The contribution of wool production to the sustainability of crop/pasture production systems in the Southern Cape

by

Tayla Hazel David

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Supervisor: Dr. W.H. Hoffmann

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Declaration

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Abstract

Population growth, urbanisation, and economic development worldwide continues to place significant pressure on producers to expand and intensify production systems to meet growing demand, while arable land and natural resources become strained. This necessitates a move from conventional agriculture towards more sustainable methods of food, feed, fibre, and fuel production. Conservation agriculture (CA) offers a holistic, sustainable approach to agricultural production.

The concept of CA is based on three interlinked principles namely minimum soil disturbance, the maintenance of permanent soil cover, and improved crop diversity through crop rotation systems. Since the late 1990s, CA has been widely adopted throughout the Southern Cape region, mainly implemented on large commercial winter cereal farms with crop rotations forming the basis of these systems.

The introduction of annual legume pastures in rotation with cash crops has enabled producers to diversify farming enterprises to include a livestock component. Sheep grazed on legume pastures and cash crop residues aim to improve soil health through nutrient recycling while supplementary income from meat and wool helps to mitigate crop production risks, thereby improving income stability and resilience of the whole farm. Soil compaction due to livestock trampling and overgrazing are; however, direct threats to the successful implementation of CA. In order to mitigate this risk, mixed crop-livestock systems require proper herd and pasture management with emphasis on suitable stocking rates and rest periods for pastures. This study primarily aimed to evaluate the potential role of sheep enterprises on the sustainability of selected cash crop/pasture systems in the Southern Cape.

The complexity of modern agricultural systems elicits a systems thinking approach which enabled this study to help identify relationships and better understand the interaction and interrelatedness of all on-farm factors. A whole-farm, multi-period budget model was used to quantify the financial contribution of sheep enterprises to farm-level performance. A whole-farm budget model works to effectively integrate the physical and biological farm-level parameters and according to standard accounting principles, translate this into a financial output. The typical farm approach served as the reference point from which the budget model was built. Model inputs and assumptions were obtained through previous trial data combined with and validated by various industry experts and local producers in the Southern Cape region.

The financial performance for each of the livestock management approaches was expressed and compared using the internal rate of return (IRR). All approaches were predicted to be profitable over a 20 year period. Scenario 1, as represented by the typical livestock approach for the Southern Cape, proved to be the most profitable. Furthermore, of the two sheep breeds, the Dohne Merino was proven to be the more favourable breed. Whole-farm profitability remained resilient against changes in both meat and wool product prices, thus further highlighting the importance that mixed crop-livestock systems may have on farm income, stability, and sustainability.

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List of Abbreviations

CA: Conservation Agriculture

CFW: Clean Fleece Weight

FD: Fibre Diameter

Ha: Hectares

IRR: Internal Rate of Return

NFI: Net Farm Income

NPV: Net Present Value

SL: Staple Length

SS: Staple Strength

SSU: Small Stock Units

Chapter 1: Introduction

1.1 Introduction

The world population increases every year. By 2050 the total world population is projected to reach 9.7 billion. Within the next thirty years Sub-Saharan Africa will undergo the most rapid growth, estimated to double in size reaching a total of about 2.1 billion people (United Nations, 2019). Population growth, urbanisation, and economic development throughout the world have placed a greater demand on agriculture to produce more food, beverages, feed, fibre, and fuels.

To meet the growing demand of the population, producers are continuously under pressure to expand and intensify production systems. By 2050, producers will need to increase food production by 70% to meet the global food demand (Friedrich *et al.*, 2009). However, producers are faced with another challenge, a reduction in available agricultural land. Agricultural output is dependent on both land and water resources. Globally, the amount of available farm land per capita has fallen from 0.39 ha in 1960 to 0.21 ha in 2007 (Evans, 2010). This trend leaves producers under constant pressure to increase production with less and less land. Agricultural expansion and intensification have traditionally relied on an increased use of external inputs such as industrial fertilisers, herbicides, and pesticides to meet production goals. This continues to significantly impact the natural environment, natural farming resources, and ecosystem services (Hathaway, 2016; Sanderson *et al.*, 2013).

At present, there is a much-needed shift from the current agricultural paradigm of maximum profit and production to one of “sustainable production intensification”. This is a concept which acknowledges the need for productive and viable agricultural practices but which will also preserve and enhance environmental resources and services (Friedrich *et al.*, 2009). The growing demand for agricultural products accompanied by the increasing threat to the environment presents farmers with an opportunity to adopt a more sustainable approach towards agriculture. A number of sustainable agricultural practices aim to satisfy consumer’s food, feed and fibre needs, reducing the use of external inputs, improve management of soil and crop health while preserving environmental resources and maintaining economic viability of the farming enterprise (Billig, 2017).

Conservation agriculture (CA) is a strategy implemented by many farmers as a sustainable way of improving yields and increasing profitability while minimising the environmental impact. Conservation agriculture relies on three underlying principles that aim to enhance farm ecosystem services, namely:

(1) minimum soil disturbance,

(2) maximum or maintenance of permanent soil cover and

(3) crop rotation systems (Erenstein *et al.*, 2012; Sanderson *et al.*, 2013).

This study focuses on the contribution of livestock and the principles of conservation agriculture in the geographical region of the Southern Cape in South Africa.

The Southern Cape, as shown in Annexure A, is one of the main winter cereal producing regions in the Western Cape. The typical Mediterranean climate makes it a favourable environment to incorporate winter cereal production, in rotation with a variety of crops. Crop rotation systems in this area traditionally produce wheat in rotation with barley, oats, canola, lupins and lucerne. In limited cases, seasonal medics as a pasture are also used while a few producers also use triticale, a hybrid of wheat and rye. The inception of CA was based on the aim of negating erosion due to run-off water during heavy rains. The broader benefits were only experienced later. Combinations of CA principles have been widely implemented by the majority of producers with the importance of soil health and crop rotation forming the basis for most of the farming operations in the region. Producers in the Southern Cape have further diversified farming enterprises to incorporate livestock grazing on pasture to further supplement their income through wool and meat production. A major advantage of the Southern Cape as opposed to other parts of the province, is that rainfall is more evenly dispersed throughout the year. Roughly 40% of annual rainfall occurs during the summer months. The Swartland, which is situated along the West Coast, has 95% dispersion during the winter and is renowned for very hot and dry summers. This makes perennial pasture production unfeasible.

The integration of livestock and crop production systems is a common practice in the Southern Cape and throughout South Africa. Mixed crop-livestock farming systems is an important economic and social contributor within the region, providing both employment opportunities and livelihoods to the surrounding rural towns and communities (Ghahramani & Bowran, 2018; Herrero *et al.*, 2010). Small stock such as sheep are commonly farmed in the Southern Cape region and complements the cropping system, with sheep grazing on the lucerne pastures and crop residues (Cloete & Olivier, 2010). The diversification from crop rotation systems to also include sheep farming allows producers to offset the production and price risk of cropping systems during years of crop failure and low yields as a result of drought or disease, as well as through periods of unstable grain prices and price shocks, thus improving resilience and stability across the whole farming system (Cloete & Olivier, 2010; Sanderson *et al.*, 2013).

The majority of the research conducted within the Southern Cape has traditionally focused on either cash crop rotation systems or sheep enterprises. The integration of the two is a complex matter and has yet to be evaluated within a whole farm systems context. While the financial implications of crop rotation systems combined with various livestock management strategies are still unknown, it also remains an important consideration for Southern Cape producers. There is therefore a need to investigate how these mixed crop-livestock systems perform in financial terms within full conservation farming principles. It is thus important to maintain current best practices throughout, and then consider within a CA framework the profitability implications of alternative strategies involving sheep.

1.2 Problem statement

Currently, there is a lack of knowledge on the integration of the physical/biological input implications of sheep enterprises with the financial performance of the farm on selected cash crop/pasture systems farmed within a CA context. One of the key issues currently unknown is the choice between a sheep breed, one that is more meat orientated or more wool orientated.

The research question is therefore:

What is the expected financial impact, when incorporating alternative wool sheep, on the sustainability of selected cash crop/pasture systems in the Southern Cape?

1.3 Research aims & objectives

The main objective of this research project is to evaluate the potential financial role of alternative wool sheep enterprises on the future sustainability of selected cash crop/pasture systems in the Southern Cape.

To support this objective the following goals are identified:

- To establish the link between sustainability and conservation agriculture (CA),
- To determine the importance of sheep enterprises as a component of the cash crop production systems as farmed under full CA principles,
- To explore the factors that influence wool production or quality from a farming perspective,
- To analyse the specific contribution of wool and meat production on farm level performance, and
- To evaluate the sensitivity of selected variables on the contribution of meat and wool enterprises on farm level performance.

1.4 Proposed method

To understand the importance of sheep enterprises as a component of selected cash crop/pasture production systems within the Southern Cape, an overview of the literature was conducted. The literature review aimed to identify factors that influence various wool production and quality characteristics. The literature review was combined with expert input from agricultural specialists and producers within the region through existing study group results and trends.

Determining the set of relevant interrelationships and various factors that impact on the physical, biological, and financial performance of a farming system, is a complex and multi-faceted challenge. To account for this complexity a systems thinking approach combined with multidisciplinary expert knowledge was applied in this study. Expert knowledge obtained from a team of agricultural economists, animal scientists, soil scientists, agronomists, pasture management and producers in the Southern Cape through previous expert group discussions was used throughout the model construction. Validation of the model was performed by local agricultural extension officers. These officers have direct access to study group information and can easily test for validity in terms of the relationships and equations the model works on.

A whole-farm financial model approach was used to evaluate the financial implications of various sheep enterprises as a component of cash-crop/pasture systems in the Southern Cape. The model integrates various on-farm management and environmental factors and is able to translate these physical and biological processes into a standardised financial outcome. A typical farm for the region was developed prior to construction of the model and serves as the reference point for the whole-farm financial model. Physical properties of a typical farm were identified, and assumptions validated by agricultural specialists and producers within the area. The model, therefore, relies on the input from experts to ensure biological and social sustainability from which the financial outcome of such factors can be calculated and thus, determine the financial (economic) sustainability. This could assist producers with the ability to consider alternative management options to not only improve profitability but also improve the resilience of the crop-pasture resource.

1.5 Layout of study

Chapter 2 consists of a literature review and starts off with a description of the agricultural production systems in the Southern Cape. Conservation agriculture is introduced as a more sustainable approach towards agricultural production, its principle characteristics, origins, adoption rates throughout Southern Africa, the benefits, and the constraints are discussed. Part of the CA discussion highlights the concern for integrating livestock and the impact this may have of cropping systems within CA systems. Lastly, the South African wool industry is introduced followed by a description of wool parameters and the factors which influence its quality and production.

Chapter 3 highlights the complexity of modern agricultural systems and aims to provide an understanding of the systems approach. The chapter further describes the construction of a whole-farm, multi-period budget model, and model components as a way of assessing whole-farm profitability. The concept of a typical farm approach is also introduced.

The first part of Chapter 4 quantifies and describes the parameters and assumptions of the typical Southern Cape farm in both physical and financial terms. The results and findings are presented and discussed in the second part of Chapter 4. A financial evaluation of different livestock management strategies in terms of farm-level performance is conducted using a whole-farm budget model followed by a sensitivity analysis of profitability in response to a change in product prices.

Chapter 5 provides conclusions based on the research findings, a summary of the study, and recommendations for possible future research.

Chapter 2: Literature review

2.1 Introduction

As discussed in Chapter 1, an increase in global food demand due to rising population growth, improved income and lifestyle continues to pressure producers to expand and intensify production systems. Traditional methods of agricultural intensification continue to impact the environment and natural farming resources (Sanderson *et al.*, 2013). Conservation agriculture (CA) is one of the proposed sustainable agricultural methods aimed at improving production while protecting and enhancing the surrounding environment (Kassam *et al.*, 2009). South Africa is the leader in terms of CA adoption in Sub-Saharan Africa, with large scale implementation on commercial winter cereal farming systems in the Western Cape province (Kooper, 2020). Complementary to these cropping systems, producers in the Southern Cape incorporate livestock to further supplement income through meat and wool production. This practise is benefitted by the relative equal dispersion of rainfall throughout the year. With a more or less equal spread of rainfall between summer and winter, lucerne (alfalfa) as a perennial pasture crop for grazing, is successfully incorporated into crop rotation with annual cereals and oilseeds.

The main objective of this project was to evaluate the potential role of sheep enterprises on the sustainability of selected cash crop/pasture systems in the Southern Cape. This chapter consists of an overview of the current literature and begins with a description of the typical cereal production systems within the Southern Cape region. This is followed by an introduction into the principles of conservation agriculture, as well as the benefits and constraints thereof. Mixed farming systems and the implications of livestock integration into CA systems is discussed further. The chapter continues with an overview of the South African sheep and wool industry and concludes with a review of the factors that influence wool quality traits and production parameters from a farming perspective.

2.2 The Southern Cape

While agriculture only contributes 2.5% towards the country's total GDP (World Bank, 2020), the sector plays an important role within South Africa as an earner of foreign exchange in addition to providing employment opportunities, and improving livelihoods, predominantly within rural towns and communities. Winter cereal crop production systems in the Western Cape are crucial for communities such as these, as it plays an integral part in employment, local economies and on a broader level, contributes toward strengthening food security in the country by providing affordable staple food crops.

After maize, wheat is the second most consumed grain crop in South Africa and provides an affordable staple, predominantly bread, for the majority of the population (DAFF, 2019). The Western Cape is the largest wheat producer in South Africa and accounts for roughly 48% of the total wheat production in the country (DAFF, 2019). The Southern Cape is one of two important agricultural regions located within the Western Cape, the second being the Swartland. Together it contributes 85% of the total wheat produced in the province (Hoffmann, 2010a).

The Southern Cape, as illustrated in Annexure A, falls within the winter rainfall region of the Western Cape. The area has a typical Mediterranean climate characterised by warm, dry summers and cool, wet winters. The Southern Cape receives roughly 60% of its annual precipitation during the winter months (Swanepoel *et al.*, 2016). Rainfall distribution and quantity in Mediterranean-type climates are known to be random and unpredictable from season to season. This causes production uncertainty amongst dryland producers in terms of planting schedules and yield performances.

Until the late 1990's, wheat was traditionally cultivated in monoculture cropping systems in the Southern Cape. Greater availability and accessibility to commercial fertilisers, improved herbicides and pesticides, as well as government subsidies all contributed towards the success of wheat monoculture production systems (Basson, 2017). Following the deregulation of the South African agricultural economy in the 1990s, wheat production has decreased due to a number of economic and environmental challenges (Hoffmann & Kleynhans, 2011).

The profitability of wheat production has since declined as a result of rising production and input costs (fertiliser, seed, etc.), making it impossible for producers to compete internationally, or against cheap imports required to meet the domestic demand (De Wet & Liebenberg, 2018). The introduction of alternative crops into the Southern Cape, such as barley, canola, oats and triticale has, therefore, become increasingly important to producers (Hoffmann & Kleynhans, 2011; De Wet & Liebenberg, 2018). Environmental factors such as the change in weather and rainfall patterns, and in some cases extreme weather events (drought and flooding), creates additional challenges and uncertainty for producers given that rainfall is considered the most important factor to influence yield performance (Hoffmann, 2001).

In order to remain competitive within the international market, local producers had to find new ways to adapt and improve production systems. The introduction of CA into the region allowed for a more sustainable alternative to conventional practices. At least one or more CA principles have been widely implemented by the majority of local wheat producers in the Western Cape, with crop rotation, minimum tillage and soil cover forming the foundation for most of the farming operations in the region (Modiselle *et al.,* 2015). Crop rotation systems in the Southern Cape typically incorporate wheat in rotation with barley, canola, lupins, medics, and alfalfa. Producers are thus able to reduce potential financial risk by producing a more diverse range of cash crops and under CA, negate land degradation associated with conventional wheat monocropping through maintenance of soil cover and minimum soil disturbance.

To further diversify income, producers include wool and meat production by introducing livestock enterprises that graze on the pasture component of crop rotation systems. Livestock primarily farmed in the region is sheep, grazed on annual legume pastures and crop residues that forms part of the crop rotation system. The integration of sheep within cropping systems provides producers with the opportunity to ensure greater resilience and financial stability of the whole farming system while minimising potential risk, especially during periods of unstable grain prices, poor yields or crop failure (Cloete & Olivier, 2010). While the integration of livestock into cropping systems has many benefits there is, however, concern surrounding the impact that livestock may potentially have on the success of practices carried out under CA. This is mainly due to the potential compaction effect livestock trampling has on wet soils after rains as well as overgrazing. In the next section, the concept of CA, mixed farming systems and the implications of mixed crop-livestock farming within CA-based systems are discussed.

2.3 Conservation agriculture

Soil forms the basis from which an estimated 95% of all humanity’s food is directly or indirectly produced (FAO, 2015). Healthy and fertile soils provide a range of additional ecosystem services that contribute towards greenhouse gas regulation, carbon storage and flood mitigation (Kopittke *et al.*, 2019). The sustainable management of soil thus remains crucial in maintaining life both above and below ground in order to support increasing yields, ensure food security as well as contributing towards the mitigation of climate change.

Decades after the dustbowls of the 1930's in the United States occurred, producers advocated for better soil management and reduced tillage practices to preserve soil health and reverse the loss of organic matter (Hobbs *et al.,* 2008). Further momentum followed the green revolution of the 1960's, characterised by intensive tillage-based production practices, monocropping systems with limited crop rotations and high input use of chemical fertilisers and pesticides. Tillage left soils exposed resulting in physical degradation and severe soil erosion. The concept of CA arose from initial no-till and conservation tillage practices, further evolving to incorporate crop rotation and soil cover components (Knott, 2015).

CA can be described as "a practical concept to achieve improved soil health and better soil, crop, nutrient, and water management leading to ecologically and economically sustainable agriculture" (Friedrich *et al.*, 2009).

The concept of conservation agriculture is based on three, interlinked principles namely:

1. Minimum soil disturbance,
2. Maximum and/or maintenance of permanent soil cover, and
3. Crop rotation systems.

Therefore, CA systems aim to mimic natural ecosystems by minimising soil disturbance through no-till practices, promoting soil health and enhancing biodiversity (Aune, 2012). It is the combination of these three individual principles working simultaneously that constitutes the ecological foundation of CA systems.

Table 2.1 highlights the key differences between conventional farming practices and CA systems. Minimum tillage, conservation tillage and mulch tillage are all forms of reduced tilling practices. There is some confusion within academic literature surrounding these different types of tillage practices as sometimes these methods are referred to and carried out under CA research, producing results that are inconsistent

(Knott, 2015). For this study, CA is characterised as a no-tillage or zero tillage-based farming system. Furthermore, while CA differs in terms of tillage practices, crop rotation systems and the retention of crop residues from conventional practices, the use of fertilisers and pesticides are still permitted. However, studies have shown that over time the use of fertilisers and pesticides decrease (Friedrich *et al.*, 2009).

Table 2.1: *A comparison of the key differences between agricultural systems.*

	Conventional Agriculture	**Conservation Agriculture**
Tillage	Yes	No
Crop rotation systems	Limited	Yes
Residues retained	No	Yes
Use of mineral fertilisers	Yes	Yes – limited
Pesticide use	Yes	Yes – limited

Conservation agriculture is widely adaptable allowing for these systems to be practiced under a variety of different climatic conditions and soil types at both the commercial and subsistence scale (Kassam *et al.*, 2018). To this extent, the area under CA continues to expand throughout all regions of the world. The adoption of CA in South Africa has increased from an area of 368 000 hectares (ha) in 2013/14 to 439 000ha in 2015/16 and thus South Africa continues to be the largest adopter of CA in Sub-Saharan Africa followed by Zambia (316 000ha) and Mozambique (289 000ha) (Kassam *et al.*, 2018).

In South Africa, CA systems have been widely implemented in the Western Cape province, with uptake largely practiced on commercial winter cereal producing farms. The Western Cape is the leading province in the country in terms of CA uptake and implementation with roughly 90% of farmers having adopted CA principles according to Strauss, as cited by Mudavanhu (2015). The area of focus for this research is the commercial wheat farms of the Southern Cape region in the Western Cape, where current farming best practices follow a CA approach.

2.3.1 The benefits of CA practices

Conservation agriculture serves as the foundation for sustainable agricultural production intensification through the enhancement of natural biological processes and preservation of the soil (Friedrich *et al.*, 2012). As a resource-saving production system, CA provides numerous environmental and financial benefits for producers, as discussed in this section.

2.3.1.1 Minimum soil disturbance

Intensive tilling practices result in the chemical, physical and biological breakdown of the soil resulting in the loss of soil carbon and a reduction in biological activity within the soil. This breakdown further contributes to increased soil erosion, surface run-off and crusting (Thierfelder *et al.*, 2015). Minimum soil disturbance through no-till practices reduces the rate of breakdown in the soil allowing for the build-up of soil organic matter, a major indicator of sustainability. This results in improved soil structure and the productive potential of the soil, providing an ideal environment for root development of subsequent crops (Kassam *et al.*, 2009).

2.3.1.2 Maximum soil cover

Complementary to no-till practices, the maintenance of maximum soil cover through cover cropping, mulching or residue retention improves soil porosity, facilitating increased water filtration and aeration of the soil. Greater water filtration and the retention of residues improves soil moisture, a potential buffering factor that becomes significant especially during dry periods or drought (Thierfelder *et al.*, 2015). Mulching under CA also helps to moderate soil temperatures, promoting greater biological activity within soils. Furthermore, the combination of soil cover, to protect from compaction and the impact of raindrops, and improved water filtration plays an important role in the reduction of surface crusting, run-off as well as soil and wind erosion (Hobbs *et al.*, 2008; Thierfelder *et al.*, 2015).

2.3.1.3 Crop rotation

Crop rotation is a management tool that refers to the planting of at least three or more different crops, consecutively on the same piece of land (Nell, 2019). The diversification of winter cereal cropping systems to include nitrogen-fixing legumes allows for increased biodiversity both above and below ground. This increased biodiversity is beneficial against the build-up of pathogenic organisms, pests and disease outbreaks resulting in better crop health, improved pest control as well as reduced pesticide use (Hobbs *et al.*, 2008; Thierfelder *et al.*, 2015).

Crop rotation is also beneficial in the control of weeds. Weeds have been identified as a problem, especially during the initial implementation stages of CA. Over time crop rotation systems, cover cropping and effective residue management help to suppress weed growth (Kassam *et al.*, 2012), and as a result the use of herbicides is reduced. The incorporation of a livestock component into the farming system would further contribute to weed control through the direct grazing of animals during the pasture phase (Basson, 2017).

The productivity of CA systems is positively affected by incorporating legumes (nitrogen-fixing crops) into rotation systems. This helps to improve soil fertility through the fixation of nitrogen in the soil, making it readily available to subsequent crops. It was noted that wheat yields increased by 22% when preceded by canola and 25% when preceded by legumes such as medics, lupines and lucerne (Hoffmann, 2010b). Furthermore, observations reported by Kassam *et al.*, (2012) found CA systems under no-till practices, with improved moisture and nutrient availability exhibit an increase of 20 to 120% in yields when compared to conventional monocropping systems. Monocropping systems tend to deplete nutrients in the soil resulting in the need for large amounts of chemical fertilisers to replace the nutrient loss, whereas a crop rotation system works to re-introduce nutrients back into the soil by alternating leguminous crops (e.g. lucerne) with N-absorbing crops (wheat) (Kooper, 2020). Additional available nitrogen in the soil reduces the application rate of chemical fertilisers to the cropping system.

The implementation of crop rotation systems within CA provides multiple environmental benefits, specifically within the soil. These agronomic benefits ultimately translate into financial benefits for producers. Improved yields through enhanced soil health and a reduction in input costs due to the reduced need for pesticides, herbicides and chemical fertilisers are the main such benefits. In addition, the use of machinery required for land preparation and planting is reduced, resulting in lower maintenance and operational costs and also providing producers with more time and additional labour. The decrease in fuel further lessens producers' reliance on fossil fuels (Stead, 2021).

