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Exploring the use of Unmanned Aerial Vehicles (UAVs) to reduce production loss on farms in South Africa.

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A research report submitted to the Faculty of Commerce, Law and Management, University of the Witwatersrand, in partial fulfilment of the requirements for the degree of Master of Management in the field of Digital Business

Johannesburg, 2023

DECLARATION

I, Mukandangalwo Mukumela (Student number 0713768M), declare this research report, which I hereby submit for the degree of Master of Management in the field of Digital Business at the University of Witwatersrand, is my own work and has not previously been submitted by me for a degree at this or any other institution.

Signature **Date**

M. Mukumela

07 December 2023

DEDICATION

This research is dedicated to my parents, Takalani and Azwifaneli Mukumela. Thank you for your constant sacrifice and support throughout my life.

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I'd like to thank my Maker and Ancestors for guiding me through this journey and all the challenges I encountered along the way.

- My parents Azwifaneli and Takalani Mukumela for doing your absolute best to give my siblings and I the best possible upbringing and opportunities, regardless of how tough the circumstances. Thank you for instilling the importance of education in all of us from a young age.
- My siblings Azwi, Mavhungu and Thama. We're a unit and reliable support structure to each other.
- My children, Oratilwe and Mbilu. I do all of this for you.
- The three beautiful angels I gained during the process of completing this research. My aunts Gladys Mukumela and Kone Masenya and grandmother, Livhuwani Christinah Mukumela. We will always love you.
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- The seven participants who contributed their time and expertise which ensured that I can successfully contribute to the existing body of work. Thank you.

ABSTRACT

Production loss has been a longstanding hinderance to farmers that not only impacts the quality of harvest and quantity of yield but the profitability they are able to realize. The literature emphasizes the current state of agriculture in South Africa, the impact of production loss in the food production process, Unmanned Aerial Vehicles (UAVs) and the adoption of technology in agriculture whilst the study aims to explore the use of UAVs to reduce production loss on farms in South Africa.

Qualitative research was the chosen strategy, and seven research participants were interviewed through semi-structured interviews conducted online and field observations at a Forestry operation utilizing drones in Mpumalanga.

The findings of the study highlight that the adoption of UAVs has the potential to reduce production loss on farms in South Africa with participants expressing optimism in drone technology to address losses through a more data informed view of farms, enhanced efficiency, and improved on farm practices. Factors that are either driving or limiting adoption of drones have been identified for future agricultural stakeholders to consider.

The study's findings contribute to agriculture and modernization in the industry by helping researchers and stakeholders develop an understanding of the various uses of drones and their role in improved efficiency and increased productivity on farms. The managerial implications stemming from the study suggest that a focus should be put on small-scale farmers who sit at the bottom-end of the adoption curve, issues related affordability should be addressed through government incentives and subsidies which will help reduce the upfront costs of adopting drone technology, improve farmers skills and knowledge as farmers need education and training on the effective use of drones and the benefits of drones and promote entrepreneurship which will directly lead to new innovations in software and hardware, more affordable drones, and value creation for agricultural end-users of UAVs.

KEYWORDS

Drones, agriculture, adoption, technology, production loss.

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LIST OF ABBREVIATIONS

(ASC): Agricultural Supply Chain

(AI): Artificial Intelligence

(AUVSI): Association for Unmanned Vehicle Systems International

(DAFF): The Department of Agriculture, Forestry and Fisheries

(EU): European Union

(FAO): The Food and Agriculture Organization of the United Nations

(GDP): Gross Domestic Production

(FWL) Food Wastage and Loss

(GISs): Geographic Information Systems

(GPS): Global Positioning System

(ICTs): Information and communications technologies

(IDT): Innovation Diffusion Theory

(IoT): Internet of Things

(KZN): KwaZulu Natal

(Lidar): Light Detection and Ranging

(ML): Machine Learning

(NDVI): Normalized Difference Vegetation Index

(NGOs): Non-government organisations

(NIR): Near-infrared

(OECD): The Organisation for Economic Co-operation and Development

(PHL): Post-harvest loss

(RPL): Remote pilot’s licence

(PPPs): Public and private partnerships

(R&D): Research and development

(RDP): Reconstruction and Development Programme

(RPAS): Remotely Piloted Aircraft Systems

(RTK): Real-time kinematics

(RVs): Returnable values

(SASRI): The South African Sugarcane Research Institute

(SDGs): Sustainable Development Goals

(SSA): Sub-Saharan Africa

(SMEs): Small and medium-sized enterprises

(STI): Science, Technology, and Innovation

(TVWS): Television White Spaces

(UASs): Unmanned Aerial Systems

(UAVs): Unmanned Aerial Vehicles

(WWF): The World Wide Fund

CHAPTER 1. INTRODUCTION

Chapter outline:

The purpose of this chapter is to:

- Present production losses and impact on farms.
- Articulate the study's research questions.
- Emphasize the significance and delimitations of the study.
- Provide definition of terms and assumptions in the study.
- Outline the chapters that this thesis is comprised of.

1.1 BACKGROUND OF THE STUDY

Approximately 20% and 40% of global agricultural productivity is lost as result of pathogens, animals, and weeds (Oerke, 2006) and constitute the largest percentage share of losses to food producers. According to (Savary et al., 2012), safeguarding plants and protecting crops against plant diseases, have a clear role to play in addressing the increased demand for food quality and quantity. (Zheng et al., 2023) found that fragmentation limits farmers' access to machinery and new technologies and hinders the development of agricultural infrastructure such as irrigation and drainage, resulting in high agricultural costs. Manual crop inspection which is highly time-consuming and laborious has been identified as an inefficient (Li et al., 2022) is further exacerbated by the vastness of farms, making visual inspection for crop damage and disease impractical (Riedell & Blackmer, 1999). Section 2.4 will discuss production loss experienced by farmers in South Africa.

Inefficient practices on farms impact agricultural productivity and several studies have highlighted the importance of adopting agroecological practices, conservation agriculture, and sustainable farming techniques to address inefficiencies in agricultural production (Wezel et al., 2013). The importance of improved agricultural productivity is highlighted in the 2030 Agenda for

Sustainable Development, adopted by all United Nations Member States in 2015 which identified 17 Sustainable Development Goals (SDGs), which are an urgent call for action by all countries. Target 2.4 focuses on ensuring sustainable food production systems and implementing resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality (FAO, 2020). Section 2.3.2 of this research paper provides an overview of the state of technology and modernization on farms in South Africa and Section 2.5 speaks to UAV technology and its application in agriculture.

Although there is a growing realisation on the importance of science, technology and innovation (STI) in improving agriculture and ultimately food and nutrition security, the contribution to current literature to improved food and nutrition security in developing countries is relatively scant (Tinarwo & Uwizeyimana, 2019). This study explores Unmanned Aerial Vehicles and how they can contribute to reducing production loss on farms in South Africa.

1.2 RESEARCH PROBLEM

Pests and diseases management, soil health and water availability are amongst the biggest contributors to the quantity and quality of outputs in agriculture. Pest and diseases have always been among the critical factors that restrict the increase of production, causing substantial economic losses to agriculture (Gao et al., 2020). The quality and fertility of the soil can also affect crop growth and yield. Different crops have specific soil requirements, and farmers need to manage soil fertility through appropriate fertilization and soil management practices (Nkurunziza et al., 2020). With South Africa being a semi-arid region, access to irrigation is critical to farmers especially during dry seasons. The diseases occurring in the crop or plant leaves cannot be avoided, so detecting of these diseases plays a major role in agriculture. Different types of viruses, bacteria, fungi etc. are the main reasons causing crop diseases (Sravan et al., 2021).

Numerous advanced technologies such as Artificial Intelligence (AI), Machine Learning (ML), Internet of Things (IoT) are being implemented across the agricultural sector to address production loss. UAVs, which are in focus for this study, such as drones, and geographic information systems (GISs) are used to collect aerial imagery for mapping and monitoring damage on crops, crop yield or livestock location (Nel, 2016). However, research around the potential benefits of UAVs to South African farmers remains a gap that to be explored. Despite the multiple reports and case studies, evidence remains mixed (Tsan et al., 2019)

Furthermore, the South African agritech industry is yet to find ways to expand the opportunities unlocked by digitalisation of the sector to emerging and small-holder farmers, who constitute a majority of the South African sector (Aguera et al., 2020).

1.3 RESEARCH QUESTIONS

This research was directed by the following research questions:

I. What factors contribute to production loss and impact output yields on South African farms?
II. How can Unmanned Aerial Vehicles (UAVs) help South African farmers reduce production losses on their farms?
III. What are the factors that promote, limit or moderate adoption of UAVs on South African farms?

1.4 SIGNIFICANCE OF THE STUDY

This research aims to underpin the use of UAVs on farms in South Africa. This research also aims to provide a view into the state of innovation in the South African agricultural sector with a particular focus on the implementation of UAVs and their contribution to reducing production losses incurred on farms. The study contributes to the practice of drones by offering insights into the state of digitalisation on South African farms, postulating a clearer understanding of how innovative practices are leveraged in South African agriculture. This will better guide key stakeholders in crafting important decisions regarding the adoption of drone technology to address factors that contribute to production loss on farms.

1.5 DELIMITATIONS OF THE STUDY

The following factors should be taken into consideration when reviewing the delimitations of this study:

1. Data collection was limited to participants in South Africa.
2. The study was focused on the agricultural industry, overlooking the use of drones in other industries in South Africa.

1.6 DEFINITION OF TERMS

The key concepts in this study are **drones, agriculture, production loss and adoption.** The definitions of these key terms are provided below.

Drones, otherwise known as unmanned aerial vehicles (UAVs) are remote controlled aircraft with no human pilot on-board (Giacomo & David, 2018).

Agriculture is the most comprehensive word used to denote the many ways in which crop plants and domestic animals sustain the global human population by providing food and other products (Harris & Fuller, 2014).

Production losses are those that occur in the production process. The losses include agricultural residues (e.g. roots and straw), unharvested crops and the losses during harvest (Harris & Fuller, 2014)

Adoption refers to the process through which individuals or organizations accept and integrate a new technology into their existing practices and systems (Straub, 2017).

1.7 ASSUMPTIONS

This study is underpinned by a number of assumptions. It was assumed that:

- the participants were aware of tasks and activities required to carry out their responsibilities.
- the participants were able to verbally articulate their views and perceptions regarding UAVs, in their language of choice when necessary.
- the views expressed by the participants were sufficiently expressive of UAVs.
- the researcher was able to support the participants to express their views regarding UAVs.
- Qualitative research was the most practical method to explore participants' perceptions of UAVs.
- The sampling methods used were suitable for gaining participants' views relating to the UAVs.

1.8 CHAPTER OUTLINE

Chapter 1 of this proposal presents the topic of production loss on farms and outlines the research objectives of the study and proposed research questions. Implied assumptions and delimitations relating to the study are also reflected. This is followed by the definitions of key terms, as well as a list of assumptions in the study.

Chapter 2 provides an overview of state of the agricultural sector in South Africa followed by a discussion on production loss incurred by farmers and concludes with an account of UAVs, the IoT systems that make up the network of technology that add value to imagery captured by UAVs and the various uses of UAVs in agriculture.

Chapter 3 highlights the chosen research approach, design as well as the method of data collection employed. This is followed by a summary of the chosen sample and sampling methods to be employed. This chapter also presents an overview of the data analysis process and concluded with an account of ethical considerations to be taken into account throughout the study.

Chapter 4 provides a background of the study participants followed by an in-depth presentation of the emerging themes that were identified from analysing the data collected. The themes that were identified are; Factors contributing to production loss on South African farms, Ways in which drones can help reduce production loss, and Factors promoting, limiting or moderating adoption.

Chapter 5 presents the findings of the study which aim to answer the research questions. The report is concluded by a summary of the research conducted, conclusions and suggestions for future research.

CHAPTER 2. LITERATURE REVIEW

Chapter outline:

The purpose of this chapter is to:

- Provide an overview of the state of agriculture in South Africa.
- Highlight the impact of loss in the food production process.
- Discuss Unmanned Aerial Vehicles and related technologies.
- Outline the concept of adoption of agricultural technologies.
- Discuss the analytical framework that guided the researcher.

2.1 INTRODUCTION

As rising population growth, worsening economic conditions, climate change and more recently the global pandemic that is COVID-19 continue to put pressure on dwindling natural resources and food supply, how long can we continue to feed ourselves? The current model of an ever-increasing population relying on finite resources is clearly unsustainable and increases the importance of ensuring that we strive for “resource efficiency” within a “circular economy” (Mc Carthy et al., 2018).

The Department of Agriculture, Forestry and Fisheries (DAFF) is responsible for the development of agricultural policies and to manage support programmes to ensure that South Africans are able to produce their own food and reduce food insecurity (Maluleke, 2019).

This chapter provides an overview of the state of the agricultural sector in South Africa as well as insights on the impact of loss in the food production process. This is followed by an overview of UAVs and their various applications in agriculture and concluded by the concept of adoption of agricultural technologies.

2.2 BACKGROUND DISCUSSION

The 2030 Agenda for Sustainable Development, unanimously embraced by every United Nations Member State in 2015, provides a collective blueprint for promoting peace and prosperity for people and the planet, both presently and in the years to come. At its core are the 17 Sustainable Development Goals (SDGs), representing a call for action by all countries, developed and developing in a global partnership.

SDGs target 2.4 of ensuring sustainable food production systems and implementing resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality (FAO, 2020) are the areas of focus in this study.

(Deloitte, 2015) found that the amount of food lost each year due to post-harvest loss (PHL) is enough to feed the total number of undernourished people globally. In sub-Saharan Africa (SSA) alone, which unfortunately is home to over 230 million people suffering from chronic undernourishment, 30-50% of production is lost at various points along the value chain. Efforts to reduce PHL thus provide an attractive opportunity to improve food security across the globe, but especially in SSA.

Ward (2018) highlighted losses generated during primary (on-farm) production which can be broadly categorised as ‘practice-based’ and ‘market-based’. ‘Practice-based’ refers to direct loss generated during the operations of growing and harvesting the crops. ‘Market-based’, on the other hand, is loss that is generated because of external market events that influence production on the farm. For this study, ‘practice-based’ losses are in focus and looking at ways in which Unmanned Aerial Vehicles can help to reduce them.

2.3 THE STATE OF AGRICULTURE IN SOUTH AFRICA

South Africa stands as Africa's foremost industrialized and multifaceted economy, holding the position of the second-largest economy across the African continent, trailing only behind Nigeria. It boasts the highest GDP per capita on the continent, securing its status as an upper-middle-income nation (OECD, 2020). South Africa has the largest agricultural land on the African continent. As of 2020, the country's agricultural land amounted to over 96 million hectares, representing almost 80 percent of the total land area (Cowling, 2023). Although the country is ranked high against its continental counterparts when looking at GDP per capita and size of agricultural land, agriculture only contributed 2.43% to the GDP in 2021 (Stats SA, 2022), although this increased to 2.83% in 2022, it is low in contrast to other African countries. Figure 1 below from the World Bank provides a ranking of the top ten African countries by GDP share of agriculture. The average based on 44 countries where data was available was 16.6%, the highest value being Ethiopia at 37.6% and the lowest Libya at 1.6%.

Figure 1: Value added in the agricultural sector as percent of GDP, 2022 - Country rankings.

Countries ▲▾	GDP share of agriculture, 2022 ▲▾	Global rank ▲▾	Available data ▲▾
Ethiopia	37.64	1	1981 - 2022
Mali	36.42	2	1967 - 2022
Comoros	36.41	3	1980 - 2022
Liberia	36.19	4	2000 - 2022
C.A. Republic	29.33	5	2009 - 2022
Burundi	27.57	6	1970 - 2022
Guinea	27.32	7	1986 - 2022
Benin	26.9	8	1960 - 2022
Rwanda	24.89	9	1965 - 2022
Tanzania	24.27	10	1990 - 2022

Source: Adapted from World Bank (2023).

Figure 2 below contrasts the contribution of Agriculture as a share of GDP in relation to other similar emerging economies and at 2.83%, South Africa ranks the lowest. The contribution of agriculture remains higher in developing countries in comparison to developed economies which is evident in the agricultural sector in Africa contributing 35% of the continental GDP which is twice the global average (Nachum, 2023).

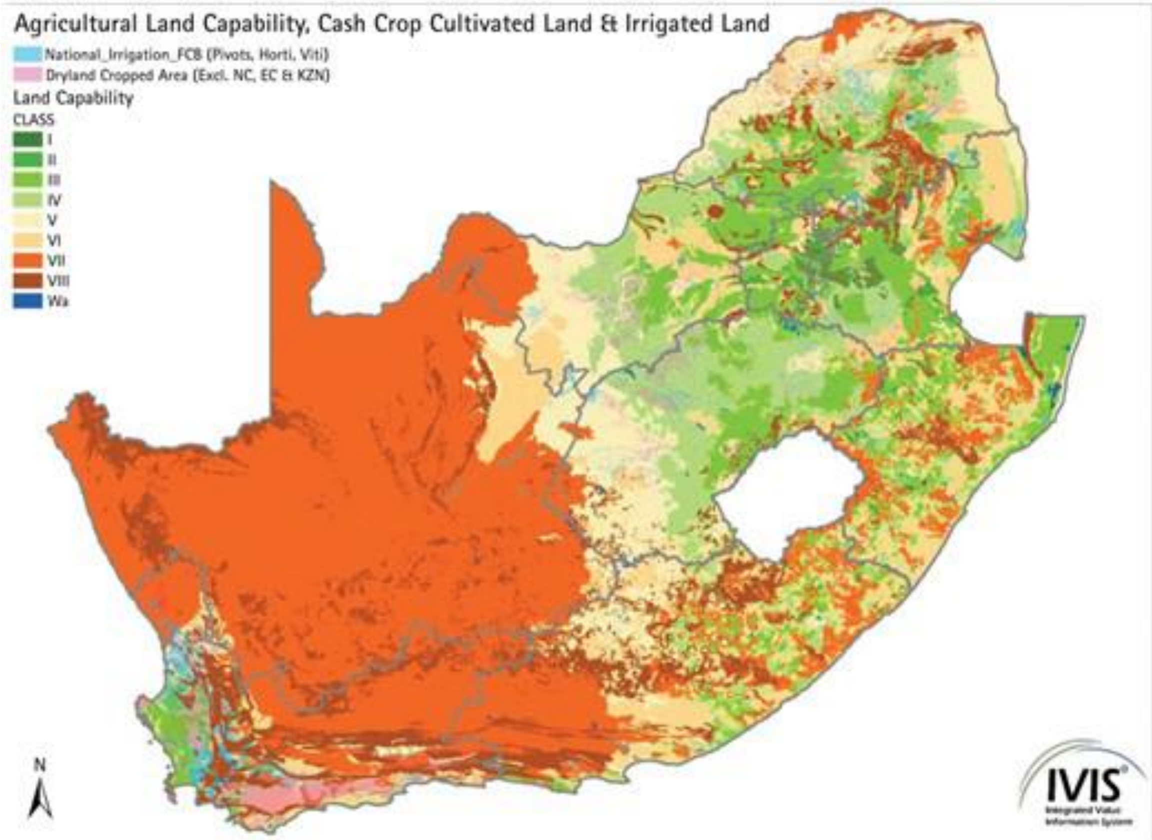
Figure 2: Agriculture as a share of GDP.

Country or region ↑↓	↑ Agriculture as a share of GDP % of GDP • 2022	↑↓ GDP per capita In constant 2017 international $ – World Bank international-$ in 2017 prices • 2022
India	16.73%	$7,112
China	7.30%	$18,188
Brazil	6.81%	$15,093
Mexico	4.03%	$20,255
Russia	3.90%	$27,450
South Africa	2.83%	$13,479

Source: Adapted from World Bank (2023).

Although the country has 96 million hectares of agricultural land, South Africa is a semi-arid country with a weak resource base for agriculture with only 12.5% of the land classified as arable (Sikuka, 2019). Figure 3 below highlights the limited land capacity of the country with areas in Class V-VIII classified as low-to-medium potential and only suited to external grazing.

Figure 3: Agricultural land capability map of South Africa.



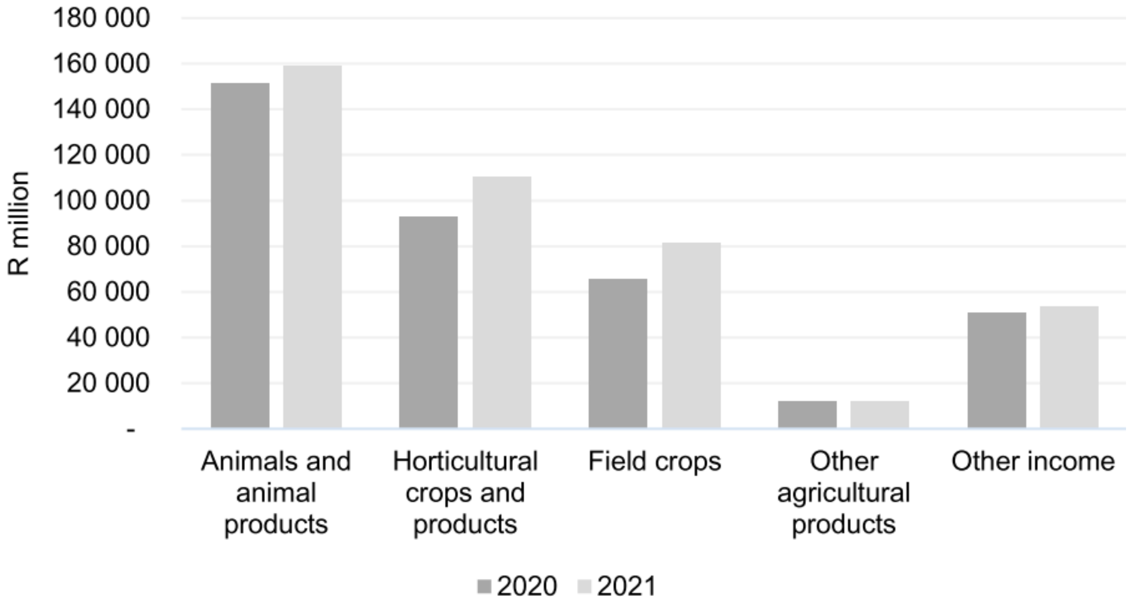
Source: Adapted from BFAP (2018).

