The financial implications of different crop rotation systems for the Goue Rûens

By

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Declaration

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Abstract

The world population is expected to increase to 10.9 billion by 2100 and consequently demand for food will increased. Increasing food production will most likely place more pressure on natural resources, and lead to environmental problems. These challenges create an urgent need for improved crop production systems and conservation focussed agriculture to aid in the management of such challenges.

Conservation farming hold the three pillars of crop rotation, minimum soil disturbance and cover cropping. This study focus on the crop rotation aspect of conservation agriculture in the geographical region of the Goue Rûens. The main research objective was to evaluate the whole-farm long-term financial implications of different crop rotation systems within the Goue Rûens area. The crop rotation systems consisted of cash crops and livestock grazing on pastures. This study placed significant emphasis on the interactions between the crops.

The systems approach served as the scientific foundation for this study, and entailed integrating the expert knowledge of relevant role players. The farming system is inherently complex, therefore the proposed method had to accommodate and integrate the interrelated factors of the system. Systems thinking was identified as a suitable tool for managing the associated complexities. The Delphi method was followed to integrate scientific crop rotation trial data with expert knowledge to assess the impacts of systems on whole farm level.

Farm-level, multi-period budget modelling was employed to evaluate crop rotation systems in terms of the expected financial performance of the farm system under different rotation systems. A farm-level budget model incorporates crop rotation systems with associated investment requirements and production activities by the integration of physical, biological and financial factors. Standard accounting principle present the results in a format that famers understand.

A typical farm served as point of departure for the model construction. Expert knowledge was employed to validate the assumptions regarding the physical properties of such a typical farm. A whole-farm multi-period budget model approach was used to evaluate the financial implications of each identified crop rotation system within the Goue Rûens area. This whole-farm multi-period model is able to integrate each system’s individual components, with their particular investment requirements and climate variability. Financial modelling, as a method, was successful in achieving the research goal.

Each of the individual crop rotation systems included in the Tygerhoek crop rotation trial was simulated in a whole-farm context through a multi-period budget to calculate the expected financial performance of each system. The output gained from this research method allowed for the financial comparison of the various systems, using the internal rate of return on capital investment (IRR). The range of the IRRs for the different crop rotation systems at a whole-farm multi-period level was relatively narrow. No system was observed that significantly outperformed any of the other respective systems. It did however indicate the importance of combinations of crops and wheat as well as barley in the same system.

Opsomming

Die wêreld bevolking sal na verwagting toeneem tot 10.9 biljoen teen 2100 en gevolglik sal die vraag na voedsel ook toeneem. Toenemende voedselproduksie sal waarskynlik meer druk op natuurlike hulpbronne plaas en lei tot omgewingsprobleme. Hierdie uitdagings skep ‘n dringende behoefte vir verbeterde gewasproduksie stelsels en bewarings gefokusde landbou om te help met die bestuur van die uitdagings.

Bewaringsboerdery hou die drie pilare voor van gewas-wisselbou, minimum grondversteuring en dekgewas bewerking. Die studie fokus op die gewas wisselbou aspek van bewaringsboerdery in die geografiese gebied van die Goue Rûens. Die hoof navorsingsdoelwit was om die geheelplaas, langtermyn finansiële implikasies van verskillende gewas wisselboustelsels in die Goue Rûens area te evalueer. Die gewas- wisselboustelsels bestaan uit kontantgewas stelsels en kontant en weidings gewas stelsels met ’n vee komponent. Die studie benadruk die interaksies tussen die verskillende gewasse.

Die stelselsbenadering dien as die wetenskaplike fondasie vir die studie en omsluit die integrasie van ekspert kennis van verskillende rolspelers. Die boerdery stelsel is inherent kompleks daarom moet die voorgestelde metode die verskillende interafhanklike komponente van die stelsel akkommodeer en integreer. Stelsels denke is geïdentifiseer as toepaslike hulpmiddel om die gepaardgaande kompleksiteit te hanteer. Die Delphi metode is gevolg om wetenskaplike wisselboustelsel data te integreer met ekspert kennis om die verwagte impak van die verskillende stelsel op die geheelplaas te assesseer.

Plaasvlak, multi-periode begrotings modellering is aangewend om die verskillende gewasverbouingstelsels te evalueer in terme van geheel plaas finansiële prestasie. ’n Plaasvlak begrotingsmodel inkorporeer die gewas wisselboustelsels met geassosieerde investeringsbehoefte en produksie aktiwiteite deur die fisies/biologiese en finansiële aspekte van die boerdery te integreer. Standaard rekeningkundige beginsels bied die resultate in ’n verstaanbare formaat vir produsente.