Lastly, it is important to note that while each of the three principles contribute positively to conservation agriculture, it is through the incorporation of all three interacting together that provides the most optimal results. However, the benefits of adopting all three CA principles still take several production seasons to manifest as clear improvements (Knott, 2015).

2.3.2 Constraints of CA

Although CA practices may provide several benefits that lay the foundation for a more sustainable intensification of agricultural production, it is not a "one-size-fits-all" solution for all farming systems. Several challenges and constraints exist that currently hinder the widespread adoption of CA globally.

For decades, producers have used conventional farming methods such as tilling to prepare the land to plant and grow crops. The belief of producers to continue to use such methods poses a challenge towards the adoption of CA. The introduction of new, "foreign" concepts and technologies requires a change in mindset to accommodate new ideas, and a desire/willingness to explore more sustainable practices to maintain the long-term viability of the farming enterprise.

The adoption of all three CA principles and conversion from conventional farming systems are a complex, knowledge-intensive process (Kassam *et al.*, 2009). One of the main constraints towards the adoption of CA is thus the site-specific knowledge required for each individual farming region. Under typical resource conditions in the Southern Cape, significant differences are often present between camps and even within the same camp. Such differences include variations in soil type and depth as well as rainfall and climatic conditions. This variation in land resources results in the dependence of producers on precision agricultural equipment for full conversion to CA farming. This comes at a significant capital investment requirement and ultimately affects the adoption of new farming practices. The implementation of CA should thus be based upon a more experimental learning approach (Kassam & Friedrich, 2010). Continued support by fellow producers, researchers and stakeholders remains a key component for the adoption of the CA process by providing producers with knowledge of current best practices and relevant information based on the latest technologies and necessary inputs applicable to the region (Knott, 2015).

Complementary to the required capital for machinery, in order to maintain yield levels similar to conventional systems, additional inputs of herbicides, pesticides and fertiliser as well as labour is required during the initial stages of CA (Kooper, 2020; Wall, 2007).

CA, however, is not simply achieved through the acquisition of new equipment and machinery, but also through the changes in farm management pertaining to weed control practices, crop residue retention, crop rotation systems and planting and harvesting practices (Wall, 2007). Furthermore, it is important for producers to note that the introduction of CA into an existing farm is a longer-term process with gradual change and ecological and economic benefits becoming more evident over time.

The maintenance of soil cover through retention of crop residues is one of the main principles of CA. Where the integration of livestock into cropping systems is concerned, there is often a trade-off between the retention of crop residues for soil cover and the use of residues as fodder for livestock, the latter often outcompeting residue retention. This is often the case throughout rural communities and farming regions where livestock play an integral role in the viability of the farming enterprise (Thierfelder *et al.*, 2015). The implications of livestock within CA systems are of particular interest in this study and will be discussed in further detail throughout Sections 2.3.3 and 2.3.4.

2.3.3 Mixed farming systems

Mixed crop-livestock farming systems are characterised by the integration of both crop and livestock enterprises on the same farm. Often the aim is to financially diversify and seek synergies between crops and livestock. Crop-livestock systems provide ample management opportunities through practices of diverse crop rotations, cover cropping and nutrient recycling, owing to the increased biodiversity and sustainability of agricultural systems (Sanderson *et al.*, 2013).

Risk management is a key driver for the integration of livestock into cropping systems, as producers are often considered to be risk averse (Sanderson *et al.*, 2013). Diversification from a single enterprise to include a livestock component allows producers to offset the production and price risk of cropping systems during years of drought or disease that may result in poor yields or crop failure. Periods of unstable grain prices may also be overcome through the diversification of income (Cloete & Olivier, 2010). This added diversity and reduced risk provides a possible stabilisation of income, thereby improving the resilience of the whole-farm system. In the Southern Cape, livestock enterprises consist largely of sheep, farmed for both wool and meat production. These two products are unrelated in terms of market prices and thus inherently add to diversification in markets. Livestock presents an added financial benefit in that the inherent value of the productive asset (animals) constantly appreciates. Along with land itself it forms the only items in a typical balance statement that appreciate in value. The equipment acquired for crop production on the other hand is depreciating assets.

Another incentive for crop-livestock integration is the exploitation of spatial variability of farmland. Larger farms, such as the winter cereal cropping systems in the Southern Cape, consist of both fertile land ideal for cultivation, while other parts of the farm remain less productive. The exploitation of the spatial variability to include value-adding enterprises may prove useful in maximising profit for producers (Bell & Moore, 2012).

The potential synergies and complementary practices between enterprises further add to the benefits of the mixed crop-livestock farming systems as outputs from one enterprise can often be used by another. Majority of producers within the Southern Cape incorporate this strategy by grazing livestock on crop residues and pastures that are in rotation with cash crop systems. In doing so, livestock can convert low-quality pastures or residues into a higher-value protein source or product (fibre). This also reduces the amount of supplementary feeding required by producers. Livestock in turn complements cropping systems by enhancing the efficiency of nutrient cycling in the soil. Grazing livestock only take in a small portion of the nutrients that are ingested, typically returning more than 60% of nutrients from ingested plant biomass back into the soil as manure and urine (Haynes & Williams, 1993). Nutrient recycling together with legumes under CA may reduce the dependence of producers on synthetic fertilisers. The trade-off, however, is that nutrients may become poorly distributed, resulting in uneven plant growth throughout pastures. Grazing management and stocking rates play an important role in the preservation of the soil, the pasture and ultimately the success of crop-livestock integration under CA.

The supposed effects that livestock-induced compaction and overgrazing has on the soil and potential crop production present the biggest drawbacks for crop-livestock integration for producers (Sanderson *et al.*, 2013). Concern currently exists over the success of livestock integration and CA systems. The next section will discuss the impact of mixed-farming systems with a focus on the importance of sheep enterprises as a component of crop/pasture production systems and the implication that this has on conservation agriculture principles.

2.3.4 The implications of crop-livestock integration on CA

The success of CA farming systems depends on the effective integration of all three CA principles. Within a CA context, the inclusion of livestock increases the complexity of farming systems and the management thereof, various synergies also arise, contributing to the resilience of the whole-farm. (Sanderson *et al.*, 2013). The implications of mixed farming systems in relation to CA principles are discussed in further detail below.

2.3.4.1 Crop rotations

Crop rotation systems allow for the added diversity and cultivation of multiple crops. The transition away from monocropping systems offers a better alternative that provides a variety of environmental and financial benefits for producers as discussed in Section 2.3.1.3.

Establishing legume pastures in crop rotation systems enhances soil fertility as a result of nitrogen fixation and increases biological activity and organic matter within the soil. Crop rotations that include annual legume pastures have been observed to have a positive effect on subsequent cash crop yields, where wheat yields have been known to increase by 25% when preceded by leguminous crops (Hoffmann, 2010a). However, it is the inclusion of annual legume pastures, with livestock that may hold the most potential for cropping systems.

Incorporating annual legume pastures in rotation with cash crops further enables producers to diversify farming enterprises by adding a livestock component. These pastures together with crop residues from cash crops provide an ideal source of grazing for livestock. By integrating livestock into CA systems, producers can improve nutrient cycling in the soil, mitigate production risks through diversification of enterprises and stabilise income to some degree.

2.3.4.2 Maximum soil cover

Maintaining soil cover through cover cropping in pasture systems and the retention of crop residues post-harvest provides multiple benefits to CA systems. In part, soil cover is responsible for enhancing biological activity within the soil, increasing biodiversity both above and below ground as well as increasing the amount of soil organic matter. A property that is also proven necessary to prevent surface crusting, compaction and erosion (Fisher *et al.,* 2012; Hobbs *et al.*, 2008). Grazing livestock may, therefore, directly contribute to environmental degradation through the removal of ground cover as fodder.

The inclusion of grazing livestock whilst maintaining sufficient levels of soil cover may pose a challenge for producers. Producers are often faced with a trade-off between the retention of crop residues for increased ground cover or the use of cover crops and crop residues as a feed source. These trade-offs are often dependent on the biophysical and socio-economic characteristics of the farm (Valbuena *et al.*, 2012). The offset of residues as a feed source is often considered short term and producers can earn money by utilising it as feed. The benefits of residue retention are seen as a more long-term orientated. The value of residue retention on the soil and CA systems compared to the value of residues as a feed source and the benefits incurred by livestock integration becomes an important consideration for producers implementing mixed farming systems under CA. The agroecological benefits of crop residue retention as discussed in Section 2.3.1.2, results in reduced environmental degradation and improved soil fertility which translates into improved yields and thus higher income over time. Alternatively, the meat and wool markets as well as the price of supplementary feed determines the value of crop residues as a feed source (Basson, 2017), together with the agroecological benefits of nutrient recycling and risk mitigation through diversification.

The presence of livestock in cropping systems under CA and cover crops does affect soil properties to some extent, depending on how grazing is managed. The effects can have either a positive or negative influence. For instance, when overstocked, complete residue extraction may occur, resulting in lower carbon and nitrogen stocks, reduced organic matter and a decline in soil quality and possible environmental degradation (de Faccio Carvalho *et al.*, 2010).

To graze livestock and maintain sufficient levels of soil cover requires strategies that complement both CA and mixed crop-livestock systems. In a study conducted by Lilley and Moore (2009), the trade-offs between productivity and soil cover in mixed crop-livestock farming systems were examined by modifying stocking rates and the levels of ground cover. The results indicate that maintaining ground cover levels at a 30% threshold with a constant stocking rate, had minimal impact on annual ground cover and little impact on farm gross margins. A threshold of 30% soil cover is generally accepted according to most of the literature (Erenstein, 2002; Hobbs *et al.*, 2008). Partial residue extraction through proper herd and pasture management is key to maintain adequate levels of soil cover for grazing livestock in conservation agricultural systems.

2.3.4.3 Minimum soil disturbance

Minimum soil disturbance through zero-tillage practices is a core principle of conservation agriculture. This plays a key role in maintaining physical, biological, and chemical soil properties, contributing to improved soil fertility and the success of subsequent crop production. In mixed crop-livestock systems the two main causes for soil disturbance is tillage and livestock trampling (Basson, 2017). Livestock-induced compaction due to trampling is believed to have a negative impact on physical soil properties potentially affecting crop production. The impact is more pronounced during the grazing of pastures or residues in soils with a higher moisture content (Sanderson *et al.*, 2013). This ultimately presents potential drawbacks for crop-livestock integration when producers implement CA practices.

Soil compaction occurs when an applied load is greater than the load-bearing capacity of the soil, causing a modification of soil physical properties (Bilotta *et al.*, 2007). The three main properties typically used to quantify the extent of soil compactness are: soil strength and increased bulk density, reduced soil porosity, and reduced soil infiltration capacity (Nawaz *et al.,* 2013; Southorn & Cattle, 2004). Different stocking rates, livestock grazing strategies, and rest periods for pastures are three of the main management factors that determine the impact that grazing has on the physical properties of soil that may lead to compaction (Basson, 2017).

Physical soil properties often depend on grazing management; therefore, stocking rate is an important management tool in the control of livestock trampling and grazing. Increased stocking rates does affect soil bulk density and soil strength; however, compaction is limited to the upper 5cm-15cm of the soil surface (Greenwood & McKenzie, 2001). Livestock grazing can also reduce porosity and infiltration rates in the soil. Soil compaction decreases aeration which may be detrimental to soil biota as well as water movement through the loss of macropores, which may further contribute towards surface runoff and erosion (Batey, 2009; Bell *et al.*, 2011). However, as with bulk density and soil strength, effects are limited to the top surface layer. Although the relationship between stocking rate and soil damage varies in the literature, soil damage at greater depths has been linked to the grazing of wet soils, reduced ground cover or recently tilled soils (Drewry *et al.,* 2008; Greenwood & McKenzie, 2001). Given that tillage does not fall within CA farming practices, the effect of livestock trampling on the soil surface may be reduced through proper grazing and pasture management decisions as well as the maintenance of sufficient ground cover.

As a management tool, grazing strategies influence physical soil properties linked to compaction. Rotational grazing, as opposed to the traditional set stocked continuous grazing is believed to benefit not only the productivity and resilience of pastures but may also benefit soil quality. In a study conducted by Southorn and Cattle (2004) different grazing strategies, set stocking (SS), high intensity short duration rotational grazing (HI-SD) and un-grazed (control) techniques were compared to determine the impact of grazing patterns on physical soil properties, specifically macroporosity. Rotational grazing was found to maintain levels of macroporosity similar to that of un-grazed soils, while macroporosity decreased under set stocking practices over time. Rotational grazing systems offers an alternative grazing strategy more capable of preserving soil structure while also promoting the recovery of soil and pasture to maintain sufficient productivity and groundcover.

The resting periods for pasture and the effect of livestock trampling are associated with stocking rate and grazing patterns. Rest periods form a crucial part of pasture management to reduce the effect of livestock trampling, especially for wet soils or reduced ground cover and in pasture recovery. Several researchers concluded that grazing livestock on wetter soil increases the risk of compaction (Bilotta *et al.*, 2007; Fisher *et al.*, 2012). Taking the necessary precautions to temporarily relocate livestock to drier pastures or fields with better drainage during rainfall periods, allows soil to recover and reduce the impact of livestock trampling. The rest period associated with rotational grazing further assists in the recovery of both soils and pastures from livestock.

Maintaining surface residues and organic matter in the soil plays an important role in resisting the pressure of compaction. This stabilises soil structure, decreases bulk soil density and strength, making the soil more resistant to degradation (Hamza & Anderson, 2005). Plant roots provide a major source of organic matter, both while growing and through decomposition. Roots help to stabilise soil structures and further limit soil compaction with the production of macropores, thereby increasing aeration and water infiltration in the soil (Greenwood & McKenzie, 2001; Hamza & Anderson, 2005). The retention of crop residues as well as cover cropping under CA may ensure a greater resilience for pastures towards soil compaction in crop-livestock systems, provided that the groundcover threshold is maintained, accompanied by sufficient rest periods in these pastures.

Perhaps one of the key trade-offs for producers in terms of soil disturbance is the benefits of integrating livestock versus the impact of grazing on physical soil properties and the effect that this may have on crop yields and thus, profitability. Various researchers have concluded that the degradation of soil physical properties due to livestock grazing appears to be too small in magnitude or depth to have a significant influence on subsequent crop yields (Bell *et al.*, 2011; Hunt *et al.*, 2016). This presents producers with the opportunity to incorporate livestock and gain the potential benefits thereof without any additional risk of livestock trampling.

Through proper herd or flock management, rotational grazing practices, the maintenance of sufficient ground cover, and the retention of crop residues and organic matter, the risk of compaction can be managed. This can better maintain minimum soil disturbance in line with CA farming principles. The success of CA farming systems depends on the effective integration of all three CA principles. Crop-livestock farming systems can only be as successful as the management strategies together with CA principles implemented by the producer. For the purpose of this study, appropriate management practices are assumed, as the aim is to establish principles that are applicable across time and place thus, not situation specific.

It becomes clear that integrating livestock in CA systems is indeed possible. It allows producers the opportunity to diversify farming enterprises and reduce risk without compromising on crop performance. This adds to the resilience of the whole-farm system. In addition, incorporating livestock and implementing farming practices according to CA principles may provide producers with a way to improve on production in a more sustainable manner and reduce the impact livestock production currently has on the environment under conventional farming systems.

2.4 The South African sheep and wool industry

In 1789 the first Merino flock arrived in the Cape from Europe. Soon after the wool industry was established making it one of the oldest agricultural industries in South Africa (Merino SA, 2021). Since the introduction of the Merino sheep into the Cape, sheep farming has spread throughout the country and is practiced under a range of different environments. These include the winter-rainfall region of the Western Cape under pasture-cropping systems, the arid, extensive conditions of the Northern Cape, throughout the Karoo and Suurveld regions of the Eastern Cape and Free State provinces (Merino SA, 2021; Uys, 2020).

Wool is produced both on commercial scale and by emerging and communal farmers in South Africa. Roughly six thousand commercial wool producers and four thousand communal producers supply wool to the SA wool industry (NWGA, 2021). The wool industry is an important economic and social contributor of the South African agricultural sector, providing additional job opportunities and improving livelihoods for many South African communities (Cloete & Olivier, 2010).

The south-western and central regions of South Africa hold the majority of commercial sheep flocks, while 80% of all communal flocks are located in the Eastern Cape (Cloete & Olivier, 2010). The Eastern Cape (38%) and Free State (22%) are the two top producing provinces followed by the Western Cape (17%). Wool production in the Western Cape is situated around the western and eastern seaboards, namely the Swartland and Southern Cape regions. The typical Mediterranean climate allows for the successful integration of sheep enterprises with winter cereal cropping systems (Cloete & Olivier, 2010).

Roughly 45 million kilograms of wool are produced in South Africa per annum. Of the total wool production, roughly 90% is exported, contributing 2-3% of the global wool supply and 12% of the world’s apparel wool (NWGA, 2021). Being predominantly an export product, wool plays a key economic role in South Africa as an earner of foreign exchange (DAFF, 2016). Throughout the 2018/2019 season, the wool sector contributed an income of nearly R4.5 billion (Cape Wools SA, 2019a). The major export destinations for the national clip (greasy or semi-processed) are China (44%) followed by the Czech Republic (36.8%), Italy (8%) and India (5.2%) (Cape Wools SA, 2019a).

The free market price for wool is determined by supply and demand, where the cost is closely linked to the international price of apparel wool. In turn this is controlled by the Australian market (DAFF, 2016). Following the 2018/2019 season, the average clean yield per kilogram of wool came to R217.90/kg, a 17.13% increase from R186.04/kg attained in the 2017/2018 season (Cape Wools SA, 2019a). Despite the competition from synthetic, more affordable and often fossil fuel-based fibres, Figure 2.1 shows that over the last decade the demand for wool has remained steady as the drive towards more sustainable and environmentally friendly fibres become more important. Wool remains a popular alternative due to its dynamic versatility and natural, biodegradable and renewable properties (Erdogan *et al.*, 2020).

As discussed, integrating livestock into winter cereal cropping systems enables greater diversification (and therefore lower risk), possibly increasing producer’s supplemental income and adding financial sustainability to the crop farming system. The additional benefit of integrating wool sheep into the farming enterprise and further boosting profitability is the inclusion of meat production. In the past meat production was considered a by-product of the wool industry; however, in recent years the increasing economic value of meat, as seen in Figure 2.2, has meant that about two-thirds of the total income from wool sheep is generated from mutton and lamb (Hoon *et al.*, 2000; Snyman *et al.*, 1998). It is, therefore, necessary for farmers to choose the correct sheep breeds to maximise profits from both wool and meat.

The main wool producing breeds used in the Southern Cape are the pure-bred Merino followed by merino-type breeds such as the Dohne Merino. The modern Merino remains the most renowned of the wool breeds since its introduction into South Africa. It is regarded as the most economical wool breed, producing high standard wool, a “marketable” carcass, it is hardy and adaptable (Merino SA, 2021). The Dohne Merino, a dual-purpose, composite (Merino cross SA Mutton Merino) breed characterised by its easy-care and adaptable nature given its ability to thrive under varying environmental conditions, has since become a popular alternative for producers, providing both top-quality meat and wool (Van Wyk *et al.*, 2008).

The South African wool industry has become renowned for producing a clip of a high quality, consistently meeting the standard of the textile industry, and further contributing towards the economic growth of the agricultural sector. However, it remains necessary for producers to continuously find new ways to improve on wool production systems and optimise the cost thereof to remain competitive, meet consumer demands and maintain financial stability.

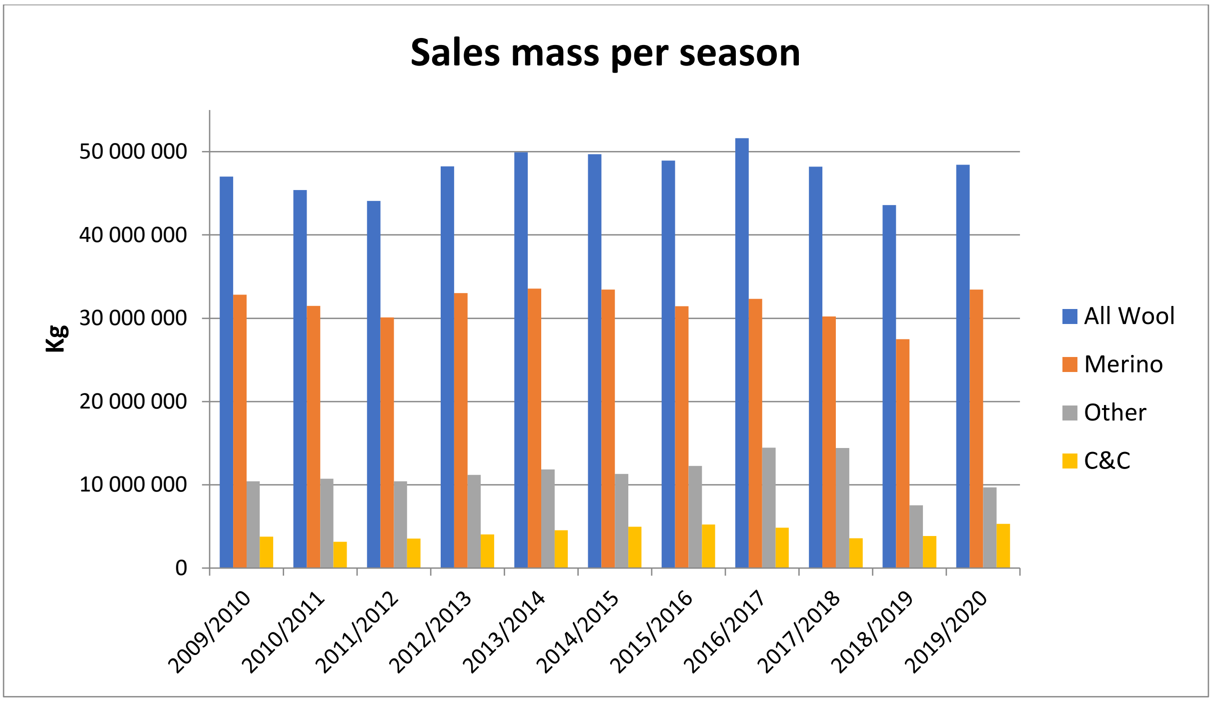

Figure 2.1*The total sales mass of wool per season in South Africa (Cape Wools SA, 2019b).*

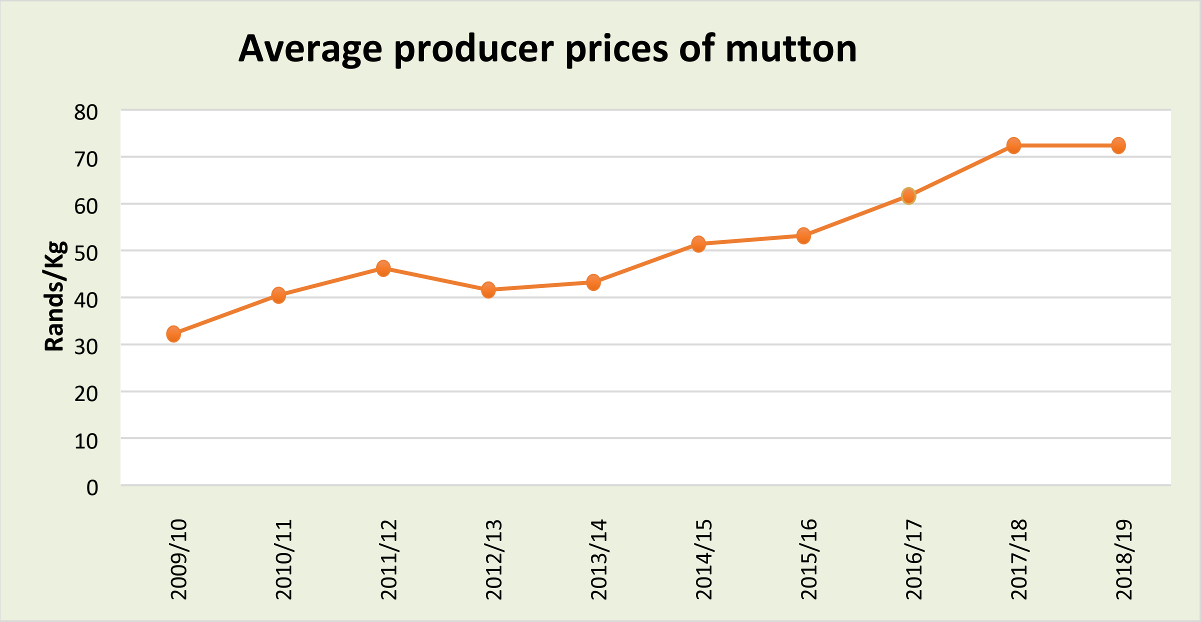

Figure 2.2 *The average producer price for mutton in South Africa* (DALRRD, 2020).