Further to being a semi-arid country, South Africa is also faced with challenges posed by unpredictable rainfalls and limited water resources (Bonetti et al., 2022) and the country has implemented smart agricultural practices with the aim of increasing the resiliency of agricultural systems, improve water and soil management and promote sustainable production methods (Mathews et al., 2018).

2.3.1 *Composition of South African agriculture by output*

The agricultural sector encompasses the cultivation of key grains (excluding rice), oilseeds, both deciduous and subtropical fruits, sugar, citrus fruits, wine, a wide range of vegetables, as well as livestock such as cattle, dairy cows, pigs, sheep, broilers, ostriches, and egg production (Sikuka, 2019). The total income earned in the agriculture and related services industry as reflected in Figure 4 below was R417,1 billion in 2021 an increase of 11,9% on 2020.

Figure 4: Income by type of product in the agriculture and related services industry, 2020 and 2021.



Source: Adapted from StatsSA (2022).

Livestock farming is the largest agricultural sector with approximately 69% of the country's land surface suitable for grazing and in 2021, 'animals and animal products' which comprise of cattle, sheep, pigs, live chickens, and other animals generated the largest sales (R159,3 billion) with cattle contributing the largest share at 59%. The South African national cattle herd has increased by about 6 million head since the 1970s and now stands at near 14 million (Palmer & Ainslie, 2006).

This is followed by 'horticultural crops and products' which are made up of vegetables, fruits, and seeds. South Africa produces a wide range of vegetables, including tomatoes, green beans, beetroot, carrots, sweet potato, pumpkins, lettuce, peas, and chillies (Horticulture, 2021). The country is one of the world's largest producers of citrus, including oranges, lemons, limes, and grapefruit and a significant producer of deciduous fruit, such as apples, pears, peaches, and plums (Sydow, 2010). These crops generated R110,4 billion in 2021.

Field crops generated R81,4 billion in the same year. These include maize, wheat, soybeans, and sugar canes. Maize is the country's most important crop, driving 53% of total field crop sales in 2021, serving as a staple in the populations diet, a source of livestock feed and an export crop. Although wheat sales were up 40.5% in 2021 as shown in Figure 5 below, South Africa relies heavily on wheat imports, with yearly imports totalling 1,8 million tons (Crop Trust, 2022) due to insufficient local production to meet consumption needs, international wheat prices and local weather conditions.

Figure 5: Details of sales of goods in the agriculture and related services industry, 2020 and 2021.

Type of field crop	2020[1]		2021[2]		% change
	R'000	% contribution	R'000	% contribution	
Maize	36 035 884	55,1	42 728 406	52,6	18,6
Wheat	6 043 263	9,2	8 488 269	10,4	40,5
Sugar cane	7 168 780	10,9	9 032 822	11,1	26,0
Other field crops	16 250 901	24,8	21 111 829	25,9	29,9
Total	**65 498 828**	**100,0**	**81 361 326**	**100,0**	**24,2**

[1] Revised figures.
[2] Preliminary figures.

Source: Adapted from StatsSA (2022).

2.3.2 *Technology and modernization.*

Incorporating digital technology into agriculture offers significant potential for Sub-Saharan Africa, and the role of digitalization is set to grow in importance in harnessing agricultural opportunities across the continent with some of the trending technologies in agriculture including data management, machine learning, artificial intelligence, automation, and drone-based applications (International Trade Administration, 2021).

The importance of developed agricultural systems is highlighted by (Tinarwo & Uwizeyimana, 2019). The authors discuss the importance of science, technology, and innovation (STI) in improving agriculture and ultimately food and nutrition security. With most developing countries at various levels of socio-economic fragility, STI offers some options to realise the untapped potential of agriculture that is essential in enhancing food and nutrition security, ending hunger and malnutrition and ultimately attain socioeconomic transformation. In South Africa, the agricultural industry in South Africa is vital for ensuring food security, generating employment, and fostering economic growth. Nevertheless, for the sector to sustain productivity, sustainability, and competitiveness, substantial modernization and the integration of advanced technologies are essential (Buchana, 2023).

Nakasone & Torero (2016) investigated the importance of STI, the three C's (connectivity, content and capacity) and R&D as key for improving agriculture and national food security. The authors found that under certain situations, ICTs can improve rural households' agricultural production, farm profitability, job opportunities, adoption of healthier practices, and risk management. (Agriculture Portal, 2023) explored how emerging digital technologies such as precision agriculture, smart farming, and digital marketplaces have the potential to transform South African agriculture by improving productivity, efficiency, and transparency across the value chain.

Strides have also been made in improving connectivity although challenges still remain with South Africa ranking 46th out of 70 countries in the Global Connectivity Index and 4G/5G availability still an area of improvement in many rural areas (FAO, 2020). Access and availability to localized agricultural content is imperative, however, the use of digital platforms remains low, especially among less educated farmers (Simpson & Calitz, 2014). (Karssing, 2024) identified the lack of capability within agricultural ministries and extension services as impeding the rollout of digital adoption initiatives. Addressing these capacity limitations through training and capacity-building efforts is essential to promote sustainable adoption of technology. R&D was highlighted as the third pillar in improving agriculture and food security by Nakasone & Torero (2016) and research by (Chaminuka et al., 2019) found that in comparison to the rest of Africa, South Africa spends a relatively large amount on agricultural R&D, with research spending intensity ratios remaining higher than the recommended 1% target. However, it still lags behind its BRICS counterparts.

2.4 The impact of loss in the food production process

Food loss is a poor use of resources and is socially, economically, and environmentally detrimental. Food losses on the farm comprise those elements of the crop (food and inedible parts) that end up not being used in the food chain, including output foregone (i.e. reduced yield) due to inefficient on-farm operations (Ward, 2018). Food losses extend beyond the farm through the entire supply chain with about 30% of food produced globally being lost or wasted along the food supply chain (Oliveira et al., 2021). The highest percentage of food loss happens at the farm stage in both developing and developed countries (Despoudi, 2021). Magalhães et al., (2021) also contended that food loss and waste occur at all stages of the food supply chain. Since their causes are interconnected and may influence each other, approaches with holistic supply chain perspectives are useful to map their relationships and guide the selection, design, and implementation of the appropriate mitigation strategies.

Oliveira et al., (2021) looked at the concept of food loss through a different lens. The authors conducted research on the concept of circular economy which is more related in terms of reduction, reuse and recycling than the idea of a systematic change in the food supply chain. Wang et al., (2021) studies the current linear model of FLW (Food Loss and Waste) management (incineration and landfill) and how it creates a linear path of nutrients utilization, which threatens food security and environmental sustainability in the long run.

Although the concept of a circular economy discussed contribute immensely to the topic of food loss, the need for future studies that associate food losses and wastes with the circular economy remains a global challenge, especially for developing countries. Wang et al., (2021) also support this and believe a lot of work remains to translate this ‘‘circular model’’ into an actionable plan.

Food production is expected to increase 70% to meet the worldwide food supply needs by 2050 (Arivazhagan et al., 2016). However, one third, approximately 1.3 billion tonnes, of the total produced food to be consumed is still lost or wasted each year, thus wasting the 0.9 million hectares of land and 306 cubic kilometres of water needed for its production (Priefer et al., 2016).

2.4.1 *Food losses at Producer level*

Despoudi (2021) explores the different ways which have been suggested to reduce food losses at producers' level such as investments in technology, changing regulations, and development of collaborative relationships. His study aims to explore the challenges that the European Union (EU) Agricultural Supply Chain (ASC) producers are facing in their efforts to reduce food losses using Contingency Theory.

Ward (2018) also noted that addressing food losses at a producer level is a multi-faceted challenge as there is no single solution. While a range of initiatives may be proposed, such initiatives must make commercial sense from the farmer's perspective, otherwise they will fail. The research identified policy and ensuing regulation as very powerful tools that will fail to have impact if they make the farming operations commercially unviable. Ward (2018) acknowledged that this is a complex area at the interfaces between technology, economics, and human behaviour.

Despoudi (2021) uncovered five major categories of challenges in reducing food losses at producers' level which are: lack of technology adoption, lack of understanding of the changing market requirements and the changing regulations, lack of farm-related skills and the need for modern agricultural practices, collaboration issues, and the impact of climatic change.

2.5 Unmanned Aerial Vehicles (UAVs)

The key techniques on which precision agriculture is based are remote sensing. One of the most used techniques in novel time is to capture production areas from the air (Mooney & Johnson, 2014). Remote control platforms used for gathering essential data from a series of land-based photographs can include satellites, balloons, aircraft, and drones. The use of satellites and aircraft can be both costly and time-intensive, making it impractical for frequent data collection. In contrast, drones present a more straightforward operational approach, equipped with well-suited sensors (including optical, infrared, radio detection and ranking sensors, among others) and a variety of camera types such as RGB

(Red, Green, Blue) which refers to the three primary colours used in digital imaging and displays, NIR (Near-Infrared) which is a portion of the electromagnetic spectrum that is just beyond the range of visible light MultiSpec, and ThermoMap. They offer the advantage of conducting frequent flights over the target area, all at a significantly reduced cost (Zhang & Kovacs, 2012). Figure 6 below shows the DJI Agras Drone which carries 10 litres of pre-mixed Roundup, and sprays 2 to 2.5 ha per hour from an elevation of around two to three metres above the ground.

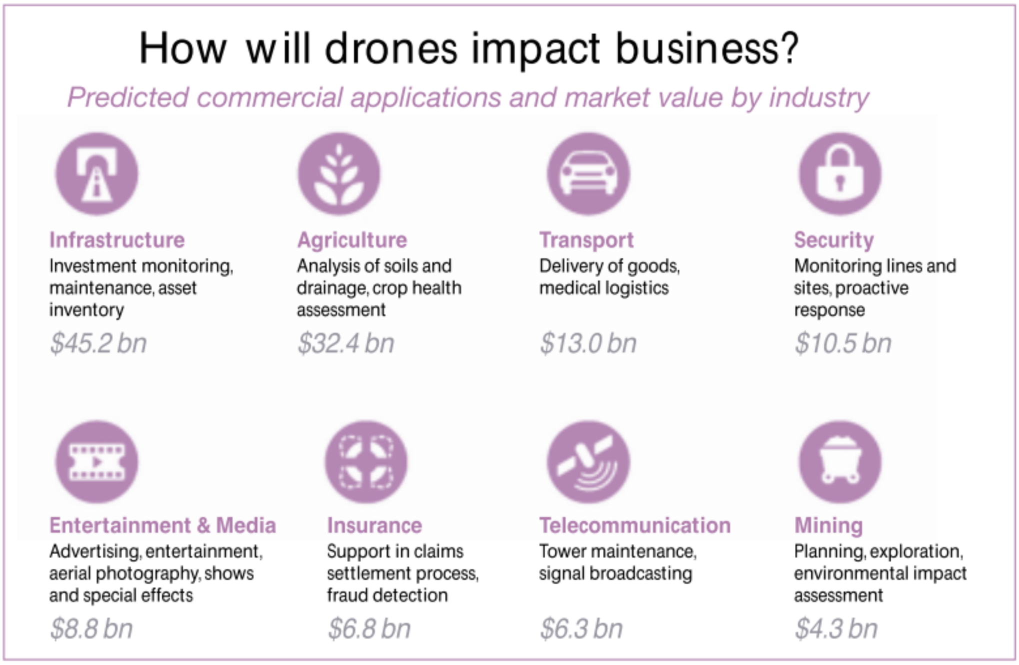
Figure 6: DJI Agras MG UAV

Source: Author (2022)

UAVs are a form of modernization that has extended across multiple industries and their value to the agricultural sector, has not only resulted in commercial but social benefit in improving crop yields from farms and higher contributions to food supply across the globe. According to the Food and Agriculture Organization of the United Nations (FAO), crop pests and diseases cause a significant loss of global crop production, estimated to be up to 40% annually and in China, pests and diseases cause a loss of approximately 40 million tons of grain each year (FAO, 2021). The use of drones and IoT technology in agriculture can help monitor the incidence of crop diseases and pests from both ground and air perspectives, respectively (Food and Agriculture Organization of the United Nations, 2017). UAV-based spraying systems employing machine learning techniques are a recent advancement in precision agriculture for precise spraying, promoting saving chemicals (pesticide/herbicide), and enhancing their effectiveness (Khan et al., 2021).

Agricultural modernization involves the use of IoT and UAVs to monitor crop health. IoT technology can collect real-time weather parameters of crop growth through inexpensive sensor nodes. Meanwhile, UAVs can capture images of farmland using spectral camera technology, which can be analysed to detect the occurrence of pests and diseases in crops (Gao et al., 2020).

Figure 7: The business of drones



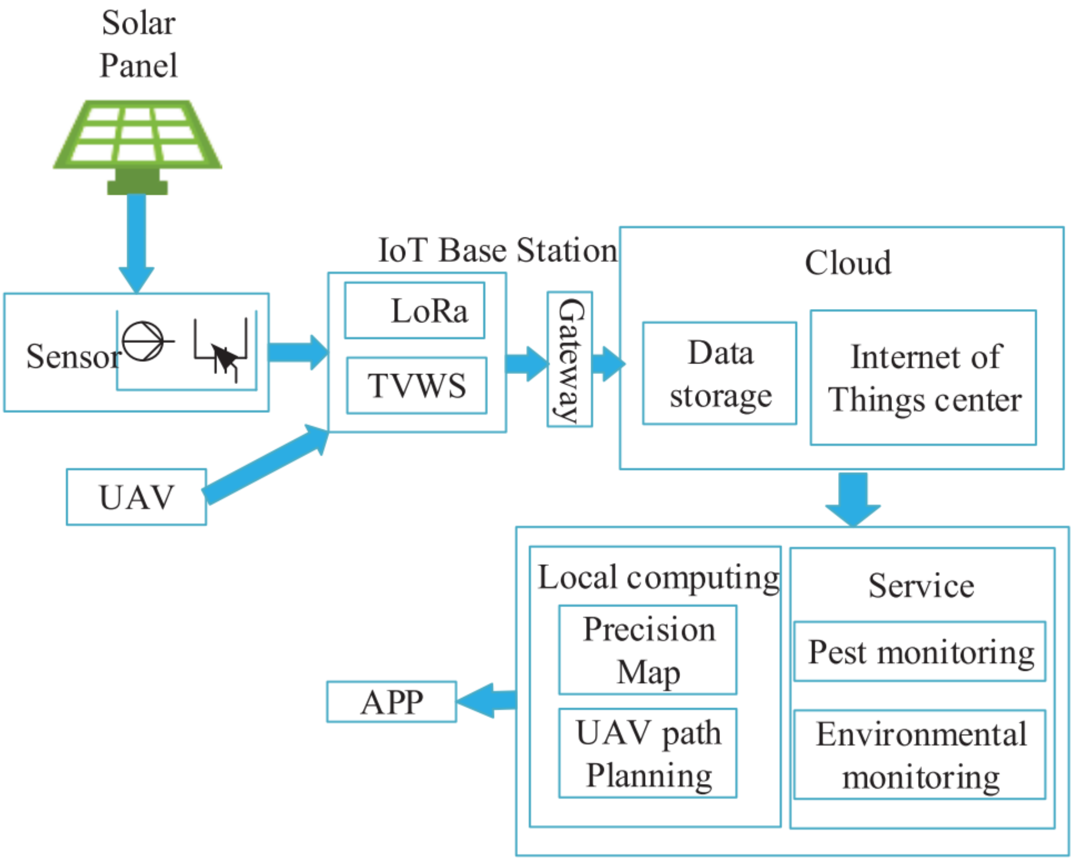
Source: Adapted from PwC (2016)

Figure 7 highlights the size of the agricultural drone industry globally, making up 25% of all business and driving the second highest value of sales after infrastructure.

2.5.1 *Agricultural IoT Systems*

UAVs do not work in isolation but are part of a network of technologies that ensure that the data collected by the drones can be processed and analysed in a way that adds value to farmers. An overview of the system is given in Figure 8 below and consists of the following components: An energy supply device such as a solar system, IoT base stations which are mainly composed of TV White Spaces (TVWS) and LoRa sensor connection modules LoRa technology which are utilized for collecting information by connecting the sensors deployed in the farm. In this system, UAVs are used to periodically capture the images of crops with a spectral camera and transmitting these images to the cloud data center which are stored for data analysis. With the aid of image processing technology, these images can be analyzed to determine whether there are pests and diseases or not (Zhang & Kovacs, 2012), precision maps and path planning can be conducted and all the information be available to farmers via an application based platform.

Figure 8. Overview of the agricultural IoT platform

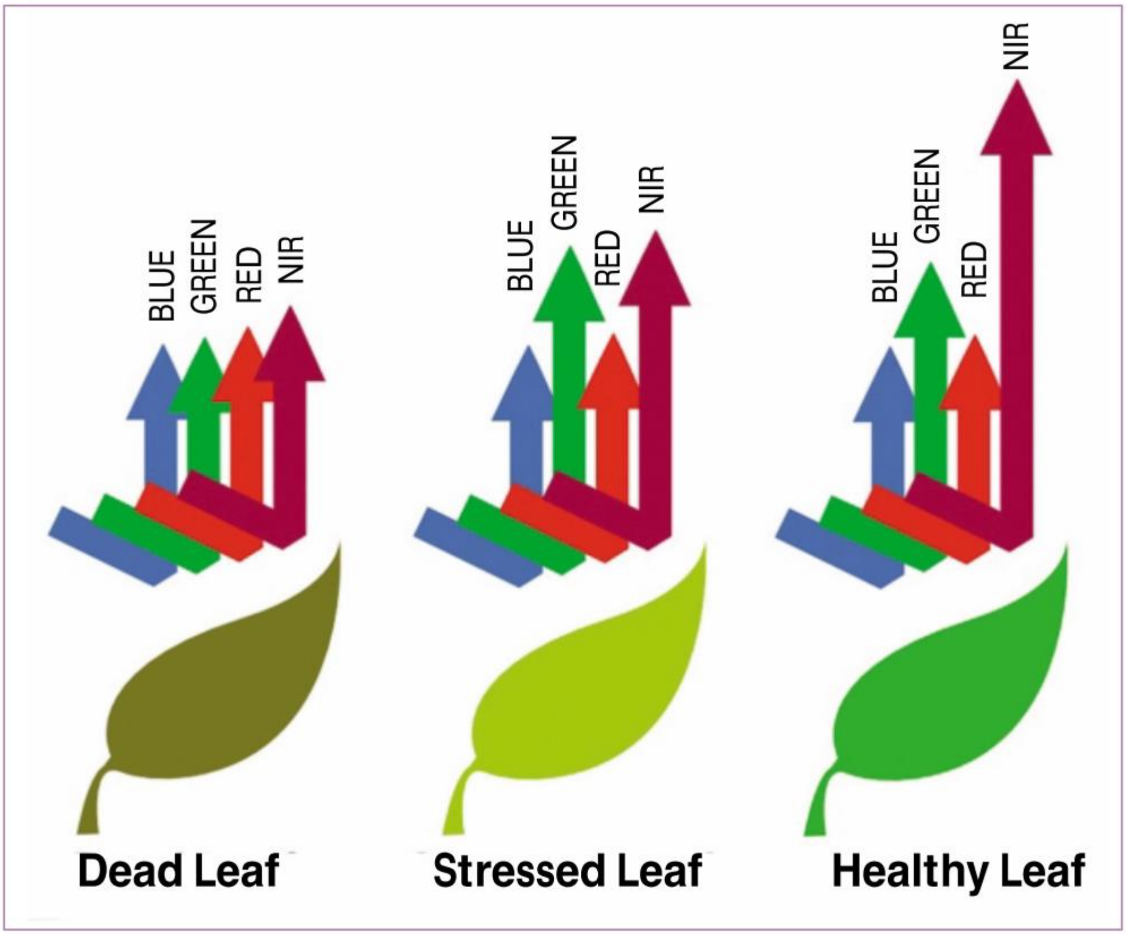


Source: Adapted from (Gao et al., 2020)

2.5.2 *Uses of UAVs in Agriculture*

One of the key uses of UAVs in agriculture is crop health monitoring and early pest and disease detection. Crop and plant diseases are inevitable, so early detection of these specific diseases a crucial aspect of agriculture. Various factors like viruses, bacteria, fungi, and more are the primary culprits behind crop ailments. These diseases typically start in three plant components and eventually affect all parts, such as plant tissues, leaves, stems, roots, seeds, and fruits. Therefore, to prevent this further spreading of diseases which affects the entire crop, early detection and classification of crop diseases is imperative (Sravan et al., 2021). Drones can create Normalized Difference Vegetation Index (NDVI) maps, which indicate areas of healthy vegetation and stress. Farmers use these maps to make informed decisions about irrigation, fertilization, and pest control. The fundamental concept behind NDVI relies on the fact that leaves reflect a lot of light in the near infrared (NIR). When a plant experiences dehydration or stress, its leaves reflect less NIR light while maintaining a consistent level of reflectance in the visible spectrum (as shown in Figure 9). Consequently, by mathematically merging these two signals, it becomes possible to distinguish between vegetation and non-vegetation, as well as identify healthy plants from those facing distress (Sylvester, 2018).

Figure 9. NDVI and Plant Health.



Source: Adapted from www.agrobotix.com.

UAVs are used for field mapping and path planning. Field mapping provides accurate elevation information and the ability to characterize landscapes, individual plants, and animals, and their various stressors (Delheimer, 2023). This information can be used to optimize crop production, reduce waste, and increase efficiency by allowing farmers to identify any irregularities in the field and make more informed decisions (Croptracker, 2023). UAV path planning allows for autonomous navigation of UAVs as drones must be able to rapidly compute feasible and energy-efficient paths to avoid collisions and navigate through complex environments (Gugan & Haque, 2023). UAVs are also used to assess soil moisture levels and plant hydration, helping farmers make informed decisions about irrigation scheduling and water conservation. (Gugan & Haque, 2023) studied the use of drones equipped with multispectral remote sensing to map maize water stress status and monitor its spatial variability at a farm scale. The results showed that drones can be used to accurately map water stress in maize crops.