‘n Tipiese plaas dien as vertrekpunt vir die model konstruksie. Ekspert kennis is aangewend om die aannames aangaande die fisiese omvang van die tipiese plaas te valideer. ’n Geheelplaas multi-periode begrotingsmodel benadering is aangewend om die finansiële implikasies te evalueer van elke geïdentifiseerde gewas-wisselboustelsel in die Goue Rûens area. Die geheelplaas multi-periode model is in staat om die verskillende individuele komponente te integreer met elke toepaslike investerings behoefte en klimaat wisselvalligheid. Finansiële modellering was suksesvol aangewend ten einde die navorsingsdoel te bereik.

Elke gewas wisselboustelsel wat in die Tygerhoek wisselboustelsel proewe ingesluit is, is gesimuleer in ʼn geheelplaas konteks deur middel van ʼn multi-periode begrotings model om die verwagte finansiële prestasie te bepaal. Die uitset van die navorsingsmetode laat toe vir die finansiële vergelyking van die verskillende stelsels deur gebruik te maak van die interne opbrengs koers op kapitaal investering (IOK). Die reeks IOK's vir die verskillende stelsels op duie geheelplaasvlak is relatief nou. Geen gewasstelsel is waargeneem wat beduidend beter gevaar het as die ander stelsels nie. Daar is egter aanduiding van die belangrikheid van verskillende gewas kombinasies en van koring en gars in dieselfde stelsels.

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List of Abbreviations

CA: Conservation Agriculture

FAO: Food and Agriculture organization of the United Nations

Ha: Hectares

IRR: Internal rate of return

NFI: Net farm income

NPV: Net present value

SSU: Small stock units

Chapter 1

Introduction

1.1 Introduction and background

The world's population is continuing to increase and is projected to increase from 7.7 billion in 2019 to 9.7 billion in 2050 and to 10.9 billion by 2100. This amounts to a 42% expected increase in global population between 2019 and 2100 (UN, 2019 and Gerland et al., 2014). The most remarkable change over this period is anticipated to be in Africa. The African population is projected to increase nearly 3.5-fold, from around 1.3 billion in 2019 to 4.3 billion by 2100 (Rosner et al., 2019).

These population growth projections indicate that by 2050 current food production will have to increase by 70% in order to meet the demands of a projected world population of almost 10 billion (Tilman & Clark, 2015). Food production is already on a trajectory to double by 2050. This is because of a growing middle class with increasing incomes, which results in a global dietary shift towards consuming more meat and higher amounts of calories (Schneider et al., 2011). The increased demand for food will lead to environmental problems caused by increased food production. Food production poses substantial threats to the environment, mainly through greenhouse gas emissions and pollution from pesticides and fertilisers (Tilman & Clark, 2015).

These increased threats to the environment mean that farmers have a responsibility to adopt more sustainable production practices. Farmers should focus more on long-term sustainability by switching from a maximum output mindset to a long-run environmental and financial sustainability mindset. Being more environmentally sustainable has the added benefit of increased long-run financial sustainability.

Conservation agriculture is one of several solutions currently available to farmers as a more efficient farming practice that could substantially reduce their environmental impact while providing increased yields and profitability, which bring about financial benefits in the long run.

The three pillars underlying conservation agriculture are:

- Crop rotation,
- Continuous minimum soil disturbance, and
- Permanent soil cover, either by crop residue or cover crops.

This study focuses on the crop rotation aspect of conservation agriculture in the geographical region of the Southern Cape in South Africa.

The Southern Cape is a well-known grain production region, with a variety of crops that could be incorporated into crop rotation systems, because of the region's climate. It has a typical Mediterranean climate, with a relatively broad rainfall distribution throughout the year, which makes it ideal for producing alfalfa as a grazing crop within crop rotation systems.

A well-known production area within the Southern Cape is the Goue Rûens, which is a relatively high-yield area. This region is ideal for crop rotation, and all three pillars of conservation agriculture are practised successfully in it by almost all farmers. The potential gains to farm productivity currently offered by science and technology are increasingly marginal. The crops that are cultivated in the Southern Cape are well adapted, and livestock integration is also well established. Further improvements would have to be made within the current systems, in seeking to unlock the benefits of crop sequencing and the interactions between crops and pastures. This necessitates a scientific approach.