2.5 Wool parameters

Wool is a natural fibre grown from sheep and holds many desired properties considered valuable in the textile industry. By the early 20th century, synthetic fibres were created and have since dominated the textile industry diminishing the market for wool products (Erdogan *et al.*, 2020). While wool cannot compete with synthetic fibres in terms of price, it remains competitive as a high-value fibre of good quality. The future of wool is promising as consumer interest shifts towards more environmentally-friendly products, allowing wool producers the opportunity to provide a fibre that is natural, renewable and sustainable (Erdogan *et al.*, 2020).

2.5.1 Wool quality traits

The quality and quantity of wool is influenced by several genetic, physiological and environmental factors (Hergenhan, 2014; Khan *et al.*, 2012). Wool quality traits are of great economic importance to wool producers and processors as these are essentially the fleece characteristics that influence the price and the end use of the product (Khan *et al.*, 2012). The main factors determining the quality of the wool are yield, fibre diameter, staple length and staple strength, and colour. These traits will be discussed throughout Section 2.5.1.

2.5.1.1 Yield

The raw, unprocessed wool collected from a sheep is classified as greasy wool and contains various impurities such as wax, suint (natural wool grease), dust and vegetable matter. These contaminants are removed by scouring and carbonising processes before being further processed or sold in the commercial market as clean wool (DAFF, 2016). The clean yield thus refers to the greasy wool yield that no longer contains impurities, expressed as a percentage (Holman and Malau-Aduli, 2012; Jones *et al.*, 2004). This forms a good estimate of the quantity of usable wool fibre available.

Several wool quality factors such as clean fleece weight (CFW), fibre diameter, staple length and staple strength all contribute to wool yield (Safari *et al.,* 2005). Thus, wool yield is an important parameter as producers are commonly paid per kilogram according to the clean fleece weight, such that wools of greater CFW yields often are of greater commercial value (Holman and Malau-Aduli, 2012).

2.5.1.2 Fibre diameter

Fibre diameter (FD) is considered to be a major determinant of wool's value. It accounts for 75 - 80% of the raw wool price, thus, becoming the most important trait when assessing the quality of wool (Holman and Malau-Aduli, 2012; Jones et al., 2004). Fibre diameter is measured and graded according to the micron length of the fibre and arranged into groups of fine (<20μm), medium (20.1-22.0μm) and strong (>22.1μm) wool strains (Cape Wools, 2002). The majority of wool found throughout South Africa has a fibre diameter that ranges between 17-24μm (Uys, 2020). Regular selection for finer wool is common amongst producers as it often sells at a premium. However, it has been found that reducing fibre diameter by 1μm, on average reduces fleece weight by 8-9% and body weight by 4% (Adams & Cronjé, 2003; Khan *et al.*, 2012). A trade-off exists for producers depending on their production goals to either reduce fibre diameter and maximise wool income or focus on increasing body weight at the expense of wool quality to maximise meat income.

Genetic factors have the biggest influence on fibre diameter. As a result, variation in fibre diameter is often common between sheep breeds and within the same sheep breed (Khan et al., 2012). In previous studies based on the relative performance of various sheep breeds, it was established that the fibre diameter of Dohne Merinos and Merinos of both sexes are relatively similar (21.8μm– 22.0μm) (Cloete *et al.*, 1999). While fibre diameter is highly heritable in sheep, on-farm factors such as the environment and nutrition also have a smaller part to play in wool quality (Kuffner & Popescu, 2012; McGregor *et al.,* 2016).

2.5.1.3 Fibre length

Wool's fibre length is commonly referred to as the staple length (SL), and is described as a function of the individual fibre lengths and the degree/level of crimping (Khan *et al.*, 2012). Staple length, in addition to staple strength have become increasingly more important factors for wool quality and have a key influence on the processing performance and end-use of the wool product (Nolan *et al.*, 2014).

In a study conducted by Huisman and Brown (2008) to determine the genetic relationship between bodyweight traits and various other traits in sheep, it was found that there is a positive phenotypic correlation between staple length and the live weight. In contrast, McGregor *et al*. (2016) argues that as sheep increase in age, the fibre diameter increases while the staple length decreases. Results from this study suggest that ratios of fibre length and fibre diameter are controlled by different biological factors and are therefore, not suitable in assessing the efficiency of wool growth. However, staple length can be influenced by liveweight up to a certain age (McGregor *et al.*, 2016; Uys, 2020).

2.5.1.4 Staple strength

As previously mentioned, SL and staple strength (SS) have both become increasingly important in determining wool quality and processing performance. Staple strength is measured as the amount of force required to break a staple of wool (Holman and Malau-Aduli, 2012; Nolan *et al*., 2014). The efficiency with which the wool is combed during processing, along with the amount of fibre breakage and fibre wastage as a result, is all influenced by the SS (Nolan *et al.*, 2014). In South Africa the strength of the wool staple is graded in one of two ways: subjectively using the “flick test”, or more commonly used in staples longer than 50mm, the force is objectively measured in Newtons per kilotex (N/ktex). Wool staples that have a high tensile strength of greater than 30 N/ktex, is classified as ‘sound wool’ whereas a tensile strength below 25 N/ktex is graded as ‘tender wool’, a condition characterised by wool that break easily when gentle stretching is applied (NWGA, 2017).

Several researchers concluded that the SS is primarily influenced by both the fibre diameter and variation in fibre diameter along the staple, where FD variation is associated with a change in liveweight due to seasonal changes affecting the quality and availability of pastures (Friend & Robards, 2006; Masters *et al.*, 1998). Managing staple strength can be a challenge given the complex interaction several factors such as genotype, the environment, nutrition, liveweight change, physiological state and disease all have on the SS (McGregor *et al.*, 2016). Thompson and Hynd (1998) found that sheep fed to maintain their liveweight produce more sound wool. Similar results in response to uniform nutrition and liveweight, under controlled feeding conditions have also been observed in later research (Friend & Robards, 2006).

2.5.1.5 Colour

In relation to other fibres in the textile industry, wool has the strong advantage that products can hold a more uniform colour as the fibre is able to take up dye more readily during processing (Nolan *et al.*, 2014). The colour of raw, unprocessed wool ranges from near white to various shades of cream to yellows and brown (Cottle, 2010). However, fleece faults such as stains and various pigments resulting in a yellow colour can significantly affect the commercial value of the wool given the extra processing costs and limiting the range of colours with which the wool can be dyed (Sumner, 2005). The parameters that are considered important commercially, are the yellowness and brightness of raw wool (Wang, Mahar, Liu, *et al.*, 2011).

Wool colour has been proven to be hereditary, with heritability values ranging from 0.39 to 0.56 (Mortimer *et al.*, 2009; Wang *et al.*, 2011); wool producers therefore incorporate the selection of clean wool colour into their breeding objectives (Uys, 2020). Furthermore, studies have shown a strong, positive genetic correlation (0.57) between the FD and wool colour. Sheep selected with a lower FD, produce offspring that have whiter wool (Hebart & Brien, 2009; Sumner, 2005).

Additionally the time of shearing is an important aspect of herd management that can have a significant influence on the wool colour, as sheep shorn in winter or early spring produce whiter wool compared to those shorn in the summer (Sumner, 2005). Given that summer is dryer, greater susceptibility of wool contamination by dust and vegetable matter, including sweat and prolonged sun exposure can occur. Environmental effects in various grazing environments influence the colour of wool to a great extent. This will be discussed in Section 2.6.3.

2.5.2 Production parameters

Various production parameters are considered important for the long-term success of the sheep farming system. Improving such parameters allow the sheep farming enterprise to grow and contribute to the sustainability of the whole-farm system.

2.5.2.1 Lambing percentage

The lambing percentage refers to the number of lambs born per number of ewes mated, expressed as a percentage. Apart from genetic factors, lambing percentage is largely determined by ewe and ram fertility, this is dependent on liveweight and body condition at joining. Earlier research by Coop (1962), showed that for each extra kilogram of ewe weight, the lambing percentage will increase by 1.3%. Multiple studies reported a positive relationship between liveweight at mating and the percentage of twin-bearing ewes. This is most likely due to an increased ovulation rate related to heavier liveweight at mating (Haslin *et al.*, 2020; Thompson *et al.*, 2019).

In sheep production systems, multiple births (twins etc.) are a desirable reproductive trait as more lambs born would potentially result in greater profits. In South Africa, good lambing percentages for Merino-type breeds range from 120% - 150% (Brand & Franck, 2000). Proper management and nutrition play a major role in obtaining desirable lambing percentages which contribute to the success and continuation of sheep production systems.

2.5.2.2 Weaning percentage

The weaning percentage can be described as the number of lambs weaned per number of ewes mated, expressed as a percentage. This helps producers to identify reproductive issues during the breeding season with respect to the ewe's ability to successfully rear strong lambs of good quality and weight as well as the pre-weaning management of both ewes and lambs. The weaning percentage is an important factor that contributes towards improved reproduction efficiency and productivity resulting in greater profitability of the sheep enterprise (Denney, 1990).

From birth to weaning the average lamb deaths range from 10% loss for singles, up to 30% loss for twin-born lambs with most mortalities (>80%) occurring within the first 48 hours after birth (Hinch & Brien, 2014). Differences in birthweight are a major contributor to the risk of lamb survival. Twin lambs tend to weigh less at birth when compared to single-born lambs. Lambs born below optimal birthweight are, therefore, at greater risk of starvation, exposure or predation (Hinch & Brien, 2014). Differences are also observed between breeds: Dohne Merino lambs tend to be heavier at birth than Merino lambs and show greater survival to weaning, with weaning percentages reaching 123% and 119% for Dohne Merino and Merino lambs respectively (Cloete & Cloete, 2015). These results appear to be higher than those reported in previous studies (Cloete *et al.*, 1999; Schoeman, 1990). However, values can vary considerably between farms given different management techniques, feeding regimes and environments.

Weaning takes place at 80-100 days of age and can be a stressful time for lambs as they move from a liquid diet to solid feed. To limit stress, producers implement strategies such as providing creep feed to stimulate the intake of solid feed before weaning occurs. The producer's goal is to increase flock numbers and meet production in a sustainable manner in order to maximise income. Providing the proper environment, management, and nutrition for both the ewe prior to lambing and lambs pre-weaning can help improve survival rates. This can increase weaning percentages as well as provide a smoother transition through the weaning process.

2.5.2.3 Carcass weight

Mutton, lamb, and wool are the main products of sheep farming in South Africa. In recent years, favourable meat prices have resulted in producers incorporating meat production into sheep farming systems. In terms of wool production systems, roughly 60% of income is generated through meat and 40% through wool production in Merino sheep, while in the Dohne Merino, 70% of income is meat and 30% wool (Snyman, 2014). Meat (mutton and lamb) production as well as the meat price determines the income from sheep production systems.

The cold carcass weight of an animal refers to the carcass of the animal once it has been slaughtered, dressed, and cooled. Producers are paid according to the cold carcass weight of the animal in Rands/kilogram. The carcass weight serves as an indicator for income per animal sold/slaughtered. Various factors can influence the carcass weight of livestock, including breed, sex and age. A study comparing slaughter traits between breeds, found the average carcass weight of the Dohne Merino to be greater than the Merino, with weights of 22.4kg and 16.0kg respectively (Cloete *et al.,* 2012). Given that the Dohne Merino is a dual-purpose breed, selected for both its wool quality and meat traits, it is likely to gain a higher meat price due to having a greater liveweight and, thus, carcass weight.

2.5.2.4 Wool growth rate

The growth rate of wool can be influenced by a number of factors such as genotype, physiological state of the animal as well as environmental and nutritional factors (Khan *et al.*, 2012). Breeds vary in their capacity to grow wool and of various qualities. Research was conducted to compare the wool growth rate across four breeds of sheep in South Africa. Researchers found Merino sheep to have the highest wool growth rate of 12.943g/day, while the lowest rate of wool growth was observed in the Dormer (8.487g/day) (Van der Merwe *et al.,* 2020). Wool growth rates did not differ significantly (P>0.05) for the South African Mutton Merino (10.553g/day) and the Dohne Merino (9.720g/day). This was attributed to the differences in liveweight (Van der Merwe *et al.*, 2020). Both classified as dual-purpose breeds, the Dohne Merino is favoured more for wool production, whereas the SA Mutton Merino is orientated more towards meat (Cloete *et al.*, 1999). In terms of wool production and quality, the Merino is the most favoured wool breed while the Dohne merino has been found to produce wool of similar quality to that of the wool Merino (Van der Merwe *et al.*, 2020). These two breeds, therefore, serve as the two main wool producing breeds throughout the region.

2.6 Factors influencing wool parameters

On-farm management, animal nutrition, physiological state and the environment are some of the main factors that influence the quality and quantity of wool produced by sheep. To improve and maintain efficient wool production and quality, these factors need to be managed optimally.

2.6.1 Management

The management of sheep is an important driver of profitability and refers to the controllable factors of sheep production. These factors are discussed separately throughout this section.

2.6.1.1 Age and sex

Wool production and wool quality characteristics are greatly influenced by the age and sex of the animal. In sheep, it has been observed that maximum fleece weight occurs between three to five years of age, with wool production subsequently declining as the sheep ages (Brown *et al.*, 1968; Khan *et al.*, 2012). In young sheep, less wool per unit of feed intake is produced as nutrients are directed/required more towards tissue growth, alternatively in older sheep, changes in feed intake and feed selection result in a reduction of wool growth (Khan *et al.*, 2012). Wool quality traits in Merino breeds have been observed to progressively deteriorate as sheep age, the fibre diameter increases and the staple length decreases, reducing fleece value (Hatcher *et al.*, 2005; McGregor *et al.*, 2016).

Compared to wethers and ewes, rams are more likely to produce more wool as they are greater in size and receive better quality feed, meanwhile late pregnancy and early lactation has a significant impact on the ewe and leads to a reduction in the wool growth rate (Khan *et al.*, 2012). Brown *et al.* (1968) observed that rams grew to be 40% larger and produce 33% more clean wool compared to ewes. However, because sexes are usually separated throughout the year, apart from mating season, provision of better quality feed for rams and the additional nutritional requirements during gestation and lactation for ewes, comparisons between sexes for wool quality and quantity are seldom useful (Hergenhan, 2014).

2.6.1.2 Stocking rate

Stocking rate (SR) is an important aspect of pasture management. It represents the relationship between livestock and the forage resource. Stocking rate can be defined as the number of animals grazing a piece of land, for a specific amount of time (Sandhage-Hofmann, 2016). High stocking rates can often lead to overgrazing, increasing the risk of potential land and soil degradation, especially in wetter soils. Low SR can lead to selective grazing resulting in the establishment of weeds, an issue currently experienced in CA systems (Pratley & Virgona, 2010). The goal of the producer is to balance the forage demand of livestock with the forage production of the pasture.

The stocking rate depends on pasture production, which is largely influenced by a variety of factors. These include average annual rainfall and seasonal conditions, the type of livestock and their physiological state as well as the grazing period. Stocking rates are adjusted according to pasture growth and the availability of forage for livestock.

In terms of wool production with increased SR, individual animal performance decreases due to greater competition and less available forage, while the total wool per hectare is increased. Various researchers have observed that an increase in stocking rate reduces clean wool production by 650-750g per sheep, while fibre diameter decreases by 1.8 microns for every 1 kilogram decrease in CFW (Thompson *et al.*, 1994; White & McConchie, 1976). Both per-animal and per-hectare production reach an accelerated decline once the stocking rate passes the optimum grazing pressure (Pratley & Virgona, 2010).

Given that yield and FD are both major determinants of wool price, the stocking rate is therefore a major determinant of profitability for the sheep farming enterprise. For producers, the inclination to farm at a maximum SR is not necessarily the most sustainable SR and must therefore balance the optimal SR for profitability with the optimal SR for sustainability while also maintaining adequate nutrition for livestock.

2.6.1.3 Parasites and disease

Viruses, bacteria, and internal and external parasites all contribute to health conditions leading to reduced animal growth, production and wool quality in sheep. Gastro-intestinal parasites, lice, fleece rot, foot rot and blowfly strike are some of the most common parasites and diseases found among sheep in South Africa (McGregor *et al.*, 2016). Infectious diseases invoke an immune response in sheep. Symptoms such as fever and inflammation lead to a reduction in appetite and as a result reduces the rate of wool growth. Additionally, when exposed to various diseases or parasites, it can also prompt a stress response. Elevated levels of cortisol can reduce wool growth and in some cases, when hormone levels are too high, stop growth completely (Hergenhan, 2014).

The greasy wool yield and FD are both negatively affected by gastrointestinal parasites as a result of liveweight loss experienced from reduced appetite due to the immune response (McGregor *et al.*, 2016; Thompson & Callinan, 1981). Footrot, a bacterial disease, can lead to varying degrees of lameness in sheep. Sheep with more severe cases, show a reluctance to move around and graze resulting in reduced bodyweight and is therefore likely to produce less wool (Cottle, 2010).

For producers to maximise efficient wool production and profitability, it is essential that sound animal health and welfare be monitored and maintained. Future planning, proper nutrition and rotational grazing practices are among the few management strategies implemented to help aid in disease prevention and management (Cottle, 2010).

2.6.1.4 Shearing

The timing of lambing and shearing are two important management decisions that can have an influence on several fleece characteristics. When to shear influences both wool production and sheep health. Aspects such as yield, fleece weight and fibre diameter are all influenced by the time of shearing, as the pattern of fibre growth changes in response to the change in pasture quality, nutritional requirements, and the physiological state throughout the year. The staple length is dependent on the frequency of shearing (Campbell *et al.,* 2011).

In the Southern Cape, sheep are traditionally sheared every twelve months during the spring and autumn months, in accordance with the lambing seasons. Ewes are shorn at two to four weeks prior to lambing to reduce handling and stress closer to birthing. Shearing prior to lambing has been shown to improve lamb birthweight by up to 0.7kg depending on when shearing took place during the pregnancy (Cloete *et al.,* 1994; Morris *et al.*, 1999). It has been suggested that an increase in lamb birthweight further improves lamb survival rates. At the optimal birthweight of between 3.5-5.5kg, lambs are more likely to reach the weaning phase (Dalton, *et al.,* 1980; Kenyon *et al.*, 2003). The added benefit of shearing ewes prior to lambing is that this allows the ewe to become more attuned to their surroundings and allows for better care and further increased survival of lambs to weaning, especially in times of unfavourable weather conditions (Kenyon *et al.*, 2003).

2.6.1.5 Breeding and selection

Breeding and selection are of great benefit to producers. The main goal of implementing a breeding program is for producers to improve their productivity, animal management, profitability and sustainability based on desired breeding objectives (Cottle, 2010). In sheep wool production systems, the traits of greatest economic importance include growth and body weight traits, fleece traits, reproductive efficiency and parasite and disease resistance (Matebesi *et al.*, 2009). Greasy fleece weight, fibre diameter, staple length and colour are among the fleece traits that are moderate to highly heritable with estimates ranging between 0.3-0.6 (Khan *et al.*, 2012; Safari *et al.*, 2005). Traits with higher heritability's are easier to change through selection. Breeding and selection, therefore, serve as a useful tool to improve various economically important wool quality characteristics.

Many traits are correlated, among these relationships Huisman and Brown (2008) found fleece weight (0.21) and fibre diameter (0.18) to be positively correlated with bodyweight and thereby selecting for one will improve the other, several studies have found similar results (Fogarty, 1995; Safari *et al.*, 2005). Caution is however required when selecting for a particular trait as to not negatively affect other production characteristics, a clear understanding and knowledge of inheritance and the relationships and correlated responses between traits is thus required for any successful breeding program (Cottle, 2010; Khan *et al.*, 2012) .

Merino and merino-type breeds make up around 74% of the total wool sheep in South Africa (DAFF, 2011). The modern Merino and the Dohne Merino are the two main producing wool breeds in the Southern Cape. A comparison of the production performance between the two breeds found Dohne Merinos to be more favourable in terms of growth, mature liveweight and lamb survival, whereas the Merinos outperformed Dohne Merinos for wool traits such as fleece weight and clean yield (Cloete & Cloete, 2015). Terminal crossbreeding of dual-purpose rams with wool-type dams is often practiced by producers in order to obtain offspring portraying both desirable meat and wool traits (Cloete & Olivier, 2010). Research in South Africa has yet to focus on a comparison of these breeds within financial terms.

2.6.2 Nutrition

While the genetics of an animal determines its capacity for wool production and the quality thereof, it is through the modification of several factors, the most important being nutrition, in which the true genetic potential may be achieved. Nutrition provides a useful way to manage current flock performance.

2.6.2.1 Physiological state

The ewe’s capacity to produce wool is significant to producers. Any changes as a result of the reproductive cycle will impact the profitability of the whole-farm enterprise. The physiological state is an important determinant for wool production in breeding ewes. The maintenance of liveweight, body condition as well as supplying adequate nutrition, remain the most important components of any breeding management program, ensuring success throughout the reproductive cycle.

Pregnancy and lactation are two of the most nutritionally demanding stages throughout the ewe’s reproductive cycle and can significantly affect the quantity and quality of wool. During this time the dry matter intake will increase. The efficiency with which the dry matter is converted and used for wool production is reduced (SCA, 1990). A decrease in wool production as well as quality is primarily a result of nutrient partitioning, where nutrients that are usually allocated for maintenance and wool growth are redirected towards foetal growth or milk production (McGregor *et al.*, 2016). Pregnancy and lactation result in reduced wool growth, with wool characteristics also reflecting a decrease in quality. The CFW, FD and SS are directly related to a change in liveweight, a result of greater energy demands during foetal development and milk production that yields wool of a smaller FD and weaker SS (Ferguson *et al.*, 2011). A larger litter size has been linked to a further reduction in SS, with twin-bearing ewes exhibiting lower SS given the even greater nutritional demands when compared to single-bearing ewes (Ferguson *et al.*, 2011). The negative effects on wool production have been found to be short term as intake and liveweight increase after weaning as a result of compensatory growth (Lee & Atkins, 1995).

The primary and secondary wool follicle population is established during pre-natal development. Primary wool follicles develop during mid-pregnancy while secondary follicle development commences during late pregnancy up to parturition and matures through to early post-natal life (McGregor *et al.*, 2016). The number of secondary wool follicles are genetically determined, with no new follicle development initiated after birth. Secondary wool follicles are of great economic importance to producers as these are known to generally produce wool of a smaller fibre diameter in relation to primary follicles, the ratio of secondary to primary wool follicles influences both the CFW and the FD of wool (Thompson *et al.*, 2011). Overall wool production will decrease if the number of secondary wool follicles, both initiated and matured are reduced (Kelly *et al.,* 2006).

