeable companies in the agricultural sector would encourage farmers to adopt precision farming and remind them of their financial goals, yield increases, reduced input costs, and contribution to future generations.

5.3.2 Farmers

- Forming local support groups to encourage and motivate neighbouring farms to continue with precision farming and convince other farmers to adopt precision farming would be beneficial. Learning from farmers with experience and expertise could help when farmers are struggling with their technology, machinery, and data.
- It is recommended that farmers actively seek assistance from professionals such as agriculturalists and agents when purchasing machinery and contemplating grid sampling. Professional help from knowledgeable people to guide them and their farm to their optimal level would benefit the farmer financially and strategically.
- Lastly, precision farmers must research when choosing risk mitigation companies to provide grid sampling and prescription services. Independent agriculturalists with no hidden agenda when prescribing specific amounts of fertiliser have the farmer and their interests in mind and not a financial motive.

When considering these recommendations, the known barriers to adopting and implementing precision farming could be reduced. Increasing precision farmers would benefit the agricultural economy and improve food security, as outlined in Chapter 2.

The following section demonstrates the possible limitations of the study that could impact the results.

5.4 LIMITATIONS OF THE STUDY

The limitations of the study were isolated as much as possible, but some limitations should be acknowledged:

- **Geographic limitations**

  The size of the maize triangle in South Africa exceeds 2,000,000 hectares of maize farms. Interviewing 14 participants, while their locations were scattered across the maize triangle, limited the perceptions gathered.

- **Sample Size**

  As with the geographic limitations, the sample size of this study is small. Data saturation was reached and does give insight into the perceptions of precision farmers in the maize triangle, but it should not be generalised.

- **Time Constraints**

  The time allocated to reach participants and gather data impacted the number of participants that could be interviewed. Having more time could have resulted in a larger sample size across a larger area of the maize triangle.

5.5 SUGGESTIONS FOR FURTHER RESEARCH

After completing this study, a few suggestions could be made to further the research in precision farming in the maize triangle and the whole of South Africa. Further aspects of the possible research should be considered:

- This research should be expanded to other crops on irrigation and dryland farms. While it is not anticipated that extreme differences would occur on farms that grow other crops, it could provide insight into yield differences across various crops.

- Further research should be done on how the farmers financed the adoption of precision farming, whether from personal loans, grants, or other avenues. This could be valuable when discussing the financial costs of implementing precision farming.

- A study should be conducted on how the agriculturalists and sales agents of the technology assist and support the farmers while learning the technology and navigating the data and restructuring how the available support systems work could add strategic value to the companies and farmers.

- Lastly, a comparative study should be done between traditional and precision farmers, comparing their yield, profits, and soil health. The value lies in demonstrating the differences in yield, which could persuade conventional farmers to adopt precision farming.

5.6 SUMMARY

Precision farming technology will continue to be developed, pushing farmers further into Agriculture 4.0, as discussed in Chapter 2. Each new generation will become more tech-savvy than the previous, and the technology barrier will fade as autonomous farming becomes the norm. However, replicating and replacing farmers' knowledge and experience will be challenging. Utilising the advanced Agriculture 4.0 technology with precision farming, paired with their expertise, will allow farmers to make faster and more accurate decisions to contribute to food security.

Exploring how precision farming is adopted and implemented is vital to establishing motivations, perceived benefits, and defeating barriers to increase food security while preserving the environment and being profitable. The research has shown that the barriers to adopting precision farming have changed over the years and differ from farmer to farmer but can be subjugated. Thus, it is predicted that the precision farming implementation will increase.

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ANNEXURE A: DATA COLLECTION TOOL

Semi-structured interviews were utilized; thus, no instrument was used in this study. The primary focus was to explore the adoption of precision farming in the maize triangle in South Africa. Depending on how the participants respond to the interviews will create the themes and sub-themes needed to analyse the data, as illustrated in Chapter 4.