2.6 Adoption of agricultural technologies

The adoption of technology in agriculture is critical to improving agricultural productivity and the state of farming operations and the modernization of the agriculture sector through agricultural technology adoption has been identified as a key factor in addressing poverty and improving food security (Mufariq et al., 2022). Although the benefits of modernization have been identified, a perplexing phenomenon in Sub-Saharan Africa is the poor rate of adoption of seemingly profitable technologies (Takahashi et al., 2019).

Numerous factors have been identified as having an influence on technology adoption and (OECD, 2001) identified the adoption of technologies for sustainable farming as multi-disciplinary, and that the choices on technology adoption are made with uncertainty and a large element of “trial and error” is applied. According to (Ruzzante et al., 2021), the age, education level, family size, and farm size are among the social and demographic factors that affect adoption. (Lin, 2008) spoke to perceived ease of use, usefulness, and compatibility with existing systems as factors influencing adoption while (Kinyangi, 2014) identified the cost, affordability, and level of expected benefits as influencing adoption. (Milkias, 2018) noted the role of government policies and regulatory frameworks in influencing adoption and use of new agricultural technology has been emphasised.

It is important for stakeholders in agriculture to understand the various factors that have the potential to hinder or promote the successful adoption of agricultural technological and their integration into existing farming practices in order to improve productivity and efficiency.

2.7 Conclusion of Literature Review

(WWF-SA, 2020) recognizes agriculture as the foundation of developing economies and as one of these economies, South Africa must prioritize the well-being of its agricultural sector which plays a vital role in bolstering the nations GDP, ensuring food security, enhancing social welfare, and contributing to job creation.

The importance of STI and ICTs in improving sluggish growth in farm productivity is another area of focus. Unmanned aerial vehicles have become popular in various areas of everyday life including agriculture and allow for the capturing of images which are transmitted to the cloud for analysis and could prove effective in reducing food loss on farms due to pathogens. According to the Association for Unmanned Vehicle Systems International (AUVSI) there are more than 2900 Unmanned Aerial Vehicles (UAV) across more than nine hundred companies providing services around the world in 2020 (del Cerro et al., 2021). Unmanned aerial vehicles have become popular in various areas of everyday life including agriculture. The aircrafts allow for the capturing of images which are transmitted to the cloud for analysis and could prove effective in reducing food loss on farms due to pathogens.

Heading into the future, drones will allow farming to become a highly data-driven industry, which eventually will lead to an increase in productivity and yields. Due to their ease of use and low cost, drones can be used for producing time series animations showing the precise development of a crop (Mazur et al., 2016).

Table 1: Consistency table: research questions and propositions

Exploring the use of Unmanned Aerial Vehicles (UAVs) to reduce production loss on farms in South Africa.							
Main Objective Here : To explore Unmanned Aerial Vehicles and how they can contribute to reducing production loss on farms in South Africa.							
Sub-Aims/Objectives	**Literature Review**	**Hypotheses /Propositions**	**Research questions**	**Variables(Independent & Dependent)**	**Source of data**	**Type of data**	**Analysis**
To investigate the factors that contribute to production loss and negatively impact yields.	Despoudi (2021)	Challenges in reducing food losses at producers' level identified as lack of technology adoption, lack of farm related skills, need for modernization and lack of understanding of changing market requirements.	What factors contribute to production loss and impact outputs on South African farms?	MV1= Production losses DV1= Farm outputs	Online and literature review Observations Questionnaire/ Semi-structured interview (Q3)	Primary and Secondary Data	Thematic Analysis
To expore the impact of UAV's towards reducing losses on farms	(Gao et al., 2020) (Khan et al., 2021)	UAVs have become popular in agriculture and allow for the capturing of images which are transmitted to the cloud for analysis and could prove effective in reducing production loss on farms.	How can Unmanned Aerial Vehicles (UAVs) help South African farmers reduce losses on their farms?	CV1= UAVs MV1= Production losses	Online and literature review Observations Questionnaire/ Semi-structured interview (Q2, Q4, Q5, Q6)	Primary and Secondary Data	
To investigate factors that promote and those that are currently hindering adoption of drones	(Chuang et al., 2020)	Lower adoption levels of Smart Agriculture technologies may be attributed to inadequate information, missing knowledge, lack of awareness of the technologies, and lack of perceived practical value.	What are the factors that promote or limit the adoption of Unmanned Aerial Vehicles (UAVs) on South African farms?	MV1= Factors impacting adoption DV1: UAVs	Online and literature review Questionnaire/ Semi-structired interview (Q7-Q10)	Primary and Secondary Data	
Drones, agriculture, technology, production loss, South Africa							

2.8 ANALYTICAL FRAMEWORK

An analytical framework is an integrated overview that's designed to guide and structure a researcher's thoughts and help in sense-making and understanding. The theoretical and conceptual framework explains the path of a research and grounds it firmly in theoretical constructs. The overall aim of the two frameworks is to make research findings more meaningful, acceptable to the theoretical constructs in the research field and ensures generalizability (Adom et al., 2018)

Below are both the theoretical frameworks and presumed overall conceptual framework including unstudied components which were adopted for this study.

2.8.1 *Theoretical Framework*

The above literature review looks at the field of digitalisation in agriculture and how it can contribute to reducing losses on farms if correctly adopted. The researcher sees it fitting to derive theory related to both the acceptance and usage of technologies as well as agricultural productivity theory.

The aim of acceptance and usage theories and models is to convey the concept of how users may understand and accept the new technology and how they may use it (Momani et al., 2017). In agriculture, productivity measures how well farmers and agribusiness companies combine inputs to produce output. Growth in productivity reflects increases in the efficiency of the production processes which, in turn, occur as a result of improvements in technology or knowledge (Momani et al., 2017).

Innovation Diffusion Theory (IDT) is selected as it provides tools for assessing the likely rate of diffusion of a technology, and additionally, identifies numerous factors that facilitate or hinder technology adoption and implementation (Fichman, 1992). Dearing & Cox, (2018) identified a series of steps in the diffusion of innovation:

- A person learns about an innovation that they think may have important consequences for them or those they serve.
- Uncertainty about how to respond typically leads to a search for further information, so the potential adopter can better assess whether the innovation's attributes warrant further exploration and,
- The pros and cons related to relative advantage, complexity, compatibility, observability, and trialability are codified.

With regards to agricultural productivity, several theories have been formulated, some of which targeted the individual employees/consumers, production systems, process or a combination of any two or more of the target spheres for productivity to be raised (Momani et al., 2017). The researcher has chosen new growth theory which incorporates the fundamentals of formal growth theory that express output growth as a function of growth in inputs and efficiency with which inputs are transformed into outputs. New growth theory incorporates growth as endogenous (through technical change, research and development and capability building activities) (Ogbeide & Ogbeide, 2015)

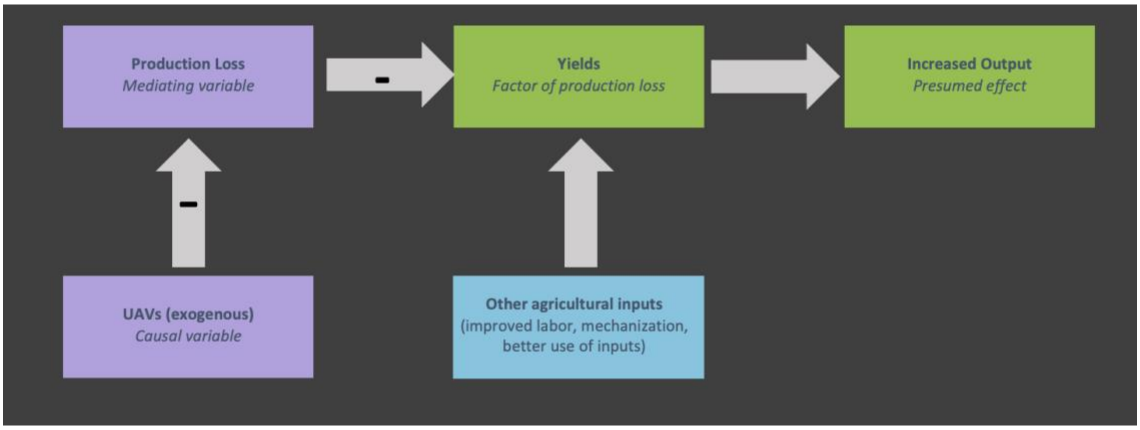
The researcher believes that deriving theory on diffusion and agricultural productivity is well suited to the study and getting an in-depth understanding on the implementation of UAVs.

2.8.2 *Conceptual Framework*

A conceptual framework is a structure which the researcher believes can best explain the natural progression of the phenomenon to be studied (Camp, 2001). It illustrates what the expected findings of the research are, highlights the variables for the study and how they may relate to each other.

Figure 10 below illustrates the presumed conceptual framework that the researcher feels best explains the phenomena to be studied. The variables in purple are to be studied and those in green are those that were inferred.

Figure 10: Presumed overall conceptual framework including unstudied components.



CHAPTER 3. RESEARCH METHODOLOGY

Chapter outline:

The purpose of this chapter is to:

- Provide an overview of the research approach employed by the researcher.
- Highlight the chosen research design.
- Describe the data collection process.
- Outline the research instrument chosen.
- Postulate an overview of the data analysis procedure.
- Outline factors related to the research quality and trustworthiness.
- Present the ethical considerations that guided the study.

The purpose of this study was to to explore Unmanned Aerial Vehicles and how they can contribute to reducing production loss on farms in South Africa. The philosophical worldview that the researcher brought to the study is that of interpretivism. Interpretivism theory assumes that reality consists of people's subjective experiences of the external world; thus, they may adopt an inter-subjective epistemology and the ontological belief that reality is socially constructed (Schindler, 2019). Furthermore, the researcher's intent is to make sense of (or interpret) the meanings others have about the world. Rather than starting with a theory, inquirers generate or inductively develop a theory or pattern of meaning (Hutagalung, 1967).

3.1 Research approach

In order to analyse the data related to different participants' views of Unmanned Aerial Vehicles, the study was best suited to qualitative research methodology.

Unlike quantitative research methods, the researcher and manager (research sponsor) often have significant involvement in collecting and interpreting the data.

Qualitative research lends itself to more exploratory research and allows for open-ended questions, data to be collected in the participants setting, and puts focus on individual meaning. Qualitative research is also designed to help researchers understand people, and the social and cultural contexts within which they live (Eisenhardt, 1989).

The philosophies that guide qualitative research are different from those that inform quantitative research. According to Uwe Flick (2009) the essential features of qualitative research are the correct choice of appropriate methods and theories: the recognition and analysis of different perspectives; the researchers' reflections on their research as part of the process of knowledge production; and the variety of approaches and methods.

The abovementioned affirm the choice of research approach in achieving the objectives of the study.

3.2 Research design

The design to be adopted is that of empirical research. Empirical research is based on observed and measured phenomena and derives knowledge from actual experience rather than from theory or belief (Bearden, 2021). Empirical evidence can be analyzed either quantitatively or qualitatively, and the researcher can answer empirical questions which have to be clearly defined and answerable with the findings (Adi Bhat, 2018). In this study, data was analysed to understand how Unmanned Aerial Vehicles (UAVs) can help reduce production loss on farms in South Africa.

This study is descriptive and answers questions related to how UAVs can help reduce production loss on farms in South Africa. Descriptive design was selected as it allows for a clear description of a specific phenomenon or experience, aligning with the limited scope of the research question, sample size, and data generation and analysis methods (Kilcullen, 2007).

The researcher conducted semi-structured interviews as a primary method of collecting data and the time dimension was cross-sectional, representing a snapshot at a specified period. The advantages of a cross-sectional study are that it can be accomplished more quickly, at a lower cost, and error sources caused by changes over time are minimized (Schindler, 2019).

3.3 Data collection methods

Data collection design involves the measurement of variables and the search for relationships between those variables. It also involves a large number of decisions related to how, when, how often, and where data was collected.

For this study, data was collected primarily through semi-structured interviews as well as participant observation and online literature research.

Additional adjustments can be made to data collection instruments at a later stage, such as the addition of questions to an interview protocol or questions to a questionnaire (Harris & Sutton, 1986). In other situations, adjustments can include the addition of data sources in selected cases. In theory-building research, investigators are trying to understand each case individually and in as much depth as is feasible, thus, if a new data collection opportunity arises or if a new line of thinking emerges during the research, it makes sense to take advantage by altering data collection, if such an alteration is likely to better ground the theory or to provide new theoretical insight (Eisenhardt, 1989).

The primary method of data collection to be used is semi-structured interviews which have features of both structured and unstructured interviews and therefore use both closed and open questions. As a result, it has the advantage of both methods of interview (Sönmez, 2013).

Schindler, (2019) stated that semi-structured interviews used in qualitative research are distinct from the structured interview in several ways. They:

- Rely on developing a dialog between interviewer and participant.
- Require more interviewer creativity.
- Use the skill of the interviewer to extract more and a greater variety of data.
- Use interviewer experience and skill to achieve greater clarity and elaboration of answers.

Semi-structured interviews offer an advantage by facilitating open-ended conversations, giving participants the freedom to deviate from set questions. This flexibility allows them to introduce new ideas or topics during the interview (Merriam, 2002).

Observation is a method that collects data through all our primary senses; it involves listening, reading, smelling, tasting, and touching and during observations, participants engage in actual behaviors with processes, objects, environments, and people (Schindler, 2019). Participant observation involved the researcher observing from a members perspective but also influencing what is observed due to participation (Uwe Flick, 2009).

Spradley, (1967) distinguishes three phases of participant observation:

1. *descriptive observation*, at the beginning, serves to provide the researcher with an orientation to the field under study. It provides nonspecific descriptions and is used to grasp the complexity of the field as far as possible and to develop (at the same time) more concrete research questions and lines of vision.
2. *focused observation* narrows your perspective on those processes and problems, which are most essential for your research question.
3. *selective observation*, towards the end of the data collection, is focused on finding further evidence and examples for the types of practices and processes, found in the second step.

3.3.1 *Procedure for data collection*

The researcher created a list of subject matter experts and firms through accessing LinkedIn, the professional networking platform. An introductory message or email was sent explaining the background of the study, rights of potential participants and a request to conduct a recorded interview.

This was followed by recorded video meetings via Zoom with interviews lasting between eighteen and forty-nine minutes (Appendix G).

For the observations, an introductory email was sent to Integrated Aerial Systems explaining the purpose of the study and requesting permission to contact a willing client.

After a suitable farm was identified which was Thuthuka Forestry in Piet Retief, Mpumalanga, an introductory call was made, and permission was granted to come out to their operations and spend two days on the field with their UAV crop spraying team.

Schindler (2019) stated that recruiting top-quality participants is one of the most important jobs of the qualitative researcher. Without the right people, deep meaning will not be achieved. Researchers want people who:

- Share common characteristics, so they can be comfortable with each other.
- Have a range of life experiences.
- Hold different perspectives on issues.
- Can articulate their ideas, experiences, feelings, attitudes, and beliefs.
- Want to share their ideas/experiences.
- Want to hear the ideas/experiences of others.
- Like to collaborate to solve problems.

The following sections discuss the target population, sample and the sampling methods employed.

3.3.2 *Population*

The aim of this research is to understand how UAV's can reduce production loss on farms. With the fundamental aim of the study in mind, the following principles for choosing the target population, from which the study sample was derived, are as follows:

- To limit the study to the use of UAVs in the agricultural space, the only participants who were interviewed were those with knowledge or experience in agriculture.

The target population for this study therefore comprised all individuals with experience using UAVs in agriculture with the actual population being all agricultural stakeholders in South Africa. This study might be generalizable as a large number of farming techniques and methods are standardized, as a result, this is likely to reach a population of similar South African agricultural operations.

3.3.3 *Sample and sampling method*

The sample of the study were individuals in the agricultural sector who have experience or knowledge of UAV implementation in farming.

Theoretical sampling was adopted in this study. Theoretical sampling is a form of sampling in qualitative research that is not bounded by the limits of a priori selection. Rather, theoretical sampling entails jointly collecting and analysing data to decide what data to collect next and where to find them in order to develop theory (Conlon et al., 2020)

According to Mackelprang et al., (2014) the reason for employing a purposive sampling strategy is grounded in the researcher's anticipation, informed by their pre-existing theoretical comprehension of the phenomenon under investigation. This assumption posits that specific cases (such as individuals, firms, or events) may offer unique, varied, or significant perspectives on the phenomenon, thereby warranting their inclusion in the sample.

3.3.4 *Demographic profile of respondents*

As outlined in Table 2 below, a total of seven participants were interviewed for this study. Six of the participants were male and one was female. Five of the participants were White by racial group and two were African. Two of the participants were drone pilots, two were entrepreneurs in the space with one of them also being an author and three came with an extensive research background.

Table 2: Participant profiles

Participant Code Name	Firm/Industry	Area of expertise	Duration	Sex
P1	Forestry	Drone Pilot	18:36	Male
P2	Professional Drone Services & Analytics	Entrepreneur	38:35	Male
P3	Sugar & Macadamia Farming	Drone Pilot, Entrepreneur	28:16	Male
P4	Aviation, Advocacy	Author, International Speaker, Entrepreneur.	49:40	Female
P5	Agricultural Research	Senior Researcher: Geo-informatics and Remote sensing.	20:03	Male
P6	Agricultural Research	Crop physiologist	34:50	Male
P7	Precision Agriculture Research	Senior Researcher	24:37	Male

3.4 The research instrument.

Semi-structured interviews were conducted as they leave the option for the researcher to probe and ask follow-up questions and allow the respondents to diverge from the questions and possibly introduce a theme that was not previously identified by the researcher.

The interviews took the form of a broad, central question being asked which allowed the respondent to share their perspectives, however varied or possibly unrelated to the question it may be. The researcher then asked no more than five to eight sub questions in addition to the central question to identify additional themes which may not have been spoken to in the first response. A series of probing questions had been prepared to support understanding of the sub questions where need be, not all the probing questions were asked.

The researcher also made a concerted effort to consider the language used when conducting interviews and ensure that questions are easily understandable. See Appendix E.

3.5 Data analysis and interpretation

An important aspect of data analysis in qualitative case study is the search for meaning through direct interpretation of what is observed by the researcher as well as what is experienced and reported by the subjects (Sönmez, 2013). Bogdan and Biklen (2003) define qualitative data analysis as “working with the data, organising them, breaking them into manageable units, coding them, synthesising them, and searching for patterns”.

In this study, the semi-structured interviews were recorded and transcribed and through this process, personal experiences and useful information may can be uncovered. The individual responses were analysed, compared and categorised with the results of transcription and subsequently triangulated and interpreted to draw conclusions (Sönmez, 2013)

Thematic analysis was applied to the collected data which is a qualitative research method that can be widely used across a range of epistemologies and research questions. It is a method for identifying, analysing, organizing, describing, and reporting themes found within a data set (Nowell et al., 2017). Thematic analysis is also useful for summarizing key features of a large data set, as it forces the researcher to take a well-structured approach to handling data, helping to produce a clear and organized final report (King, 2004).

Atlas.ti software was utilized to code and identify themes from the data collected during interviews.

3.6 Limitations of the study

The study used semi-structured interviews for data collection and as a result, all the limitations associated to semi-structured interviews were applicable to the study. Adams (2015) identified the following as possible limitations to semi-structured interviews in qualitative research.

- Semi-structured interviews are time-consuming, labour intensive, and require interviewer sophistication.

- Interviewers need to be smart, sensitive, poised, and nimble, as well as knowledgeable about the relevant substantive issues.
- The process of preparing for the interviews, setting up the interviews, conducting the interviews, and analysing the interviews is not nearly as quick and easy as you might think.
- The time and effort required to do all of it right is considerable. Semi-structured interviews usually entail the arduous task of analysing a huge volume of notes and sometimes many hours of transcripts.

3.7 Trustworthiness of the study

The traditional criteria for ensuring the credibility of research data, objectivity, reliability and validity are used in scientific and experimental studies but in contrast, qualitative studies are usually not based upon standardized instruments and they often utilize smaller, non-random samples (Schindler, 2019).

Uwe Flick, (2009) suggest trustworthiness, credibility, dependability, transferability, and confirmability as criteria for qualitative research.

The following subsections present an overview of trustworthiness in qualitative research and outline the methods employed to ensure trustworthiness in this study.

3.7.1 *Transferability*

Research findings are transferable or generalisable only if they fit into new contexts outside the actual study context (Sönmez, 2013).

Seale (1999) advocates that transferability is achieved by providing a detailed, rich description of the settings studied to provide the reader with sufficient information to be able to judge the applicability of the findings to other settings that they know.

Transferability will be relatively high because of the standardized nature of farming operations and commonality in having issues around production loss. The

The researcher believes other farmers will be able to apply the findings to their own operations. The researcher made use of purposive sampling to guarantee that the research focuses primarily on farm operations using UAVs.

3.7.2 *Credibility*

Credibility in qualitative research is defined as the extent to which the data and data analysis are believable and trustworthy (Sönmez, 2013) .

Because people who are intimately involved with the use of UAVs and other technologies were engaged, that facilitates credibility. Over and above the insights collected via interviews and focus groups, the researcher conducted an in-depth analysis of all documents and data provided on the case sites to ensure objectivity.

The researcher also debriefed their supervisor frequently to discuss and developing ideas related to the case. Lastly, the researcher ensured that participants were always cognizant of the fact that they were free to remove themselves from the data collection process at any point.

3.7.3 *Dependability*

Dependability is analogous to reliability, that is, the consistency of observing the same finding under similar circumstances (Uwe Flick, 2009)

Because semi-structured interviews are to be included in data collection and a detailed description of the research design adopted for this study, a degree of dependability was achieved.

3.7.4 *Confirmability*

Confirmability is the degree to which the research findings can be confirmed or corroborated by others Sönmez (2013) and is established when credibility, transferability, and dependability are all achieved (Nowell et al., 2017).

Confirmability is facilitated as participants that span across different functions, sub-industries and hold differing agricultural expertise have been selected for the research.

3.8 Ethical considerations

The way a researcher enters and conduct themselves in the field raises imperative ethical issues. This being a qualitative study, the researcher must interact deeply with the participants and the tutor, thus entering their personal domains of values, weaknesses, individual learning disabilities and the like to collect data. (Silverman, 2000). (Uwe Flick, 2009) identified the following as important ethical considerations in carrying out research on the field:

- Informed consent
- Employing ethical procedures
- Avoiding harm for participants in collecting data
- Doing justice to the participants in analysing the data

The following sub-sections explain how the researcher took cognisance of the abovementioned ethical considerations when conducting research.