Nutrition of the ewe during pregnancy and lactation affects the development of the secondary wool follicle population in their offspring; thus, affecting their future production potential. Schinckel & Short (1961) observed the influence of poor nutrition on ewe liveweight and the effect this had on wool parameters of offspring. Restricting nutrient intake during pre-natal life reduces the total number of follicles formed in offspring while post-natal restriction reduces the capacity for the follicles to grow wool. A more recent study by Thompson *et al.* (2011) demonstrates the effects of manipulating feed intake and ewe liveweight and the influence this has on wool parameters in their offspring. Ewes that were heavier at mating or that maintained a constant weight throughout pregnancy produced offspring with finer wool (−0.2 µm/10 kg ewe liveweight). Furthermore, ewes which showed an increase in liveweight during pregnancy also produced offspring with finer wool (Thompson *et al.*, 2011). Additional factors such as birth-type was also found to influence CFW and FD, with single-born lambs producing more wool of smaller fibre diameter, largely as a result of differences in birthweight between the two. Single-born lambs weighing 1.1kg more at birth than twin-born lambs exhibited a 0.15kg increase in CFW and a decrease of 0.20µm in FD (Thompson *et al.*, 2011).

2.6.2.2 Level of feed intake

Feed intake is a function of liveweight. Liveweight changes as a result of sheep growth towards mature size or seasonal changes in nutrient availability (McGregor *et al.*, 2016). Wool growth and liveweight tend to be measured simultaneously. It is, therefore, not possible to differentiate between the nutritional effects on wool growth from sheep growth. According to Khan *et al.* (2012) the rate of fibre production as well as different fleece characteristics are significantly influenced by a variation in the supply of nutrients to the wool follicles. This statement is in line with research by Schinckel (1960) who observed that an increase in wool growth is related to an increase in feed intake. Furthermore, various researchers have also noted that fleece characteristics, most notably FD, is influenced by a change in nutrient availability as a result of seasonal change, variations in stocking rate and the physiological state (Friend & Robards, 2006; McGregor *et al.*, 2016). The intake level of nutrients is an important factor in maintaining sheep condition as well as production and quality of wool.

2.6.2.3 Seasonal changes

The Southern Cape is characterised by cool, wet winters and warm, dry summers. As a result, the quality and quantity of feed varies throughout the year. Liveweight fluctuates with the change in season. The low digestibility of pastures during the late summer/autumn period results in a loss of liveweight and as pasture digestibility improves, liveweight gain occurs (McGregor *et al.*, 2016). Wool growth, in response to a change in liveweight also varies according to the available nutrition between seasons (Khan *et al.*, 2012). As previously mentioned, it is impossible to distinguish between the effects of nutrition on the growth of the sheep and wool growth; however, a change in season and the availability of nutrients warrants a need for producers to provide feed during the dry summer months. To maintain livestock conditions and minimise the effect of seasonal changes on productivity, producers typically provide supplementary feed to complement the low protein and energy content of the pasture until availability and quality improves.

A similar concept applies to livestock during periods of drought when the quality and quantity of feed is low. Under such conditions, the carrying capacity of pastures decreases and producers must in response, adapt stocking strategies. To preserve the current available pasture, the stocking rate is decreased with males and old females typically sold off first. The breeding herd is often retained as these animals are the most important for recovery and re-establishing the herd (Jolly & Cottle, 2010). Complementary to various other livestock and pasture management strategies pertaining to drought plans, producers manage the effects of the drought on livestock through supplementary feeding. Livestock are typically fed only for maintenance during this period with feed in the form of roughage, residues and pellets, provided to meet the minimum requirements of the animal, quality is not a priority. Supplementary feeding is costly, given that feed becomes expensive and in short supply with livestock prices also decreasing and may; therefore, become financially unsustainable in the long term. It becomes necessary for producers to base management decisions on the cost of feeding animals versus the cost of re-establishing the herd at a later stage.

Drought evidently has a large effect on production across all farming enterprises. In years with crop failure and disease, it is with livestock integration that producers may diversify income; thus, reducing risk and potentially ensuring greater resilience and financial stability for the whole farming system

2.6.3 Environment

Different environmental conditions impact grazing and have the potential to significantly influence the quality of wool, causing faults which result in price penalties. Several biological and non-biological agents in the environment such as bacteria, urine, dust and dipping solutions are the most common factors producing stains and various pigment faults in wool (Khan *et al.*, 2012). Variation in ambient temperature promotes yellowing of wool through increased sweating (Sumner *et al.,* 2004), in addition, the heat stress experienced by sheep in extreme temperature conditions reduces feed intake efficiency and utilisation (Marai *et al.*, 2007). The weathering of wool due to prolonged sun exposure, dust and vegetable matter contamination are also common faults that can affect the fleece quality (Khan *et al.*, 2012).

2.7 Conclusion

Conservation agriculture serves as a base for sustainable agricultural intensification and contributes positively towards enhancing natural biological processes, preserving the soil resource as well as the financial performance of the farm. CA is widely adaptable and practiced around the world under various conditions, both at small- and commercial scale. The Western Cape is the leader in terms of CA uptake in South

Africa with practices largely implemented on commercial wheat farms. Producers from the Southern Cape region have further diversified farming enterprises to include sheep production.

Integrating livestock, grazed on legume pastures in rotation with winter cereals can help mitigate production risks and add to the financial sustainability of the farm. Various herd and pasture management strategies, such as stocking rates, rotational grazing, and rest periods, play an important role in managing the risks of overgrazing and livestock-induced compaction that may occur over time. The maintenance of surface residues and soil organic matter attributed to CA principles further contribute towards resisting soil compression induced by livestock. The success of crop-livestock integration within CA based farming systems depends not only on the implementation of effective livestock management strategies but also on the extent to which CA principles are carried out by the producer.

Relative to fossil-fuel based synthetic fibres, wool serves as a natural alternative that is both renewable and more sustainable. The Merino and Dohne Merino are the main breeds farmed in the region, producing both wool and meat of a high standard. CFW, FD, SL, SS, and colour determines the quality of the wool; thus, influencing the wool price to varying degrees. In turn, on-farm factors that influence both production and quality traits were identified as livestock management, nutrition, and environmental factors. The optimisation of these factors from a farming perspective allows producers to improve on wool quality and production and therefore, profitability.

Chapter 3: Method

3.1 Introduction

Chapter 2 outlined the fundamental principles of conservation agriculture as well as the implications of livestock integration within CA farming systems. The relationship between wool traits and management, nutritional and environmental factors are also discussed. Agricultural systems are becoming increasingly complex. Traditional scientific methods are reductionist by nature and have become limited in their ability to solve complex physical-biological, socio-economic and management issues. Alternative research methods capable of integrating knowledge previously fragmented due to specialisation, are required.

The systems approach is a multi-disciplinary, holistic tool capable of managing complex agricultural systems. Advances in computer technology and software have further facilitated the development of the systems approach through the application of modelling and simulation (Hirooka, 2010; Knott, 2015).

The first part of Chapter 3 aims to provide an understanding of the systems approach and its practical use within agricultural systems research. This is followed by the methods used to capture and quantify the data required to construct a whole-farm, multi-period budget model in order to financially analyse the contribution of sheep enterprises to farm level performance.

3.2 Systems approach in agriculture

Over the 20th century scientific research has developed towards a more systems thinking approach. In the past, complex problems in agricultural systems have typically been solved using more traditional and scientific methods. This type of analytical approach aims to break down complex problems into smaller components in order to better understand and solve each part in isolation. Whilst this approach has contributed a great deal of current knowledge, the reductionist nature of this approach has led to research fields becoming more specialised and, thus, fragmented over time (Hirooka, 2010).

Limitations of the traditional scientific approach have become increasingly apparent as present-day agricultural systems become more complex. Systems are typically made up of individual parts or components that are all linked and interact, resulting in complex behaviour arising. Typically, the components give the system structure while the various interrelationships provide function. The properties of a system are therefore not contained within individual parts but rather, emerge as a result of components interacting (Cilliers, 2008). The study of components in isolation has thus proven insufficient in the understanding of complex systems and the interrelationships between components. A systems thinking mentality thus emerged and offered researchers a way in which to further investigate the increasing complexity of, in this case, agricultural systems (Jones *et al.*, 2016; Kooper, 2020).

Systems thinking is a holistic approach that enables researchers to study complex systems that include the component interactions that make up that system rather than each discipline in isolation. The adoption of a systems thinking mindset provides the ability for one to view the problem in a broader sense and thus assist in better understanding the interrelatedness between components (Nell, 2019). In terms of agricultural systems, identifying these relationships and understanding how the interactions affect the system, can assist producers to make better informed decisions regarding the performance of the whole farm (Jones *et al.*, 2016).

Agricultural systems are inherently complex and multifaceted. Such systems are based on biological, mechanical, management and economic systems, all of which are interrelated and contribute towards the functioning of the whole farm system (Knott, 2015). Wheat production in the Southern Cape for instance, can also be regarded as a complex system given that many factors are involved. This includes crop rotations, soil health, land management, mechanization, as well as the financial aspect. Additionally, the integration of a livestock component such as sheep, grazed on legume pastures, further adds complexity to the farming system given the interactions that are found between livestock, soil, and crops. A method is needed to bridge the gap between disciplines and integrate knowledge that may have become fragmented over time due to specialisation.

Modelling and simulation are tools often used in the application of a systems thinking approach that can integrate knowledge acquired across disciplines. This project makes use of a whole-farm budget model based on data captured by Hoffmann (2010b), Nell (2019) and Kooper (2020), through multi-disciplinary, expert group discussions. Group discussions serve as a platform for the generation of new ideas, validation of information and to obtain a better understanding of the problem while also discussing possible solutions (Nell, 2019). Expert knowledge gained from a team of agricultural economists, animal scientists, soil scientists, agronomists, pasture scientists as well as local producers was used to characterise winter cereal production systems in the Southern Cape.

3.3 Farm modelling and simulation

Agricultural modelling and simulation are two quantitative methods often designed in order to process information to help decision-makers and researchers better understand and predict the behaviour of complex systems in order to make informed on-farm management decisions (Jones *et al.*, 2016; Strauss, 2005). The additional benefit of using modelling and simulation, is that these techniques are easy to replicate without disrupting the physical system itself through real-life experiments, and thus serve as a more time- and cost-efficient way of evaluating systems at the farm-level (Hoffmann, 2010a; Jones *et al.*, 2016).

Quantitative methods are widely used in modern agriculture by researchers, industry experts, policymakers, and producers. These techniques offer a more objective and scientific way of evaluating alternative management strategies for maximizing production-, financial- or sustainability-goals. While these tools may guide producers, quantitative methods alone are not enough for on-farm decision-making. Producers must still rely on intuition and experience when making the necessary decisions (Hoffmann, 2010a).

3.3.1 Modelling

A model is best defined in the literature as a simplified representation of the real world based on a set of assumptions and observations (Hirooka, 2010; Knott, 2015). Daellenbach and McNickle (2005) further define it as a description or analogy, used to help one visualise something that cannot usually be observed directly.

Models are used to simulate the behaviour of systems (Nell, 2019). Given the complex interrelationships found between the physical-biological, socio-economic and management components within the farming system, modelling is a valuable research tool. Its usefulness lies in the ability to organise available information of a particular farming system and it helps to identify gaps in knowledge; thus, prompting further investigation into the better understanding and management of that system (Hirooka, 2010).

Through the present advancements in computer software and technology, computer models have become widely used in various agricultural fields. As a research tool, models prove to be well suited due to its practical use and is well known and understood amongst producers (Hoffmann, 2010a).

3.3.2 Approaches to modelling

The approach to modelling farm systems is directed by the purpose of the model and the aim of the research. The two main approaches to modelling are the normative and positive approach.

A normative approach focuses on what ‘ought to be’. Normative questions are not exclusively answered by facts, as statements are typically based on value judgements, often influenced by cultural, religious, and philosophical beliefs. Normative models do not rely on historical data, with the use of basic knowledge proving sufficient for the system being modelled. These models are typically optimisation models and aim to determine the best possible solution (Hoffmann, 2010a). The main disadvantage is the inability to compare alternative predicted scenarios.

Alternatively, a positive approach focuses on ‘what is’, ‘what was’ or ‘what will be’ (Hoffmann, 2010a). Positive models rely on observed and statistical data of historically proven interrelationships in order to represent real systems as accurately as possible. Empirical evidence is used to prove positive statements as either correct or incorrect. Positive models are used to run a series of simulations that aim to establish the influence of specific variables or parameters on real systems (Hoffmann, 2010a). The researcher typically requires an in-depth understanding of the components and their interrelationships in order to build a system that is the most realistic. However, the downside to this is that the model construction and validation process may become time consuming and costly (Strauss, 2005).

A positive approach is best suited to this study as the purpose of the research project is to accurately define a typical farm in the Southern Cape and simulate the impact of various on-farm management decisions on farm profitability and sustainability through a number of scenarios.

3.3.3 Types of models

Stochastic and deterministic models are two basic types of models. Deterministic models function without the use of probabilities, all system relationships are constant, random variables and risk are not included. Given a set of specified inputs, deterministic models simulate specific outcomes (Strauss, 2005). For this research project, all input values are known and fixed; therefore, a deterministic model is best suited. This model was used to evaluate the financial implications of sheep enterprises as a component of the cash crop production system.

3.3.4 Simulations

Once a model has been constructed, experimentation follows. A simulation is expressed as a form of experimentation. Given that a model is a simplified representation of a real-world system, the objective is to replicate the relationships between individual components to predict the most likely outcome or behaviour of these components within a particular system by simulating specific scenarios (Strauss, 2005).

Simulation models are thus able to generate ‘new’ information in response to the factors involved in the decision-making environment in which a farm is managed, thus, reducing uncertainty for producers. Simulation provides insight into the potential impact of alternative management options and serves as a platform to inform decisions at farm-level (Hoffmann, 2010a).

Physical models are often implemented in the agricultural sciences field to represent real-world scenarios. In Agricultural Economics, however, there are often too many variables to sufficiently incorporate into a physical economic model. Therefore experiments are mostly conducted using computer-based simulation models to effectively represent a whole-farm model (Strauss, 2005).

3.4 Whole-farm budget model

Whole-farm budget models are essentially simulation models. Spreadsheet programmes are typically used to develop budget models and express complex and sophisticated calculations and relationships in a simpler way. The sophistication of such a model lies in the amount of variables that can be integrated into the system and thus the ability to allow for greater detail, adaptability of variables and userfriendliness (Keating & McCown, 2001). According to Hoffmann (2010a), budget models are an ideal research tool amongst farm system researches for a number of reasons:

- The simplicity of the model allows for the explanation of budgets to participants at all levels of education,
- Budget models are well known to producers and results can be effectively communicated,
- The development of budget models can be based on any group of resources, in addition to financial resources,
- Budget models can accommodate a large number of variables and relationships, thus, increasing trust in the model and method among participants if relationships are accurately and thoroughly understood,
- Model developers and participants can decide on which performance indicators or criteria to use.

Budget models exhibit similar limitations to those of simulation models and are often criticised for:

- The lack of an optimisation goal: budgets are non-optimising and are not capable of determining the ‘best’ possible solution, but rather compare alternative predicted scenarios,
- A thorough understanding of the system is required by the modeller in order to represent the model accurately,
- Model construction and the validation processes may become time consuming and costly.

Despite the limitations mentioned, budgeting remains a useful research technique and decision-making tool among agricultural economists and in farm management. Profitability criteria, such as, net farm income (NFI), the internal rate of return (IRR) on capital invested or cash flow are usually calculated by whole-farm budgets. The incorporation of both physical and financial parameters into the model allows for these calculations to be done (Hoffmann, 2010a).

The incorporation of physical parameters further allows for the model to effectively capture the sustainability of such farming systems. The model design is based on input data that reflects typical farming practices within the region. Sustainable agricultural practices are strongly reflected through these farms under the guide of conservation agriculture, where cropping systems and machinery use, for example, are based on the current, best farming practices and are thus reflected in the model assumptions.

In terms of farm management, producers are continuously faced with various on-farm decisions and often require the skills and tools needed to cope in uncertain situations (Nell, 2019). Constructing a whole-farm budget model using a systems approach allows for a more comprehensive view and, thus, a better understanding of the farming system across disciplines. This allows one to predict behaviour and become capable of making informed management decisions. The whole-farm budget attempts to solve the whole problem in a general sense, rather than solve individual parts of the farm completely and accurately (Hoffmann, 2010a).

3.5 The typical farm approach

Farms are idiosyncratic by nature. A farm is defined as the integrated set of land, capital, management, and labour. This means that by nature no two farms can be similar. The goal of this approach is to establish the most frequently occurring farm in the region, rather than the average; thus, reducing the effect of any misleading outliers (good or bad) (Knott, 2015). The aim is to have a model that is most representative of a group of farms (or what a group of farmers do) in a homogenous region that producers can relate to (Feuz & Skold, 1992). The parameters for the Southern Cape homogenous region in this study is characterised by farms of similar size, ownership of land, land-use patterns, cultivation practices and the carrying capacity of livestock.

From this model, researchers are able to adapt the model to a particular farm and simulate various scenarios with the aim to help guide the decision-making process and management on that specific farm (Knott, 2015). In this study, the typical farm approach serves as a basis for comparison (of specific scenarios) in which to determine the effects of different on-farm livestock management decisions on profitability.

Given that this research focuses on one homogenous region in the Southern Cape, namely the Goue Rûens, as identified by Hoffmann (2010a), the typical farm approach is most suitable for this study. When constructing a typical farm, it is necessary to incorporate the knowledge and views of the local producers and agribusinesses in the area. The input and feedback on the model by various industry experts, producers and agricultural economists is vital throughout the validation process (Hoffmann, 2010a).

3.6 Structure of a whole-farm budget model

The aim of this research project is to evaluate the potential financial role of alternative wool sheep enterprises on the future sustainability of selected cash crop/pasture systems in the Southern Cape. CA is regarded as the most holistic cereal production system within the umbrella of sustainability. To assess the impact of one component in isolation can lead to misconceptions. A framework is required that can simultaneously accommodate the design of a CA function and also measure the effects on the financial outcome (profitability) which is by definition part of a sustainable system. The profitability of a farm is affected to a large extent by factors that directly or indirectly influence the quantities and prices of inputs and outputs. Of these factors, some can be influenced to some degree through management practices. Exogenous factors are typically determined by the market and macro environments and thus, beyond the control of producers. A whole-farm, multi-period budget model is constructed in order to determine the potential impact of these factors on farm profitability.

Firstly, the budget model is used to establish the current position of the typical farm from a financial perspective and secondly, to measure and compare the financial implications of alternative livestock management approaches. Whole-farm budget models allow for a number of variables to be incorporated. This allows for the modeller to gain greater insight into different factors and how the interrelationships of these factors may influence the farm's financial performance. In this case, the model is used to express the financial implications of production considerations that influence sustainability. For example, the model translates "better" practices such as a more moderate carrying capacity into a financial output. It is also important to simulate the system over a longer period to allow for the capturing of the system dynamics. Farm size, stocking rate, crop rotation systems, replacement of machinery, input costs and own versus borrowed capital are among some of the many adaptations that can be accommodated in the spreadsheet budget model. The model incorporates various sets of input data and according to standard accounting principles calculates a financial measured output. Figure 3.1 illustrates the three components of the budget model, namely, the input, calculation and output component. In this sub-section, the three components and the various parts within each component will be discussed.

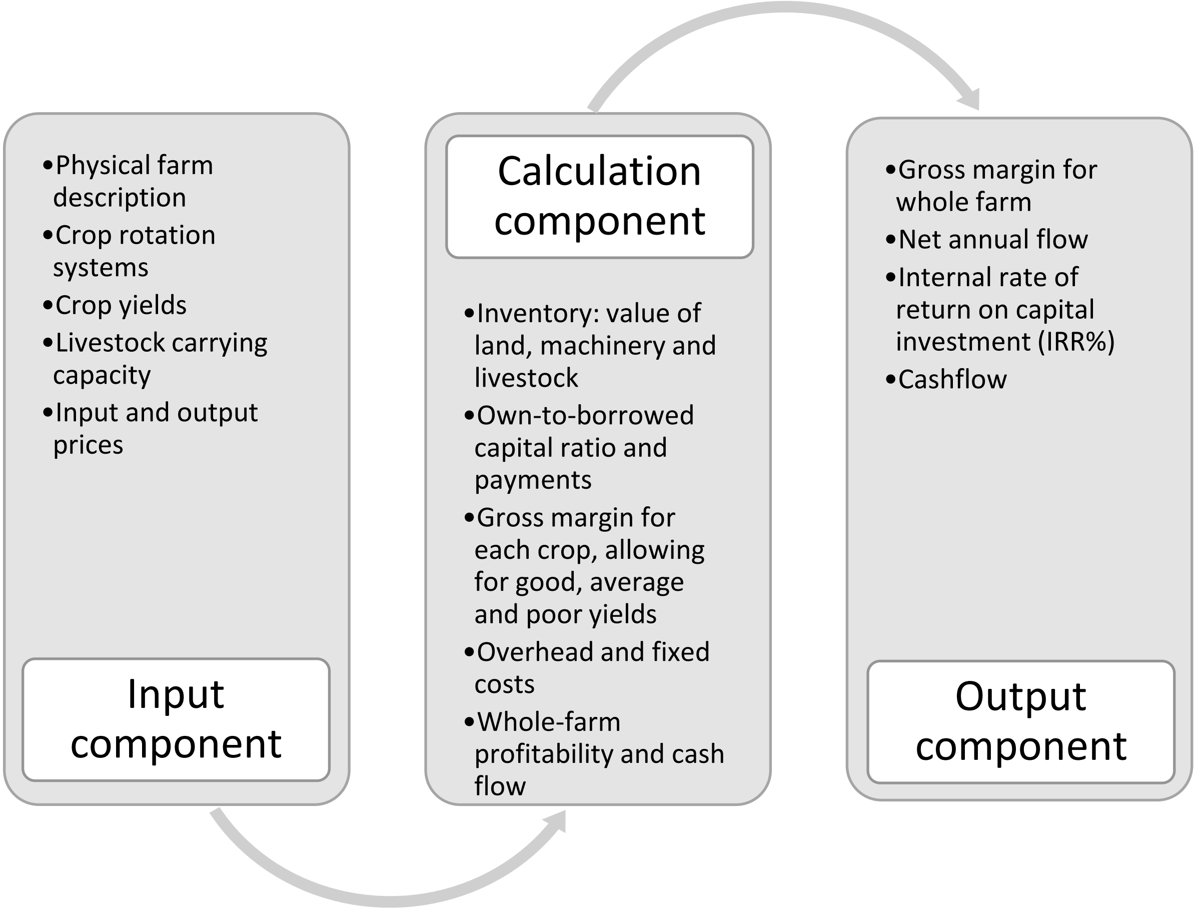

Figure 3.1 *Components of a whole-farm, multi-period budget model.*

Source: Hoffmann & Kleynhans (2011)

3.6.1 The input component

A budget model simply translates physical/biological processes and relationships into a financial outcome through a sequence of equations based on standard accounting principle. The input component of a whole-farm budget model is comprised of; the physical farm description, crop rotation systems, land-use patterns and input, and output prices. These factors can be adapted to suit each individual farm. The adaption of these factors will have an immediate effect on the output component.

3.6.1.1 Physical description of the farm

The physical description of a typical farm model is based on several assumptions. To illustrate the model, a typical farm was simulated. The functioning of the model can be applied to actual situations. It is important to note that the dimension of the typical farm serves only to illustrate the implications of alternative livestock strategies. The sustainability of the farm system is; however, dependent on adjusting various alternative production processes. As mentioned earlier the crop phase is relatively well adapted to full CA and this model focuses more on the livestock component. More environmentally friendly production practices in crop phases can easily be incorporated. Total farm size is the first assumption of importance within the whole-farm model which ultimately determines several other factors included in the physical farm. Cropping and livestock systems, machinery requirements, fencing and water supply for livestock, livestock handling facilities, and the number of permanent staff among other fixed costs are factors most often dependent on the total farm size.

Land ownership and land utilisation are among the assumptions that influence farm profitability. Both owned and rented land and combinations thereof form what is the total farmland. In terms of land utilisation, poor soils, dams and rivers, roads, housing, and livestock infrastructure form the part of the farm that is not suitable for cultivation. Farm profitability is still affected given that these areas are included as part of the total farm area and the required capital investment; however, these do not generate a direct income.