ANNEXURE B: INFORMED CONSENT

Exploring the adoption of precision farming in the maize triangle of South Africa

Introduction

You have been asked to participate in a study to investigate the adoption of precision farming technology in the maize triangle of South Africa. You have been chosen by non-probability, as you are a client of Agropedo Pty Ltd. It is necessary to read this document thoroughly to ensure that you understand why the research is being done and how you will participate. Your participation is voluntary, and if you choose to participate, your participation will not negatively impact you. You have the right to withdraw from participation at any time.

Purpose of the study

This study aims to examine why farmers in the maize triangle of South Africa have chosen precision farming. Previous studies have shown that the technology needed to practice precision farming is rigorous, the initial input costs are high, and the data associated with it is complicated, and because of this, prospective farmers shy away from precision farming. This study iis study aims to establish whether the perceived advantages of precision farming adoption outweigh the difficulties and how current farmers can potentially assist future farmers to overcomein the known obstacles. This study will be a mini-dissertation for the completion of the researcher’s MBA degree at North-West University.

The study procedure

This study will be done with in-depth semi-structured interviews. This interview will take about 15 minutes. This document will have been emailed to you to read and sign before the interview can take place. When this has been done, an interview can be arranged on a date that suits you as a participant. The interview will be recorded to be transcribed.

Risks

There are no expected risks when participating. Personal information, such as financial inputs and profits on your farm will be gathered to establish the validity of the disadvantages and advantages of implementing precision farming.

Advantage of participating

The data gathered could be useful for prospective precision farmers when doubting their ability to comprehend the technology of precision farming, the costs associated with it, as well the potential profit increases.

Confidentiality

This study is anonymous. Your identity or the information you provide will not be known to anyone except for the researcher, the research supervisor, and the transcriber. After the study, the recordings will be deleted.

Payment

There is no payment associated with participation in this study and is voluntary.

Right to withdraw

As a voluntary participant, you have the right to withdraw at any time with no consequences. You will have the right to request that none of the data obtained is used if you so wish.

Questions and doubts

You have the right to ask for clarification on the research, research questions or any questions you might have about the procedure. You can reach the researcher, Rouxet Buitendag, by telephone on 082 070 7502 or by email at 23292873@mynwu.ac.za anytime.

Consent by participant:

Your signature below indicates that you are participating willingly and have read and understood the information provided above, stated in an easily understood manner. You know you have the right to withdraw at any time without consequence and ask any questions before, during and after the interview. A copy of this informed consent will be given to you.

ANNEXURE C: ETHICS APPROVAL

NWU®
NORTH-WEST UNIVERSITY
NOORDWES-UNIVERSITEIT
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Private Bag X1290, Potchefstroom
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Tel: 018 299-1111/2222
Fax: 018 299-4910
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Senate Committee for Research Ethics
Tel: 018 299-484
Feziwe.Mseleni@nwu.ac.za

31 March 2023

ETHICS APPROVAL LETTER OF STUDY

Based on approval by the **Economic and Management Sciences Research Ethics Committee (EMS-REC)** on 31/03/2023, the Economic and Management Sciences Research Ethics Committee hereby **approves** your study as indicated below. This implies that the North-West University Senate Committee for Research Ethics (NWU-REC) grants its permission that, provided the special conditions specified below are met and pending any other authorisation that may be necessary, the study may be initiated, using the ethics number below.

Study title: Exploring the adoption of precision farming in the maize triangle of South Africa

Study Leader/Supervisor (Principal Investigator)/Researcher: Prof C Bisschoff – MBA
Student: Buitendag, R (23292873)

N	W	U	-	0	0	5	8	7	-	2	3	-	A	4
Institution				Study Number						Year			Status	

Status: S = Submission; R = Re-Submission; P = Provisional Authorisation; A = Authorisation

Application Type:
Commencement date: 1/4/2023 **Risk:** Low
Expiry date: 1/5/2024
Approval of the study is initially provided for a year, after which continuation of the study is dependent on receipt and review of the annual (or as otherwise stipulated) monitoring report and the concomitant issuing of a letter of continuation.