3.8.1 *Informed consent*

In order to adhere to the principles of informed consent the researcher firstly highlighted the background of the study and what the objectives were. A consent form was made available to all the participants for their perusal. The consent form addressed anonymity, confidentiality and how the collected data was to be used.

3.8.2 *Ethical procedures*

Formal approval for this study was requested from the WBS Ethics Committee. The researcher emphasised to each participant that they are not obligated to respond to any questions that they are uncomfortable with. The researcher also emphasised that the participants are free to terminate the interview at any stage, for any reason whatsoever.

The researcher also obtained permission from the participants by firstly, issuing a letter requesting permission to conduct research and, secondly, requesting a formal letter in response granting permission.

3.8.3 *Avoiding harm to participants in collecting data*

During data collection, the researcher ensured that the participants were always comfortable and would refrain from coercing participants for responses. The interview style was conversational and designed to keep participants at ease with sharing their perspectives.

3.8.1 *Doing justice to participants in analysing data*

The researcher explained to all the participants how their data would be analysed after collection and that the research would be made available to all who contributed to it. The researcher would also assign code names to all participants to ensure confidentiality and anonymity, readers of the final report should not be able to recognise who the individuals in the participating farms are.

3.9 Chapter summary

The researcher's intent is to make sense of (or interpret) the meanings others have about the world. Rather than starting with a theory, inquirers generate or inductively develop a theory or pattern of meaning (Hutagalung, 1967). This study is classified as qualitative, adopting an empirical research design.

The sample of the study would be individuals in the agricultural sector who have experience or knowledge of UAV implementation in farming. Theoretical sampling which involved purposive sampling as a non-probability sampling technique of additional data while theory is being built is the method that was be adopted in this study.

Semi-structured interviews were conducted, and thematic analysis was be applied to the collected data which is a qualitative research method that can be widely used across a range of epistemologies and research questions.

CHAPTER 4. DATA ANALYSIS AND INTERPRETATION OF RESULTS

Chapter outline:

The purpose of this chapter is to:

- Provide an overview of the background of the study participants.
- Illustrate the emerging themes that were derived from the data collected.
- Present the main findings of the study and their relation to each research question.
- Provide an account of the factors that contribute to production loss on South African farms.
- Present the ways which drones can help reduce production loss.
- Reveal the factors impacting adoption of drones.

4.1 INTRODUCTION

Chapter 3 provided a detailed summary of the research design used in the study. This chapter discuss the background of the case participants, the data analysis stage, and a presentation of the study findings. The themes derived from the data and the key findings of the study and how they relate to each research question are presented in this chapter. The main themes and subthemes emerging from the findings of the study are summarized in Fig 10 (pg. 58) and Appendix F with the main themes being: *Factors contributing to production loss on South African farms, Ways in which UAVs can reduce production loss on farms, Factors promoting or limiting the adoption of UAVs on farms*. The findings focus on the benefits of UAVs in addressing causes which have been identified as contributing towards production loss on farms and reveal that there are factors which either limit, moderate or promote the adoption of UAVs on farms in South Africa. The chapter is concluded with an executive summary of the main findings.

4.2 BACKGROUND OF STUDY PARTICIPANTS

This study focuses on how UAVs can reduce production loss on farms, and it is imperative to have an understanding the background of the study participants as it impacts how they relate to the research topic. All the participants had personal experience with UAVs at the time of research. The excerpts below illustrate this:

> *“I own an Aviation Consulting Company and I'm an advocate for the drone industry. I've created and organised the drone professional book series that's used to showcase professional drone applications around the world and drone stories of people that have started their businesses and what they're doing.”*

> *“I've always been involved in drones, and I've had my RPL for about four years. We were involved in all kinds of mapping and bridge inspections using DJI products at that point in time.”*

In addition to participants who had operational level experience as well as the necessary training and certification, other participants were deemed eligible to participate because of their extensive experience in fields such as research and technology development in UAV technology and its application in agriculture. Some participants revealed this in the excerpts below:

> *“We are not a service provider to industry and don't own crop spraying drones. We don't provide spraying services or survey services to growers, we are more in the space of developing technologies and applications that can, together with contractors and service providers be to the benefit of farmers.*
>
> *We only have typical survey drones which we’ve fitted with thermal and multi spectral cameras an use those for research and development, to build models for crop health assessments.”*

> *“I am in remote sensing and GIS application. I've been in this field for more than 25 years. Although I've been using satellite*

images, such as Sentinel and Landsat as part of remote sensing but with the advancement of UAV's, we have started adopting them around 2017-2018."

4.3 EMERGING THEMES WITHIN THE STUDY

The data collected in this study was analysed using thematic analysis and the Atlas.ti qualitative data analysis software was used to first create codes, then to merge similar codes and create sub-themes from which the main themes were derived.

The study adhered to the data analysis process detailed in Section 3.5 (p. 49), and the coding and theming process employed by the researcher is depicted in Figure 11. After conducting interviews, the raw data was transcribed and a total of 72 codes were created in this stage.

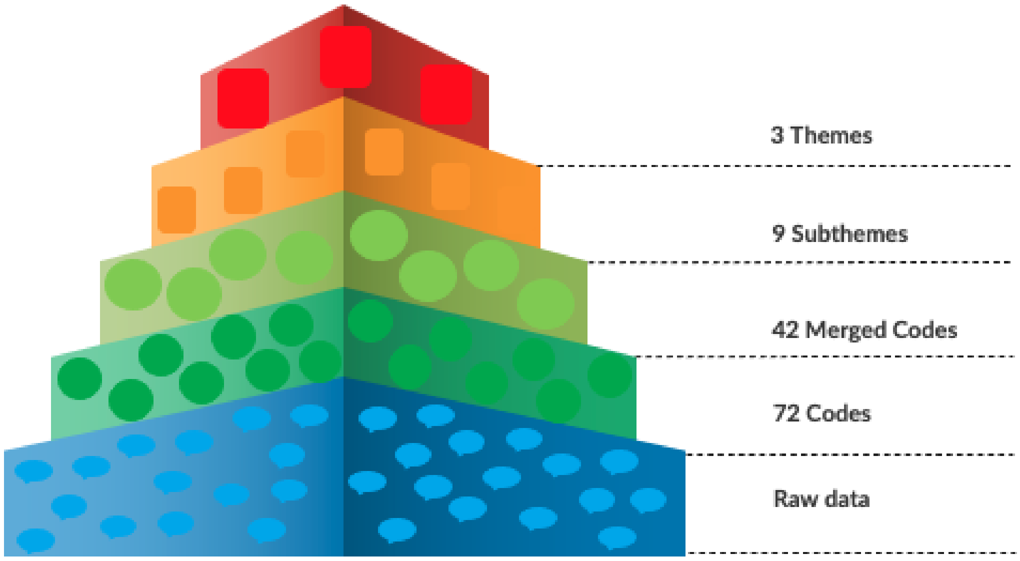
The chosen codes were guided by the transcribed data. The assertion below was a response from a participant:

"I've observed how ripening of sugar cane crops add huge profitability to farmers in the large-scale sector. Without that the growers are often highly susceptible in terms of struggling to get good crop maturity and overall good quality at harvest which then largely impacts profitability."

In this case, the quote was coded as "Crop ripening".

This approach was taken with coding all data and after the first iteration of codes was produced, similarities were identified which resulted in 42 merged codes.

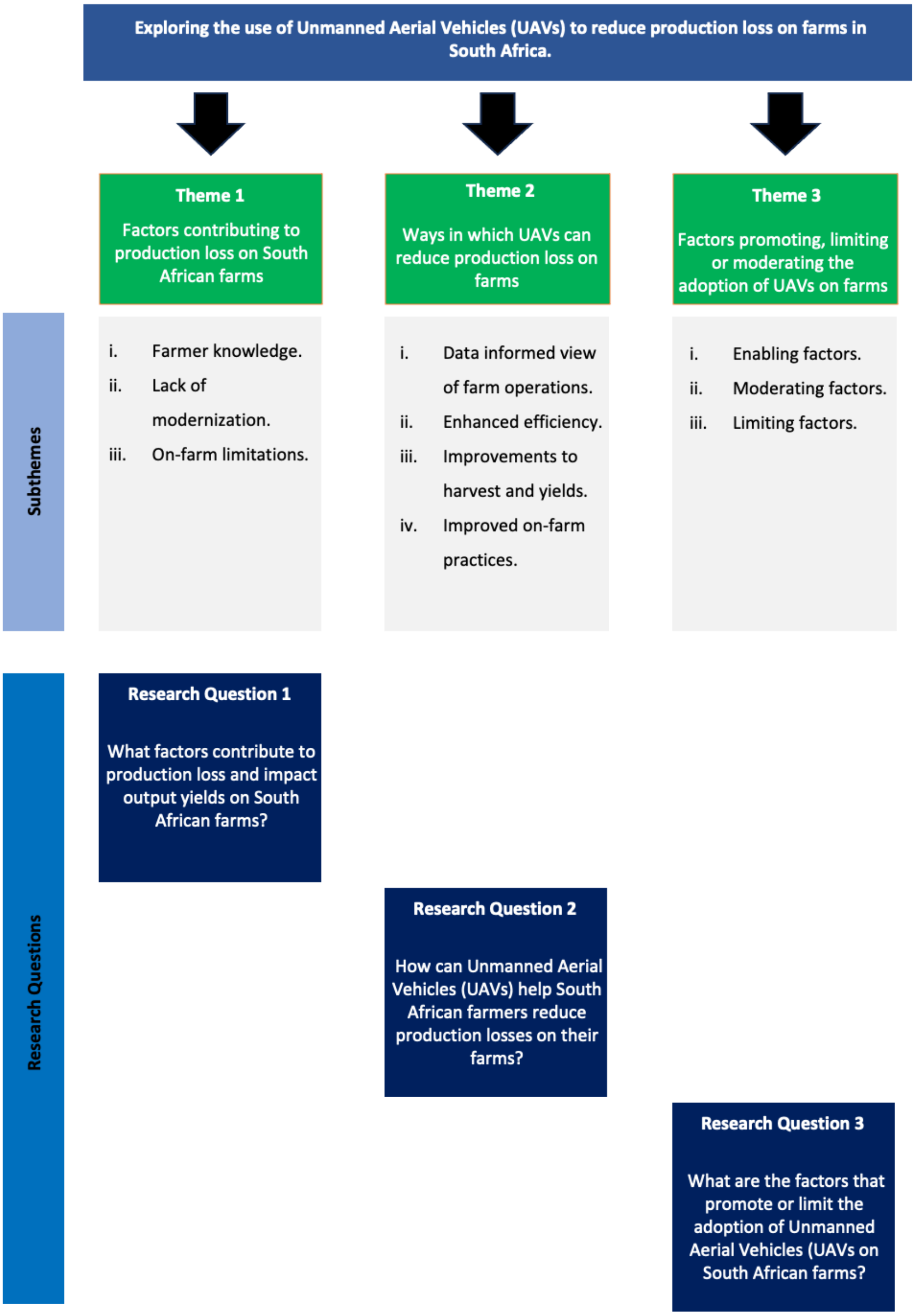
Figure 11: The coding and theming process



To establish more significant themes from the merged codes, codes with a strong connection were further merged resulting in nine sub-themes and three main themes; *Factors contributing to production loss on South African farms, Ways in which drones can help reduce production loss, and Factors promoting, limiting, or moderating adoption.*

The link between the research questions and the themes is illustrated in Fig 12. The three main themes and their connected subthemes are discussed in the proceeding sub-sections.

Figure 12: The main themes and subthemes identified in the study



4.4 Factors contributing to production loss on South African farms.

Insights on participants' experience of factors that may be contributing to production loss were important to the study. This section addresses the findings related to the first theme, which relates to the first research question as shown in Figure 12 above.

Findings related to limited farmers knowledge and how it impacts the ability to address production loss are discussed first followed by findings related to how lack of modernization contributes to production loss. The section is concluded with the researcher highlighting the constraints experienced every day on farms that impact the quantity and quality of farm outputs.

4.4.1 *Farmer knowledge*

A plethora of limitations have been identified by previous researchers that are related to a lack of knowledge by farmers which ultimately contributes to increased losses on their farms. (Dannson et al., 2004) identified knowledge and skills related to business management as key and stated that farmers may experience challenges in business management, production planning, and commercial understanding, impacting their ability to establish and sustain dependable connections with processors and participate effectively in agribusiness partnerships while (Chuang et al., 2020) investigated how farmers' knowledge and attitudes regarding smart agriculture affect their adoption of smart technologies

Two research participants in the study support (Syngenta Global, 2023). The following subsection provides an overview of the participants views.

a) Technical skills and knowledge

Several major agricultural producers like Nigeria, Guinea, and India are grappling with a scarcity of mechanization in their farming practices. The preference for conventional and rudimentary tools persists, overshadowing the adoption of modern machinery in the agricultural processes (Jiva.ag, n.d.). (Chuang et al., 2020) collected survey data from 321 farmers who participated in a Smart Agriculture training program and the results revealed significant and positive correlations between knowledge, perceived importance, and adoption behavior. The study found that lower adoption levels of Smart Agriculture technologies may be attributed to inadequate information, missing knowledge, lack of awareness of the technologies, and lack of perceived practical value.

One research participant stated that:

> *"Technical skills are important. When you are collecting this drone data you can get pictures which can literally just show you what is there but you can also get multi spectral images which then require some level of expertise for you to analyze them and identify whether the crop is stressed, be in a position to discriminate weeds from a crop and be in a position to estimate the soil properties.*
>
> *So those are things that maybe a constraint to some people who want to get into this space and those are things that will need to be addressed for drone technology to be fully deployed, particularly to assist small-scale farmers in improving their production.*

The second research participant reiterated the importance of technical knowledge of UAV technology:

> *"It depends on the form of education because you need to pass a certain exam for you to get accredited."*

The same participant also shared that:

> *"Some farmers are not educated at that level as compared to commercial farmers who are really equipped and have all the necessary resources to adopt drones."*

Participants views are aligned to the literature regarding the importance for farmers to be educated in the technical skilled needed to fully adopt and leverage the benefits of drone technology.

4.4.2 *Lack of modernization*

Literature in section 2.3.2 highlighted the importance of technology and modernization in addressing production loss on farms with Hertel et al., (2020) investigating how sluggish growth in farm productivity in Sub-Saharan Africa has brought to the fore the key role of agricultural technology in alleviating future food insecurity.

Table 3 outlines the frequency with which participants mentioned factors contributing to the lack of modernization. The data revealed three key factors, which will be elaborated upon in the subsequent subsections.

Table 3: Factors contributing to the lack of modernization.

Factors contributing to the lack of modernization	Frequency
The use of fixed wing aircraft and manned helicopters.	10
Limited access to small scale farmers	2
Low rate of technology adoption	1

a) The use of fixed wing aircraft and manned helicopters.

The continued use of fixed wing aircraft and manned helicopters was mentioned a total of ten times. Below are some of the sentiments shared:

> *"In my field of cane quality management research, the use of ripening chemicals is a very important part of sugar cane farming and over the decades these chemicals have been applied with normally fixed wing, aircraft, helicopters, micro lights, etc. so that's still the dominant way of doing it, especially in your large sugar cane fields."*

The same participant highlighted the limitations of fixed wing aircraft and manned helicopters:

“Because of the small field sizes and other land uses around the fields often things like trees and cattle, farming, vegetable farming, homesteads etc. it makes it impossible for fixed wing and helicopters to really operate in those environments. So currently, the small-scale growers are not reaping any of the benefits that the large growers are very often reaping from ripening using drones.”

An important consideration called out by multiple participants is the trade-off between precision and coverage when comparing UAVs to traditional methods of spraying based on the size of farm. One participant observed that:

“The disadvantage on the crop spraying side is, conversely, you're not able to cover the same large areas that, for example, manned planes or helicopters can cover. They don't spray as precisely, but they're able to do it especially for large areas more cheaply and much, much quicker at the moment.

The range of 10 to 100 hectares is where we generally are able to outcompete the manned craft because the manned craft cost of mobilization is far higher than ours so I think it is accessible to relatively small-scale farmers and I would say that's probably our biggest client base now rather than the industrial scale, 1000 hectare plus farms.”

Another participant put more emphasis on this trade-off when comparing the different methods of spraying to the other:

“If you take the fixed wing application or if you take an application method like a helicopter, they are obviously doing way more volume than we can do on a one-to-one scale but if you have five drones, then you can definitely compete with the aircraft or the helicopter.”

b) Low rate of technology adoption.

One participant spoke to the impact of the low rate of technology adoption, particularly related to use of drones for ripening in the small-scale sector:

> *"Although the small-scale sector is at the absolute bottom end of the adoption curve with regards to drones because it's a very new technology and there's a lot of hurdles in the small-scale sector that will first have to be overcome to get commercial implementation of drone ripening."*

Some of the hurdles to adoption of new technologies by small-scale farmers were identified by (FAO, 2023) as lack of capital such as access to credit and savings and market constraints like weak supply chains. Farmers and SMEs may be unwilling to change their farming practices, or they could lack vital information around the profitability of technologies. These barriers to adoptions are discussed in detail in a later section.

c) Limited access for small-scale farmers

Although the low rate of technology adoption impacts the agricultural space at large, as alluded to in the preceding subsection, the small-scall sector is at the bottom of the adoption curve.

One participant spoke to the missed opportunities experienced by small scale farmers as a result of limited access to drone technology:

> *"Because of the small field sizes and other land uses around the fields and obstructions such as trees and cattle, farming, vegetable farming, homesteads etc. it makes it impossible for fixed wing and helicopters to really operate in those environments. So currently, the small-scale growers are not reaping any of the benefits that the large growers are very often reaping from ripening."*

Another participant echoed a similar sentiment:

"With regards to small-scale farmers, we had a study in the Vembe district and one of our partners in the project was conducting a survey and even though the farmers appreciate and would love to have these gadgets for purposes of monitoring the crop and applying inputs, they are unable to afford drones."

The researcher noted how the participants made particular mention of the impact of low access to small-scale farmers in South Africa which may suggest a need address modernization or lack thereof by farm-size.

4.4.3 *On-farm limitations*

While the factors mentioned in the two preceding sections relate to the lack of knowledge by farmers and the impact of slow modernization and how it increases production loss, there are day-to-day factors that are experienced on farms which contribute to increased production loss. Table 4 below lists the factors that increase production loss as identified by the research participants.

Table 4: On-farm limitations that increase production loss.

On-farm limitations	Frequency
Pests and disease	5
Inefficient procedures	2
Manual crop inspection	2
Fragmentation	1
Lack of data	1
Lack of irrigation	1

a) Pests and disease

Four of the participants regard pests and diseases on farms as a crucial hinderance to increase output for farmers stating that:

"If I can take one for this crop diseases monitoring that we've done. we realize that yes, there are losses that are incurred, and crops are being affected by diseases, but it is only due to when farmers do not have adequate information."

“I know up in the North-West and that kind of area, they have a huge problem with locusts, and they are, are quite a pesky guy because they are so easily deterred by any movement.”

“Eldana is also a big problem for farmers In the sugar farms because the mill won’t grade their sugar cane as highly if it isn’t Eldana free. A lot of farmers don't spray Eldana and the guys that do, the cane is absolutely amazing compared to their competitor. “

Pests and diseases were mentioned the most frequently as limitation that contributes to increased production loss.

b) Inefficient procedures

Practices on farms that result in incorrect resource allocation and utilization and wastages in time or effort have been identified as contributing to production loss with participants stating that:

“Instead of spending thousands on spraying the whole area, they're now spending less and targeting those key areas so being able to use resources far more efficiently, especially when they're becoming more expensive.”

“When using a knapsack, you’re just spraying blindly and by the time you are finished, the disease would have spread.”

The data shows that by not adopting to more efficient practices, farmers will continue with non-directed approaches to managing diseases on their farms and spend more money than they would by adopting to the benefits of precision agriculture offered by crop spraying drones.

c) Fragmentation

Data collected highlighted the effects of fragmentation to farmers and how it contributes to production loss. One participant stated:

> *“The fields in the large-scale sector are usually quite uniform in size. It makes up blocks of several hectares that can be sprayed at once, whereas in the small-scale sector, it is often fragmented and it makes it less viable for an external contractor to build a sensible case to apply because of long transport distances and uncertainty in the current way in which small scale farmers, farm fields and growers are being recorded or documented. It makes it more difficult to build a business case for external contractors.”*

Research by (Lu et al., 2018) revealed that land fragmentation impacts crop yields by influencing the allocation of various agricultural inputs. The division of land into small and scattered plots not only raises the time required but also results in the loss of agricultural inputs during the transfer of plots. Additionally, these fragmented plots diminish the effectiveness of fixed assets, which are indivisible in agriculture. The increased presence of boundaries and ridges between these small and scattered plots leads to a decline in irrigation efficiency and wastage of time in agricultural operations, ultimately resulting in inadequate field management.

d) Lack of irrigation

Literature in section 2.3 by (Sikuka, 2019) noted that South Africa is a semi-arid country with a weak resource base for agriculture with only 12.5% of the land classified as arable highlighting the importance of irrigation. One participant supported the importance of irrigation in improving yields indicating that:

> *“… and we’ve seen that, particularly in areas where they do dry farming and do not use irrigation, they do not get the ideal yields per hectare that they expect to due to deficiency of moisture in the soil amongst other factors.”*

Water and irrigation management is therefore an important factor in ensuring crop health and increasing yields.

e) Manual crop inspection

One participant spoke to the missed opportunities of manually inspecting crops:

> *"You could survey a thousand hectares in the space of a week with multi-spectral imagery, thermal imagery, high resolution, visual and process that into reports and maps that you can use to make decisions on regarding the management of your crop and the farm.*

I would go so far as to say impossible to do that with manual inspection."

Another participant highlighted the negative impact of manual crop inspection in potato farming:

> *"You can't even walk into the field with some crops without running the risk of spreading diseases in that crop. Potatoes for example are very sensitive crops so even the farmers themselves will tell you that walking inside that crop is quite a huge risk as there are disease that can destroy the field within 4 or 5 days.*
>
> *This is where drones will then become useful for scouting the condition of that crop."*

Data from participants suggests that manual crop inspection impacts outputs on farms by being an inefficient practice that could also lead to the spread of disease.