The total cultivated area and the crop rotation system determines the layout and number of hectares allocated for each crop as well as livestock and stocking rates. Given the systems nature of the model, this allows for the ideal capturing of interrelationships between the physical-biological and economic factors to be programmed into the model.

3.6.1.2 Crop rotation systems

Crop rotation forms one of the three principles of CA and contributes in part towards enhancing sustainable land use. Of the various benefits related to crop rotation systems, as discussed throughout Chapter 2, factors of particular interest include:

- Leguminous crops such as lucerne/alfalfa which improve the fertility of the soil through nitrogen fixation,
- The ability to incorporate a livestock component into the farming enterprise through grazing annual legume pastures in rotation with cash crops,
- A break in disease (fungal and bacterial), weed and insect pest life cycles through crop rotation allows for protection of crops and soil. A reduction in weed

resistance by alternating herbicides according to type of crops and stage of growth (Hoffmann, 2010a). Over time, the need for pesticides, herbicides and chemical fertilisers is reduced,

- Enhancing whole-farm profitability, while minimising risk through the diversification of crops and the incorporation of livestock; thus, improving stability and resilience of the whole-farm system.

According to Hoffmann (2010a), two factors determine the type of crops that can be planted in rotation systems. The first factor to consider is the climate, terrain, and soil type and the second factor is availability of a well-established market for the grown produce. Previous studies conducted by Hoffmann (2010b) and Kooper (2020) established, through workgroup discussions, the crops that are typically incorporated into crop rotation systems in the Southern Cape, which are:

- Wheat production forms the basis of winter cereal cropping systems in the Southern Cape. Second to maize, wheat is the most consumed grain product in South Africa providing an affordable staple in the form of bread as well as pasta and confectionaries. Until the late 1990’s, wheat was typically produced in mono-culture systems in the Southern Cape; however, the rising production and input costs has since seen profits decline. The introduction of additional crops in rotation with wheat has become increasingly important to producers as well as beneficial to wheat yields.
- Barley is a winter cereal crop with production limited to specific regions across South Africa. The Western Cape province, in particular the Goue Rûens and Middle Rûens of the Southern Cape region are the largest producers of barley in the country, supplying roughly two-thirds of the total production volume (DAFF, 2017). The crop is used as malt barley in the beer brewing industry, an industry that is well-established in South Africa. Poor quality barley that does not meet malting standards is used for animal feed. Within crop rotations, the characteristics for barley are similar to those of wheat (Hoffmann, 2010a).
- Oats are produced in rotation systems as a feed source for livestock, either as a form of direct grazing or stored as silage.
- Canola is an oilseed crop that provides an oil product extracted from the seed and utilised for both human consumption and as an ingredient in the animal feed industry. The canola market is well established in South Africa. As a crop

in rotation, canola provides multiple benefits to successive wheat yields, where a 22% yield increase in wheat production after canola can be expected (Hoffmann, 2010a). The tap root systems allows for deeper penetration into the soil improving soil structure, aeration and water infiltration rates (Basson, 2017). The broad-leaf nature of the crop allows for the use of alternative agrochemicals compared to the grain cropping phase, limiting the build-up of weed resistance to specific chemical products. Canola can only be planted on the same piece of land once every four years due to the occurrence of the disease, black stem.

- Lupin is a nitrogen-fixing legume with similar benefits to canola in crop rotation systems. The nitrogen-fixing properties of lupins helps to enhance soil fertility resulting in improved yields of subsequent crops. Its high protein content provides an ideal source of animal feed or grazing for livestock.
- Alfalfa, also called lucerne, is a perennial legume crop cultivated as pasture grazing for livestock. Seasons of good rainfall also allow for good yields and the opportunity for producers to bale and store feed for the drier summer months. The nitrogen fixing ability of lucerne further benefits the soil and successive crop yields.
- Triticale is a hybrid of wheat and rye and is produced solely as a feed source for livestock in the form of grazing, hay, or silage.

It should be noted that the yield and input assumptions that crop components are based on is assumed to be in a full CA system with associated input and output levels. These assumptions are based on existing study group data, long term rotation trials in the area, and data published on agribusiness websites, and that of GrainSA.

3.6.1.3 Financial description of the farm

The financial description of the typical farm expresses the physical farm parameters in financial terms and is presented in the form of an asset register or inventory. The assets of a typical-farm inventory include land, fixed improvements, machinery, equipment, and livestock with the value of each of the items included in the financial description. These assets are all interrelated and ultimately dependent on the total farm size. By altering the farm size, all the related assets will automatically adjust. Model assumptions were made based on current best farming practices in the area and agreed upon and validated during group discussions. Model parameters and assumptions are not fixed and can be adjusted by the user to determine the impact of different parameters on profitability through a variety of scenarios, for example, a change in the livestock stocking rate.

3.6.1.4 Input and output prices

In the budget model, lists of input prices and product prices are arranged into data tables. These data tables form the basis from which calculations are done. Through the use of Excel spreadsheet functions and the relevant information from the data tables, gross margins can be calculated. Information provided in the data tables include: the sales units of products, unit prices and typical application rates, and yields per hectare. The separation of data and function is the core contribution of modelling in this fashion as it allows for testing of the responsiveness of profitability to specific changes in either quantities or prices.

Shearing costs, feed costs and medical (dosing and sponging) costs are all included in livestock production costs. Cost information is based according to industry norms, provided by industry experts in the Southern Cape region. Feed costs may vary in response to good, average, and poor years, with feed becoming increasingly more expensive in poorer years due to limited yields and increased demand for possible supplementary feedstuffs, all while the production cost per hectare remains constant.

In terms of running costs for machinery, values were obtained from the *Guide to Machinery Costs* (2014/15). For each activity, the total running cost is calculated by combining the costs of the implement set, consisting of both a power source (tractor) and an implement.

3.6.2 The calculation component

Model data as described by the input component is processed through the calculation component via a sequence of equations. Following standard and established accounting principles, the model effectively links the physical/biological information of the farm with valid financial outputs.

3.6.2.1 Inventory

The inventory is a register of all assets used to determine the expected capital requirement necessary for the sustainable operation of the whole farm. Land and fixed improvements, machinery, equipment, and livestock form the main components of capital items, where land is the largest contributor of the required capital investment.

A typical inventory for the Southern Cape can be found in Annexure B. This includes both physical (capacity, age, annual usage etc.) and financial descriptions of all farm assets.

The prices and costs for new items were based on the *Guide to Machinery Costs* (2014/15). The typical farm size, crop rotation system, and management of livestock all determine the mechanisation required, including the size of the machinery and its capacity (Basson, 2017). The *Guide to Machinery Costs* recommends a replacement period of every 12 years for machinery while annual machine use is based on 1000 hours per annum. However, in the Western Cape, machines have a relatively low annual utilisation rate of 300 to 350 hours per annum, this in combination with financial constraints occasionally often means producers only replace machinery after 15 years or longer (Hoffmann, 2010a).

Herd size and composition determine the required investment in livestock. The model uses the area allocated to available pasture and carrying capacity to calculate the possible herd size. The composition of the herd is calculated by assumptions regarding ram-ewe ratio and the ewe replacement rate. These livestock assumptions were based on previous studies and were verified and updated by local agricultural specialists and producers according to industry norms.

3.6.2.2 Gross margin

Gross margin calculations for each enterprise incorporated into the crop rotation system were done on a per-hectare basis. Each gross margin was calculated according to good, average, or poor yields determined by a variation of good, average, or poor years in terms of rainfall distribution through the growing season (March to October). In order to calculate the gross margin on a per hectare basis for each crop, the total production cost (directly and non-directly allocatable costs) is subtracted from the gross/total production value. In Annexure C, an example of a gross margin per hectare calculation for one of the crops, typically farmed in the Southern Cape, is shown. Using these values, the multi-period budget model would calculate the total farm gross margin for a particular year through the sum of all individual crop gross margins.

3.6.2.3 Overhead and fixed costs

Fixed costs make up a portion of the farm’s total costs that tend to reoccur regardless of the scale or intensity of production. Fixed costs do not vary in the short-term (Knott, 2015). The overhead and fixed costs used in this model is typical for the Southern Cape region and was verified and updated by local producers and industry experts in the area. Permanent labour, insurance, farm vehicle licences, electricity and water tariffs, admin fees, maintenance on fixed improvements, and farm vehicle maintenance are among the costs that typically account for the overhead and fixed costs on a farm. The full list of values for overhead and fixed costs for a typical farm are shown in the multi-period budget as part of Annexure D, and further summarised for each livestock management strategy in Annexure E.

3.6.3 The output component

The financial output of the model is expressed through the internal rate of return (IRR) as an indicator of whole-farm profitability. In addition, cash flow is a measure of the affordability of borrowed capital. The financial indicators are useful for the comparison of various on-farm management decisions regarding livestock and cropping systems.

3.6.3.1 Farm profitability (IRR)

The multi-period budget model was based on a 20-year production period. There are two motivations for this extended period. Firstly, it is to capture the nature of repeating crop rotation systems as well as the longer-term impact of livestock on pasture systems. Secondly, to account for the machinery and equipment replacement schedule.

To measure farm profitability, both the net present value (NPV) and internal rate of return (IRR) can be used. The NPV and IRR are closely related. The NPV measures the present value (discounted to the current year) on the expected future cash flow in monetary terms. The IRR measures the growth generated by the cash flow, represented as a percentage return on the initial capital investment. When used as an interest rate, the IRR returns an NPV equal to zero (Hoffmann, 2010a).

For this research project, the expected whole-farm profitability for each management scenario was expressed through the IRR. Since all scenarios were modelled using the same typical-farm model and initial capital investment. The IRR was preferred and better serves as an effective measure to compare the impact of a variety of management strategies on whole-farm profitability, while the NPV better serves as a comparison on projects of different start times, conducted over different periods or different size capital investments (Hoffmann, 2010a). The IRR values for each of the different livestock management strategies are illustrated in Annexure E.

3.6.3.2 Cash flow

The cash flow budget is used to measure the affordability of the investment and to further show the effect of borrowed capital and interest. Cash flow budgets typically include cash items only and can show the effect of interest payments on the bank balance of the farm. The breakeven-year and periods of positive and negative cash flow are calculated by the cash flow budget. The affordability of borrowed capital and the impact of machinery replacement on farm cash flow can thus be established in the cash flow budget.

3.7 Conclusion

Agricultural systems are complex and multifaceted. These complex systems are based on biological (crop and livestock), mechanical, management, and financial system components, all of which are linked and interact simultaneously contributing towards the functioning of the entire farming system. The adoption of a systems thinking approach allows producers to better understand the farming system as a whole. By identifying the interrelationships between components and how the overall system is affected can thus assist producers in making more informed on-farm management decisions. Modelling and simulation techniques provide an effective way of understanding and predicting the behaviour of complex systems. Such models further provide an objective way for producers to evaluate alternative management strategies for maximising production-, profitability-, and sustainability-goals.

To account for the complexity of agricultural systems, given the multitude of disciplines encountered across farming enterprises, a systems thinking approach combined with multidisciplinary expert knowledge is incorporated into model design, development, and the validation processes. The unique contribution of experts across multiple research fields allows producers to bridge the gap across disciplines in order to integrate knowledge and improve the understanding of complex agricultural systems.

Prior to model construction, a typical farm is developed. In terms of terrain, climate, and soil, no two farms are the same. The typical farm approach aims to represent the most frequently occurring farm in the region. This serves as the basis for comparison in which to determine the implications of different livestock management approaches on farm profitability.

A whole-farm, multi-period budget model was constructed to quantify the financial contribution of sheep enterprises to farm-level performance in the Southern Cape region. The model integrates various physical-biological sets of data with standard accounting principles and translates into a financial output. The model is used in this instance to allow for altering the farm system to fit into the norms and parameters for full CA. This in other words simulates a system that is based on enhanced ecological sustainability. The model translates this alternative system design into profitability parameters. Systems alterations in terms of its effect on the responsiveness of profitability are instantly shown by the model. In terms of profitability criteria, the IRR is used to measure and compare expected farm profitability and the expected financial performance of each livestock management approach can be established.

Chapter 4: Results

4.1 Introduction

The main aim of this research project is to evaluate the potential financial role of alternative wool sheep enterprises on the future sustainability of selected cash crop/pasture systems in the Southern Cape. The design of the production system is done based on current best practices under CA. The model calculates the effect on expected profitability through a sequence of equations based on standard accounting principles. The long-term success of any production system is captured by its ability to generate a profit while simultaneously conserving the surrounding farm resources. In this chapter, a whole-farm budget model, as described Chapter 3, is used to evaluate, in financial terms, the contribution of sheep enterprises on whole-farm profitability.

In the first part of Chapter 4, the parameters and assumptions that characterise a typical farm in the Southern Cape is quantified. Model input was obtained and validated through expert groups and previous studies conducted within the region and based on current best practices for full CA systems. The calculation model and model dynamics are also described. This is followed by a comparison of the farm-level financial performance of each livestock management strategy in terms of the expected profitability (IRR). Separate models were developed for each of the management strategies with model parameters based on the typical farm adjusted accordingly. The last part of Chapter 4 aims to evaluate the sensitivity of whole-farm profitability to external factors. The two external factors simulated are the change in wool price and the change in meat price.

4.2 Assumptions regarding the typical farm

The typical farm is a representation of the most frequently occurring group of farms (or what a group of farmers do) within a homogenous region. The typical farm can be used as a tool capable of assessing farm profitability as well as the ability to determine the effect that a number of variables, and variations thereof, may have on farm-level profitability (Hoffmann, 2010a). For this project the typical farm approach serves as a point of departure in which to evaluate and compare the effects of different on-farm livestock management strategies (within crop pasture systems) on whole-farm profitability.

The information incorporated into the typical farm model was based on data captured by Hoffmann (2010b), Nell (2019) and Kooper (2020), through multidisciplinary, expert group discussions. Model parameters were discussed and agreed upon by participants of the expert group. Livestock assumptions regarding herd composition and production parameters were obtained through literature and past studies and further validated by industry experts. Table 4.1 highlights the main assumptions that are incorporated into the physical description of the typical farm.

Table 4.1 *Physical description of a typical farm in the Southern Cape winter cereal production region.*

Homogenous region	Goue Rûens/Southern Cape
Farm size (ha)	2 500
Land price (R/ha)	R70 000
% Arable land	90%
Arable land (ha)	2 250
Pasture/crop ratio	50 : 50
Livestock	Dohne Merino

4.2.1 Farm size and crop rotations

The total farm size forms one of the most important assumptions made regarding the typical farm. This factor typically determines the cropping system, livestock system, machinery requirements, number of permanent staff and various other fixed costs related to the farming operation. Farms located in the Goue Rûens homogenous region of the Southern Cape are typically 2 500 hectares in size. The land is valued at R70 000 per hectare, which equates the total land value to R175 000 000 for a typical farm. In terms of arable land, 90% is cultivatable (2 250ha) while the remaining 10% (250ha) of non-cultivatable land is allocated to roads, riverbeds, slopes, and sandy areas as well as housing and livestock infrastructure.

The land use patterns of a typical Southern Cape farm as well as the crops that are in rotation are shown in Table 4.2. The 2 250 ha of cultivatable land of the typical farm was divided into three crop rotation systems: System 1 covering 10% of arable land, System 2 covering 65% and System 3 covering 25%. It was assumed that all camps in the same crop rotation system are the same size.

Table 4.2 *Land use patterns, percentage, hectare- and crop-allocation of a typical crop rotation system in the Southern Cape.*

Year	System 1 (10%)	System 2 (65%)	System 3 (25%)
1	Wheat	Wheat	Wheat
2	Barley	Barley	Wheat
3	Wheat	Wheat	Canola
4	Canola	Barley	Wheat
5	Wheat	Wheat	Oats
6	Lucerne	Barley	Lucerne
7	Lucerne	Lucerne	Lucerne
8	Lucerne	Lucerne	Lucerne
9	Lucerne	Lucerne	Lucerne
10	Lucerne	Lucerne	Lucerne
Total Ha allocated	**250**	**1625**	**625**

Overall, the typical farm was planted with about 55% crops and 45% pasture, resulting in a crop to pasture ratio of around 55 to 45 as stated in

Table **4.3**. Table 4.3 further highlights the land use patterns and total farm hectares allocated to each crop.

Table 4.3 *Land use patterns and total crop allocation.*

Crop	Ha allocated	Percentage allocated
Wheat	750	30.0%
Barley	512.50	20.5%
Canola	87.5	3.5%
Oats	62.5	2.5%
Lucerne	1 087.50	43.5%
Total: Crops	**1 412.50**	**~55%**
Total: Pastures	**1 087.50**	**~45 %**
Total	**2500**	**100%**

4.2.2 Crop yield assumptions

The Western Cape receives the majority of its annual rainfall in the winter months; however, distribution and quantity in the Mediterranean-type climate is known to be unpredictable. The seasonal variability of rainfall and the subsequent risk to crop yield performance must be considered by the whole-farm model. In order to accommodate this risk in the model, good, average, and poor years and the frequency thereof had to be identified. In previous studies conducted in the same region by Hoffmann (2010a) and Kooper (2020), it was concluded that however unpredictable the sequences of good, average and poor years may be, their prevalence over a 20-year period is most certain. Trial data obtained from the Tygerhoek Experimental site in the Goue Rûens, combined with information obtained from participants of the multidisciplinary expert group discussions, determined the prevalence of rainfall over a ten year period. This information along with yield numbers are presented in Table 4.4.

Table 4.4. *The expected crop yields for wheat, barley, canola, and oats and the associated prevalence of good, average, and poor yield years.*

	Wheat		Barley		Canola		Oats	
	Yield (ton/ha)	Across 10 years	Yield (ton/ha)	Across 10 years	Yield (ton/ha)	Across 10 years	Yield (ton/ha)	Across 10 years
Good	4.1	4	3.8	4	1.8	4	3.2	4
Average	3.3	5	3.5	5	1.6	5	2.5	5
Poor	2.3	1	2.4	1	1.2	1	1.4	1

A good year is when sufficient rainfall occurs and falls at precisely the right times required for optimal crop growth and performance. An average year occurs when the total rainfall is sufficient yet dispersed poorly across the growing season. While a poor year still receives sufficient rain but at the complete wrong time in the growing season compounded by reduced rainfall during critical points in the crop growth phase (Hoffmann, 2010a).

4.2.3 Livestock assumptions

The introduction of livestock into crop/pasture production systems provides a way for producers to mitigate some production risk, by diversifying farming enterprises, utilising spatial variability and land resources not suitable for crop production. The inclusion and enhancement of complementary interactions between crop and livestock further contributes to the resilience and sustainability of the whole-farm system.

Profitability is a major determinant of the economic and therefore overall sustainability of the whole farm. In terms of herd characteristics and the management thereof, the carrying capacity of pastures, lambing rates and weaning rates all contribute towards farm income. The carrying capacity of a pasture is the stocking rate at which livestock may graze sustainably per unit land area (hectares) over a period of time. This ultimately determines the number of grazing livestock that a farm can hold with the production/yield per animal contributing significantly towards farm profitability. Higher lambing rates and weaning rates further translates into greater profit. For the typical farm, a total of roughly 2 400 sheep is maintained. Table 4.5 lists the general livestock parameters that influence the profitability of a typical farm in the Southern Cape.

Table 4.5 *Livestock assumptions for Dohne Merino and Wool Merino.*

Livestock assumptions	Southern Cape
Carrying capacity - Breeding ewes/ha	2.8
Carrying capacity - Rams/ha	0.13
Carrying capacity - Weaners/ha	3.825
Ram/ewe ratio	1 : 20
Lambing %	140%
Weaning %	Dohne Merino – 123% Merino – 119%

Sheep enterprises consist of both meat and wool production. Depending on the breed, some sheep such as the Merino are inclined to produce mainly wool but will also contribute towards meat production whereas the Dohne Merino is a dual-purpose breed that is predominantly for meat production although it produces wool of a comparable quality to the Merino.

In terms of wool production, the two most important parameters that have an influence on profitability is the wool yield (Table 4.6) and fibre diameter (Table 4.7). Producers are traditionally paid per kilogram of clean fleece weight while wool of a smaller fibre diameter (FD) improves value and sells at a premium.

Table 4.6 *A comparison of average wool production (in kg) between the Dohne Merino and Merino.*

Age of sheep	Gender	Dohne Merino (kg)	Merino (kg)
5-6 months old	Ram/ewe/weaner	0.35	0.40
1 year old	Ewe/weaner	2.60	2.75
1 year old	Ram	2.90	2.99
+1 year old	Ewe/weaner	2.93	3.72
+1 year old	Ram	3.19	4.05

Table 4.7 *A comparison of fibre diameter (in microns) between the Dohne Merino and Merino.*

Age of sheep	Gender	Dohne Merino (µm)	Merino (µm)
5-6 months old	Ram/ewe/weaner	16.8	18
1 year old	Ewe/weaner	16.8	18.04
1 year old	Ram	20	18.2
+1 year old	Ewe/weaner	18.2	18.3
+1 year old	Ram	22	21.9

Rams tend to produce more wool given their larger size and surface area, but at a greater FD. The Merino produces more wool than the Dohne Merino, as expected given its classification as a majority wool breed. Selective- and cross-breeding for both wool and meat traits in the Dohne Merino has allowed the breed to remain competitive in terms of wool quality (fibre diameter) while also producing meat of a high standard.

In terms of sheep meat (mutton and lamb), the liveweight and slaughter weight influence the profitability of the typical farm given that producers are paid per kilogram. Table 4.8 indicates the sheep meat assumptions for a typical farm where the slaughter weight for a lamb was assumed to be 23kg, increasing to around 27 – 29 kg for ewes depending on the age of the sheep.

Table 4.8 *Meat slaughter traits/assumptions for Dohne Merino and Merino.*

Age	**Average liveweight (kg)**	**Slaughter percentage**	**Slaughter weight (kg)**	**Price (R/kg)**
Lambs pre-weaning	33	46%	15.18	R41.13
Lambs 5-12 months old	52	45%	23.40	R90.00
Young sheep 1-2 years old	62	44%	27.28	R86.06
Mature sheep 2-5 years old	68	44%	29.92	R69.10
Old ewes 5+ years old	65	42%	27.30	R66.02
Old rams 5+ years old	90	40%	36.00	R55.00

Previously, meat was considered to be a by-product of wool production, however, meat production can now generate up to 88% of income from wooled sheep (Cloete & Olivier, 2010). For the Merino breed, 60% of the income is generated through meat production and 40% through wool while the Dohne Merino generates 70% of income through meat and 30% through wool (Snyman, 2014; Snyman *et al.*, 1998). Producers have become more inclined to introduce predominately dual-purpose breeds into sheep enterprises in order to obtain the benefits of both meat and wool products.

4.2.4 Capital requirement

The farm inventory can be seen as a register that represents the expected capital requirement for the sustainable operation of the typical farm. Three main components make up the capital investment requirement for the typical farm. These components are land and fixed improvements, equipment and machinery, and livestock. The inventory for the typical farm can be found in Annexure B.

In terms of land, the investment requirement is often high due to a combination of relatively high land prices and the total farm size typical for a farm in the Southern Cape. A typical farm, as previously mentioned is valued at R175 000 000. This coupled with fixed improvements such as farm and labourer houses, farm offices, sheds, fencing, and livestock facilities results in a total value of R179 575 000 for both land and fixed improvements.

The use of machinery and equipment on a typical farm in the Southern Cape is based on current best farming practices, namely conservation agriculture. The capital requirement for machinery under a crop-pasture rotation system is valued at R15 353 727.

The total value for livestock has an investment requirement of R5 709 000. This value includes all rams, breeding and replacement ewes and lambs. The investment in livestock in the Southern Cape region is relatively high given the opportunities that livestock grazed on lucerne pastures may present (Hoffmann, 2010a).