Special in process conditions of the research for approval (if applicable):

-

General conditions:

While this ethics approval is subject to all declarations, undertakings and agreements incorporated and signed in the application form, the following general terms and conditions will apply:

- *The study leader/supervisor (principle investigator)/researcher must report in the prescribed format to the EMS-REC:*
  - *annually (or as otherwise requested) on the monitoring of the study, whereby a letter of continuation will be provided, and upon completion of the study; and*
  - *without any delay in case of any adverse event or incident (or any matter that interrupts sound ethical principles) during the course of the study.*
- *The approval applies strictly to the proposal as stipulated in the application form. Should any amendments to the proposal be deemed necessary during the course of the study, the study leader/researcher must apply for approval of these amendments at the EMS-REC, prior to implementation. Should there be any deviations from the study proposal without the necessary approval of such amendments, the ethics approval is immediately and automatically forfeited.*

1

- *Annually a number of studies may be randomly selected for an external audit.*
- *The date of approval indicates the first date that the study may be started.*

n the interest of ethical responsibility, the NWU-SCRE and EMS-REC reserves the right to:

- *request access to any information or data at any time during the course or after completion of the study;*
- *to ask further questions, seek additional information, require further modification or monitor the conduct of your research or the informed consent process;*
- *withdraw or postpone approval if:*
  - *any unethical principles or practices of the study are revealed or suspected;*
  - *it becomes apparent that any relevant information was withheld from the EMS-REC or that information has been false or misrepresented;*
  - *submission of the annual (or otherwise stipulated) monitoring report, the required amendments, or reporting of adverse events or incidents was not done in a timely manner and accurately; and / or*
  - *new institutional rules, national legislation or international conventions deem it necessary.*

The EMS-REC would like to remain at your service as scientist and researcher, and wishes you well with your study. Please do not hesitate to contact the EMS-REC or the NWU-SCRE for any further enquiries or requests for assistance.

Yours sincerely,

Mark Rathbone

Digitally signed by Mark Rathbone
DN: cn=Mark Rathbone, o=North-West University, ou=Business management, email=mark.rathbone@nwu.ac.za, c=ZA
Date: 2023.04.12 13:41:47 +02'00'

Prof Mark Rathbone
Chairperson: NWU Economic and Management Sciences Research Ethics Committee

ANNEXURE D: DATA REDUCTION & THEMATIC ANALYSIS

Question 1: What was the main reason for implementing precision farming?			
Participant	Quotes	Coding	Theme
1	"Yield differences were seen in areas where crops were growing better than others".	Yield differences. Weaker areas.	Addressing weaker areas.
8	"I wanted to increase my yield by addressing the weaker areas."	Weaker areas.	
7	"Because of the drought you need to manage better, and you can do that with precision farming."	Management of weaker areas.	
16	"The drought can bite us, so not all the soil is profitable. We try to cut it out with precision farming, better fertilization, and to minimize risk."	Weaker areas.	
13	"Manage the weaker areas, and the use of the data to make comparisons and correct them."	Weaker areas. .	
1	"Soil differences and types that contribute to the potential of the yield."	Potential.	Better management practices
7	"Because of the drought you need to manage better, and you can do that with precision farming."	Drought management.	
16	"The drought can bite us, so not all the soil is profitable. We try to cut it out	Drought. Fertilization.	

	with precision farming, better fertilization, and to minimize risk.”	Minimize Risk.	Better management practices
10	“To manage the efficiency of the product better.”	Efficiency. Better management.	
13	“Manage the weaker areas, and the use of the data to make comparisons and correct them.”	Use data	
14	“For efficiency.”	Efficiency.	
14	“To get the maximum potential.”	Maximum potential.	
5	“You get an optimal yield because the input is not as high.”	Reduced input costs. Optimal yield.	Lowered input costs & increased income
9	“The input costs of today are high, and you need to farm for a profit.”	Expensive inputs. Profitable farming.	
4	“My income was too low.”	Higher profit.	
4	“The capital I spent was on precision farming I gained back.”	Less input costs.	
8	“I wanted to increase my yield by addressing the weaker areas.”	Higher Yield.	