To justify the crop rotation pillar of conservation agriculture, a scientific approach is needed, and with the intention of reaching this goal, crop rotation trials were established on the Tygerhoek experimental farm.

The crop rotation trial at Tygerhoek has been running for a period of more than 16 years, and has produced insightful results. The crop rotation trials on the Tygerhoek experimental farm were designed to evaluate well-known and successful cereals, pastures and oilseed crops within different crop rotation systems.

The fact that there is pressure from the aforementioned challenges on production implies that production has to be done more scientifically. To reach this goal of enhancing scientific farming principles, the crop rotation trials at Tygerhoek were established to determine how the crop rotations perform in agronomic terms.

One shortcoming of the research done on the Tygerhoek experimental farm crop rotation trials is that the systems have not yet been evaluated in their totality within a systems context, measured in financial terms. The uncertainty here lies in the financial performance of whole systems. The sequences of crops within the systems and the crops included were identified and designed by agronomists. There is a need to investigate how these systems perform in financial terms. To producers, the financial implications of different crop rotation systems are also an important consideration.

1.2 Problem statement

The above-mentioned challenges of an increasing global population and an increasing demand for calories, as well as the need for more sustainable farming practices, create the need for improved crop production systems. To provide a fuller context to the implications of different crop systems, a whole-farm financial analysis of crop rotation practices is required.

The research question this study aims to answer is:

What are the whole-farm long-term financial implications of each evaluated crop rotation system within the Goue Rûens area?

1.3 Research objectives

The main objective of this research project was to evaluate the whole-farm long-term financial implications of each evaluated crop rotation system within the Goue Rûens area.

Within this main objective, the following specific research goals were identified:

1. To agronomically describe and financially analyse each individual system,

2. To identify and describe a typical farm that can serve as a basis for comparison, and
3. To evaluate each crop rotation system in terms of whole-farm financial implications.

1.4 Proposed method of the study

The focus of this study was on the whole-farm financial performance of various winter cereal crop rotations as implemented in the Goue Rûens. The main challenge was the evaluation of previously identified and agronomically evaluated crop rotation systems. The purpose of this study is not to identify new or alternative crops.

In order to illustrate the economic contribution of scientific cereal production principles, there is a need to employ a method that can generate trustworthy and accurate information. This can be accomplished by adhering to the following two concepts:

- The integration of existing knowledge, and
- A substantiated methodology for financial comparison.

The systems approach served as the basis used in this study, and entailed integrating the knowledge of farmers, agronomists, soil scientists and other relevant role players, who contribute to understanding and integrating the parts and relationships of the system.

The farming system is inherently complex, so the proposed method had to be able to accommodate and integrate this complexity. The farm system not only integrates the dynamics between sequential crops, but also climate variability, infrastructure and capital requirements. Crop rotations are part of these systems and are, per definition, equally diverse and complex. This necessitated a technique that could capture the complexity and present it in a financially standardised format that farmers can relate to and understand. This in why the systems approach used in this study is so important: the individual components, when studied in isolation, do not have the same properties compared with when they are studied in a systems context. The Delphi method was used to ensure that the measures used for comparison were verifiable.

A whole-farm multi-period budget model approach was used to evaluate the financial implications of each identified crop rotation system in the Goue Rûens area. This whole-farm multi-period model is able of integrating each system's individual components, with their particular investment requirements and climate variability. It is also able to integrate physical and biological factors. It is, in essence, a budgeting model, and is based on standard accounting practices. The development of budget models in a spreadsheet environment allows for the required sophistication due to the number of components and interactions it can accommodate. The use of a model based on standard accounting practices not only justifies the method, but is also in a format that farmers can effortlessly relate to and understand.

Before constructing the whole-farm multi-period budget model, a typical farm needed to be identified. The Delphi method was used to establish and validate the assumptions regarding the physical properties of such a typical farm. The typical-farm approach served as the point of departure for the whole-farm multi-period budget model.

Each of the individual crop rotation systems included in the Tygerhoek crop rotation trial was implemented on a whole-farm multi-period level to obtain an expected financial output. The output gained from this research method allowed for the comparison of the various systems in financial terms, using the internal rate of return on capital investment (IRR).

1.5 Layout of the study

Chapter 2 presents a literature review and describes the research methodology, by placing emphasis on the importance of knowledge integration when constructing whole-farm multi-period budget models. The systems approach and systems thinking are also described as an academic foundation for complex research when focussing on systems research.