4.2.5 Overhead and fixed costs

The overhead and fixed costs are recurring costs which remain independent of farm performance in terms of production scale and yield output. Overhead and fixed costs for a typical farm include items such as salaries of permanent labour, insurance, farm vehicle licences, electricity and water tariffs, administration fees, maintenance on fixed improvements and farm vehicle maintenance. These costs do, however, vary between farms in the same production region. For a typical farm in the Southern Cape, a total cost of about R1 149 500 per annum was assumed and validated by producers during the multidisciplinary discussions.

4.3 Gross production value

The gross production value is defined as the revenue associated with a product or enterprise prior to the subtraction of any costs involved (Kooper, 2020). In this case, each individual value is calculated by multiplying the area allocated to each specific enterprise/crop, their respective yields, and the price per hectare of each output. The gross production value of the whole farm is therefore the sum of all individual gross production values associated with each enterprise. The product prices for each enterprise used in the whole farm budget model are found in Table 4.9 below.

Table 4.9 *Product prices for crop and livestock products/enterprises.*

Product/enterprise	**Unit**	**Price per unit (Rands)**
Wheat	Ton	R4 854
Barley	Ton	R3 400
Canola	Ton	R7 580
Oats	Ton	R3 500
Lupins	Ton	R3 750
Wool	Kg	R180.55
Meat (lamb)	Kg	R90
Meat (ewes – mutton)	Kg	~R69.10

The different crop rotation systems as well as the allocated area (in hectares) under which each crop is planted is outlined in Section 4.2.1, while Section 4.2.2 presents the estimated crop yields for a typical farm in the Southern Cape region. The resultant gross production value for the typical farm is presented in Table 4.10 for each cash crop enterprise and with respect to good, average, and poor years of rainfall.

Table 4.10 *The gross production value of a typical farm in the Southern Cape as determined by the prevalence of good, average, and poor years of rainfall.*

Crop	**Gross production value for the whole farm**					
	Good year		**Average year**		**Poor year**	
	R/farm	R/ha	R/farm	R/ha	R/farm	R/ha
Wheat	14 926 050	19 901	12 013 650	16 018	8 373 150	11 164
Barley	6 621 500	12 920	6 011 625	11 730	4 182 000	8 160
Canola	1 193 850	13 644	1 061 200	12 128	795 900	9 096
Oats	700 000	11 200	546 875	8 750	306 250	4 900

Included in the gross production value of the whole farm is the livestock component. It is assumed that the gross production value of livestock remains constant over good, average, and poor rainfall years since annual income from livestock is not influenced to the same extent as cash crop yields by annual rainfall distribution. In this way livestock acts as a buffer for producers especially during years of low rainfall and subsequent poor yields. Table 4.11 below contains the gross production values for the different livestock enterprises across the two popular sheep breeds in the Southern Cape.

Table 4.11 *Gross production values for pasture based Dohne Merino and Merino enterprises.*

	Gross production value for different sheep breeds			
	Dohne Merino		**Merino***	
Livestock enterprise	R/farm	R/ha	R/farm	R/ha
Wool	1 343 664	1 236	1 622 233	1 492
Meat	2 812 355	2 586	2 480 873	2 281
Live sales	45 637	42	48 550	45
Total	4 201 656	3 864	4 151 656	3 818

*Only the Dohne Merino is part of the original whole-farm model. The Merino information is included as it becomes part of the scenarios in Section 4.7.

4.4 Variable costs

Variable costs can be described as the cost items that vary with the scale of production or intensity of the farming operation. In terms of cropping systems, the variable costs involved include seed costs, fertiliser, chemical pesticide and herbicide costs as well as crop insurance, transport, and marketing. Variable costs in relation to cropping systems are dependent on the number of hectares allocated to each crop, as presented in Table 4.12.

Table 4.12 *The variable costs of each crop per hectare in the Southern Cape.*

Crop	**Variable cost per hectare (R/ha)**
Wheat	R5 060.13
Barley	R5 757.00
Canola	R5 313.01
Oats	R3 901.13
Lucerne (pasture)	R3 366.00

For livestock systems, variable costs consist of feed costs, veterinary costs, vaccinations, dosages and in the case of wool enterprises, marketing costs, shearing and packaging of the wool. The variable costs for livestock will mostly depend on the feed costs. In turn, feed costs will depend on the amount of feed available, often determined by seasonal changes. The poor digestibility of pastures towards late summer/early autumn results in producers typically providing supplementary feed in the form of roughage, residues, or pellets in order to maintain animal condition until environmental conditions improve. Periods of drought further provide additional expenses for producers in terms of increasing feed costs that are required to maintain herds during such harsh conditions. Table 4.13 presents a comparison in the variable feed costs for a typical year and a drought year. In a drought year the variable costs of feed increases in order to maintain the flock.

All inputs and costs related to the cropping systems as well as livestock variable costs were obtained using previous trial data (Kooper, 2020). The costs are representative of a typical farm in the Southern Cape and were validated by producers and industry experts during the group discussions.

Table 4.13 *Comparison of monthly feed requirements expenditures for a normal year and drought year.*

Feed requirements	Month/s	Expenditure on feed (typical year)	Expenditure on feed (drought year)
Maintenance - late summer/early autumn	March, April	R187 784.93	R187 784.93
Maintenance – drought	August, September	-	**R63 930.68**
Rounding off	September	R10 607.21	R10 607.21
Flush feeding & rounding off	October, November	R156 623.04	R156 623.04
Pasture (and crop residue) grazing	January, February, May, June, July, December	-	-

4.5 Gross margins

The total farm gross margin refers to the value obtained by subtracting the variable costs from the gross production value. The gross margin for each individual crop and livestock enterprise of the typical farm was calculated per hectare, and then multiplied by the area allocated to each crop/enterprise (Table 4.3) in order to obtain the per-farm gross margin. Good, average, and poor years have been incorporated into the gross margin calculations in order to accommodate seasonal variation and the effect on subsequent crop yields. Annexure C provides an example of gross margin calculations for wheat production for good, average, and poor years of rainfall in the Southern Cape. Table 4.14 and Table 4.15 show the total farm gross margins for each crop and livestock enterprises respectively.

Table 4.14 *Total farm gross margin per-farm and per-hectare for each crop across good, average, and poor years.*

Crop	**Good year**		**Average year**		**Poor year**	
	R/farm	R/ha	R/farm	R/ha	R/farm	R/ha
Wheat	9 443 188	12 591	6 530 788	8 708	2 890 288	3 854
Barley	2 517 732	4 913	1 907 858	3 723	78 233	153
Canola	532 056	6 081	399 406	4 565	134 106	1 533
Oats	315 533	5 049	162 408	2 599	-78 217	-1 251

Table 4.15 *Total farm gross margin per-farm and per-hectare for Dohne merino and merino sheep enterprises for a typical farm in the Southern Cape region.*

Sheep	**Dohne Merino**		**Wool Merino**	
	R/farm	R/ha	R/farm	R/ha
Wool, meat & live sales	3 690 671	3 394	3 658 604	3 364

4.6 Whole-farm financial performance

Profitability is a major component of sustainability and therefore, determines the potential long-term success of the farming operation. A whole farm multi-period budget model was used to determine the expected profitability for a typical farm in the Southern Cape, over a 20-year period. Separate models were developed for each of the different livestock management approaches in order to establish and compare the expected financial contribution of sheep enterprises on farm-level performance. Each of these models will be described briefly in the next section, followed by a discussion of these models according to profitability indicators. A whole-farm multi-period budget model, as shown in Annexure D, was constructed for each livestock management strategy. A summary of each model scenario is shown in Annexure E.

4.6.1 Scenario 1: Typical farm

The first scenario simulated with the budget model was the typical farm model. The typical farm, as defined in Chapter 4.2, serves as a basis for comparison. As a result, the impact of different livestock management approaches and the contribution of sheep enterprises to profitability at farm-level can be determined. The typical farm is managed according to current best farming practices that follow a conservation agriculture approach. Defining features of the typical farm include zero-till, maximum soil cover and crop rotations with a 50/50 cash crop to pasture ratio. On the pasture component, producers have diversified farming enterprises to include Dohne merino sheep, grazed at a full stocking rate. The Dohne merino is the most popular of the sheep breeds in the Southern Cape due to its favourable contribution of both meat and wool products.

4.6.2 Scenario 2: Alternative breed - Merino

While the Dohne merino is renowned for its competitiveness in terms of meat and wool characteristics, the merino sheep remains superior for its wool production (see Table 4.6 and 4.7). In this second scenario the use of merino as an alternative sheep breed was simulated with the budget model to compare the financial contribution at farm level of a primarily wool breed to the dual-purpose Dohne merino. Characteristics of a typical farm, similar to Scenario 1 was implemented, with a CA approach, 50/50 cash crop to pasture ratio and full stocking rate maintained.

4.6.3 Scenario 3: Less area under pasture

Scenario 3 is representative of a change in the cash crop to pasture ratio from a typical ratio of 50/50 to one of 75% cash crops and 25% pasture. More area is allocated for cash crops while the amount of available pasture is halved, thereby reducing the stocking rate for livestock. This model aims to establish and quantify the importance of crop rotation systems and the benefits of a pasture component on subsequent cash crop yields.

4.6.4 Scenario 4: Reduced stocking rate

The fourth scenario involves reducing the optimal stocking rate by 10%. This strategy represents a more conservative approach to livestock farming in favour of CA. Given that livestock-induced compaction due to trampling is a concern, reducing the stocking rate by 10% allows producers to limit the potential for soil compaction. This ensures longer rest periods for pastures which improves the overall resilience of the crop-pasture system.

4.6.5 Profitability (IRR)

The financial performance of each livestock management strategy discussed is expressed using the IRR. The annual net flow of funds over the 20 year period is used to calculate the expected IRR. The annual net flow of funds is calculated by subtracting the capital expenditure, overhead and fixed costs from the whole farm gross margin. Table 4.16 shows the IRR values of the different livestock management approaches as calculated using the model.

***Table 4.16** The expected profitability of the typical farm under alternative livestock management scenarios as expressed by the IRR. Source: Own calculations*

Livestock scenarios	Internal Rate of Return (IRR)
1 – typical	6.43%
2 – alt. breed	6.40%
3 – ∆ cash crop pasture ratio	3.60%
4 – less 10% SR	6.17%

The average nominal interest rate over a three year period (2019-2021) was 8.25%, the inflation rate 5.9% and a real interest rate of 2.22% (South African Reserve Bank, 2022). Crop-livestock production systems that produce an IRR below the real interest rate of 2.22% over a 20-year period would indicate a farming enterprise that is not profitable. In this study, all livestock models produced an IRR above 2.22%, thus all systems are projected to be profitable over the 20-year period.

Scenario 1, representing the typical farm, has the highest expected IRR value and is therefore the most profitable, followed by Scenarios 2 and 4 respectively. When comparing Scenario 1 and 2, the only factor that differs being the breed of sheep. The Dohne Merino offers a marginally higher return on capital investment. In terms of wool production, the Merino sheep breed is renowned for both its quality and quantity of wool. The Dohne merino, however, remains a competitive producer and what the breed lacks with regards to wool is offset by the production of mutton or lamb meat. As stated previously in the Chapter 2, meat production was originally considered to be a by-product of the wool industry. However, in recent years the contribution of meat towards sheep enterprises represents roughly 70% of income in the Dohne merino and 60% from wooled sheep such as the Merino. The combination of both meat and wool enterprises for the Dohne merino appears to slightly outcompete the Merino in terms of profitability, thus making the Dohne merino a more desirable breed within crop-livestock farming systems in the Southern Cape.

By incorporating livestock into cropping enterprises, farm-level profitability is buffered against years of poor rainfall and subsequent poor yields. For Scenario 1 and 2, the stocking rate was set at an optimum in order to maximise the benefits of livestock farming. However, in a particularly wet year, the risk of soil compaction is greater given a large number of animals trampling on wet soil. In a drier year, producers' risk over-exploiting pastures and causing damage by removing soil cover. The integration of livestock into CA farming systems therefore requires proper pasture and herd management throughout the year in order to avoid circumstances which negate the benefits of CA practices.

A more conservative approach was modelled for Scenario 4, in favour of a conservation agriculture approach. The stocking rate was reduced by 10%, as described in Section 4.6.4, with the profitability dropping slightly resulting in an IRR of 6.17%. Reducing the stocking rate and allowing for the rest and recovery of the pasture along with crop rotation limits the risk of potential soil compaction and benefits production by enhancing soil cover as well as soil physical properties through improved macroporosity, aeration in the soil and biological activity. This positive influence on the soil further translates to increased crop yields and therefore profitability under CA with reduced livestock stocking rates. In a good year as determined by rainfall, profitability is positively impacted with high gross margins generated by crops in rotation, while in a poor year, the yield of cash crops decrease significantly, yet the cash flow is buffered by the livestock component. In this way the farm-level performance remains competitive, albeit marginally weaker than Scenario 1 and 2, as the benefits of CA farming practices with livestock are realised over the 20-year period.

Scenario 3 had the lowest expected IRR value resulting from a change in the cash crop to pasture ratio. A typical farm traditionally incorporates half cash crops and half pasture in rotation, together the benefits of crop rotations, as discussed in Section

2.3.1.3 are achieved. In this scenario a larger area is under cash crops (75%) while the area allocated to pasture is halved to 25%. Crop margins in this scenario tend to be lower as the yield response is penalised by to a reduction in the amount of cash crops following pasture. Yields are reduced after losing the benefits related to crop rotation, specifically N-fixing leguminous crops. The extra machinery required to cover the additional land allocated to crops increases the capital requirement, contributing further to the negative impact on farm-level performance. As with the previous scenarios, in a good rainfall year producers can take advantage of the higher gross margins obtained from crop production. However, in this case the yield response will naturally be lower. In a poor year, livestock aim to buffer the cashflow, but not to the same extent as in Scenarios 1, 2 and 4 given the reduced allocated pasture for grazing and thus limited stocking rate of livestock. Over a 20-year period, Scenario 3 is therefore observed to be the least profitable strategy.

4.7 Sensitivity analysis

Sensitivity analysis aims to identify how external factors may affect the outcome of farming strategies. Producers often have little to no control over these factors, therefore a sensitivity analysis helps to increase confidence in the model and bridge the gap of uncertainty by providing valuable insight into which on-farm management strategies are the most suitable (Basson, 2017; Gorris & Yoe, 2014).

Farm-level income from sheep production is comprised of both meat (mutton/lamb) and wool enterprises, of which the price is determined according to external, market related factors. In this next section, a financial sensitivity analysis is used to evaluate the sensitivity of whole-farm profitability to a change in both meat and wool product prices.

Market related factors that determine the price of wool are separated from those for meat as the two industries are ultimately unrelated. One cannot therefore increase both products simultaneously. For this reason, a sensitivity analysis was performed on both a change in wool and a change in the meat product price independent of one another.

4.7.1 Changes in wool price

The wool price in South Africa is typically determined by supply and demand with roughly 90% of the South African wool clip being exported. Wool prices tend to be relatively volatile as a result of its close link to the international price of apparel wool which in turn is controlled by the Australian market (DAFF, 2016; NAMC, 2012). Fluctuations within the international wool price may thus affect whole-farm profitability for wool producers. The sensitivity of whole farm profitability due to a change in the wool price is shown in Table 4.17.

Table 4.17 *The impact of a change in wool price on expected profitability of the whole farm. Source: own calculations.*

Whole farm model Wool R/ton	**Change in wool price**						
	Initial state	**UP 10%**		**UP 20%**		**DOWN 10%**	
Livestock scenario	**IRR**	**IRR**	**Relative change in IRR**	**IRR**	**Relative change in IRR**	**IRR**	**Relative change in IRR**
1	6.43%	6.51%	1.30%	6.59%	2.60%	6.34%	-1.30%
2	6.40%	6.50%	1.60%	6.60%	3.20%	6.30%	-1.60%
3	3.60%	3.66%	1.50%	3.71%	3.00%	3.55%	-1.50%

From Table 4.17 above, the results follow the expected trend, an increase in wool price will increase the IRR and vice versa. However, the relative change appears to be insignificant.

In the Southern Cape, farm income streams are comprised of wool, meat and cash crop enterprises, these different facets of income all contribute towards the resilience and stability of the farming system. In this instance, a change in the wool price will have a relatively small effect on farm-level income with any risk being offset by the inclusion of cropping systems and meat production.

4.7.2 Changes in meat price

As with the price of wool, meat prices are determined by external market related factors. Mutton and lamb prices tend to be relatively stable in comparison to that of wool. Given that meat is the main contributor of the livestock component towards whole-farm profitability, a change in the meat price may have an effect on the overall financial performance of the farm. Table 4.18 shows just how sensitive whole-farm profitability is to a change in the meat price with regards to the IRR.

Table 4.18 *The impact of a change in meat price on expected profitability of the whole farm. Source: own calculations.*

Whole-farm model Meat R/kg	**Change in meat price**						
	Initial state	**UP 10%**		**UP 20%**		**DOWN 10%**	
Livestock scenario	**IRR**	**IRR**	**Relative change in IRR**	**IRR**	**Relative change in IRR**	**IRR**	**Relative change in IRR**
1	6.43%	6.60%	2.66%	6.77%	5.32%	6.26%	-2.66%
2	6.40%	6.55%	2.35%	6.70%	4.71%	6.25%	-2.35%
3	3.60%	3.71%	3.06%	3.83%	6.13%	3.49%	-3.06%

As the price of meat increases, so does expected farm profitability and vice versa. The relative change in IRR also appears to be insignificant. When comparing breeds (Scenario 1 and 2) in terms of meat production, the meat to wool ratio favours the Dohne Merino (70%) to the Merino (60%). When meat prices increase, the Dohne Merino appears to be the more favourable breed. In turn, when the meat price decreases the production of the Dohne breed may become riskier.

In terms of both the wool and meat price, meat is a larger contributor to farm-level income than wool; thus, the income appears to be more sensitive to a change in the meat price.

4.8 Conclusion

A whole-farm budget model, as defined in this chapter was used to quantify and compare the contribution of wool and mutton production to farm-level performance under different livestock management strategies within full CA production systems. For all scenarios, full CA practices were simulated. Separate models were developed and adjusted for each of the various strategies according to the parameters as set out in the typical farm model. The dynamics of the model typically allow for the complex, interrelated variables to be incorporated within the whole-farm system. Using the adjusted parameters within each livestock strategy, the expected profitability of the whole farm was calculated and expressed in terms of the IRR.

The results show that all scenarios were profitable; however, Scenario 1 was found to be most profitable over a 20-year period. Scenario 1 served as the typical farm within the Southern Cape and was managed according to current best farming practices under a conservation agriculture approach. In rotation with cash crops, sheep, specifically the Dohne Merino are grazed on pastures as well as uncultivatable parts of the farm. The integration of livestock into the cash crop/pasture system provides a buffer to cash flow and farm-level profitability, especially in years of poor rainfall and subsequent poor cash crop yields.

The final part of this chapter aimed to evaluate the sensitivity of whole-farm profitability to a change in meat and wool product prices. A change in both the wool and meat price did not appear to significantly affect farm-level performance. Overall, the whole-farm profitability appears to be more sensitive to a change in the meat price as to wool due to a higher relative change in the IRR across all scenarios. A contributing factor may be the ratio of meat to wool of the Dohne Merino breed. Given that income from livestock is mostly due to meat, an increase in the meat price will favour the Dohne, while a decrease may prove riskier for the breed.

Multiple facets of income help to stabilise and improve the resilience of whole-farm systems in response to external factors. The typical farm in the Southern Cape consists of both cash crop and livestock enterprises. By diversifying away from one production system to include multiple enterprises, producers offset the risk of one enterprise with another and maintain the sustainability of the whole-farm system.

Chapter 5: Conclusions, summary, and recommendations

5.1 Conclusions

Producers are under constant pressure to expand and intensify production systems in order to meet the growing demand of the rising world population. Conventional farming methods as well as the associated use of external inputs continue to harm the environment, natural farming resources, and ecosystem services. The continued challenge of having to produce more food with increasingly less agricultural land further highlights the need for more sustainable approaches towards agricultural intensification and food production.

Conservation agriculture (CA) is viewed as one of the most holistic approaches to sustainable agriculture. The concept of CA is based on three interlinked principles; the first being minimum soil disturbance through no-till practices. The second, the maintenance of permanent soil cover by cover cropping and residue retention. The third is increased diversity through crop rotation systems. CA aims to enhance biological processes and preserve soil health resulting in several ecological and economic benefits. The high initial capital investment, the required site-specific knowledge, and integration of livestock currently present the greatest challenges towards CA adoption.

The Southern Cape is one of the main grain producing regions of the Western Cape and plays an integral role in producing affordable staple food crops for the rest of South Africa. The Southern Cape is characterised by its typical Mediterranean climate, providing an ideal environment for wheat in rotation with barley, oats, canola, and lucerne pastures. Until the late 1990’s, wheat was traditionally cultivated in monocropping systems. Following the deregulation of the agricultural economy, rising production, and input costs as well as environmental factors, led to producers incorporating a variety of crops in rotation and the adoption of one or more CA practices in order to limit production risks.

The introduction of crop-pasture production systems further provides producers with the opportunity to introduce livestock. Sheep grazed on lucerne pastures and crop residues which further help to supplement income by contributing both meat and wool to the farming enterprise. The added diversity allows producers to offset price shocks and production risks, especially during years of poor rainfall and subsequent lower crop yields. Some uncertainty still remains with regards to the integration of sheep into CA systems and the implications grazing and possible soil compaction has on soil properties, and the overall farm performance. It remains necessary to establish the financial implications of crop rotations combined with various livestock management strategies under CA practices as this remains an important consideration for Southern Cape producers. The main objective for this research project is to evaluate the potential financial role of alternative wool sheep enterprises on the future sustainability of selected cash crop/pasture systems in the Southern Cape.

Present-day agricultural systems are complex and multifaceted. A research method that can accommodate the complexity and interrelatedness of various on-farm factors that have an impact on the physical, biological, and financial performance of a farming system over time is required. The systems thinking approach served as an appropriate tool in which to address the relevant complexities of these agricultural systems. Improving understanding of the relationships between on-farm factors can assist producers in making better, more informed decisions regarding the performance of the whole farm.

Modelling and simulation are tools often implemented in the application of the systems thinking approach and can integrate knowledge from across multiple disciplines. A whole-farm, multi-period budget model was used in this research project to evaluate the financial implications/profitability of various sheep enterprises as a component of cash-crop/pasture systems in the Southern Cape. The dynamics of such a model effectively allows for the integration of various on-farm management and environmental factors within a spreadsheet environment, and with the use of standard accounting principles, translates the physical and biological processes into a financial outcome.

The typical farm approach served as the point of reference from which a whole-farm budget model was constructed. Model inputs and assumptions for the typical farm was comprised of both scientific trial data and multidisciplinary expert knowledge in the form of group discussions, captured in previous studies (refer to Chapter 4.2). Multidisciplinary expert group discussions serve as a platform for the sharing of current, specialised knowledge, the generation of new ideas, and the validation of information whilst also providing a better understanding of the current farming system.

Model input and feedback by various industry experts, producers, and agricultural economists remained an important aspect in maintaining model validity throughout the modelling process. By using multi-period, whole-farm budget models it is possible to effectively capture the complexity of the farming system under each livestock management strategy within crop/pasture systems and successfully quantify the financial implications thereof. The financial performance was measured in terms of expected profitability, as represented by the IRR. The model converts the implementation of more sustainable production practices, in this case full CA, into the financial implications at the whole-farm level. Whole-farm level is important as the interaction between the crops within the crop production phase and between crops and pastures and livestock is important. Multi-period budgets are necessary to capture the implications of long-term crops rotation systems and the replacement of movable assets.

All strategies were found to be profitable through the financial analysis of each livestock management approach. This shows that a livestock component contributes positively towards the whole-farm financial performance. Scenario 1, representative of a typical farm, had the highest IRR of 6.43%. The integration of cash crops in rotation with lucerne pastures, grazed by Dohne Merino sheep at full stocking rate proved to be the most profitable approach for producers. Scenario 3 proved to be the least profitable and highlights the benefits of leguminous crops in rotation with cash crops and the positive yield response this may incur on subsequent yields.