8	"To save on costs."	Save on costs.	Lowered input costs & increased income
11	"The saving that it brings to the farm, the yield increase, and the profit."	Saving. Profit. Yield.	
13	"Saving on costs."	Save on costs.	
3	"Save on costs."	Save on costs.	
3	"To create a raiseable business for myself."	Increase profit.	
2	"To minimize costs and increase yield."	Reduce costs. Increase yield.	
12	"Savings."	Saving.	
12	"Reduced input costs."	Reduce input costs.	

Question 2: What was the biggest obstacle when implementing precision farming?			
Participant	Quotes	Coding	Theme
1	"Expensive equipment"	Costs.	Expensive investment.
9	"Very big capital expenditure."	Capital	
4	"The capital."	Capital.	
8	"Very expensive"	Expensive.	

7	“Very expensive.”	Expensive.	Expensive investment.
7	“Machinery is expensive.”	Expensive.	
16	“The costs.”	Costs.	
10	“Costs.”	Costs.	
13	“Costs.”	Costs.	
3	“The finances.”	Finances.	
2	“Expensive.”	Expensive.	
14	“The machinery is expensive.”	Expensive.	
12	“The capital investment.”	Capital.	
5	“To understand the technology.”	Technology.	Lack of support.
5	“Needed more intelligent workers.”	Needs.	
9	“Scared of the technology.”	Technology.	
4.	“Unsupportive older generation.”	Support.	
8	“To understand the technology”	Technology.	
8	“Inadequate support.”	Support.	
10	“My father.”	Support.	
11	“My father.”	Support.	
11	“Unskilled labour.”	Needs.	
13	“My father.”	Support.	
2	“My father.”	Support.	

Question 3: What were the initial costs to implement precision farming?			
Participant	Quotes	Coding	Theme
4	“R200 000.”	R200 000	R200 000
8	“R200 000.”	R200 000	R200 000
2	“R300 000.”	R300 000	R300 000
12	“R400 000.”	R400 000	R400 000
10	“R450 000.”	R450 000	R450 000
14	“R450 000.”	R450 000	R450 000
13	“R500 000.”	R500 000	R500 000
9	“R800 000.”	R800 000	R800 000
11	“R1 000 000.”	R1 000 000	R1 000 000
1	“R1 000 000”	R1 000 000	R1 000 000
5	“R1 300 000.”	R1 300 000.	R1 300 000.
3	“R3 700 000.”	R3 700 000	R3 700 000
3	“I plan everything out exactly.”	All in in	Immediate implementation
1	“I went all in.”	All in in	
5	“I implemented systematically.”	Systematically	Sequential implementation
9	“I got the basic stuff.”	Basic	
4	“Systematic implementation.”	Systematically	
8	“In phases.”	Phases	
16	“I got a combination of everything.”	Combination	
10	“I purchased the basic minimum.”	Minimum	

11	"I started small."	Small	Sequential implementation
11	"I saw it was working and decided to switch over all my machines."	Switched over	
2	"It was a start."	A start	
12	"I invested more afterwards."	Invested more	
14	"It was an initial investment."	Investment	
8	"Worth every sent."	Worth it	The costs were an investment.
7	"There were a lot of expenses, including technology and training, but it worked out well."	Expensive	
3	"I see this as an investment."	Investment	
14	"The return is good."	Return on investment	

Question 4 : What training did you receive to comprehend the technology, machinery, and data?			
Participant	Quotes	Coding	Theme
1	"I learned on the go."	On the go.	Self-taught
1	"I learned a lot on my own."	On my own.	
1	"You hear it and you implement it yourself."	Implement it yourself.	
5	"Learned as you went along."	As you went along.	
4	"None – we were the guinea pigs."	No training.	
4	"No training was given."	No training.	
8	"Trial and error."	Self	