The proceeding section focuses on ways in which UAVs can contribute to reducing production loss on farms.

4.5 Ways in which drones can help reduce production loss.

After investigating what participants perceived to be factors that contribute to increased production loss on farms in South Africa, the researcher sought to understand how drone technology can be introduced onto farms as a means of addressing production loss. This section presents the findings related to Theme 2 as presented in Figure 12 (p. 58).

4.5.1 *Data informed view of farm operations*

A similar approach as that adopted in the previous section was used to investigate the benefits offered by drones, the first being a data informed view of farm operations. The participants identified five benefits of a data informed view of farm operations.

Table 5: Data informed view of farm operations.

Data informed view of farm operations	Frequency
Analytics driven decision-making	13
Data collection	11
Real-time data	2
Clear imagery	1

a) Analytics driven decision-making.

The benefits offered by analytics driven decision-making were mentioned a total of thirteen times. The following excerpts illustrate the findings:

> *"…Those guys are now basing some of their decisions such as whether to put lime or whether to put nitrogen on the soil based on the kind of information that they can derive from drone data."*

> *"It's also how we use data analytics to inform our spraying. That is something that is non-existent in any other competing method of spraying."*

> *"You could survey a thousand hectares in the space of a week with multi-spectral imagery, thermal imagery, high resolution, visual and process that into reports and maps that you can use*

to make decisions on regarding the management of your crop and the farm."

"There is an exception and that's that with crop spraying where the drone is actually performing the end service, which is spraying pesticides or herbicide on the crops but in saying that our data analytics do inform our crop spraying, so for us it's an aerial platform that's a means to an end. That end is either actionable data analytics and reporting and, or crop spraying."

"Drone data itself is useful for purposes of crop monitoring but in our case, as researchers, we use it to collect high resolution data which we can use for developing algorithms that can be upscaled to satellite level and thereby be in a position to generate information at regional level."

"Once you can get that information, be it at tillage stage, that information can be processed to reveal the amount of nitrogen content in the soil, to indicate the Ph of the soil that can be very useful to a farmer in making decisions."

Insights from the research participants strongly indicates that the ability to make analytics-driven decisions using drones is important on farms in South Africa.

b) Data collection

Data collection as a benefit provided by drones was mentioned eleven times and indicates that drones are a more inventive way of enabling data to be collected and that farmers appreciate the information that they can derive from drones. The following excerpts provide more detail:

"We got access to collect data and it's enough to make some exploration to how useful drones can be in the management of the farm."

“The level of data you get is unmatched. It's not even matched by satellite, which is much lower resolution so that's a huge advantage”.

“I must mention we were working on a production farm that belongs to private individuals… We got access to collect data and it's enough to make some exploration to how useful drones can be in the management of the farm.

One participant spoke to the cost-comparison versus other methods of collecting data:

“We are able to price competitively and get much higher quality data than you ever really were able to get.

The level of data available to farmers which allows them to make more informed decisions on their farms has been increased with the progression of drone technology and is highlighted by one participant:

“Ten years ago, it would have been impossible to get data to the level of precision that we have now with drone platforms."

c) Real time data

The benefit of having access to data in real time was mentioned twice. The following excerpts illustrate the findings:

“With the introduction of UAVs, it means that information is gathered in real time and that information can be shared with farmers in real time and they'll be able to implement the measures, and this will increase their yields as compared to other sensors such as Sentinel and Landsat”.

“With UAV’s, you are able to check in real time. You don't have to wait for the revisit of the satellite which means information is passed through to the farmers and they'll be able to use that information… We're using the UAV imagery which can be able

to inform the farmers in real time what kind of diseases they might expect so that if they add pesticide or if they are to filter."

The data suggests that the ability to access data in real time empowers farmers with the ability to detect diseases early and proactively implement measures to prevent further spreading on farms.

d) Clear imagery

One participant mentioned the below with regards to the clear imagery provided by drones:

"That ability to get down to a plant-by-plant level with drone technology and especially for people whose farms are too small to come up on the satellite imagery clearly enough."

The imagery provided by drones is of a higher resolution than satellite and this is extremely beneficial to small-scale farmers by empowering them with information that allows them to employ more efficient agricultural practices.

4.5.2 *Enhanced efficiency*

In addition to offering a data informed view of farm operations, data collected supports UAV technology and its ability greatly enhances efficiency on farms. Efficiency on farms refers to the ability to achieve the highest level of output given a set of inputs, such as land, labour, and resources (Gaviglio et al., 2021). Table 6 indicates the frequency that contributors to enhanced efficiency were mentioned by participants.

Table 6: Enhanced efficiency

Enhanced efficiency	Frequency
Speed & Efficiency	40
Precision	23
Cost-effectiveness	21
Cost reduction	7
Technological advancement	7
Ease of use	4

a) Speed and Efficiency

Speed and efficiency can contribute to improved efficiency on farms by reducing waste and increasing productivity. The ability of drone technology to improve speed and efficiency was mentioned the greatest number of times and some of the insights from participants included:

“Drones provide an opportunity that you can meet the farmer's goals of getting more yields, but you do so in a more efficient and inherently environmentally friendly way.”

“I do think that we've got to feed people and we've got to feed people more efficiently and with more environmental awareness and these the drones are providing the opportunity.”

“There is a perfect example of improving efficiency and reducing unnecessary loss and damage and targeting what you want and that that's perfect.”

“Instead of spending thousands on spraying the whole area, they're now spending less and targeting those key areas.”

“It provides them with the ability to monitor the crop as it grows, and that's important in in making sure that you have a good quality product at the end of the season and secondly, you are using the resources available to you efficiently”.

“Using UAVs is more efficient, if you are dealing with large area as compared to manual methods which take longer, even days, but using UAVs is much quicker and you are then able to detect diseases early and you are not spraying haphazardly”.

“It's much more efficient, it’s faster and your results are a lot better compared to when you spray with a tractor.”

“We spray a lot more hectares per month than before we had the drones.”

One participant spoke to the efficiency offered by drones in the sugar industry when ripening cane:

“In terms of crop sugar cane production, ripening is the last step that happens in a relatively short time before harvest and the chemical that small scale growers would most likely use typically gets applied anything between 6 and 9 weeks before harvest and at that point in time your sugar cane crop is very tall already. This makes it very difficult to apply ripener and you need this very specialized hand boom that is very tall…

…with your drone you can spray much bigger areas because with hand booms it's very hard work and you dependent on labour which often, with your small-scale growers is costly.”

The speed and efficiency offered by drones are not limited to on-farm activities such as spraying and disease detection but extend to surveying and data collection. One participant highlighted this:

“You could survey a thousand hectares in the space of a week with multi-spectral imagery, thermal imagery, high resolution, visual and process that into reports and maps that you can use to make decisions on regarding the management of your crop and the farm.”

From the data collected, speed and efficiency were mentioned the most frequently of all the benefits offered by drones. What is also important to note is the innovation in the UAV space that will continue to make the technology more efficient than it currently is. The excerpt below highlights the outlook of innovation that will contribute to increased efficiency:

“In the next few years, we will have the ability to swarm which means to fly up to three craft from one specific ground station

with one pilot and that will triple your efficiency. That excludes all the efficiency, battery, and hardware improvements that the crop spraying drones are getting updated with on an annual basis at the moment."

b) Precision

A study by (Muscad, 2023) found that farmers using precision technology saw a 4% increase in crop production, 7% increase in fertilizer placement efficiency, 9% reduction in herbicide and pesticide use, and 6% reduction in fossil fuel use. Precision was mentioned 23 times, and the excerpts below provide additional insights related to the precision of drone technology:

"Using multispectral cameras and all the various software and algorithm programs that are showing where the plants are stressed and show you where to target the solution so your crop scout can go and see what that problem is."

"Instead of spending thousands on spraying the whole area, they're now spending less and targeting those key areas so being able to use resources far more efficiently, especially when they're becoming more expensive".

"Sometimes you realize that the whole field is not affected but they are particular spots where there are pests or where diseases are attacking. We can guide the UAV to go to certain places which makes the mitigation and prevention very easy".

"The drone is more precise. When it says it sprays 30 litres per hectare, you get 30 litres per hectare. With a knapsack you can't tell if a guy sprays what he says he did."

"With crop spraying drones, what you're really getting is a much better application of your specific chemical compared to any traditional means. That's compared to tractors, manual spraying, aerial fixed wing, or manned helicopter spraying."

“You're getting coverage to the leaf's edge. You can spot spray and exclude areas that don't need to be sprayed and there's very little pesticide drift because you’re so close to the tree or the crop canopy.”

The benefits to large scale sugar cane growers were highlighted by one participant:

“So that's a huge benefit to some of the bigger large-scale growers. They are tapping in on much more refined precision agriculture way of cane quality management that were not possible previously.”

The excerpts above highlight how precision agriculture, particular with the use of drones, has allowed for more precise application of water, fertilizer, and chemicals, reducing waste and environmental impact on farms. Figure 13 below shows the pesticide utilized to fend off wattle which grows between the gum trees on forestry operation where observations were conducted.

Figure 13: Poquer 120 EC Pesticide

Source: Author

c) Cost-effectiveness

The cost-effectiveness of UAV technology was mentioned a total of 21 times and supported research by (Rejeb et al., 2022) which noted that compared to traditional methods and aircraft, drones are highly cost-efficient and easy to set up. Below are excerpts from the research findings:

> *"You don't want them to waste money on input costs that are not needed. So that's where we see ourselves as the big role player towards sensible adoption of some of their own ripener".*

> *"With information of this nature, you can customize the application of inputs and by so doing you are more likely to reduce the cost of input application, because you only apply in areas where there is a need and avoid the wastages."*

> *"We are able to price competitively and get much higher quality data than you ever really were able to get."*

“With cabbages and the more edible fresh produce, a lot of big commercial farmers need to start looking at adopting more financially viable options like using unmanned aircraft.”

Ownership of drones versus the use of contractor services was mentioned by numerous research participants and is presented as a separate subsection later in the paper. One participant mentioned that:

“It's probably more affordable if you're getting somebody to come in periodically when you need them, as opposed to investing in them fully for your own farms, especially for subsistence farmers”.

Another participant highlighted the cost-effectiveness of drones outside of agriculture:

“It's just been amazing watching what the Ukrainian government has been doing with drones that we can buy off the shelf. This isn't military drones that are millions upon millions of dollars. These are a couple of $100 drones that they're using.”

Data from research participants notes the cost-effectiveness of adopting drone technology for farmers but also emphasises the cost of ownership compared to utilizing external service providers. This is discussed as a subsection later in the paper.

d) Cost reduction

The reduction in operational costs that is realized by implementing UAV technology on farms mentioned seven times. Below are some excerpts:

“The operational cost of running the farm is now reduced and you are monitoring the crop so at the end of the day, you want to send a good product in terms of quality to the market. That is the benefit that I see for emerging farmers who are trying to get into a position where they supply the market.”

“Whether it's reducing the production cost of water, or whether it's the chemicals that are being used for insect or other pests. 10% to 20% seems to be around about the general statement that I've seen from for a variety of crops and in some cases, maybe getting a bit closer to 30%, but I would say 20% was around about the average. That money saved was of great benefit.”

“In all the growth stages of the crop you can be supplied with information as a farmer and be in a position to minimize the cost of production and increase your output at the end of the season.”

“It'll have a massive effect on our operational efficiency and ultimately the margins that we're able to make which allow us ultimately to bring down the prices and make us more competitive on a hectare-by-hectare basis compared to traditional means of spraying.”

One participant who is an experienced researcher and program manager highlighted the financial benefits of drone spraying from trials conducted in the sugar cane industry:

“There was an unsprayed portion and then a drone sprayed part and we contracted a drone company to do the spraying for us and then we compared the benefit of drone ripening in an economic sense between the unsprayed and sprayed part of the field and then used the yield information to work out a basic gross margin in terms of rand per hectare benefit.

We considered the yield advantage that the grower got in the drone ripened part of the field but also factored in what the cost of application was, the contractor costs for harvesting the field, *transporting the sugar cane to the mill and used that information to work out a rand benefit from ripening.*

The range of benefit in these 16 demonstration trial fields, ranged between around R1,600 up to R9,000 per hectare benefit."

The reduction in costs was noted by numerous participants and supports research by (Rejeb et al., 2022) which noted that drones are highly cost-efficient and easy to set up compared to aircraft, making them a practical investment for farmers.

e) Technological advancement

The advancements in drone technology across both the hardware and software have been noted as contributing to enhanced efficiency on farms. Participants highlighted the following:

"Drone technology is advancing at an extremely fast pace in terms of payload capacity, precision, battery efficiency."

"We are developing an app for disease detection and we're using the UAV imagery which can be able to inform the farmers in real time what kind of diseases they might expect."

"We feel technology is advancing towards drones as it improves efficiency."

"Drone hardware and software has shown huge advancements over the last five years, and it's become a really reliable and feasible tool as a replacement a lot of traditional survey and inspections where five years ago it would be an unknown for companies wanting to adopt drone inspection and surveying to where it's the norm now."

"The rate of advancement that we saw about five years ago in drones in terms of the flight time, obstacle avoidance, precision

and the payload capacity, we're now seeing in the crop spraying drone development space."

Drones equipped with multispectral sensors have the capability to swiftly scan vast, extensive fields, collecting data that farmers can leverage to enhance crop health and increase yields. This technology minimizes the need for manual labour and improves the decision-making process for farmers.

f) Ease of use

The usability of drone technology was mentioned four times with participants articulating that:

"The new models come out frequently. The parts are easily accessible, and the software is user friendly. "

"The system that we are using is very easy and user friendly. It's easy to navigate and to understand the intricacies on how to operate it effectively because flying a UAV is quite simple once you get the hang of it".

Although the ease of use of drone technology has been highlighted as offering benefits that increase efficiency, the importance of education on drone technology was emphasized by one participant:

"It's ease of use for them as it is for us, I think that a lot of farmers and people in agriculture are just needing the education behind the technology that the drones possess rather than another form of aircraft that is actually manual and can cause human error compared to a technological error".

Ease of use of technologies can reduce the learning curve and increase efficiency by ensuring that users can get more done in less time with fewer errors.

4.5.3 *Improvement to harvest and yields*

This section focuses on the benefits offered by drones that improve the harvest quality and output yield on farms. Table 7 lists the benefits mentioned by participants.

Table 7: Improvements to harvest and yields.

Improvements to harvest and yields	Frequency
Increased yields	11
Improved harvest quality	3

a) Increased yields

Increased yields as a benefit of drone adoption on farms was mentioned a total of eleven times, below are some excerpts:

> *"Drones provide an opportunity that you can meet the farmer's goals of getting more yields, but you do so in a more efficient and inherently environmentally friendly way."*

> *"The value that drones are bringing to enable people to increase their yields is being shown. Often when I give presentations, I'm specifically trying to find the evidence and there are indications that, especially at subsistence level, which is where the majority of farming takes place, especially in Africa, they are having benefits by significantly improving yields."*

> *"When you're looking at commercial farming. It often seems to be 10 to 20% improvements in yields".*

> *"The farmers in the beginning of the season don't really get good RVs (returnable values) on the sugar because of the wet in Natal. About 90% of the farmers that I have seen have actually improved their RVs between 1.5% and some guys up to 3% on average which is absolutely extraordinary".*

Findings from the research support those of (Croptracker, 2023) which found that drones capturing field data help farmers plan their planting and treatments to achieve the best possible yields, and using precision farming systems has the potential to increase yields by as much as 5%.

b) Improved harvest quality

The potential of drones to improve the quality of harvest for farmers was highlighted three times with participants noting that:

> *"The quality of the cane has increased so the sucrose levels have risen quite substantially between 2% and 3%".*

> *"I've observed how ripening of sugar cane crops add huge profitability to farmers in the large-scale sector. Without that the growers are often highly susceptible in terms of struggling to get good crop maturity and overall good quality at harvest "*

(Monteiro et al., 2021) stated that aerial images captured by drones can be used to monitor crop maturation, identify potential issues, and provide early warnings about deviations in growth rates or crop quality. This allows farmers to proactively put measures in place such as applying ripener as observed in the sugar cane industry.

4.5.4 *Improved on-farm practices.*

The previous subsections discussed the benefits obtainable by drones by offering a data informed view of farm operations, the ability to greatly enhance efficiency on farms, and how harvest quality can be improved, and yields can be increased. In this section, the fourth subtheme under the benefits offered by drones is discussed, the ability to improve practices on farms that contribute to reducing production loss. Table 8 illustrates the subthemes identified.

Table 8: Improved on-farm practices.

Improved on-farm practices	Frequency
Crop spraying	22
Crop monitoring	11
Early detection of pests and diseases	10
Crop ripening	8
Access to complex terrain	7
Field mapping	6
Reduced environmental impact	5
Soil monitoring	4
Water savings	2
Stock taking	1

a) Crop spraying

The benefits of crop spraying offered by drones resonated with five of the participants and was mentioned a total of 22 times. Below are excerpts related to the use of drones for crop spraying:

"What it basically does is that it stunts and actually kills the growth point of the sugar cane so it can't grow taller, it just grows fat and produces more sugar."

"We have two spray seasons between around August to the first week in January. We spray for a pest called eldana and it pulls into the sugarcane and eats away from the inside, so we spray pesticide."

"If you watch the UAV on a field compared to a helicopter or plane, they have GPS, so they follow the flight routes, but they are manually opening and shut and overriding the shutoff for the chemicals whereas ours is completely GPS coordinated."

One participant spoke to the comparison of spraying with drones compared to manned helicopters:

"You watch a helicopter, and those guys are going at 150 to 200 Kms/h and when they are opening and closing the gates, there's a lot of spray and they're having to leave a 10-metre

border around some of the fields because if there's young cane next to mature cane, they don't want to ripen the young cane and then have to cut it. It's not viable for the farmers.

When you watch, especially the Agras T30 from DJI which has got 16 nozzles, when it gets to the end of the field, the front nozzles switch off and the back ones come on, making sure that the aircraft gets the exact amount correlating to the speed as it gets to the end of the field."

Another participant mentioned the ability of drones to spray over vast areas of land:

"We are not limited to 100 hectares by any measure. We've sprayed well into the few hundred hectares just in the last couple of months".

Although drones have been proven to be of benefit for crop spraying, one participant mentioned that some farmers still use previous, less modern means of spraying:

"The use of ripening chemicals is a very important part of sugar cane farming and over the decades these chemicals have been applied with fixed wing, aircraft, helicopters, micro lights, etc. so that's still quite the dominant way of doing it, especially in your large sugar cane fields."

The ability of drones to apply chemicals with better precision than previous methods was echoed by multiple participants and supported by research by (Iost Filho et al., 2019) which found that drones offer advantages such as ease of deployment, reduced operator exposure to pesticides, and potential reduction of spray drift.

b) Crop monitoring

The ability to monitor crops aerially using drones was mentioned eleven times with participants highlighting the following uses of UAVs:

> *"Using multispectral cameras and all the various software and algorithm programs that are showing where the plants are stressed and show you where to target the solution so your crop scout can go and see what that problem is. That facility is undoubtedly having a benefit."*

> *"We have also been using drones to study the crop at various growth stages where we look at wheat infestation at the biomass accumulation and we intend to further use it for purposes of monitoring crop nutrient stress, disease stress or water stress".*

> *"When the crop emerges, you need information to see where the crop emerged and where it hasn't then you can do re-planting. As it grows you need to monitor for weeds and where you see problems of wheat infestation, you can identify those in early enough and then apply herbicide".*

One participant in the research field spoke to the investment that their institution will be making towards crop monitoring drones:

> *"In our case investing in higher resolution, powerful drones that have different sensors, be it. hyper spectral, Lidar and other sensors will be beneficial in developing algorithms that can be used for crop monitoring in the country."*

Another participant, also in the research field mentioned the following regarding the missed opportunity of not leveraging the data collected by crop monitoring drones:

> *"In crop disease monitoring that we've done. we realize that yes, there are losses that are incurred, and crops are being*

affected by diseases, but it is only due to when farmers do not have adequate information. They will see that their produce is not up to the tonnes that they expected, but sometimes they do not know.

c) Early detection of pests and diseases

A study by (Upadhyaya et al., 2021) found that drones equipped with various sensors, such as those for soil moisture, electrical conductivity, and surface temperature, have been utilized to identify diseases and pests, contributing to the reduction of overall agricultural production costs and increased production efficiency. The below excerpts from research participants further highlight the use of drones for early detection of pests and diseases:

“I see drones, with the more efficient and effective use of water, catching problems early so that the loss isn't so great”.

“It has been shown in different locations around the world for example, where farmers are picking up unhealthy plants early and identifying opportunities then to either stop the spread and replant or do something else. They're getting an early warning system so that they don't lose almost the whole crop and then have lost time to be able to replant and recover from that loss.”

“So, it's the early warning data that I believe is really helping with farmers reducing their production loss and equally being able to use what resources they have more efficiently”.

“As the crop grows you need to monitor for weeds and where you see problems of wheat infestation, you can identify those in early enough and then apply herbicide.”

“We're using the UAV imagery which is able to inform the farmers in real time what kind of diseases they might expect so that if they add pesticide”.

d) Crop ripening

The importance of crop ripening, especially in sugar cane was highlighted by (Gigi, 2020) who spoke to a trial conducted in the Midlands South region of Kwazulu-Natal that found that crop-spraying drones over selected sections of a sugarcane farm resulted in a small yet significant increase in recoverable value in the ripened areas, indicating the potential for improved crop quality and yields. Excerpts below from data collected further reiterate the benefits of crop ripening using drones in the sugar cane industry:

> *"The use of drones for applying ripening chemicals has increased mostly in the large-scale grower sector. We've also been doing a project that I've completed last year, where we demonstrated to small scale sugar cane growers the potential of using crop spraying drones for their own spraying needs. It is a new area and we've been busy with projects in that space for about the last 3 years".*

> *"I've observed how ripening of sugar cane crops add huge profitability to farmers in the large-scale sector. Without that the growers are often highly susceptible in terms of struggling to get good crop maturity and overall good quality at harvest which then largely impacts profitability".*

The ability to reach over the sugar cane when it reaches a certain height compared to previous methods of ripening is highlighted below:

> *"The problem with knapsacks is that in terms of crop sugar cane production, ripening is the last step that happens in relatively a short time before harvest and the chemical that small scale growers would most likely use typically gets applied anything between 6 and 9 weeks before harvest and at that point in time your sugar cane crop is very tall already".*

The cost of ripening using drones as a reason for slow adoption with small-scale farmers was mentioned by one participant:

“One must consider the input cost aspect with the small-scale growers that already financially struggling, and they've only got X amount of money to spend on input costs. That is a very real issue because we can promote the drone ripening in the small-scale sector and that's going to cost the farmer.