Included in the financial analysis was a sensitivity analysis of whole-farm profitability in response to external factors, these being a change in the meat price and in the wool price. Neither enterprise had a significant effect on whole-farm profitability, possibly due to the relatively small contribution that both meat and wool enterprises make to the overall financial performance of the farm. However, in years of price shocks and poor yields related to the grain industry, the livestock component remains an important buffer to farm profitability.

The main conclusions of this research project are:

- The integration of livestock within CA systems is possible through proper herd management and maintaining sufficient ground cover thereby reducing the potential risk of possible soil compaction and overgrazing. In this way, minimum soil disturbance in line with CA principles is maintained and further provides opportunity for producers to diversify farming enterprises without compromising on future crop performance.

- Winter cereal cropping systems that aim to incorporate livestock grazed on leguminous pastures in rotation with cash crops holds the greatest potential for producers in terms of financial performance. In this study, Scenario 1, as represented by a typical farm in the Southern Cape proved to be the most profitable.
- Crop rotations positively contribute towards subsequent crop production. A reduction in pasture size within crop rotation systems, as seen in Scenario 3, results in reduced crop margins due to a lower positive yield response in cash crops. This is attributed to the loss of benefits in the soil related to N- fixing leguminous crops.
- The Dohne Merino is the more desirable breed, given that the majority of income from sheep is derived from meat and an increase in the meat price favours the Dohne Merino breed.
- Production systems comprised of a diverse number of enterprises helps to stabilise farm income and limit the risks and sensitivity to price shocks related to external factors.

5.2 Summary

The pressure to intensify agricultural production systems in order to meet the demand of the growing population has traditionally relied on the increased use of external, chemical-based inputs and as a result continues to impact the environment and natural farming resources.

Chapter 1 highlights the need for a more sustainable approach to agricultural production. Conservation agriculture is one of the alternative strategies proposed and discussed to overcome the challenges faced by conventional production systems. CA is a concept based on three underlying principles, namely: minimum soil disturbance, maximum or maintenance of soil cover, and crop rotation systems. It is further noted that while CA provides multiple benefits, it is the inclusion of pastures with livestock, in this case sheep, that holds the most potential for winter cereal cropping systems in the Southern Cape. Therefore, the main objective for this research project was to determine the potential role of sheep enterprises on the sustainability of selected cash crop/pasture systems in the Southern Cape.

Chapter 2 is comprised of a literature review. The focus was to determine the importance of sheep enterprises as a component of cash crop production systems and to identify the factors that influence wool quality and production at the farm-level. The chapter consists of four sections and begins with a brief overview of the agricultural production systems and farming practices within the Southern Cape region. This was followed by a thorough discussion of CA as a sustainable production approach, its characteristic principles, the origins and adoption rates throughout Southern Africa, the benefits of such a practice, and the constraints. Producers in the Southern Cape diversified farming enterprises to include livestock grazed on legume pastures in order to reduce production risks and further supplement income through meat and wool. The impact of livestock integration on CA systems and the implications this has on soil compaction and soil cover under CA has various benefits. The two main wool producing breeds in the region are Merino and the dual-purpose Dohne Merino. Wool parameters and the influence that management, nutrition, and the environment have on wool quality and production traits is an important consideration in relation to including sheep in the production system.

Agricultural systems are inherently complex and multifaceted. The biological, mechanical, management, and economic components are all linked and interact simultaneously towards the functioning of the whole-farm system. Therefore, one cannot study each part in isolation but rather the component interactions within the system. The first part of Chapter 3 provides an understanding of the systems approach and the practical use of systems modelling as a research method within agricultural systems research. In order to financially determine the specific contribution of sheep enterprises to farm level performance, a whole-farm, multi-period budget model is proposed. The methods used to capture and quantify the data required by the model aim to accurately simulate the impact of livestock on the whole system and measure the expected financial implications. Sets of physical-biological data are integrated through the model and according to standard accounting principles translated into a financial output. The concept of a typical farm approach is introduced. It is representative of a group of farms within a homogenous region. In this study, the typical farm serves as a point of departure from which one is able to model, compare and determine the effects of different livestock management strategies on whole-farm profitability.

The results and findings for this research project are presented in Chapter 4. Physical parameters such as farm size, crop rotation systems, crop yields, and livestock carrying capacity as well as financial parameters such as the capital requirement, overhead, and fixed costs were some of the validated parameters and assumptions discussed. The financial evaluation of farm-level performance according to different livestock management strategies is done within the framework of a multi-period, whole-farm budget model. A separate model was developed for each of the different livestock management strategies with model parameters adjusted accordingly.

Four scenarios were simulated by using the budget model. These are:

- The typical farm that simulates the status quo and serves as the control,
- The shift to Merino instead of Dohne Merino,
- Less area under pastures (more cash crops), and
- Reduced (more conservative) stocking rate.

Each one of the scenarios was profitable; however, Scenario 1 was found to be the most profitable with the highest IRR of 6.43%. Scenario 3 was the least profitable having the lowest IRR of 3.60%. The last part of Chapter 4 includes a sensitivity analysis in order to evaluate whole-farm profitability in response to external factors. A change in the wool and meat product prices was found to have no significant effect on profitability.

The main conclusions reached, indicates that with proper management, integrating livestock with cash crops in a crop rotation system in the Southern Cape can be beneficial. This has various ecological benefits and does not have a negative effect on profitability while it lowers investment requirements in depreciating assets. A reduction in the relative area under pastures eventually leads to lower profits due to the loss of the positive effect on scale of the leguminous pasture crops.

5.3 Recommendations

The main objective of this research project was to determine the role of sheep enterprises on the sustainability of cash crop/pasture production systems within a CA context. The use of both scientific trial data and multidisciplinary expert knowledge obtained through group discussions provided the knowledge and assumptions required to construct and validate the whole-farm budget model for a typical farm in the Southern Cape. The model aimed to establish how different livestock management approaches within crop/pasture systems compare financially. Given that there is some uncertainty regarding the integration of livestock and the effect this may have on soil properties, significant emphasis was placed on the interaction of livestock within CA systems and the financial implications thereof.

In this study, results from the whole-farm budget model indicate that what is defined as the typical farm in the Southern Cape is the most profitable. The sheep used in this study, typical for such a farm, were Dohne Merinos. Sheep are beneficial to a production system as both meat and wool enterprises add to the diversity of the crop farming system. It is the addition of sheep gazed on leguminous crops in rotation that holds the greatest potential in mixed farming systems. Multiple facets of income help to stabilise and limit production risk in the event of price shocks; thus, improving resilience for the whole farming systems. Greater diversity in terms of crop and livestock enterprises is encouraged as a way of improving/maintaining farm and financial sustainability.

The true benefits of conservation agriculture may only be realised through the adoption and implementation of all three principles simultaneously. However, CA remains site-specific and knowledge intensive. While producers should actively aim to incorporate all principles as well as livestock, there is a need for regular collaboration between producers, researchers, and stakeholders and the provision of relevant information and training based on current best farming practices and technologies. This may prove useful in promoting greater adoption of CA strategies throughout the region.

While sheep are the most popular form of livestock grazed extensively in the Southern Cape, producers also incorporate other forms of livestock such as beef cattle. Using the same methodology of expert group discussions combined with farm modelling exercises, further study on the role of alternative livestock enterprises, such as that of beef cattle, on the financial performance of selected cash crop/pasture production systems would prove beneficial to producers.

The Southern Cape is one of two main winter cereal producing regions in the Western Cape, the second being the Swartland. The Swartland is a rain-fed, semi-extensive cropping system with sheep, also characterised by a Mediterranean-type climate. However, the Swartland differs from the Southern Cape in that the summer months are hot and dry with the absence of any possible rainfall. Such a difference in climate results in this region implementing completely different cropping systems year round. A similar study, but in the Swartland region, is recommended to determine how the contribution of livestock enterprises and crop margins would interact.

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Annexures

Annexure A: Map indicating the homogenous region of the Southern Cape

Source: Cape Farm Mapper (version2.6.11)

Annexure B: Inventory for the typical farm

Item	Amount (ha)	R/unit	Value
Land: (a)	2500	70000	**R175 000 000.00**

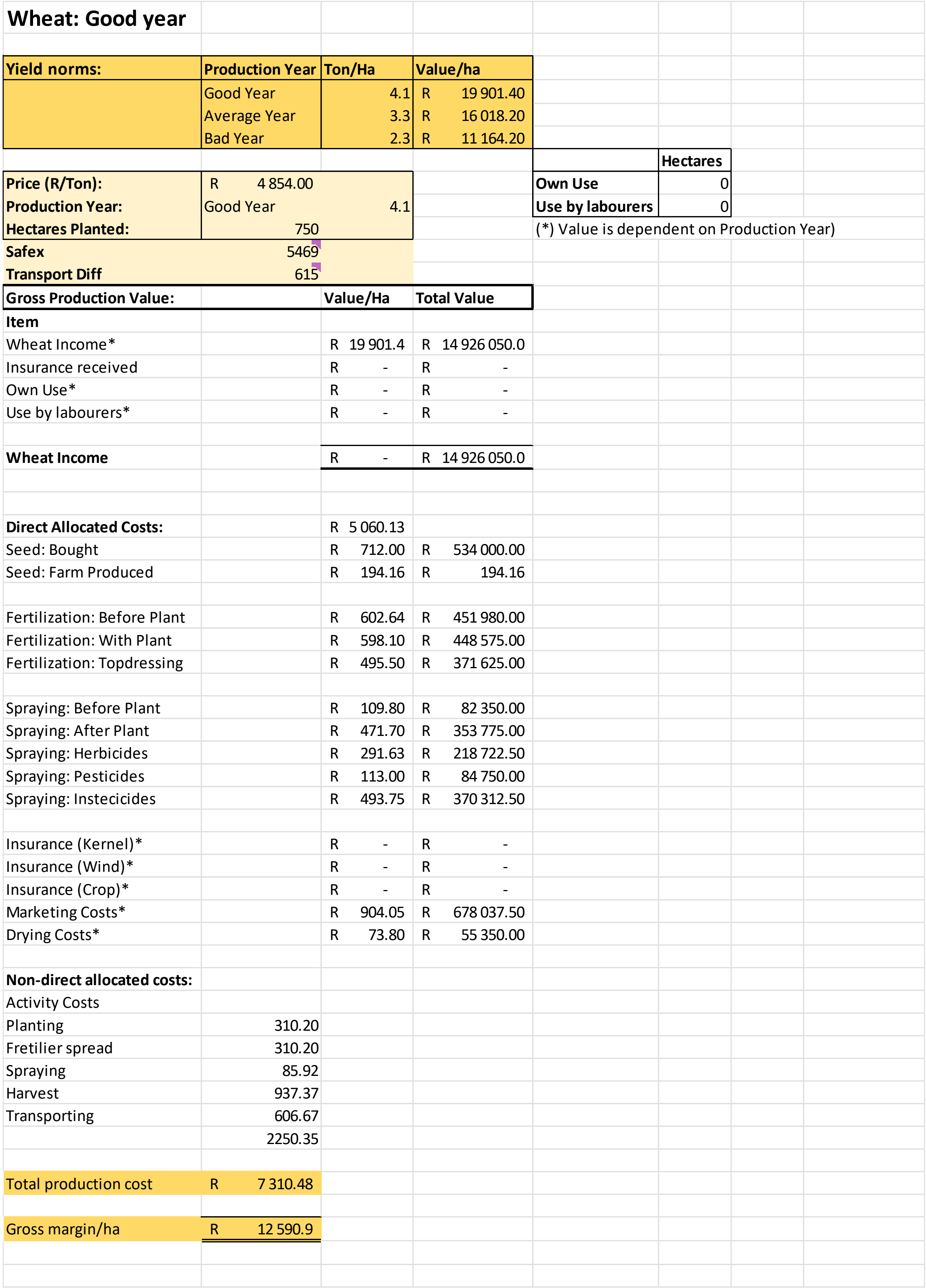
Total fixed Improvements: (b)	**R 4 575 000.00**

Mechanization:	Price/new R	Current age (years)	Expected lifetime	Depreciation	Value
Vehicles			**Km**		
D/Cab 3L	650 000	7	240 000	48 750	308 750
X/Cab 3L	450 000	7	240 000	33 750	213 750
S/Cab 3L	320 000	10	240 000	24 000	80 000
Motorcycles					
Honda XR 125cc (x2)	57 000	5	100 000	4 560	34 200
Trucks					
Single Differential Dropsides 8 ton	530 000	7	300 000	15 900	418 700
Single Differential Dropsides 8 ton	515 000	17	300 000	15 450	252 350
Tractors			**Hours**		
Tractor 240kW	2 200 000	7	12 000	165 000	1 045 000
Tractor 145kW	1 266 300	3	12 000	94 973	981 383
Tractor 145kW	1 266 300	6	12 000	94 973	696 465
Tractor 80kW	666 681	9	12 000	50 001	216 671
Tractor 80kW	666 681	9	12 000	50 001	216 671
Tractor 75kW	609 350	4	12 000	45 701	426 545
Harvesters					
Harvester 405kW	6 648 000	10	12 000	498 600	1 662 000
Harvester 240kW	4 182 000	5	12 000	313 650	2 613 750
Harvester Heads					
Head 9 meter (x3)	2 248 194	6	12 000	131 145	1 461 326
TLB					
TLB 70kW	990 000	4	12 000	37 125	841 500
Fertilizer Spreader					
Fert spreader Double Disc 1100L (x2)	225 752	6	3 000	9 030	171 572
Fert spreader Double Disc 1100L	112 876	5	3 000	5 079	87 479
Boom Sprayers					
Trailed 18 Meter Boom 2400L (x2)	621 540	7	1 500	49 723	273 478
Trailed 18 Meter Boom 2400L	310 770	5	1 500	27 969	170 924
Planter					
Trailed Planter 33 row	2 091 988	6	1 500	188 279	962 314
Trailed Planter 16 row	1 091 988	6	1 500	98 279	502 314
Trailed Planter 17 row	1 091 988	6	1 500	98 279	502 314
Tillage Equipment					
Hydraulic Offset 2.75m	58 700	8	2 500	5 283	16 436
Ripper 7 shank	99 284	7	3 000	8 936	36 735
Windrower					
Self Propelled Windrower	1 500 000	9	4 000	67 500	892 500
Other					
Slasher 2.5m	65 000	12	2 000	2 925	29 900
Fire Fighting Water Cart 2500L	130 000	3	2 000	5 850	112 450
			Years		
Content of Workshop	250 000	11	20	11 250	126 250
Total equipment: (C)					**R 15 353 727.29**

Livestock:	Number	Price/unit	Value
Ewes: 1-2 years old	1142	2 000	2 284 000
Rams: 2-3 years old	114	6 500	741 000
Ewes: 3-4 years old	571	2 500	1 427 500
Ewes: 4-5 years old	400	2 500	1 000 000
Old ewes	171	1 500	256 500
Total livestock: (d)			**R 5 709 000.00**

Total Assets: (a+b+c+d)	**R200 637 727.29**

Annexure C: Example of gross margin calculations for wheat production in the Southern Cape according to good, average, and poor years as determined by rainfall distribution.



Wheat: Good year

Yield norms:	**Production Year**	**Ton/Ha**	**Value/ha**
	Good Year	4.1	R 19 901.40
	Average Year	3.3	R 16 018.20
	Bad Year	2.3	R 11 164.20

Price (R/Ton):	R 4 854.00	
Production Year:	Good Year	4.1
Hectares Planted:		750
Safex		5469
Transport Diff		615

	Hectares
Own Use	0
Use by labourers	0

(*) Value is dependent on Production Year)

Gross Production Value:		**Value/Ha**	**Total Value**
Item			
Wheat Income*		R 19 901.4	R 14 926 050.0
Insurance received		R -	R -
Own Use*		R -	R -
Use by labourers*		R -	R -
Wheat Income		R -	R 14 926 050.0
Direct Allocated Costs:		R 5 060.13	
Seed: Bought		R 712.00	R 534 000.00
Seed: Farm Produced		R 194.16	R 194.16
Fertilization: Before Plant		R 602.64	R 451 980.00
Fertilization: With Plant		R 598.10	R 448 575.00
Fertilization: Topdressing		R 495.50	R 371 625.00
Spraying: Before Plant		R 109.80	R 82 350.00
Spraying: After Plant		R 471.70	R 353 775.00
Spraying: Herbicides		R 291.63	R 218 722.50
Spraying: Pesticides		R 113.00	R 84 750.00
Spraying: Instecicides		R 493.75	R 370 312.50
Insurance (Kernel)*		R -	R -
Insurance (Wind)*		R -	R -
Insurance (Crop)*		R -	R -
Marketing Costs*		R 904.05	R 678 037.50
Drying Costs*		R 73.80	R 55 350.00
Non-direct allocated costs:			
Activity Costs			
Planting	310.20		
Fretilier spread	310.20		
Spraying	85.92		
Harvest	937.37		
Transporting	606.67		
	2250.35		
Total production cost	R 7 310.48		
Gross margin/ha	R 12 590.9		

Wheat: Average year

Yield norms:	Production Year	Ton/Ha	Value/ha
	Good Year	4.1	R 19 901.40
	Average Year	3.3	R 16 018.20
	Bad Year	2.3	R 11 164.20

	Hectares
Own Use	0
Use by labourers	0

(*) Value is dependent on Production Year)

Price (R/Ton):	R 4 854.00	
Production Year:	Average Year	3.3
Hectares Planted:	750	
Safex	5469	
Transport Diff	615	

Gross Production Value:		Value/Ha	Total Value
Item			
Wheat Income*		R 16 018.2	R 12 013 650.0
Insurance received		R -	R -
Own Use*		R -	R -
Use by labourers*		R -	R -
Wheat Income		R -	R 12 013 650.0
Direct Allocated Costs:		R 5 060.13	
Seed: Bought		R 712.00	R 534 000.00
Seed: Farm Produced		R 194.16	R 194.16
Fertilization: Before Plant		R 602.64	R 451 980.00
Fertilization: With Plant		R 598.10	R 448 575.00
Fertilization: Topdressing		R 495.50	R 371 625.00
Spraying: Before Plant		R 109.80	R 82 350.00
Spraying: After Plant		R 471.70	R 353 775.00
Spraying: Herbicides		R 291.63	R 218 722.50
Spraying: Pesticides		R 113.00	R 84 750.00
Spraying: Instecicides		R 493.75	R 370 312.50
Insurance (Kernel)*		R -	R -
Insurance (Wind)*		R -	R -
Insurance (Crop)*		R -	R -
Marketing Costs*		R 904.05	R 678 037.50
Drying Costs*		R 73.80	R 55 350.00
Non-direct allocated costs:			
Activity Costs			
Planting	310.20		
Fretilier spread	310.20		
Spraying	85.92		
Harvest	937.37		
Transporting	606.67		
	2250.35		
Total production cost	R 7 310.48		
Gross margin/ha	R 8 707.7		

Wheat: Poor year

Yield norms:	**Production Year**	**Ton/Ha**	**Value/ha**
	Good Year	4.1	R 19 901.40
	Average Year	3.3	R 16 018.20
	Bad Year	2.3	R 11 164.20

	Hectares
Own Use	0
Use by labourers	0

(*) Value is dependent on Production Year)

Price (R/Ton):	R 4 854.00	
Production Year:	Bad Year	2.3
Hectares Planted:	750	
Safex	5469	
Transport Diff	615	

Gross Production Value:		**Value/Ha**	**Total Value**
Item			
Wheat Income*		R 11 164.2	R 8 373 150.0
Insurance received		R -	R -
Own Use*		R -	R -
Use by labourers*		R -	R -
Wheat Income		R -	R 8 373 150.0
Direct Allocated Costs:		R 5 060.13	
Seed: Bought		R 712.00	R 534 000.00
Seed: Farm Produced		R 194.16	R 194.16
Fertilization: Before Plant		R 602.64	R 451 980.00
Fertilization: With Plant		R 598.10	R 448 575.00
Fertilization: Topdressing		R 495.50	R 371 625.00
Spraying: Before Plant		R 109.80	R 82 350.00
Spraying: After Plant		R 471.70	R 353 775.00
Spraying: Herbicides		R 291.63	R 218 722.50
Spraying: Pesticides		R 113.00	R 84 750.00
Spraying: Instecicides		R 493.75	R 370 312.50
Insurance (Kernel)*		R -	R -
Insurance (Wind)*		R -	R -
Insurance (Crop)*		R -	R -
Marketing Costs*		R 904.05	R 678 037.50
Drying Costs*		R 73.80	R 55 350.00
Non-direct allocated costs:			
Activity Costs			
Planting	310.20		
Fretilier spread	310.20		
Spraying	85.92		
Harvest	937.37		
Transporting	606.67		
	2250.35		
Total production cost	R 7 310.48		
Gross margin/ha	R 3 853.7		