7	“On-site training.”	Self	Self-taught
16	“I taught myself.”	Myself.	
11	“I taught myself.”	Self	
11	“YouTube was a big help.”	External assistance.	
11	“I used videos.”	External assistance.	
13	“I taught myself.”	Myself	
3	“It was like climbing stairs.”	Self	
2	“I taught myself.”	Self	
12	“I taught myself.”	Self	
2	“YouTube.”	External assistance.	
5	“Social media.”	External assistance.	
5	“Information days.”	Events.	
5	“Asked others in the industry.”	Industry professionals	Agricultural professionals.
9	“Sales and installation people were helpful.”	Agents	
9	“Initially the training was good.”	Adequate training.	
9	“People were willing to train you.”	Adequate training.	
7	“Agents trained us.”	Agents.	
16	“Other farmers were helpful.”	Farmers.	
11	“Agriculturalists.”	Agriculturalists	
13	“Knowledgeable people gave assistance.”	Knowledgeable people.	

3	"Training was given when you bought the machinery."	Agents.	Agricultural professionals
2	"I relied on representatives."	Representatives.	
14	"Agents."	Agents.	
14	"Some programmes came with training."	Some training.	
4	"The trainers were also busy learning."	Trainers were too busy.	
8	"Some of the machinery didn't even work."	No support.	Inadequate training
8	"There was no help from the outside."	No training.	
8	"Assistance was never fast enough."	Slow response.	
1	"Unreliable technical teams."	Unreliable people.t	

Question 5: What support systems were used to understand the technology, machinery, and data?			
Participant	Quotes	Coding	Theme
1	"Over the phone with agents."	Agents	Agents/Professionals
5	"I relied on specialists."	Professionals	
9	"Mostly over the phone, I talked to a lot of agents."	Agents	
7	"Over the phone."	Agents	
16	"I sought advice from agents."	Agents	

10	“Agents.”	Agents	Agents/Professionals
11	“Agriculturalists.”	Professionals	
11	“Agents.”	Agents	
13	“The agents were helpful.”	Agents	
3	“Agents supported us.”	Agents	
14	“Agents.”	Agents	
14	“Agriculturalists.”	Professionals	
12	“Agriculturalists.”	Professionals	
4	“The internet.”	Self/Other sources	Self/Other sources
7	“I watched videos.”	Self/Other sources	
2	“None.”	No support	No support
4	“None.”	No support	
8	“No support.”.	No support	

Questions 6 & 7: How difficult was it to overcome the intensity of the technology, and manage the data and technology?			
Participant	Quotes	Coding	Theme
1	"The GIS departments of companies handle the data."	Data management is outsourced.	Has professional assistance.
1	"Professionals are always willing to help with the machinery and technology."	Professionals manage the machinery and technology.	
5	"Professionals helped me with to manage."	Professional management.	
4	"I leave everything to the experts."	Experts managed it.	
8	"I can rely on agriculturalists now."	Management by agriculturalists.	
11	"I don't manage it, I let the agriculturalists do it."	Agriculturalists.	
4	"It wasn't too difficult, but it wasn't easy."	Overcame it with ease.	Not difficult.
4	"It was a challenge, but I wouldn't say it was difficult."	Overcame it with ease.	
7	"It wasn't really difficult."	Not difficult	
7	"I sought help when needed."	Sought help.	
16	"Learning the technology was okay, it wasn't a problem."	Not a problem.	
16	"Managing the data was okay."	Okay.	
10	"It was relatively easy."	Relatively easy.	

13	"No, it wasn't a problem."	Not a problem.	Not difficult.
13	"It wasn't difficult."	Not difficult.	
3	"After I made a head shift, everything became easier."	Became easier.	
14	"It isn't very complex."	Not very complex.	
8	"I did everything on my own because the response was slow."	Slow response.	Difficult.
2	"I learned as the technology and data changed."	Learned.	
12	"Very difficult – but I managed."	Difficult.	