Typically, the amount a farmer will have to spend on ripening of a field would be in the range of about R500 per hectare which is not so much but that's an additional cost that we are expecting the small-scale grower to spend money on.”

Drones have proven to be beneficial to farmers in the sugar cane industry by contributing to the ripening of their crop which increases their harvest quality as well as their profit.

e) Access to complex terrain

The ability to access terrain that may be challenging by foot or tractor has been one of the many benefits reaped by farmers who have adopted drones on their operations. (Tripicchio et al., 2015) highlight the effectiveness of drones in providing farmers with a bird's eye view of their fields, enabling precise evaluations and collection of data while remaining close to the terrain. Access to complex terrain as a benefit offered by drones was mentioned seven times, some of the excerpts are below:

‘He uses part of the land for farming maize and then part of it for grazing but there are trees on his undulating terrain so it's not possible to get manned aircraft data spread accurately. The terrain is very difficult for site workers with backpacks and poison to come spray.”

“There are also situations where fields in the KwaZulu Natal coastal belt which has a lot of very steep topography and very steep hills which made conventional spraying with helicopters very challenging and dangerous so those are the micro niche areas where drones are very capable of spraying.

“Because of the small field sizes and other land uses around the fields often things like trees and cattle, farming, vegetable farming, homesteads etc. it makes it impossible for fixed wing and helicopters to really operate in those environments so currently, the small-scale growers are not reaping any of the benefits that the large growers are very often reaping from ripening.”

“There's often a problem with lodging in the field, so you will find that some stalks start to lean against each other or even topple over and that makes it impossible to walk within the field with a boom system… This makes it very difficult to apply ripener and you need this very specialized hand boom that is very tall because you need to spray the droplets at the top so they can be intercepted by the green leaves at the top of the canopy. There are booms in existence and they're not very expensive, but it is also not a very practical system when the sugar cane crop gets tall”.

“Potatoes for example are very sensitive crops so even the farmers themselves will tell you that walking inside that crop is quite a huge risk as there, a disease that can destroy the field within 4 or 5 days. This is where drones will then become useful for scouting the condition of that crop.”

“I know some guys in the Free State used to use knapsacks and they also sometimes use tractors but that's only if the field aren’t too wet because then the tractor gets stuck.”

A study by (Varela-Jaramillo et al., 2023) emphasizes the significance of drones in reaching threatened and understudied species in inaccessible terrains, demonstrating their capability to access remote and challenging environments which supports the data collected from research participants.

f) Field mapping

The need to properly map fields and the ability of drones to provide this benefit was highlighted six times with participants mentioning that:

> *"The small-scale production areas are often like a black box because field sizes and locations are very seldom properly mapped geospatially so there will have to be some mapping of small-scale areas, so that small scale regions can be grouped together".*

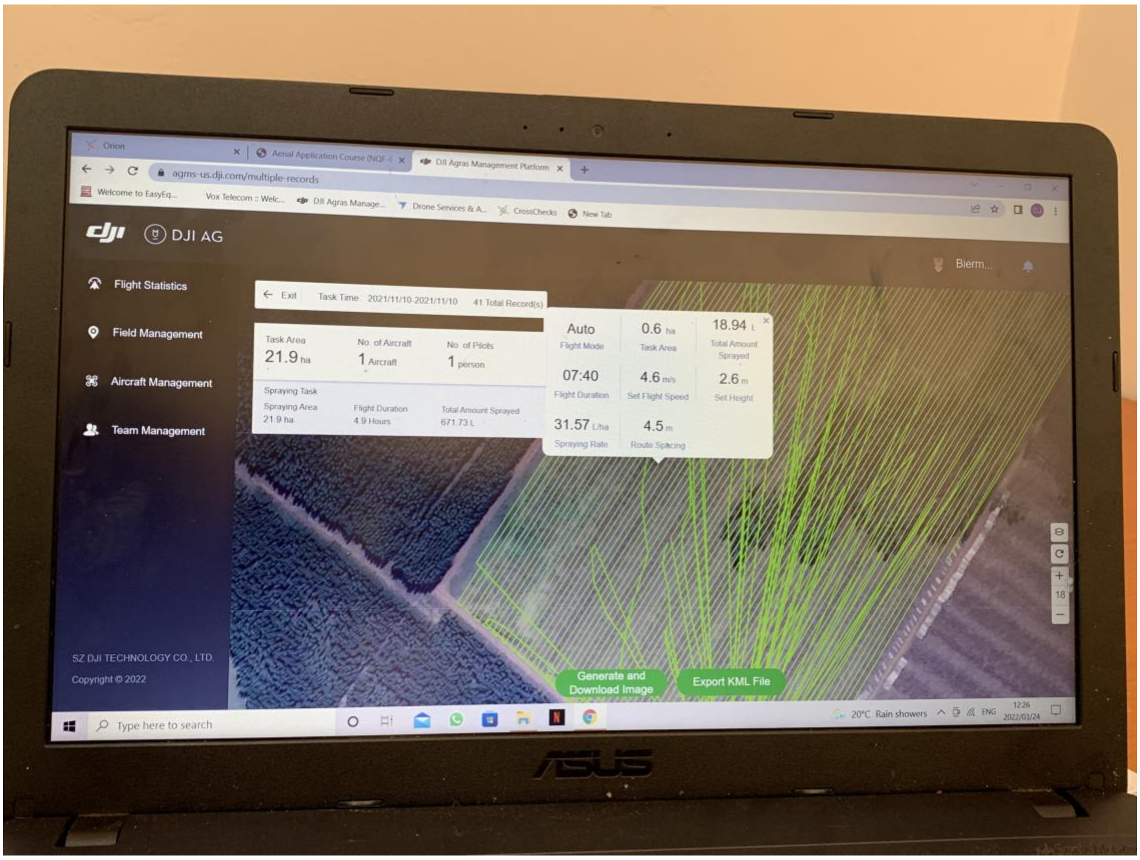
> *"We mapped it out, so we had precise centimetre grade maps for the area which fed into our crop spraying drone and it was one application and it took care of the entire woody encroachment problem that the farmer had at the time."*

> *"The fact that we're able to map and identify an area that's highly targeted, currently plagued with a pest infestation and we're able to identify that on our analytics that feed into the crop spraying drone and instead of spraying 200 hectares prophylactically, we're able to spray 12 hectares and solve the pest infestation problem for the farmer."*

> *"We're also able to use a system called RTK (real-time kinematics), which is even more accurate and basically allows you to map a field or a particular area in a 3D model. The drone can then pre-empt any obstacles for the flight path of the field."*

Data collected is in in line with research by (Al-Khowarizmi et al., 2022) which found that the ability to map land allows farmers the benefit of understanding the conditions on their farms and make more data-informed decisions. Figure 14 below highlights the field mapping abilities of the DJI drone.

Figure 14: Field mapping abilities of DJI drone



Source: Author

g) Reduced environmental impact.

(Borikar et al., 2022) found that the application of drone systems for spraying pesticides in advanced agriculture have shown to reduce the efforts of farmers and provide more accuracy and faster operation, contributing to reduced environmental impact. Excerpts from research participants below highlight their perceptions of the environmental impact of drones on farms:

> *"I see the drone as a way of working for farmers to meet their goals without compromising their farms from an environmental perspective. Often when people are told to be aware of the environment, it changes what they want to do".*

> *"I just think that that's one of the major tools with which to improve their income, improve their stability and equally do so without necessarily being so environmentally destructive".*

"It's an important tool in agriculture and of course there's a conservation interest because of my environmental background but I do think that we've got to feed people and we've got to feed people more efficiently and with more environmental awareness and these the drones are providing the opportunity".

Drones offer farmers are more environmentally friendly method to monitoring their crops and applying pesticides without having to physically make contact with soil and plants as would be the case with tractors and manual crop inspection. Chemical usage is also reduced by targeting only affected areas as opposed to spraying entire fields which is not environmentally sustainable.

h) Soil monitoring

Sensors in drones allow for nutrient content, moisture levels and overall soil health data to be collected. The ability to monitor soil from the sky was highlighted four times with some of the excerpts below:

"Once you can get that information, be it at tillage stage, that information be processed to reveal the amount of nitrogen content in the soil, to indicate the Ph of the soil that can be very much useful to a farmer in making decisions, whether to put lime, and how much of it to put in there".

"Sometimes they do not get the ideal yields per hectare that they expect you to due to deficiency of moisture in the soil amongst other factors".

"We also measure soil nutrients and also to inform them through stakeholder engagement so that when they prepare, they put enough quantities of fertilizer so that their crops will be able to grow."

(Sofia et al., 2023) conducted a pilot which found that the use of drone-based multispectral remote sensing combined with soil sampling has been shown to enhance drought monitoring and provide valuable insights into soil properties which was also found in the data collected by the researcher.

i) Water savings

With South Africa being a semi-arid country, consistent availability of water is of importance to farmers. Research participants stated the below:

> *"When you're looking at commercial farming, it often seems to be 10 to 20% improvements of yields or improvements of cost savings or water savings, but when I've seen the evidence that's popped up from a subsistence level, you're talking 30, 40 or 50% in some cases and that's massive".*

> *"I see drones, with the more efficient and effective use of water, catching problems early so that the loss isn't so great, and the measures that are taken aren't so bad".*

Drones play a role in ensuring water savings through various means such as the ability to detect leaks in irrigation systems and drone spraying systems which can reduce water usage by up to 96% compared to conventional spraying methods (Azevedo, 2021).

j) Stock taking

One participant who has experience as a registered drone pilot said the below:

> *"You can also do stock taking, counting wood in the stock yards and also count trees in the field".*

(Qubaa et al., 2022) conducted research using the Phantom 4 DJI which found that the potential of drones for stock taking in agriculture is further bolstered by utilizing UAV-borne hyperspectral and satellite multispectral images for quantitative assessment of soil properties and vegetation indices, which can facilitate comprehensive stock taking and monitoring of agricultural lands.

4.6 Factors promoting, limiting, or moderating adoption.

The factors contributing to production loss on farms and the benefits offered by drones were discussed in the preceding sections. This section presents the findings related to theme 3 as outlined in Fig. 12, pg. 58, namely the factors that promote, moderate, or limit the adoption of drones on farms. A total of 11 factors were identified and are listed in Table 9 below.

Table 9: Factors promoting, limiting, or moderating adoption.

Factors promoting,limiting or moderating adoption		Frequency
Enabling factors	Entrepreneurship (+)	4
	Access (+)	4
	Positive feedback (+)	3
Limiting factors	Cost of mobilization (-)	10
	Unrealistic expectations (-)	6
	Education (-)	4
	Industry resistance (-)	4
	Affordability (-)	3
	Risk aversion (-)	1
Moderating factors	Regulations	21
	Cost-benefit analysis	9

4.6.1 *Enabling factors*

Three factors were highlighted by research participants as factors that have the potential to improve adoption of drones in agriculture: Entrepreneurship, access, and positive feedback.

a) Entrepreneurship

The impact of entrepreneurship was mentioned four times. The following excerpts provide more detail.

"They must get licensed as pilots, they buy the drones, they take the upfront risk on the equipment, but they can get their own clients, they set their prices, and we manage their compliance. We found that that has allowed us to scale to probably the biggest fleet operator of crop spraying drones in South Africa."

"I saw an opportunity to get into the agricultural market with unmanned aircrafts because I had a background in it, and I

made the plunge and phoned Warren and Austin about all the legislative stuff and the company actually started running legally in the beginning of the year."

"I'm the director and the founder of a company called InDesign Projects and I'm also the main pilot. We're looking to expand, and my responsibilities are to find the aircraft and making sure as well that we're within the legal recommendations."

(Wang, 2019) identified entrepreneurship as a means to stimulate growth in research and development (R&D) capacity through knowledge spill over, thereby promoting productivity growth. The impact of entrepreneurship on adoption was further highlighted by (Pambudy, 2018) who stated that entrepreneurs are well-positioned to make informed decisions in emerging technology industries that exhibit high levels of technological uncertainty, facilitating the adoption of new technologies.

b) Access

Increased access to drone technology was identified as another factor that can contribute to the increased adoption of the technology in agriculture. Participants mentioned the following:

"It's important that there's a way in which people can have access to this technology and skill and that's what a lot of people are trying to think and talk about now is how do we democratize, how do we open this environment up through the legal frameworks?".

One participant who is an entrepreneur in the drone industry is giving other emerging entrepreneurs an opportunity to enter the space thereby increasing access to the technology for farmers. The excerpt below explains:

"We don't have drones and pilots all over the country and with that what we found is the best way to expand given capital constraints was to allow people who want to start a crop spraying business to operate underneath our license and what

that means is that instead of them having to wait two and a half, three years for a license at a great expense, we can have them operational in eight weeks.

One participant felt that there is no need for every farmer to have a drone.

"I personally don't think every farmer should have a drone, but I believe that it would be helpful that farmers have access to information that's collected by a drone and so long as it's supplements getting other information. Sometimes it's easy to think drones are the answer to everything, and they're not."

Data from other participants and related to different subthemes such as cost-benefit analysis, use of external contractors and cost of mobilization also suggest that drone adoption may not be suited to every farm based on the size of their operation.

c) Positive feedback

Positive feedback and recommendations based on personal experience has been identified as a contributing to the increased adoption of drones. Below are excerpts from data collected:

"What we found is the common trend is that every single farmer across crops, wheat, oats, canola, sugar and invasive species control, every single farmer has given us positive feedback on the quality of their application, and we have repeat customers and I think that tells a very good story in itself for a new technology and a new method of spraying."

"Every single client we've had in crop spraying has given positive feedback and we've got repeat work from a lot of those clients."

(Ntshangase, 2018) found a positive corelation between the positive perceptions among farmers and higher adoption rates of agricultural technology. A study by (Michels et al., 2021) also found that the intention to use drones has a positive effect on the actual adoption of drone technology, highlighting the role of positive feedback in driving adoption.

4.6.2 *Limiting factors*

Six factors were identified as limiting the rate of adoption of drones with research participants communicating the following:

a) Cost of mobilization

The cost of mobilization was mentioned most frequently as inhibiting the rate of adoption. The cost of mobilizing varies based on the type of drone, the tasks it has to perform and the size of farm. Research participants stated the following:

"One must consider input cost aspect with the small-scale growers that are already struggling financially, and they've only got X amount of money to spend on input costs. Typically, the farmer will have to spend on ripening of a field would be in the range of about R500 per hectare which is not so much in terms of other input costs but that's an additional cost that we sort of expecting the small-scale grower to spend money on."

"There's a, a company that's about 100 km's away from where some of these farmers were and they were charging R8000 ferry costs to here and then R8000 back. That's before they had sprayed any fields, so the farmers were incurring major costs when it comes to those kinds of crafts."

Other participants also highlighted the impact on small-scale farmers:

"We have a minimum of about ten hectares or at least we need to, if we do less than ten hectares, we need to bill for a

minimum of ten hectares. That's to cover our fixed costs of mobilization."

"It's very difficult for us to service smallholder farmers currently without any kind of sort of grant or government subsidy for mobilization cost of anything roughly below ten hectares comfortably so, 10 to 100 hectares is typically our operating range at the moment."

The proximity of farms adds to the cost of mobilization limiting access to farmers in more isolated areas that are further out from urban centres:

"The logistics of providing drone support in subsistence areas is interesting because it's going to cost the service provider to travel. One of the comments that was also made was that the logistics of using drones, it becomes an expensive service because you've still got to get people into these remoter areas."

One participant who had previously mentioned that farmers stand to realise upwards of 20% in increased yields stated the below:

"I imagine the cost of implementing the drones is not as close to 20%, so they're still making a net gain after covering the cost of using the drones versus what they get back in savings."

Data collected suggests that although drones offer a plethora of benefits, the cost of mobilization makes the adoption not financially viable to all farms.

b) Unrealistic expectations

A further limitation to adoption of drones in agriculture is farmers not fully understanding the technology and expecting more than what drones can offer. Below were concerns raised by participants:

“If there's a danger, I would hate for people to feel that drones are the absolute answer and there's nothing else that's needed. It's got to be part of a toolbox of responses.”

“There's still a perception that one drone is going to solve everything and that's not quite true. You've got different types of drones, you've got different sensors that they utilize different types of information, different conditions under which they can fly.”

“You really can't buy one drone and think you're going to solve all of your problems and unfortunately, that is often a way in which they're marketed.”

“There's certain farmers that will just flat out say they can do it cheaper with their tractors or they're area is so big and they need it done in a time frame that we couldn't possibly complete at the moment, like a week for a thousand hectares.”

The excerpts above highlight the importance of managing expectations with farmers in order to ensure that they do not expect immediate results and universal solutions from drone technology.

c) Education

Education as a limitation to adoption of drones was mentioned a total of four times, participant sentiments included:

“There's quite a strong education component and upskilling the small-scale farmers in making the right decisions in terms of spraying or not, because you also don't want them to waste money when they are already struggling economically.”

“In terms of what we at SASRI can do and need to do is the education part because often when people get a new technology, they take a blanket approach and just want to go out and spray all their fields with ripener.”

“they're kind of wary of technology so educating them on the benefits and actually physically showing them the results is what is going to be able to grow the industry.”

A study by (Paltasingh & Goyari, 2018) found that education plays an important role in enhancing farm productivity and promoting the adoption of modern agricultural technology and this was further purported by (Kadir & Prasetyo, 2022) who studied the level of education and its significant impact on the probability of farmers being adopters of agricultural technologies. The findings emphasize the importance of addressing the educational needs of farmers to facilitate the successful adoption of agricultural technologies, including drones, and to enhance farm productivity and sustainability.

d) Industry resistance

The introduction of drones in agriculture has faced some resistance based on perceptions around the cost, complexity, safety concerns and resistance to change. Participants expressed the below:

“What we do know just from our conversations with the Civil Aviation Authority and other operators is that there's definitely pushback from the manned crop sprayers in an attempt to protect their industry. They’re not all too happy about the foray of drones, crop spraying drones into their traditional territory. It's as with any new industry, when you threaten an incumbent, you're going to have some you're going to make some people grumpy.”

“There has been a lot of hesitancy in the markets over the past five years when it comes to replacing traditional means of surveying whether that's land surveyors on the ground or manned aircraft.”

(Jawad et al., 2019) conducted a study which found that perceptions related to the costs of drones and their associated technologies, limited flight time, power consumption, and communication distance have been highlighted as barriers that hinder the adoption of drone technology in the agriculture industry.

e) Affordability

The ability for farmers to afford the implementation of drone technology was highlighted a total of three times and should be a key consideration in light of the socio-economic conditions that exist in South Africa. Participants expressed the following:

> *"With regards to small scale farmers, we had a study in the Vembe district, one of our partners in the project was conducting some kind of survey and even though the farmers appreciate and would love to have these gadgets for purposes of monitoring the crop and applying inputs, they are unable to afford drones."*

> *"The disadvantages in the crop spraying space specifically is price for large areas is we are more expensive."*

Although there is an acknowledgement that drones are by no means cheap, it is important to compare the cost to other means of spraying. One participant stated the below:

> *"I live In a farming community, Umtumzini in the north coast of KZN and most of the farms are either macadamia or sugar. Guys are having problems with the plane, not meeting demands, not being accurate enough, the helicopter just being way too expensive for them to get up and the ferry costs being exuberantly expensive."*

(Zailani et al., 2021) discussed how the economic potential for drone usage in agriculture is weighted on factors such as decreasing prices and increasing lifespan, which can significantly impact adoption rates, particularly in developing nations.

f) Risk aversion

Literature by (Villacis et al., 2021) indicates that less risk-averse farmers are more willing to adopt new agricultural technologies. Risk aversion has a significant role on the adoption of drones with one participant highlighting the following:

> *"You can't blame someone for not wanting to just go out there and invest money without really having the proof. That's not a good businessman and that's what farmers are, they're businessmen and women so information about what is being achieve on other farms is critical."*

One of the factors that positively impact the adoption of drones was identified as positive feedback and data collected suggested that information sharing, and word of mouth may help risk averse farmers in making decisions regarding adopting drones.

4.6.3 *Moderating factors*

Two moderating factors that can either enhance or limit the adoption of drones based on numerous variables have been identified in the research. Regulations were mentioned a total of 21 times and cost-benefit analysis 9 times.

a) Regulations

Research participants mentioned the following regarding the impact of regulations on the rate and speed of adoption of drones:

> *"The space is highly regulated, so I imagine by the time you get your license, you are aware of your responsibility as a drone operator."*

> *"The regulations are important, don't get me wrong. I's unfortunate that it can be very tough in some cases, but the point being is that they're there for a reason and most of it is to keep you safe, to keep you from hurting other people or interrupting others."*

“The registrar regards drones as an aerial application method so drone operators must adhere to the aerial application specifications on the agro chemical product labels so people often think that a drone is now a silver bullet, and that you can just deviate from label specifications, and I think that's a obviously a worry to many people.”

One participant acknowledged South African laws as being less restrictive than other countries:

“South Africa has very strong regulatory framework and unlike other countries where they're still banned, it's a bit more relaxed in South Africa.”

The importance of regulation on increased access was mentioned:

“It’s important that there's a way in which people can have access to this technology and a lot of people are trying to think and talk about how we democratize, how we open this environment up through the legal frameworks while keeping everything safe.”

Cross-collaboration and information-sharing between law makers and stakeholders in agriculture in encouraged in South Africa, one participant stated the following:

“Yes, there is a forum with the Civil Aviation Authority. They're changing the name from RPAS, Remotely Piloted Aircraft Systems to Uncrewed Aviation Systems. There is a committee that enables the discussion between various groups within the authorities and within the industry.”