Chapter 3 describes the Tygerhoek crop trial layout, how the research data was gathered, and what each of the individual crop rotation systems comprised of. The construction of the farm-level budget model and its underlying components is described with the goal of measuring the farm profitability within a typical-farm context.

Chapter 4 describes the principles and process of applying both the typical-farm and the whole-farm multi-period budget models. The technicalities of how the systems were compared on the farm-level are described. Sensitivity analysis and scenarios were undertaken to determine the expected effects on the profitability of the typical farm.

Chapter 5 begins by providing the conclusions drawn from the findings of this research. It is followed by a summary of the study and recommendations for future studies.

Chapter 2

Literature review and research methodology

2.1 Introduction

The main objective of this research project was to evaluate the whole-farm long-term financial implications of a set of previously selected crop rotation systems within the Goue Rûens area. The main objective was to contextualise how it relates to addressing the challenges of an increasing global population, increased demand for calories and a need for more sustainable farming practices. This chapter reviews the literature concerning the proposed methods mentioned in Chapter 1.

Chapter 2 consists of four main sections that aim to explain the research methods applied in this study. Farm and food production systems are inherently complex due to the various interconnected components that they comprises. Farm systems are typically large-scale, interconnected systems within higher-level regional systems that include, but are not limited to ecosystems. These farming systems include climate, food processing and distribution networks, information systems, and socioeconomic systems. These consist of various interrelated factors, and they entail a variety of actors, feedback loops and interdependence mechanisms, heterogeneity, and spatial and dynamic complexity (McGuire, 2013). This complexity is explained in the first section of this chapter to give perspective on the reasons in subsequent sections for applying the methods described further on.

The concept of 'a system' is defined in the following section, and the nine key elements from which the 'systems perspective' emerges elucidate the reason for applying systems concepts. The systems approach and systems thinking are also identified as an academic foundation for complex research questions when focussing on farming systems research.

The following section emphasises the importance of knowledge integration when constructing whole-farm multi-period budget models. The Delphi research technique is presented as a method for validating farm-level data. The use of the typical-farm approach and whole-farm budget modelling to integrating knowledge is also described in this section.

Crop production systems in the Southern Cape, within the focus area of the Goue Rûens, are characterised by crop interactions, disease carryover, cultivation practices, pastures and a livestock factor, mechanisation systems, climate variability, and limited diversification options. The aforementioned characteristics, as well as climate change and volatile markets for products and inputs result in a complex system that is constantly changing over time.

This chapter concludes with an overview of the Southern Cape and Goue Rûens area. The distinguishing characteristics of the Goue Rûens are provided. The geographical location of the Tygerhoek experimental farm and how the scientific trial data from this site is applicable for use in this study are explained.

2.2 Complexity

Something is complex when it consists of multiple components and relationships. The world, as a whole, has become more complex as a result of various factors, such as an increased global population and its increased demand for resources like water, food and energy, the limited land for expanding food production, and increasing pressures on natural resources (Jones et al., 2017). The impact of climate change on global food security further increases the complexity related to farming systems (Wheeler & Von Braun, 2013).

South African farming systems increased in complexity shortly after the abolishment of the protective legislation in 1996. This had an effect on the types of crops cultivated in the Southern Cape, which led to a decrease in wheat production but simultaneously led to cash crops such as barley, canola and triticale gaining importance relative to wheat (Edwards & Leibrandt, 1998). Studying such complex systems will assist decision-making in agricultural practices and policies. Today, for instance, farmers have to cope with socio-economic and biophysical systems that create a multidimensional decision-making environment with increased complexity and less standardised and controllable production systems compared with industrial production systems (Hoffmann & Kleynhans, 2011; Cros et al., 2004 and Petherham & Clark, 1998).

Farm business model complexity has also increased for the majority of farms producing agricultural commodities (Gardner, 2002). The cost-price squeeze is another factor that drives the need for farm management research, to generate relevant information that can be used to identify ways to improve farm profitability (Hoffmann & Kleynhans, 2011). The more we know about something, the more complex we perceive it to be. Thus, studying a complex system increases its perceived complexity.

Holistic thinking is one way of addressing the previously mentioned complexities associated with farming systems. Broadly defined, holistic thinking accepts the interpretation that everything is connected or, in a certain sense, can be connected to everything else. Thinking holistically can assist in an improved grasp of differing perspectives, and in learning how to gain an understanding of these, in order to strengthen the production perspective of the farming business (Kelly & Bywater, 2005). Holistic thinking originates from the concept of holism and is discussed further in section 2.3.1.6.