Annexure D: Example of a whole farm multi-period budget model (Scenario 1) *

Multi-period budget - Typical																				
Item	Year																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Good - 1 Average - 2 Poor - 3	1	2	2	3	1	3	2	2	1	3	2	2	1	1	3	1	2	2	2	2
Income																				
Wheat	14926050	12013650	12013650	8373150	14926050	8373150	12013650	12013650	14926050	8373150	12013650	12013650	14926050	14926050	8373150	14926050	12013650	12013650	12013650	12013650
Barley	6621500	6011625	6011625	4182000	6621500	4182000	6011625	6011625	6621500	4182000	6011625	6011625	6621500	6621500	4182000	6621500	6011625	6011625	6011625	6011625
Canola	1193850	1061200	1061200	795900	1193850	795900	1061200	1061200	1193850	795900	1061200	1061200	1193850	1193850	795900	1193850	1061200	1061200	1061200	1061200
Oats	700000	546875	546875	306250	700000	306250	546875	546875	700000	306250	546875	546875	700000	700000	306250	700000	546875	546875	546875	546875
Lupins																				
Lucern	-549079																			
Wool merino	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -
Dohne merino	R 4 182 449	R 4 182 449	R 4 182 449	R 4 182 449	R 4 182 449	R 4 182 449	R 4 182 449	R 4 182 449	R 4 182 449	R 4 182 449	R 4 182 449	R 4 182 449	R 4 182 449	R 4 182 449	R 4 182 449	R 4 182 449	R 4 182 449	R 4 182 449	R 4 182 449	R 4 182 449
Total	27074771	23815799	23815799	17839749	27623849	17839749	23815799	23815799	27623849	17839749	23815799	23815799	27623849	27623849	17839749	27623849	23815799	23815799	23815799	23815799
Directly allocatble varible cost																				
Wheat	R 5 482 862	R 5 482 862	R 5 482 862	R 5 482 862	R 5 482 862	R 5 482 862	R 5 482 862	R 5 482 862	R 5 482 862	R 5 482 862	R 5 482 862	R 5 482 862	R 5 482 862	R 5 482 862	R 5 482 862	R 5 482 862	R 5 482 862	R 5 482 862	R 5 482 862	R 5 482 862
Barley	R 4 103 768	R 4 103 768	R 4 103 768	R 4 103 768	R 4 103 768	R 4 103 768	R 4 103 768	R 4 103 768	R 4 103 768	R 4 103 768	R 4 103 768	R 4 103 768	R 4 103 768	R 4 103 768	R 4 103 768	R 4 103 768	R 4 103 768	R 4 103 768	R 4 103 768	R 4 103 768
Canola	R 661 794	R 661 794	R 661 794	R 661 794	R 661 794	R 661 794	R 661 794	R 661 794	R 661 794	R 661 794	R 661 794	R 661 794	R 661 794	R 661 794	R 661 794	R 661 794	R 661 794	R 661 794	R 661 794	R 661 794
Oats	R 384 467	R 384 467	R 384 467	R 384 467	R 384 467	R 384 467	R 384 467	R 384 467	R 384 467	R 384 467	R 384 467	R 384 467	R 384 467	R 384 467	R 384 467	R 384 467	R 384 467	R 384 467	R 384 467	R 384 467
Lupins																				
Lucern	-R 1 098 158	-R 1 098 158	-R 1 098 158	-R 1 098 158	-R 1 098 158	-R 1 098 158	-R 1 098 158	-R 1 098 158	-R 1 098 158	-R 1 098 158	-R 1 098 158	-R 1 098 158	-R 1 098 158	-R 1 098 158	-R 1 098 158	-R 1 098 158	-R 1 098 158	-R 1 098 158	-R 1 098 158	-R 1 098 158
Wool Merino	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -	R -
Dohne Merino	-R 510 217	-R 510 217	-R 510 217	-R 510 217	-R 510 217	-R 510 217	-R 510 217	-R 510 217	-R 510 217	-R 510 217	-R 510 217	-R 510 217	-R 510 217	-R 510 217	-R 510 217	-R 510 217	-R 510 217	-R 510 217	-R 510 217	-R 510 217
Total	R 9 024 518	R 9 024 518	R 9 024 518	R 9 024 518	R 9 024 518	R 9 024 518	R 9 024 518	R 9 024 518	R 9 024 518	R 9 024 518	R 9 024 518	R 9 024 518	R 9 024 518	R 9 024 518	R 9 024 518	R 9 024 518	R 9 024 518	R 9 024 518	R 9 024 518	R 9 024 518
Gross margin	R 18 050 253	R 14 791 282	R 14 791 282	R 8 815 232	R 18 599 332	R 8 815 232	R 14 791 282	R 14 791 282	R 18 599 332	R 8 815 232	R 14 791 282	R 14 791 282	R 18 599 332	R 18 599 332	R 8 815 232	R 18 599 332	R 14 791 282	R 14 791 282	R 14 791 282	R 14 791 282
Overhead and fixed cost																				
Permanent Labour:	R 324 000	R 324 000	R 324 000	R 324 000	R 324 000	R 324 000	R 324 000	R 324 000	R 324 000	R 324 000	R 324 000	R 324 000	R 324 000	R 324 000	R 324 000	R 324 000	R 324 000	R 324 000	R 324 000	R 324 000
Municipal Tax	R 30 000	R 30 000	R 30 000	R 30 000	R 30 000	R 30 000	R 30 000	R 30 000	R 30 000	R 30 000	R 30 000	R 30 000	R 30 000	R 30 000	R 30 000	R 30 000	R 30 000	R 30 000	R 30 000	R 30 000
Insurance (Overheads)	R 110 000	R 110 000	R 110 000	R 110 000	R 110 000	R 110 000	R 110 000	R 110 000	R 110 000	R 110 000	R 110 000	R 110 000	R 110 000	R 110 000	R 110 000	R 110 000	R 110 000	R 110 000	R 110 000	R 110 000
Licenses:																				
Vehicles	R 2 100	R 2 100	R 2 100	R 2 100	R 2 100	R 2 100	R 2 100	R 2 100	R 2 100	R 2 100	R 2 100	R 2 100	R 2 100	R 2 100	R 2 100	R 2 100	R 2 100	R 2 100	R 2 100	R 2 100
Motorcycles	R 384	R 384	R 384	R 384	R 384	R 384	R 384	R 384	R 384	R 384	R 384	R 384	R 384	R 384	R 384	R 384	R 384	R 384	R 384	R 384
Trucks	R 14 000	R 14 000	R 14 000	R 14 000	R 14 000	R 14 000	R 14 000	R 14 000	R 14 000	R 14 000	R 14 000	R 14 000	R 14 000	R 14 000	R 14 000	R 14 000	R 14 000	R 14 000	R 14 000	R 14 000
Harvesters	R 750	R 750	R 750	R 750	R 750	R 750	R 750	R 750	R 750	R 750	R 750	R 750	R 750	R 750	R 750	R 750	R 750	R 750	R 750	R 750
Tractors	R 360	R 360	R 360	R 360	R 360	R 360	R 360	R 360	R 360	R 360	R 360	R 360	R 360	R 360	R 360	R 360	R 360	R 360	R 360	R 360
TLB	R 80	R 80	R 80	R 80	R 80	R 80	R 80	R 80	R 80	R 80	R 80	R 80	R 80	R 80	R 80	R 80	R 80	R 80	R 80	R 80
Trailed Wagon (Water)	R 50	R 50	R 50	R 50	R 50	R 50	R 50	R 50	R 50	R 50	R 50	R 50	R 50	R 50	R 50	R 50	R 50	R 50	R 50	R 50
Elecrticity	R 45 000	R 45 000	R 45 000	R 45 000	R 45 000	R 45 000	R 45 000	R 45 000	R 45 000	R 45 000	R 45 000	R 45 000	R 45 000	R 45 000	R 45 000	R 45 000	R 45 000	R 45 000	R 45 000	R 45 000
Fuel (Unspecified)	R 50 000	R 50 000	R 50 000	R 50 000	R 50 000	R 50 000	R 50 000	R 50 000	R 50 000	R 50 000	R 50 000	R 50 000	R 50 000	R 50 000	R 50 000	R 50 000	R 50 000	R 50 000	R 50 000	R 50 000
Bank Costs	R 20 000	R 20 000	R 20 000	R 20 000	R 20 000	R 20 000	R 20 000	R 20 000	R 20 000	R 20 000	R 20 000	R 20 000	R 20 000	R 20 000	R 20 000	R 20 000	R 20 000	R 20 000	R 20 000	R 20 000
Telephone	R 25 000	R 25 000	R 25 000	R 25 000	R 25 000	R 25 000	R 25 000	R 25 000	R 25 000	R 25 000	R 25 000	R 25 000	R 25 000	R 25 000	R 25 000	R 25 000	R 25 000	R 25 000	R 25 000	R 25 000
Admin	R 8 000	R 8 000	R 8 000	R 8 000	R 8 000	R 8 000	R 8 000	R 8 000	R 8 000	R 8 000	R 8 000	R 8 000	R 8 000	R 8 000	R 8 000	R 8 000	R 8 000	R 8 000	R 8 000	R 8 000
Admin Salary	R 48 000	R 48 000	R 48 000	R 48 000	R 48 000	R 48 000	R 48 000	R 48 000	R 48 000	R 48 000	R 48 000	R 48 000	R 48 000	R 48 000	R 48 000	R 48 000	R 48 000	R 48 000	R 48 000	R 48 000
Maintenance: Fixed Improvem	R 31 750	R 31 750	R 31 750	R 31 750	R 31 750	R 31 750	R 31 750	R 31 750	R 31 750	R 31 750	R 31 750	R 31 750	R 31 750	R 31 750	R 31 750	R 31 750	R 31 750	R 31 750	R 31 750	R 31 750
Maintenance: Moveable Impro	R 170 000	R 170 000	R 170 000	R 170 000	R 170 000	R 170 000	R 170 000	R 170 000	R 170 000	R 170 000	R 170 000	R 170 000	R 170 000	R 170 000	R 170 000	R 170 000	R 170 000	R 170 000	R 170 000	R 170 000
Consultations	R 5 000	R 5 000	R 5 000	R 5 000	R 5 000	R 5 000	R 5 000	R 5 000	R 5 000	R 5 000	R 5 000	R 5 000	R 5 000	R 5 000	R 5 000	R 5 000	R 5 000	R 5 000	R 5 000	R 5 000
Provision: Water distribution	R 25 000	R 25 000	R 25 000	R 25 000	R 25 000	R 25 000	R 25 000	R 25 000	R 25 000	R 25 000	R 25 000	R 25 000	R 25 000	R 25 000	R 25 000	R 25 000	R 25 000	R 25 000	R 25 000	R 25 000
Owner's Salary	R 240 000	R 240 000	R 240 000	R 240 000	R 240 000	R 240 000	R 240 000	R 240 000	R 240 000	R 240 000	R 240 000	R 240 000	R 240 000	R 240 000	R 240 000	R 240 000	R 240 000	R 240 000	R 240 000	R 240 000
	R 1 149 474	R 1 149 474	R 1 149 474	R 1 149 474	R 1 149 474	R 1 149 474	R 1 149 474	R 1 149 474	R 1 149 474	R 1 149 474	R 1 149 474	R 1 149 474	R 1 149 474	R 1 149 474	R 1 149 474	R 1 149 474	R 1 149 474	R 1 149 474	R 1 149 474	R 1 149 474
Flow before capital items	R 16 900 779	R 13 641 808	R 13 641 808	R 7 665 758	R 17 449 858	R 7 665 758	R 13 641 808	R 13 641 808	R 17 449 858	R 7 665 758	R 13 641 808	R 13 641 808	R 17 449 858	R 17 449 858	R 7 665 758	R 17 449 858	R 13 641 808	R 13 641 808	R 13 641 808	R 13 641 808

Capital investment																						Value end
Land:	R	175 000 000																				R 175 000 000
Vehicles																						
D/Cab	R	308 750.00	0	0	0	0	585000	0	0	0	0	0	0	0	0	0	0	0	585000	0	0	
X/Cab	R	213 750.00	0	0	0	0	405000	0	0	0	0	0	0	0	0	0	0	0	405000	0	0	
S/Cab	R	80 000.00	0	288000	0	0	0	0	0	0	0	0	0	0	0	288000	0	0	0	0	0	
Motorcycles																						
Honda XR	R	17 100.00	0	0	0	0	51300	0	0	0	0	0	0	0	0	0	51300	0	0	0	0	
Trucks																						
Single Differential Dropsides	R	418 700.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	R	252 350.00	0	0	0	0	0	0	0	0	0	0	0	0	463500	0	0	0	0	0	0	
Tractors																						
Tractor	R	1 045 000.00	0	0	0	0	1980000	0	0	0	0	0	0	0	0	0	0	0	1980000	0	0	
Tractor	R	216 671.33	0	0	600012.9	0	0	0	0	0	0	0	0	0	0	0	600012.9	0	0	0	0	
Tractor	R	426 545.00	0	0	0	0	0	0	0	548415	0	0	0	0	0	0	0	0	0	0	0	
Harvesters																						
Harvester	R	1 662 000.00	0	5983200	0	0	0	0	0	0	0	0	0	0	0	5983200	0	0	0	0	0	
	R	2 613 750.00	0	0	0	0	0	0	3763800	0	0	0	0	0	0	0	0	0	0	0	3763800	
Harvester Heads																						
Head	R	487 108.70	0	0	0	0	0	2023374.6	0	0	0	0	0	0	0	0	0	0	0	2023374.6	0	
TLB																						
TLB	R	841 500.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Fertilizer Spreader																						
Fert spreader Double Disc	R	85 785.76	0	0	0	0	0	0	0	0	0	0	0	0	0	203176.8	0	0	0	0	0	
	R	87 478.90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	101588.4	0	0	0	0	
Boom Sprayers																						
Trailed 18 Meter Boom	R	136 738.80	0	0	559386	0	0	0	0	0	0	0	0	0	559386	0	0	0	0	0	0	
Trailed 18 Meter Boom	R	170 923.50	0	0	0	0	279693	0	0	0	0	0	0	0	0	0	279693	0	0	0	0	
Planter																						
Trailed Planter	R	962 314.48	0	0	0	1882789.2	0	0	0	0	0	0	0	0	0	1882789.2	0	0	0	0	0	
Tillage Equipment																						
Hydraulic Offset	R	16 436.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Ripper	R	36 735.08	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Windrower																						
Self Propelled Windrower	R	892 500.00	0	0	89355.6	0	0	0	0	0	0	0	0	0	89355.6	0	0	0	0	0	0	
Other																						
Slasher	R	29 900.00	0	0	0	0	0	0	0	0	0	0	1350000	0	0	0	0	0	0	0	0	
Fire Fighting Water Cart	R	112 450.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Content of Workshop	R	126 250.00	0	0	0	0	0	0	0	58500	0	0	0	0	0	0	0	0	0	0	0	
Livestock																						
Ewes: 1-2 years old	R	2 284 000.00																				R 2 284 000.00
Rams: 2-3 years old	R	741 000.00																				R 741 000.00
Ewes: 3-4 years old	R	1 427 500.00																				R 1 427 500.00
Ewes: 4-5 years old	R	1 000 000.00																				R 1 000 000.00
Old ewes	R	256 500.00																				R 256 500.00
Total capital	R	191 949 738	R -	R 6 271 200.0	R 1 248 754.5	R 1 882 789.2	R 3 300 993	R 2 023 375	R 3 763 800	R 606 915.0	R -	R -	R 1 350 000.0	R -	R 1 112 241.6	R 8 357 166.0	R 1 032 594.3	R -	R 2 970 000.0	R 2 023 374.6	R 3 763 800.0	R 180 709 000
Net annual flow	-R	175 048 959	R 13 641 808	R 7 370 607.7	R 6 417 003	R 15 567 068.5	R 4 364 764.7	R 11 618 433	R 9 878 008	R 16 842 942.7	R 7 665 758	R 13 641 808	R 12 291 808	R 17 449 857.7	R 16 337 616.1	-R 691 408.3	R 16 417 263.4	R 13 641 807.71	R 10 671 807.71	R 11 618 433.11	R 190 587 007.71	
IRR		**6.43%**																				

*A whole-farm multi-period budget model, as shown in Annexure D, was constructed for each scenario. A summary of each is presented in Annexure E.

Annexure E: Summary of a whole-farm, multi-period budget model for each scenario

Multi-period budget model summary – **Scenario 1**

Multi-period budget - Typical

Item	Year									
	1	2	3	4	5	6	7	8	9	10
Good - 1	1	2	2	3	1	3	2	2	1	3
Average - 2										
Poor - 3										
Income										
Total	R 27 074 771	R 23 815 799	R 23 815 799	R 17 839 749	R 27 623 849	R 17 839 749	R 23 815 799	R 23 815 799	R 27 623 849	R 17 839 749
Directly allocatble varible cost										
Gross margin	R 18 050 253	R 14 791 282	R 14 791 282	R 8 815 232	R 18 599 332	R 8 815 232	R 14 791 282	R 14 791 282	R 18 599 332	R 8 815 232
Overhead and fixed cost										
Flow before capital items	R 16 900 779	R 13 641 808	R 13 641 808	R 7 665 758	R 17 449 858	R 7 665 758	R 13 641 808	R 13 641 808	R 17 449 858	R 7 665 758
Capital investment										
Total capital	R 191 949 738	R -	R 6 271 200	R 1 248 755	R 1 882 789	R 3 300 993	R 2 023 375	R 3 763 800	R 606 915	R -
Net annual flow	-R 175 048 959	R 13 641 808	R 7 370 608	R 6 417 003	R 15 567 069	R 4 364 765	R 11 618 433	R 9 878 008	R 16 842 943	R 7 665 758

	11	12	13	14	15	16	17	18	19	20	
	2	2	1	1	3	1	2	2	2	2	
Income											
Total	R 23 815 799	R 23 815 799	R 27 623 849	R 27 623 849	R 17 839 749	R 27 623 849	R 23 815 799	R 23 815 799	R 23 815 799	R 23 815 799	
Directly allocatble varible cost											
Gross margin	R 14 791 282	R 14 791 282	R 18 599 332	R 18 599 332	R 8 815 232	R 18 599 332	R 14 791 282	R 14 791 282	R 14 791 282	R 14 791 282	
Overhead and fixed cost											
Flow before capital items	R 13 641 808	R 13 641 808	R 17 449 858	R 17 449 858	R 7 665 758	R 17 449 858	R 13 641 808	R 13 641 808	R 13 641 808	R 13 641 808	
Capital investment											Value end
Total capital	R -	R 1 350 000	R -	R 1 112 242	R 8 357 166	R 1 032 594	R -	R 2 970 000	R 2 023 375	R 3 763 800	R 180 709 000
Net annual flow	R 13 641 808	R 12 291 808	R 17 449 858	R 16 337 616	-R 691 408	R 16 417 263	R 13 641 808	R 10 671 808	R 11 618 433	R 190 587 008	

IRR	**6.43%**

Multi-period budget model summary – **Scenario 2**

Multi-period budget - Alternative breed (Merino)

Item	Year									
	1	2	3	4	5	6	7	8	9	10
Good - 1	1	2	2	3	1	3	2	2	1	3
Average - 2										
Poor - 3										
Income										
Total	R 27 043 977	R 23 785 006	R 23 785 006	R 17 808 956	R 27 593 056	R 17 808 956	R 23 785 006	R 23 785 006	R 27 593 056	R 17 808 956
Directly allocatble varible cost										
Gross margin	R 18 002 294	R 14 743 323	R 14 743 323	R 8 767 273	R 18 551 373	R 8 767 273	R 14 743 323	R 14 743 323	R 18 551 373	R 8 767 273
Overhead and fixed costs										
Flow before capital items	R 16 852 820	R 13 593 849	R 13 593 849	R 7 617 799	R 17 401 899	R 7 617 799	R 13 593 849	R 13 593 849	R 17 401 899	R 7 617 799
Capital investment										
Total capital	R 191 949 738	R -	R 6 271 200	R 1 248 755	R 1 882 789	R 3 300 993	R 2 023 375	R 3 763 800	R 606 915	R -
Net annual flow	-R 175 096 918	R 13 593 849	R 7 322 649	R 6 369 044	R 15 519 109	R 4 316 806	R 11 570 474	R 9 830 049	R 16 794 984	R 7 617 799

	Year										
	11	12	13	14	15	16	17	18	19	20	
	2	2	1	1	3	1	2	2	2	2	
Income											
Total	R 23 785 006	R 23 785 006	R 27 593 056	R 27 593 056	R 17 808 956	R 27 593 056	R 23 785 006	R 23 785 006	R 23 785 006	R 23 785 006	
Directly allocatble varible cost											
Gross margin	R 14 743 323	R 14 743 323	R 18 551 373	R 18 551 373	R 8 767 273	R 18 551 373	R 14 743 323	R 14 743 323	R 14 743 323	R 14 743 323	
Overhead and fixed costs											
Flow before capital items	R 13 593 849	R 13 593 849	R 17 401 899	R 17 401 899	R 7 617 799	R 17 401 899	R 13 593 849	R 13 593 849	R 13 593 849	R 13 593 849	
Capital investment											Value end
Total capital	R -	R 1 350 000	R -	R 1 112 242	R 8 357 166	R 1 032 594	R -	R 2 970 000	R 2 023 375	R 3 763 800	R 180 709 000
Net annual flow	R 13 593 849	R 12 243 849	R 17 401 899	R 16 289 657	-R 739 367	R 16 369 304	R 13 593 849	R 10 623 849	R 11 570 474	R 190 539 049	
IRR	**6.40%**										

Multi-period budget model summary – **Scenario 3**

Multi-period budget - 75/25 cash crops to pasture											
Item					**Year**						
	1	2	3	4	5	6	7	8	9	10	
Good - 1	1	2	2	3	1	3	2	2	1	3	
Average - 2											
Poor - 3											
Income											
Total	R 19 700 334	R 17 867 525	R 17 867 525	R 13 189 456	R 20 112 144	R 13 189 456	R 17 867 525	R 17 867 525	R 20 112 144	R 13 189 456	
Directly allocatble varible cost											
Gross margin	R 12 888 613	R 11 055 804	R 11 055 804	R 6 377 735	R 13 300 422	R 6 377 735	R 11 055 804	R 11 055 804	R 13 300 422	R 6 377 735	
Overhead and fixed cost											
Flow before capital items	R 11 739 139	R 9 906 330	R 9 906 330	R 5 228 261	R 12 150 948	R 5 228 261	R 9 906 330	R 9 906 330	R 12 150 948	R 5 228 261	
Capital investment											
Total capital	R 190 704 257	R -	R 12 254 400	R 1 248 755	R 3 765 578	R 3 300 993	R 2 023 375	R 3 763 800	R 606 915	R -	
Net annual flow	-R 178 965 117	R 9 906 330	-R 2 348 070	R 3 979 506	R 8 385 370	R 1 927 268	R 7 882 955	R 6 142 530	R 11 544 033	R 5 228 261	
					Year						
	11	12	13	14	15	16	17	18	19	20	
	2	2	1	1	3	1	2	2	2	2	
Income											
Total	R 17 867 525	R 17 867 525	R 20 112 144	R 20 112 144	R 13 189 456	R 20 112 144	R 17 867 525	R 17 867 525	R 17 867 525	R 17 867 525	
Directly allocatble varible cost											
Gross margin	R 11 055 804	R 11 055 804	R 13 300 422	R 13 300 422	R 6 377 735	R 13 300 422	R 11 055 804	R 11 055 804	R 11 055 804	R 11 055 804	
Overhead and fixed cost											
Flow before capital items	R 9 906 330	R 9 906 330	R 12 150 948	R 12 150 948	R 5 228 261	R 12 150 948	R 9 906 330	R 9 906 330	R 9 906 330	R 9 906 330	
Capital investment											Value end
Total capital	R -	R 1 350 000	R -	R 1 112 242	R 16 223 155	R 1 032 594	R -	R 2 970 000	R 2 023 375	R 3 763 800	R 178 784 000
Net annual flow	R 9 906 330	R 8 556 330	R 12 150 948	R 11 038 707	-R 10 994 894	R 11 118 354	R 9 906 330	R 6 936 330	R 7 882 955	R 184 926 530	
IRR	**3.60%**										

Multi-period budget model summary – **Scenario 4**

Multi-period budget - less 10 percent livestock

Item	Year 1	2	3	4	5	6	7	8	9	10
Good - 1	1	2	2	3	1	3	2	2	1	3
Average - 2										
Poor - 3										
Income										
Total	R 26 661 742	R 23 402 771	R 23 402 771	R 17 426 721	R 27 210 821	R 17 426 721	R 23 402 771	R 23 402 771	R 27 210 821	R 17 426 721
Directly allocatble varible cost										
Gross margin	R 17 586 682	R 14 327 711	R 14 327 711	R 8 351 661	R 18 135 761	R 8 351 661	R 14 327 711	R 14 327 711	R 18 135 761	R 8 351 661
Overhead and fixed cost										
Flow before capital items	R 16 437 208	R 13 178 237	R 13 178 237	R 7 202 187	R 16 986 287	R 7 202 187	R 13 178 237	R 13 178 237	R 16 986 287	R 7 202 187
Capital investment										
Total capital	R 191 382 238	R -	R 6 271 200	R 1 248 755	R 1 882 789	R 3 300 993	R 2 023 375	R 3 763 800	R 606 915	R -
Net annual flow	-R 174 945 030	R 13 178 237	R 6 907 037	R 5 953 432	R 15 103 497	R 3 901 194	R 11 154 862	R 9 414 437	R 16 379 372	R 7 202 187

	Year 11	12	13	14	15	16	17	18	19	20	
	2	2	1	1	3	1	2	2	2	2	
Income											
Total	R 23 402 771	R 23 402 771	R 27 210 821	R 27 210 821	R 17 426 721	R 27 210 821	R 23 402 771	R 23 402 771	R 23 402 771	R 23 402 771	
Directly allocatble varible cost											
Gross margin	R 14 327 711	R 14 327 711	R 18 135 761	R 18 135 761	R 8 351 661	R 18 135 761	R 14 327 711	R 14 327 711	R 14 327 711	R 14 327 711	
Overhead and fixed cost											
Flow before capital items	R 13 178 237	R 13 178 237	R 16 986 287	R 16 986 287	R 7 202 187	R 16 986 287	R 13 178 237	R 13 178 237	R 13 178 237	R 13 178 237	
Capital investment											Value end
Total capital	R -	R 1 350 000	R -	R 1 112 242	R 8 357 166	R 1 032 594	R -	R 2 970 000	R 2 023 375	R 3 763 800	R 180 141 500
Net annual flow	R 13 178 237	R 11 828 237	R 16 986 287	R 15 874 045	-R 1 154 979	R 15 953 692	R 13 178 237	R 10 208 237	R 11 154 862	R 189 555 937	
IRR	**6.17%**										