The slow pace of policy making compared to rate of technology development was called out twice:

“As with any Aviation Authority around the world, it’s a slow process compared to the pace at which drones are developing

and the pace at which the authorities anywhere around the world are changing it. They're not compatible.”

“We are very constrained on the regulatory side. The pilots don't just need to be licensed pilots, they also need to hold a pest control operating certificate from the Department of Agriculture, which takes at least six months to get off supervision under another pest control operator and as such, it's very difficult to find and retain and train up crop spraying pilots. So that's a constraint we have.”

Although regulations have been recognized as necessary for the drone industry to ensure safety and correct application of the technology, the speed of policy making, and the cost of licences have been noted as being restrictive to adoption of drones in agriculture.

b) Cost-benefit analysis

Before choosing to adopt drone technology, farmers generally compare the benefits they will potentially derive versus the costs incurred. Research participants expressed the following:

“Some of the subsistence farming in other parts of Africa, are competing with resources being given over to biofuel productions so we can only afford a certain amount and when you can only have access to a certain amount you want to make sure you use it well and drones are providing an opportunity for that.”

“There’s still the cost element, but the benefits that are coming from those farmers that have adopted the early adopters are worth it. “I took a chance and I have seen benefits come out of this and I wish I'd use them earlier.”. These some statements you will get.”

“it's not necessarily more cost effective, but the benefits might outweigh the cost.”

"It's a cost versus efficiency thing. So for example, a farmer that would hand ripen is going to find it way cheaper because all he's going to pay is three guys labour for a day or two and if he bought equipment, the pump and stuff, they need about R30,000 to do his whole farm."

One participant mentioned how small-scale farmers are impacted by other elements in the production system compared to large scale farmers:

"There are discrepancies in return-on-investment because large scale growers usually have very organized harvesting schedule operations in place where small scale growers are often at the mercy of inefficient systems which are factors that are completely out of their control."

Although drone technology is more expensive than traditional manned crafts, the benefits in speed, efficiency and accuracy will be factors that farmers should consider when making the decision to adopt the technology.

4.7 Chapter Summary

The data analysis process began with the transcription of 7 interviews, one which was conducted in person during observations and six which were conducted virtually. The interview transcripts resulted in a total of 72 codes. These codes were then merged into 42 codes and ultimately nine subthemes. As shown in Figure 12 (p. 58), the three main themes derived from the data collection process were *factors contributing to production loss on South African farms, ways in which drones can help reduce production loss, and factors promoting/ or limiting adoption.*

Factors that impact agricultural efficiency and contribute to production loss on farms in South Africa were identified. The data indicates that a plethora of challenges from technical limitations due to inadequate technical skills and knowledge among farmers, to the utilization of outdated aerial technologies such as fixed-winged aircraft and manned helicopters and limitations experienced on farms such as pests and diseases and lack of irrigation were highlighted by research participants.

Participants spoke to 22 ways in which drones can help reduce production loss on farms with speed & efficiency, precision and crop spraying resonating the most with most across all participants. The data collected shows that drones improve on-farm practices at higher efficiency than traditional methods and improve either the quality of harvest or the output yield for farmers.

Adoption of drone technology and the various factors that either limit, promote or play a mediating role in the adoption of drones was discussed and the findings from this subsection provide a Segway to the proposed solutions of this study.

The next chapter discusses the study's findings in relation to the research questions outlined in the first chapter. The chapter will also describe the study's contribution to both theory and practice, its limitations as well as suggested recommendations for future research.

CHAPTER 5. DISCUSSION OF FINDINGS, RECOMMENDATIONS AND CONCLUSIONS.

Chapter outline:

The purpose of this chapter is to:

- Reiterate the research questions in the study.
- Summarize the main findings in relation to each research question.
- Present the main findings of the study and their relation to each research question.
- Discuss the implications of the study's findings and provide recommendations for agricultural sector stakeholders.
- Acknowledge the limitations of the study, and
- Offer recommendations for future research.

5.1 Introduction

The previous chapter introduced the findings that were derived from analysis of the data collected. This chapter makes interpretation of the findings in Chapter 4 and their implications for theory and practice for stakeholders in the agricultural industry.

The chapter begins by reemphasizing the purpose of the study and revisiting the initial research questions proposed in Chapter 1 of this research paper. The chapter proceeds to summarise the main findings of the study and their relation to each research question; namely, the factors that contribute to production loss and impact output yields on South African farms, how Unmanned Aerial Vehicles can help South African farmers reduce production losses on their farms and the factors that promote or limit adoption of UAVs on South African farms. The implications of the study's findings are discussed and recommendations for the agricultural industry proposed. The limitations of the study for both researchers and agricultural stakeholders are acknowledged and the chapter is concluded with recommendations for future research.

5.2 Summary of Findings

It is important to revisit the study's purpose and the research questions that guided the investigation in order to fully position the study's findings. The study sought to investigate how UAV technology can address production loss on farms in South Africa. To guide the research, the following research questions were outlined:

1. What factors contribute to production loss and impact output yields on South African farms?
2. How can Unmanned Aerial Vehicles (UAVs) help South African farmers reduce production losses on their farms?
3. What are the factors that promote, limit or moderate adoption of UAVs on South African farms?

In response to the research questions, the study found several causes that are contributing to increased production loss on farms and identified various ways in which drones can help in reducing losses. The findings also revealed that there are factors that are limiting adoption of drones and those that can be put in place to increase adoption of the technology. The following sub-sections provide a summary of these findings.

5.2.1 *Factors contributing to production loss on South African farms.*

The first research question sought to understand the factors that contribute to production loss. As postulated by (Despoudi, 2021), challenges in reducing food losses at producers' level include:

I. lack of technology adoption.
II. lack of understanding of the changing market requirements and the changing regulations.

III. lack of farm-related skills and the need for modern agricultural practices.
IV. collaboration issues.
V. the impact of climatic change.

The study found that research participants experienced similar challenges in their respective roles in the agricultural industry which are categorized under three subthemes. The first subtheme identified in the data was farmer knowledge or the lack thereof with participants expressing that drone technology requires a degree of technical knowledge and skills to not only operate, but to fully benefit from the data and imagery collected. A further concern is that this lack of skills and knowledge affects the small-scale farmer more than it does commercial farmers who either have the education or have access to training on modern agricultural practices. These views are consistent with (Syngenta Global, 2023) who found that limited technical knowledge may hinder farmers' ability to invest in and effectively utilize agricultural technologies, such as precision farming tools and data-analysis apps, which can enhance productivity and sustainability.

Lack of modernization was identified as increasing the impact of production loss on farms. The most frequently mentioned concern by research participants was the continued use of fixed-wing aircraft and manned helicopters for functions such as crop spraying and ripening. These traditional aircrafts do not favour farmers with small land sizes and mixed-use agricultural operations who must consider various crops, obstacles such as trees and livestock when spraying ripening agents, largely due to the inaccuracy of these aircrafts. Manned aircrafts are more favourable to large-scale farmers with a uniform crop as they can cover large areas in less time than drones, albeit at a compromised precision level. The study not only found that the low rate of technology adoption is increasing the impact of production loss but that it impacts small-scale farmers the most as they sit at the bottom end of the adoption curve. The data aligns to the findings of (Wamala et al., 2017) who studied the impact of agricultural modernization on the socio-economic status of smallholder farmers in Uganda and found that small-scale farmers often use traditional and obsolete practices, which can lead to low crop yields and, consequently, limited economic improvement.

Research participants made mention of the limitations experienced on farms as inhibiting the output potential of many operations. The most common hinderance from the data collected was pests and diseases which range from locusts in the North-West province which are easily deterred by any movement to Eldana in sugar farms in Kwazulu-Natal. It was also highlighted that the losses incurred are because of poor crop disease management due to lack of information on the farmer's end. Inefficient procedures such as the use of knapsacks and spraying fields blindly, fragmentation of farms which often leads to the increased presence of boundaries between scattered which results in inadequate field management, lack of irrigation which leads to moisture deficiencies in the soil and manual crop inspection which is highly time consuming and increases the risk of spreading diseases in crops such as potatoes were identified in the data as contributing to increased losses on farms. Participants views are supported by the third point in the research by (Despoudi, 2021) which identified lack of farm-related skills and the need for modern agricultural practices as a challenge to reducing losses on farms.

5.2.2 *Ways in which drones can help reduce production loss.*

The second research question in the study focused on ways in which UAVs can help reduce losses incurred on farms. The following section summarises the study's findings in relation the benefits offered by drones for farmers.

Research participants identified the valuable insights drones can provide in making data-informed decisions as key to reducing losses on farms. Drones can survey hundreds of hectares and provide high-definition images which can be processed into reports and maps that are used to for data-analytics and algorithm development that can be upscaled to satellite level. The imagery collected by drones is of a higher resolution than satellite imagery which is of benefit to small-scale farmers whose farms are too small to clearly appear on satellite images. Farmers are now able to get a real-time view of diseases they might expect and determine how much and what kind of fertilizer to use based on soil-based data derived from drones compared to platforms such as Sentinel and Landsat. Data from the study is consistent with findings by (Monteiro et al., 2021) who concurred that drones allow for the collection of aerial images which can be used to monitor fields, assess crop health, and detect potential issues, thereby providing valuable data for farmers.

Participants identified enhanced efficiency as a benefit farmers could derive from drones. Drones can spray over large areas of land in less time than manual methods and in a more environmentally friendly way. The multispectral cameras and various software are able to show farmers where exactly plants are stressed and instead of spending time and financial resources spraying an entire field, farmers now have the ability to precisely target the problem and get detailed reports on the amount of pesticide used. This level of efficiency and precision in crop spraying is unattainable by utilizing tractors, manual spraying, fixed-wing aircraft, or manned helicopters and contributes to increased cost-effectiveness as farmers can now customise and control their inputs based on areas that need to be addressed, reducing wastages and input costs. The operational costs of farms are decreased by adopting drone technology by reducing water and pesticide usage which has a positive impact on the profit margins realised. These benefits will continue to be realized as drone technology continues to see advancements in payload capacity, battery efficiency, and both hardware and software. These findings are aligned a study by (Daponte et al., 2019) which demonstrated that drones provide real-time monitoring, precision agriculture and data collection for crop and livestock farming which results in improved crop management and improved resource utilization.

Data highlighted the ability to improve yields on farms in a more efficient way. Research participants spoke to seeing improvements of 10% to 20% on commercial farms after adopting drones and improved returnable values of between 1.5% to 3% in the sugar cane industry. Apart from an increase in returnable values, the harvest quality which is measured by sucrose levels had risen 2% to 3% because of crop ripening agents applied by drones.

Drones have the ability to either conduct or contribute to a wide spread of practices on farms in a more efficient and modern way. Data from the study identified the capability to conduct crop spraying based on pre-determined flight routes as a more modern way of spraying compared to prior methods. The ability to monitor stress or water stress is greatly improved by the high resolution, hyper spectral and Lidar sensors found in drones and pests and diseases are able to be detected early and measures taken to prevent spreading. The sugar cane industry in Kwazulu-Natal has seen improvements in the ripening process since implementing drones compared to previous, less modern practices such as the use of hand booms. Research participants noted the ability of drones to access complex terrain where manned aircraft or site workers may not be able to as a contributor to reducing loss on farms. Steep topography and obstacles such as trees, homesteads and livestock and the risk of diseases being spread by workers walking through fields deem drones the best option for those farms. The practice of field mapping has been greatly improved with drones as farmers are now able to have centimetre grade maps and use this data to not only identify areas of concern on their farms but also pre-empt any obstacles for the flight path of the drone. Data highlights the drones ability to reveal the amount of nitrogen content in the soil and to indicate the Ph of the soil is imperative for soil monitoring. Drones are also able to detect leaks in irrigation systems and conduct stock taking of various trees and crops which further enhances efficiency on farms in South Africa. (Gao et al., 2020) found that UAVs can capture images of farmland using spectral camera technology, which can be analysed to detect the occurrence of pests and diseases in crops and (Khan et al., 2021) explored how UAV-based spraying systems employing machine learning techniques are a recent advancement in precision agriculture for precise spraying, promoting saving chemicals (pesticide/herbicide), and enhancing their effectiveness. These findings are consistent with data collected in the study.

5.2.3 *Factors promoting, limiting, and moderating adoption.*

The third research question sought to the explore the factors that promote, limit, or moderate the adoption of drones in agriculture. This study found that entrepreneurship and access to the technology had a positive impact on increasing adoption of drones with business owners scaling their operations across the country and making the technology more accessible to the agricultural sector by allowing emerging entrepreneurs to operate under their licence which has them operational in eight weeks compared to the two to three years they may wait if applying for licencing on their own. Data also highlighted the importance of positive word of mouth on increasing awareness of the technology and increasing the intent to use drones by farmers.

Findings show that participants consider the cost of mobilization as the biggest limitation to adoption of drones, more so with small-scale farmers who are more concentrated in subsistence areas and size of their operations, deem them to not be financially viable for drone operators. Participants mentioned that ferry costs are charged per kilometre to get out to farms and that they must bill for a minimum of ten hectares to cover the fixed costs of mobilization. Unrealistic expectations of drones being a silver bullet to every problem on farms and not as a part of a toolbox was highlighted as a hinderance to adoption with participants further highlighting concerns around the need to educate and upskill small-scale farmers on UAV technology. Data analysed pointed to industry resistance from manned crop sprayers in an attempt to protect their interests as threatening the rate of adoption in agriculture, this compounded by the risk aversion towards investing money into new technologies is limiting adoption in agriculture. Regulations and the cost-benefit analysis of adopting drones have been identified as moderating adoption and have the potential to either enhance or limit adoption. In certain instances, regulations have proven to be supportive of adoption with participants acknowledging how relaxed and encouraging laws in South Africa are compared to other parts of the world but also being slow and cumbersome at times. Farmers are businesspeople and the analysis of the costs incurred in adopting drone's comparative to the benefits derived could either encourage adoption if favourable or limit adoption if the farmer feels the costs outweigh the benefits. These findings on the limiting, promoting and moderating factors to adoption are consistent with findings by (Chuang et al., 2020) who noted that lower adoption levels of Smart Agriculture technologies may be attributed to factors such as inadequate information, missing knowledge, lack of awareness of the technologies, and lack of perceived practical value.

5.3 Implication of findings

The findings of this study have important implications for theory and practice. The theoretical and managerial implications are discussed next.

5.3.1 *Theoretical implications.*

The study derived theory related to both agricultural productivity and the acceptance and usage of technologies. With regards to agricultural productivity, the researcher chose New Growth Theory which incorporates the fundamentals of formal growth theory that expresses output growth as a function of growth in inputs and efficiency with which inputs are transformed into outputs. New growth theory incorporates growth as endogenous (through technical change, research and development and capability building activities) (Ogbeide & Ogbeide, 2015). The study has shown that all participants have a similar interpretation of the positive contribution that drones can make towards *productivity* on farms and as aligned to the principles in New Growth Theory, that endogenous factors such as *technological change* driven by *adoption of drones*, investment in human capital through *training and certification* of more pilots, *knowledge exchange* from commercial farmers to small-scale farmers, *increased competition* through acceptance of UAVs from manned craft operators and *government support* through subsidies and supportive legislative frameworks can significantly *increase productivity,* efficiency and *improve yields* and *harvest quality* on farms. As a result, the application of UAVs on farms aligns to the postulations of new growth theory.

The findings also indicate that participants perception of the factors that promote, limit or moderate adoption of drones in agriculture can be comprehensively understood by leveraging the principles of Innovation Diffusion Theory (IDT) which identifies numerous factors that facilitate or hinder technology adoption and implementation and provides a framework for assessing the likely rate of diffusion of a technology (Fichman, 1992). Data suggests that *entrepreneurship* has an imperative role in enabling adoption as outlined by (Ridha & Wahyu, 2017) and that increasing *access* to agricultural technologies significantly improves the welfare of farms, consistent with the views of (Belay & Mengiste, 2021). Participants identified the importance of *positive feedback* and word of mouth as a driver of increased adoption, in line with views by (Belcher, 2022) who found that agronomists, crop consultants, or other professionals who have knowledge and experience with new agricultural technologies play an important role in sharing their valuable insights and *recommendations* with stakeholders in agriculture based on their observations and expertise.

5.3.2 ***Managerial implications.***

This study investigates the role UAV technology plays in reducing production loss on farms in South Africa and the factors that influence adoption. The findings indicate that stakeholders in agriculture should:

- Focus on *small-scale farmers* who sit at the bottom-end of the adoption curve. Modernisation of agricultural practices has proven to significantly improve the welfare of rural communities but there are hurdles relating to high initial costs and lack of perceived benefits. Contractors are weary of servicing these operations as it is not financially viable for them based on the size and proximity of the farms which excludes a large percentage of the agricultural sector from the benefits of drones. Local contractor development should be encouraged through initiatives such as the Sugar Master plan that's agreed by government and Sugarcane industry which can allocate development funds towards such initiatives aimed at improving access for small-scale farmers.
- Address *affordability* through government incentives and subsidies which will help reduce the upfront costs of adopting drone technology. Small-scale farmers whose farm sizes do not justify either calling out a contractor or purchasing a drone themselves should explore collaborative agreements with neighbouring farmers to pool financial resources and purchase shared drones. This will also increase collaboration and knowledge exchange, improving the overall adoption of drones at large.
- *Government support*. Although the industry is *highly regulated* by aviation laws, government should encourage *collaboration* with industry

stakeholders and lawmakers to establish frameworks that continue to protect airspace but support innovation and increased, controlled use of drones in agriculture. Government should invest in *research and development* to not only improve UAV technology but *localize* the production of drones which will have a positive impact on the prices and address *affordability*. Lastly, government should drive *certification* of drone pilots through certified programmes with accredited institutions and subsidize *learning* and *training*.

- Improve farmers skills and knowledge as farmers need education and training on the effective use of drones and the benefits of drones such as improved efficiency, precision and profitability and share best practice and insights on how to best leverage the data derived from the technology on their farms. Training will also ensure that agricultural workers perceive drones as user-friendly and reduce their resistance to this new form technology.
- Promote *entrepreneurship* which will directly lead to new innovations in software and hardware, more affordable drones, and value creation for agricultural end-users of UAVs. Entrepreneurs have the potential to scale the technology by identifying underserviced areas by geography and have the expertise to conduct cost-benefit analysis and manage regulatory requirements, taking this responsibility away from farmers, who data in the study indicates, are still lacking the skills to conduct these practices.

5.4 Limitations of the study

The study employed a total sample size of seven participants, two drone pilots, two researchers, a crop physiologist and two entrepreneurs who are all based in South Africa. This limits the transferability of the study's finding to farms in other countries as variables such as the state of the economy and agricultural industry, climate and water conditions, and social and political dynamics could vary. The research employed semi-structured interviews and observations and consequently, the limitations related to these data collection methods apply to this study (see Section 3.6). Researchers in the future may use other qualitative data collection methods such as case studies and focus groups which will have the benefit of a larger sample size across different spheres of the agricultural sector. Quantitative data collection methods such as surveys and field trials which will enable future researchers to empirically test generalisability may also be employed in future research to better explore the use of drones in agriculture.

5.5 Recommendations for future research

Interviews were executed smoothly with all participants, but the researcher encountered participants who did not speak English as a first language and this limited the ability to probe further during interviews and in certain instances, participants struggle to articulate their points in as much detail as they would wish to, more especially with regards to the more technical aspects of drones. Researchers should consider language barriers and the possibility of a translator when conducting research going forward.

Future research should further explore the use of drones in agriculture or lack thereof and the impact on small-scale farmers who have the least access to modern agricultural practices and stakeholders in government who influence regulations and allocation of funding should be included in future research as their role in increasing adoption of the technology was highlighted repeatedly in the research.

5.6 Conclusion

The study revealed that the adoption of UAVs has the potential to reduce production loss on farms in South Africa. Farmers skills and knowledge, lack of modernization and on-farm limitations were identified as contributing to increased losses on farms and participants expressed optimism in drone technology to address losses through a more data informed view of farms, enhanced efficiency, and improved on farm practices such as crop spraying and ripening, soil monitoring and field mapping amongst other benefits. Factors that are either driving or limiting adoption of drones have been identified for future stakeholder to consider and, in conclusion, the South African agricultural sector could benefit tremendously by promoting the use of drones on farms in addressing production losses.

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APPENDIX A: PARTICIPANT INFORMATION SHEET

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

Dear Sir / Madam

My name is Mukanda Mukumela, and I am a master's student in Digital Business at the University of the Witwatersrand, Johannesburg. As part of my studies, I am undertaking a research project, and I am investigating the use of Unmanned Aerial Vehicles (UAVs) as a solution to food security in South Africa by reducing production loss on farms under the supervision of Professor Gregory Lee. The aim of this research project is to to underpin the use of UAVs on farms in South Africa. This research also aims to give insights into the current state of innovation within the South African agricultural sector with a particular focus on the adoption of UAVs and their contribution to reducing production losses incurred on farms.

As part of this project, I would like to invite you to take part in an interview and possibly a focus group discussion. This activity will involve answering five to eight open-ended questions and will take around 90 to 120 minutes. With your permission, I would also like to audio record the interview using a digital device. This recording will be stored in password protected computer and only the researcher will have access to this recording.

There will be no personal costs to you if you participate in this project, you will not receive any direct benefits from participation but there are no disadvantages or penalties if you do not choose to participate or if you withdraw from the study. You may withdraw at any time or not answer any question if you do not want to. The interview will be completely confidential and anonymous as I will not be asking for your name or any identifying information, and the information you give to me will be held securely and not disclosed to anyone else. I will be using a pseudonym (false name) to represent your participation in my final research report. If you experience any distress or discomfort at any point in this process, we will stop the interview or resume another time.

If you have any questions during or afterwards about this research, feel free to contact me on the details listed below. This study will be written up as a research report which will be available online through the university library website. If you wish to receive a summary of this report, I will be happy to send it to you. With your permission the data collected from this research project may be used by other researchers in an anonymized format. If you have any concerns or complaints regarding the ethical procedures of this study, you are welcome to contact the University Human Research Ethics Committee (Non-Medical), telephone +27(0) 11 717 1408, email hrecnon-medical@wits.ac.za

Yours sincerely,

Mukandangalwo Mukumela

Researcher:

Mukandangalwo Mukumela, Mukanda.mukumela@students.wits.ac.za, 066 395 7073

Supervisor:

Professor Gregory Lee, gregory.lee@wits.ac.za, (011) 7173626

APPENDIX B: LETTER REQUESTING PERMISSION TO CONDUCT RESEARCH.