The problem of complexity associated with farming systems in the Goue Rûens is addressed by making use of systems thinking, or systems analysis. Understanding the complexities involved in farming systems can conceivably assist in simplifying decision-making in highly variable and uncertain environments.

2.3 Systems thinking within farming systems

The previous section shows that complexity necessitates tools for undertaking studies in complexity. This section explains what a system is and how the concept of systems can be used to address complexity in farming.

Systems are used for the purpose of studying a specific part of the real world (Peart & Curry, 1998). Farming systems consist of various interconnected physical-biological and socio-economic systems that are made up of continuously interacting physical and chemical processes. Living systems consist of various components and subsystems, each with their own unique behaviour and characteristics. All of the above-mentioned contribute to the overall form and function of the farming system as a whole.

In order to determine the financial implications of each of the different crop rotation systems on a whole-farm-level, a suitable research tool is needed. When studying a system in general, emphasis should be placed on using a holistic approach, as this will help to study the behaviour of the system as a whole. The dynamics and functionality of systems and models and how they are used are explained in section 2.4.

A systems approach views the components and relationships within systems as interdependent and integrates the various factors, rather than isolating them. There are various ways of performing systems analyses, of which the two most important are qualitative systems analysis, which uses diagrams, and quantitative systems analysis, where simulations and optimisation modelling are used. This study makes use of quantitative systems analysis.

The founder of systems thinking, Ludwig von Bertalanffy, defined a system as “an entity which maintains its existence through the mutual interactions of its parts” (Hammond, 2003). This definition of systems thinking has since evolved, and is now more broadly defined. To understand the concept of systems thinking, it is important to begin by understanding what a ‘system’ is.

2.3.1 Working definition and perspective of a system

A system can be defined as a group of components that interact with each other to perform certain functions, and these functions are simultaneously affected by outside forces. Central to the working definition of a system is the concept of inseparability and the notion that systems function as an indivisible whole. When a stimulus is applied to a system, the underlying relationships within its boundaries produce a behaviour of the system as a whole that results in an outcome. The stimulus can be applied to only certain parts of the system or to the system as a whole.

As early as 350 BC, Aristotle stated that a system is a whole that is greater than the sum of its parts. The renowned systems scientist Russel Ackoff defines a system as follows: “A system is not the sum of its parts – it is the product of their interaction” and “... every system is defined by its role in a larger system” (Ackoff, 1989 and Kambiz, 2017).

The definition most relevant to agriculture, and also this study, is given by Kelly and Bywater (2005) with regard to the whole-farm systems approach and is as follows:

> A system can be defined as a grouping of elements contained within a boundary such that the elements within the boundary have strong functional relationships with each other, but limited, weak or non-existent relationships with elements or groupings outside the boundary.

The study of interacting physical biological systems is complex. These systems consist of many subsystems and components that form parts of larger systems. Each separate part has its own unique behaviours and characteristics while also contributing to the system as a whole (Peart & Curry, 1998). These components interact with each other simultaneously, and this results in the system being highly complex. When attempts are made to understand systems, it is essential to understand the interactions between their individual components. The system is thus fundamentally complex.

One of the main reasons why the systems approach is required is that the properties, characteristics and qualities of the system as a whole do not exist in its components in isolation (Ikerd, 1993). It is vital to adopt a systems thinking mindset, as it provides the skills and abilities to see the whole picture, or to view the problem with a wider lens. This assists in understanding the hidden relationships and interconnections, as well as to unveil the underlying assumptions and mental models (Kambiz, 2017) concerned.

Complexity renders the classical mathematical methods used to study non-living physical systems inadequate for studying living systems (Peart & Curry, 1998). Complex systems are better understood when making use of models. The systems-thinking approach is suitable in the management of complexity, and in some instances, it is more effective than other approaches (Bosch et al., 2013).

Systems are defined relative to the particular objectives of the analyst, and thus systems by themselves do not exist; they are defined. The three main reasons for defining a farming system are, firstly, to describe the system in order to increase an understanding of it. When the system is understood, the second reason is to make improvements to it. Finally, when goals or circumstances change, the system can be redesigned (Kelly & Bywater, 2005).

Below, the nine key elements from which the ‘systems perspective’ have emerged are defined and explained.