Question 8: Do you feel precision farming, not traditional or other farming methods, has made your farm more profitable?			
Participant	Response/Quotes	Coding	Theme
1	"Yes."	Profitable	Increased profitability
5	"Yes."	Profitable	
4	"Yes."	Profitable	
8	"Yes."	Profitable	
7	"Yes."	Profitable	
9	"Yes."	Profitable	
10	"Yes."	Profitable	
11	"Yes."	Profitable	
13	"Yes."	Profitable	

3	"Yes."	Profitable	Increased profitability
2	"Yes."	Profitable	
14	"Yes."	Profitable	
12	"Yes."	Profitable	
14	"There's more efficiency and the soil is healthier, and the rain plays a part."	Rain.	Rain is a variable
16	"Of course, the rain counts."	Rain.	
1	"The rain is also a factor."	Rain is a factor	
2	"Grain makes rain."	Rain.	
1	"The yield has increased, and I am saving money."	Cost saving	Other financial changes
9	"The cost allocation is better."	Cost allocation.	
10	"Improvement of income and efficiency."	Increased income.	
16	"I see a lot of changes, yes."	Changes.	
13	"The increased yield means more money."	More money.	
9	"Fertilizer isn't wasted."	Better fertilisation management.	Effective management
3	"The data I have now is a lot."	Lots of data.	
3	"The management is better."	Better management	

Question 9: How long was it before you saw an increase in yield? How much was the increase?			
Participant	Quotes	Coding	Theme
1	"The overall average increased…"	Increase in average	An increase was observed.
5	"Yield increased by 20 – 25% per cent."	Increase in yield.	
10	"The flat rate increased."	Increased flat rate	
4	"…it increased by half a tonne."	Half a ton	0.5 tonne
13	"…half a tonne, but it was a wet year."	Half a tonne	0.5 tonne
14	"About half a tonne."	Half a tonne.	0.5 tonne
16	"…but the increase was one tonne."	One tonne.	1 tonne.
11	"…one tonne per hectare."	One tonne	1 tonne.
2	"One tonne."	One tonne.	1 tonne
9	"One tonne…"	One tonne.	1 tonne
8	"…by one and a half tonnes."	One and a half tonnes.	1.5 tonnes
7	"Two tonnes."	Two tonnes.	2 tonnes.
3	"Two tonnes."	Two tonnes	2 tonnes
12	"…it was by two tonnes."	Two tonnes.	2 tonnes.
4	"Within the first year…"	In the first year.	Within 1 year
8	"It was by the first season…"	By the first season	
16	"It was a dry year…"	Dry year	

11	“The first year there was an increase…”	First year	Within 1 year
13	“In the first season there was an increase…”	First season	
1	“…within two seasons.”	Within two seasons	Within 2 years
12	“The second year…”	Second year	
9	“…in the year two.”	Year two.	

Question 10: How significant are the environmental effects of using precision farming management to you?			
Participant	Quotes	Coding	Theme
1	“It is important.”	Important	The effects are significant
5	“Yes, it is important.”	Important	
9	“Very important.”	Important	
4	“It is obviously very important.”	Important	
8	“Important.”	Important	
16	“It is important that the soil is taken care of.”	Important	
11	“It is very, very important.”	Important	
13	“It is important.”	Important	
3	“Important.”	Important	
2	“Very important.”	Important	
14	“Yes, it is important to me.”	Important	

12	"Very important."	Important	The effects are significant
10	"It is somewhat important."	Somewhat important.	Not significant
7	"Not really."	Not important.	
9	"We must strive to look after the environment and make a difference for the next generation."	The next generation	Preservation for the next generation.
3	"It is important for the future generations."	Future generations	
4	"Our soil is for the future."	The future	
2	"It is our responsibility."	Responsibility	
12	"The future generations need it."	Future generations	
8	"I want to farm organically as much as possible."	Organic farming	Healthier soil is achieved.
16	"I want to keep my soil healthy."	Healthy soil	
5	"The soil is healthier."	Healthier soil	
13	"It is necessary to not over-fertilise."	Not over-fertilise	
11	"It is the main concept of precision farming."	Main concept of precision farming	It is part of precision farming.
14	"It is why precision farming is important to me."	Precision farming	
1	"But it doesn't motivate me."	Is not a motivating factor	The environment is
7	"I know it has it's advantages, but it doesn't bother me."	Doesn't bother me	

10	"The environment is not my main focus."	Not my main focus	not a motivating factor