University of the Witwatersrand,

Wits Business School

2 St David’s Pl &, St Andrew Rd,

Parktown,

Johannesburg,

2193

011 717 3544

15 June 2021.

Dear Sir/Madam,

Re: Permission to conduct research.

My name is Mukandangalwo Mukumela, and I am studying for a Master of Management in the field of Digital Business at the University of the Witwatersrand.

As part of my studies, I am conducting research on *Exploring the use of Unmanned Aerial Vehicles (UAVs) to reduce production loss on farms in South Africa* under the supervision of Professor Gregory Lee.

The research will entail collecting data from industry experts, farm managers and drone specialists.

I am hereby requesting permission to conduct an online interview with you. Approximately 30 to 60 minutes will be required, and responses will be recorded.

You will be asked to give written or verbal consent before the research begins and the results will be communicated as a research report which will be available online through the university library website.

The research participants will not be advantaged or disadvantaged in any way. They will be reassured that they can withdraw their permission at any time during this project without any penalty. There are no foreseeable risks in participating in this study. The participants will not be paid for this study.

All research data will be preserved anonymously for reuse by other researchers.

Please let me know if you require any further information. I look forward to your response as soon as is convenient.

Yours sincerely,

Mukandangalwo Mukumela

____

066 3957073

mukanda.mukumela@students.wits.ac.za

Professor Gregory Lee

(011) 717-3626

gregory.lee@wits.ac.za

APPENDIX C: LETTERS GRANTING PERMISSION TO CONDUCT RESEARCH

https://drive.google.com/drive/folders/1zVVYtO-cvT8cb2pld6Hbasg05pkm622l?usp=share_link

APPENDIX D: ETHICS CLEARANCE CERTIFICATE

Graduate School of Business Administration
University of the Witwatersrand, Johannesburg

Wits Business School Ethics Committee
Constituted under the University Human Research Ethics Committee (Non-Medical)

Ethics Clearance Certificate

Ethics protocol number: WBS/DB0713768M/369

This certificate is only valid with a legitimate ethics protocol number and signed by the Researcher (below)

This certificate is only valid if accompanied by formal permission from the relevant stakeholder(s).

Project title	Exploring the use of Unmanned Aerial Vehicles to reduce production loss on farms in South Africa
Investigator / Researcher	Mr Mukandangalwo Mukumela
Nature of Project	MM (Digital Business)
Decision of the Committee	Approved, provided stakeholders and participants are guaranteed confidentialty.
Issue Date of Certificate	2021-11-11
Expiry date	Date of submission of the project report
Chairperson	Prof Anthony Stacey ☎ +27 11 717 3587 +27 82 880 4531 anthony.stacey@wits.ac.za

Declaration by Researcher

One copy must be signed by the Researcher and returned to the Chairperson of the Wits Business School Ethics Committee.

I fully understand the conditions under which I am authorized to carry out the abovementioned research and I guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I undertake to resubmit the protocol to the Committee.

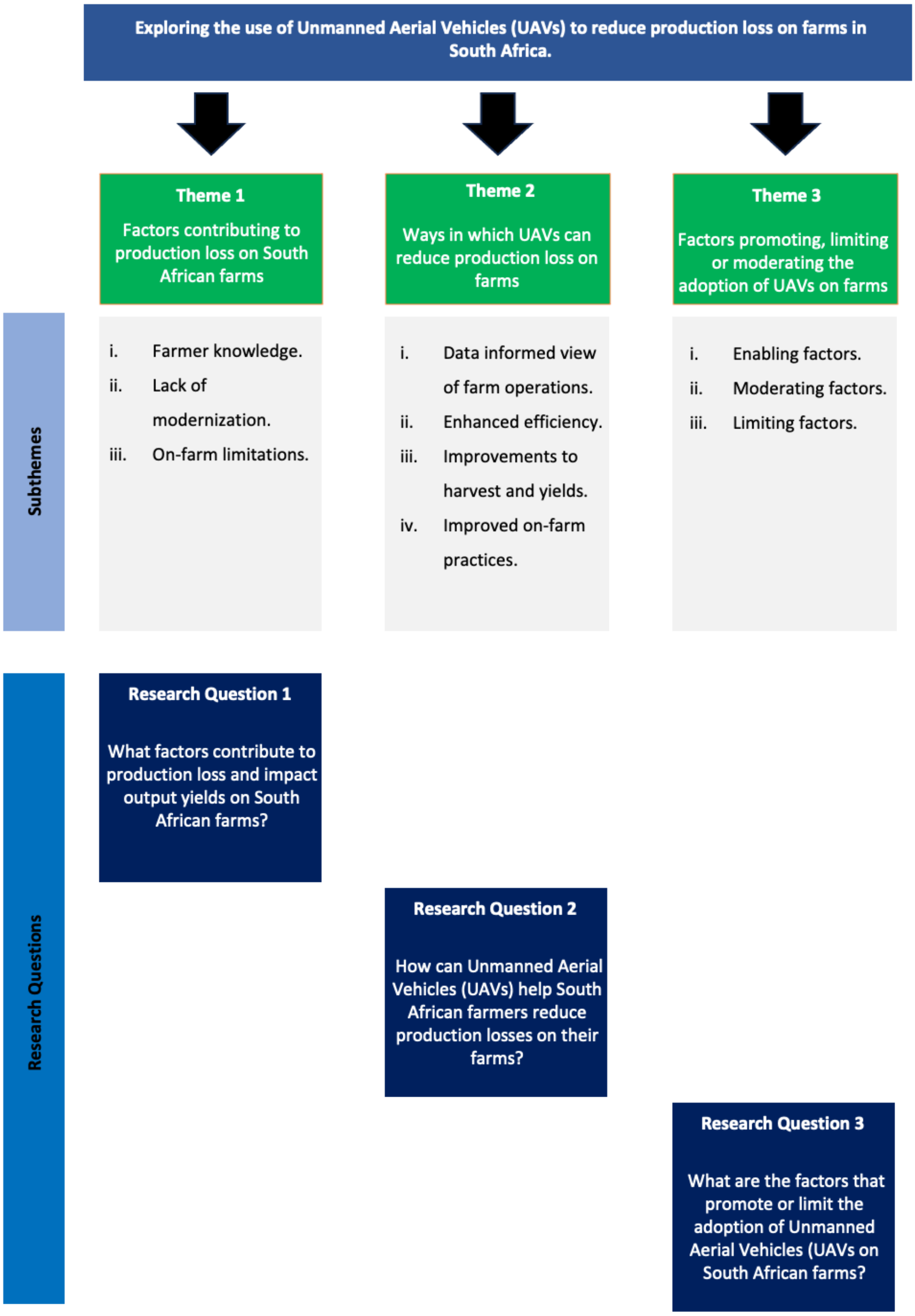
Signature

2021/11/21
Date:

APPENDIX E: INTERVIEW QUESTIONS

1. Could you please tell me more about your role within the organisation and what your responsibilities include?
    1.1. Probe question: What is your current job title?
    1.2. Probe question: How long have you been involved with the organisation?
    1.3. Probe question: How long have you been involved with the industry?
2. What is your experience with Unmanned Aerial Vehicles (UAVs) and their applications in agriculture?
3. Are you currently using UAV technology on your farm/any farms?
4. Have you experienced production losses on your farm/farms in the past? If yes, please provide some examples.
5. Did you use UAV technology to address the problem?
6. If yes, how would you rate the outcome?
7. Do you believe that UAVs can effectively address the challenges related to production loss faced by farmers?
8. What concerns would you have about implementing UAV technology on farms?
9. How would you rate the potential cost-effectiveness of utilizing UAVs to reduce production loss compared to traditional farming methods?
10. How likely are you to invest in UAV technology for your farm/farms in the next five years?
11. Do you have any suggestions or recommendations for improving the adoption and implementation of UAV technology in South African agriculture?

APPENDIX F: THEMES AND SUBTHEMES EMERGING FROM THE ANALYSED DATA



APPENDIX G: INTERVIEW RECORDINGS & TRANSCRIPTS

https://drive.google.com/drive/folders/1kb-aYg_IhDa8Gc9nnpbp81qFR43otlaq?usp=share_link

APPENDIX H: CONSISTENCY MATRIX

Exploring the use of Unmanned Aerial Vehicles (UAVs) to reduce production loss on farms in South Africa.							
Main Objective Here : To explore Unmanned Aerial Vehicles and how they can contribute to reducing production loss on farms in South Africa.							
Sub-Aims/Objectives	**Literature Review**	**Hypotheses /Propositions**	**Research questions**	**Variables(Independent & Dependent)**	**Source of data**	**Type of data**	**Analysis**
To investigate the factors that contribute to production loss and negatively impact yields.	Despoudi (2021)	Challenges in reducing food losses at producers' level identified as lack of technology adoption, lack of farm related skills, need for modernization and lack of understanding of changing market requirements.	What factors contribute to production loss and impact outputs on South African farms?	MV1= Production losses DV1= Farm outputs	Online and literature review Observations Questionnaire/ Semi-structured interview (Q3)	Primary and Secondary Data	
To expore the impact of UAV's towards reducing losses on farms	(Gao et al., 2020) (Khan et al., 2021)	UAVs have become popular in agriculture and allow for the capturing of images which are transmitted to the cloud for analysis and could prove effective in reducing production loss on farms.	How can Unmanned Aerial Vehicles (UAVs) help South African farmers reduce losses on their farms?	CV1= UAVs MV1= Production losses	Online and literature review Observations Questionnaire/ Semi-structured interview (Q2, Q4, Q5, Q6)	Primary and Secondary Data	Thematic Analysis
To investigate factors that promote and those that are currently hindering adoption of drones	(Chuang et al., 2020)	Lower adoption levels of Smart Agriculture technologies may be attributed to inadequate information, missing knowledge, lack of awareness of the technologies, and lack of perceived practical value.	What are the factors that promote or limit the adoption of Unmanned Aerial Vehicles (UAVs) on South African farms?	MV1= Factors impacting adoption DV1: UAVs	Online and literature review Questionnaire/ Semi-structired interview (Q7-Q10)	Primary and Secondary Data	
Drones, agriculture, technology, production loss, South Africa							

APPENDIX I: TURNITIN REPORT

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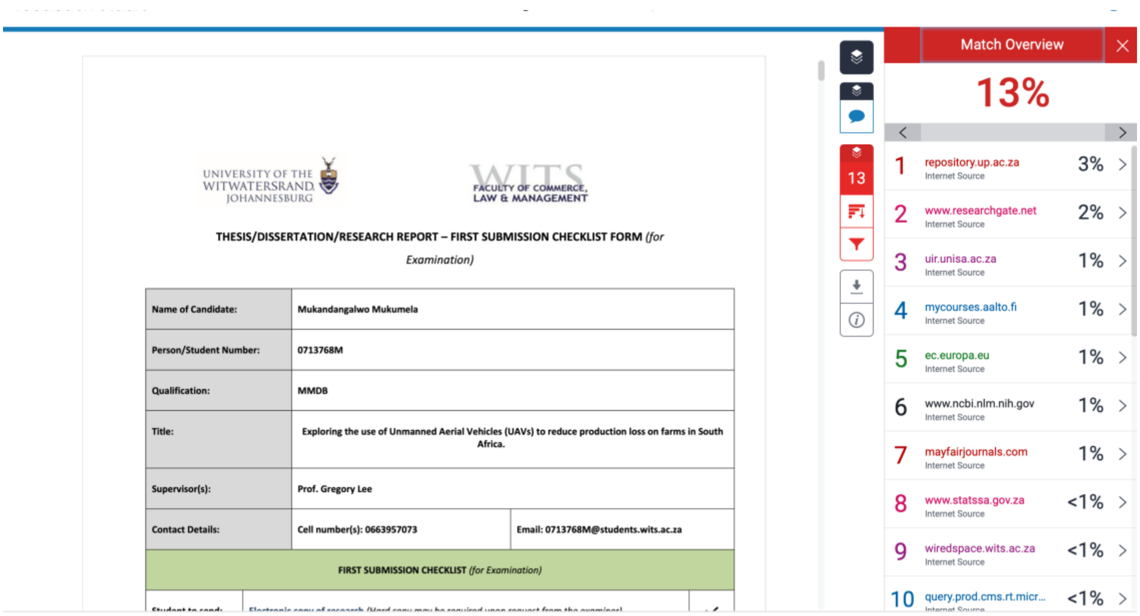

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

WITS FACULTY OF COMMERCE, LAW & MANAGEMENT

THESIS/DISSERTATION/RESEARCH REPORT – FIRST SUBMISSION CHECKLIST FORM *(for Examination)*

Name of Candidate:	**Mukandangalwo Mukumela**	
Person/Student Number:	**0713768M**	
Qualification:	**MMDB**	
Title:	**Exploring the use of Unmanned Aerial Vehicles (UAVs) to reduce production loss on farms in South Africa.**	
Supervisor(s):	**Prof. Gregory Lee**	
Contact Details:	**Cell number(s): 0663957073**	**Email: 0713768M@students.wits.ac.za**
FIRST SUBMISSION CHECKLIST *(for Examination)*		

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UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

WITS FACULTY OF COMMERCE, LAW & MANAGEMENT

THESIS/DISSERTATION/RESEARCH REPORT – FIRST SUBMISSION CHECKLIST FORM *(for Examination)*

Name of Candidate:	Mukandangalwo Mukumela	
Person/Student Number:	0713768M	
Qualification:	MMDB	
Title:	Exploring the use of Unmanned Aerial Vehicles (UAVs) to reduce production loss on farms in South Africa.	
Supervisor(s):	Prof. Gregory Lee	
Contact Details:	Cell number(s): 066395-7075	Email: 0713768M@students.wits.ac.za

FIRST SUBMISSION CHECKLIST *(for Examination)*		
Student to send:	Electronic copy of research *(Hard copy may be required upon request from the examiner)* **** WBS students are required to submit in MS Word format. All other schools must submit in PDF format.*	✓
	Full Turn-it-in Report *(signed by Supervisor)* **** For WBS Masters – this report does not require the Supervisor's approval ****	✓
	Confirmation of Ethics *(Clearance/Waiver certificate or declaration)*	✓
	Overall Supervisor Evaluation form *(MBA candidates ONLY)*	
Supervisor to send:	University Clearance Certificate *(Supervisor to complete and send directly to Faculty)*	
	Supervisor's Report *(Supervisor to complete and send directly to Faculty)*	
Faculty to check on:	Approved title and supervisor(s)	

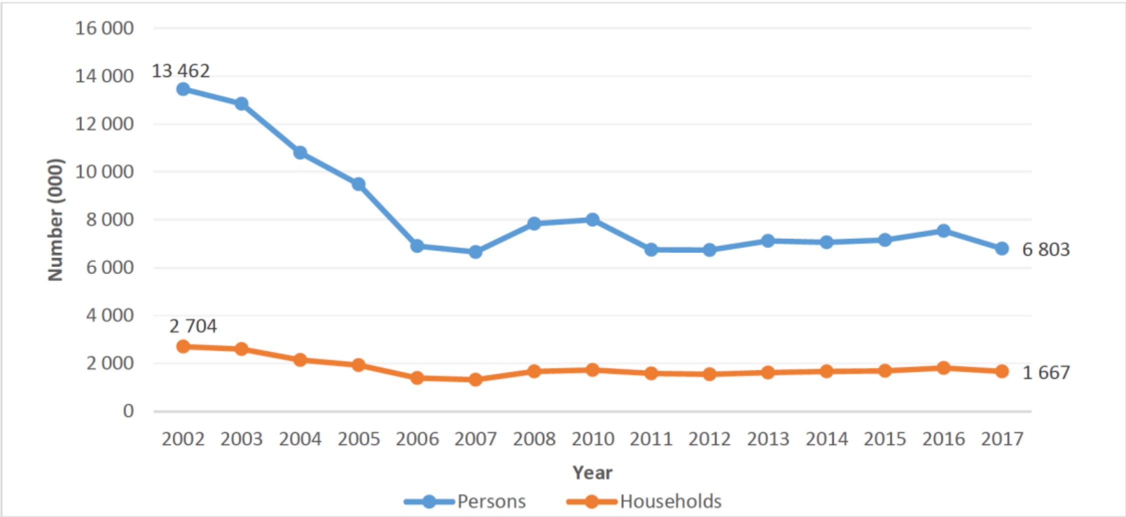
APPENDIX J: LITERATURE REVIEW ON FOOD SECURITY

5.1 The state of Food Security

Multiple factors have been placing unprecedented pressure on food systems: population growth, dietary changes, overexploitation of natural resources, increasing biofuels and biomass use, and climate change. Similarly, food security and sustainability are affected by economic, social, and environmental drivers (Campi et al., 2021). Currently, approximately one billion people (16% of global population) suffer from chronic hunger in a time when there is more than enough food to feed everyone on the planet. Food experts indicate that no one single solution will provide a sustainable food security solution into the future. In an attempt to meet the ever-changing nutritional requirements and preferences of consumers across the globe, the global agri-food sector is in a continual state of flux and restructuring (Oliveira et al., 2021).

The South African General Household Survey has been collecting data on experience of hunger since 2002. Figure 15 illustrates the number of households and persons who had experienced hunger in South Africa in the past 15 years. In 2002 there were 13,5 million South Africans who experienced hunger and this number dropped to 6,8 million in 2017 (Maluleke, 2019). Households that experienced hunger also decreased from 2,7 million to 1,7 million households within the same period.(Maluleke, 2019)

Figure 15: Figure 1: Number of households and persons vulnerable to hunger (2002 to 2017)



Source: Statistics South Africa, General Household Survey 2002-2017

5.1.1 *Global Food Security*

Mc Carthy et al., (2018) believe food security is both a complex and challenging issue to resolve as it cannot be characterized or limited by geography nor defined by a single grouping, i.e., demography, education, geographic location, or income. The authors highlight the concerns on food security and increasing food shortages for an ever-expanding world population and with a predicted increase of 1.7 billion in world population between now and 2050, mankind is placing more and more pressure on the shrinking finite resources used to produce our food.

Molotoks et al., (2021) further recognizes population growth to be the dominant driver of change in food security but also that climate change scenarios influence future crop yields. Global hunger has begun to rise, returning to levels from a decade ago and climate change is a key driver behind these recent rises. When coupled with population growth and land use change, future climate variability is predicted to have profound impacts on global food security.

Campi et al., (2021) investigates how developing an understanding of specialization patterns of countries in food production can provide relevant insights for the evaluation and design of policies seeking to achieve food security and sustainability, which are key to reach several Sustainable Development Goals (SDGs). The authors build bipartite networks of food products and food-producing countries, using FAO data from 1993 to 2013, to characterize the global food production system. In their research, two well-defined communities of food-producing countries, one that groups countries with relatively developed agricultural systems, and the other grouping countries with less developed production systems are observed and the stability of these two communities reveals persistent differences between countries specialization patterns.

A new challenge has been presented to global food supply in the form of COVID-19 and Molotoks et al., (2021) have studied the potential implications of COVID-19 on global food supply, and SDG-2 (zero hunger). The authors found that developing countries, fifteen from Africa followed by ten from Latin America, six from Oceania, and four from Asia, are the most vulnerable to changes and supply shocks. Their research concludes that the current pandemic is likely to cause transitory food insecurity across such vulnerable countries and that the effects of the pandemic on food security (SDG-2) may persist longer as a combined effect of economic slowdown and increase in poverty, limiting food supply and access beyond 2020.

The importance of approaching the issue of global food security from a multi-dimensional view and not viewing it as an isolated system is highlighted by Mc Carthy et al., (2018) who discuss how the solutions to achieving truly sustainable global food security will require a holistic systems-based approach, built on a combination of policy and technological reform, which will utilize existing systems combined with state-of-the-art technologies, techniques and best practices. The authors suggest collective stakeholder engagement as essential in bringing about the policy changes and investment reforms required to achieve a solution.

5.1.1 *Food Security in South Africa*

Since 1994, food security has been acknowledged as a national priority. This prioritisation is evident in the key guiding national policies such as the Reconstruction and Development Programme, the Integrated Food Security Strategy and later the National Policy on Food and Nutrition Security (Misselhorn

& Hendriks, 2017). Since the dawn of democracy, food security has received significant policy attention and a range of interventions have been implemented by the Government, NGOs, civil society groups and the public sector. Pereira & Drimie (2016) argue that the complexity characterizing the South African food system and the resultant negative food security outcomes require new kinds of institutional responses including governance arrangements to address these multiple challenges.

De Wet & Liebenberg (2018) discuss how the traditional concept of security has broadened over the past decades. Food security in South Africa is an imperative for human and non-human survival and the authors note that the notion of a 'secure community' changed with food security and the right to quality living becoming a social imperative. The current security approach represents a more comprehensive understanding of what security is meant to be and include, amongst others, housing security, medical security, service delivery and food security, as set out in the Millennium Development Goals and the subsequent Sustainable Development Goals.

Based on the work of De Wet & Liebenberg (2018), it would appear that the country has made strides in understanding food security and including it in its goal setting. Misselhorn & Hendriks (2017) have a differing view and identified food insecurity as an intractable problem in South Africa and that the country has a tradition of evidence-based decision making, grounded in the findings of national surveys. However, the rich insights from sub-national surveys remain a largely untapped resource for understandings of the contextual experience of food insecurity. A web-based search identified 169 sub-national food insecurity studies conducted in the post-apartheid period between 1994 and 2014 and the systematic review found that the studies used 27 different measures of food insecurity, confounding the comparative analysis of food insecurity at this level.

The current lack of public and private partnerships (PPPs) in extension, research and development increases the difficulty of solving the food security challenges in South Africa. A need has been identified by the government to encourage the participation from the private sector in agricultural extension and research development.

Since 1994, food security has been acknowledged as a national priority and although the country has made strides in addressing the matter, there is much room for improvement with collaboration needed between the public and private sector to ensure that insights from research on the topic of food security which have remained largely untapped, are considered when developing policy.