2.3.1.1 Boundaries

The system boundary is defined relative to the research question that is posed. The boundary of the system can be seen as a way of identifying the system being studied. The position of the defined system is important for suitable analysis (Kelly & Bywater, 2005).

2.3.1.2 Hierarchical

The system forms part of a hierarchy. The system is, itself, part of a higher-level system. This implies that the system in itself is a subsystem within a larger system. The defined system also has component subsystems of its own (Kelly & Bywater, 2005).

2.3.1.3 Environment

That which is outside of the distinct boundaries of the system is defined as the environment. Essentially, a system is always in interaction with its environment through a process of inflows and outflows. These flows are predominantly measurable.

2.3.1.4 Purpose

The defined system has a purpose. The purpose of the system or the objective for its existence is related to the objective of defining the system. Thus, a system with altered boundaries would have a different purpose (Kelly & Bywater, 2005).

2.3.1.5 Transformation (inputs and outputs)

When the system receives some form of variable input, the input is transformed into some form of output. This transformation is achieved in combination with resources. These resources should not be confused with the system inputs, which are transformed into outputs, while the resources are what is needed to bring about the transformation (Peart & Curry, 1998 and Kelly & Bywater, 2005).

2.3.1.6 Holism

The principle of holism is defined as a system that responds to applied stimuli as a whole, with this whole being bigger than the sum of its constituent parts (Kelly & Bywater, 2005). The concept of synergy underpins these characteristics. The structure and the interrelationships that give function to the system create synergy. A change in one part of the system may affect any other part of the system. Knowing the individual parts of the system is not adequate to predict the behaviour of the whole system. This implies that the system as a whole is different from merely the sum of its parts.

2.3.1.7 Components and relationships

Systems are comprised of components that are interconnected and organised in such a way that there is a relationship between the individual components. Allowing for both components and interactions is important for understanding or studying the dynamics of a system. This is because the components give structure to the system, and their interactions enable function. A systems approach thus allows for insight into the structure and functions that eventually define performance.

2.3.1.8 Communication and control

The objective of the system is achieved by communication and control through the transfer of information, energy, materials, and the feedback as well as feedforward mechanisms intrinsic to the system (Kelly & Bywater, 2005).

2.3.1.9 Emergent properties

The characteristics that arise from the interactions between components are called ‘emergent properties’. These emergent properties remain unknowable if the system components are studied independently.

This reverts one back to the principle of holism, meaning that the whole differs from the sum of its parts, and that only by looking at the whole system can emergent properties be discovered. Drawing conclusions about a whole system by studying only its components in isolation is not necessarily sufficient (Hieronymi, 2013).

2.3.2 Systems approach in the context of crop rotation systems in the Goue Rûens

The core benefit of the systems approach is that the relationships and components that, in this instance, the farm system consists of are recognised. Thus, the farm as a whole system was studied, and the crop sequence of various crop rotation systems, as well as the capital and mechanisation requirements, and the livestock factor were evaluated as an integrated and indivisible whole. Each crop and system were thus evaluated in terms of their effect on the performance of the farm as a whole. In this instance, the performance measure was profitability.

Farmers in the Goue Rûens have already adopted crop rotation systems, and the majority have moved away from any type of monocropping. Long-rotation cycles are typical in the Southern Cape. These usually include five to seven years of alfalfa, followed by five to seven years of cash crops. The cash crops farmed in the area comprise wheat, barley, canola and oats (Hoffmann & Kleynhans, 2011).

2.4 Integration of knowledge

Getting from data to knowledge and ultimately to wisdom is not straightforward. Terms such as ‘data’, ‘information’ and ‘knowledge’ are used interchangeably in daily conversation, and decision-making thus increases the confusion between these terms. Russell Ackoff (1989) makes an important distinction between the above-mentioned terms and describes them in a framework of the five categories of the contents of the human mind.

- Data is the most basic level and are symbols that signify the properties of events and objects. They are the building blocks for information and knowledge.
- Information can be seen as data at a higher level, which has been processed to be useful. Information provides answers to who-, what-, where- and when-type questions.

- Knowledge relates to the application of data and information. Providing answers to ‘how’ questions, where combinations of relevant information lead to problem-solving.
- Understanding is cognitive and analytical. It is the ability to grasp the bigger picture by synthesizing new knowledge out of existing knowledge. Appreciation of the ‘why’ is gained through understanding.
- Wisdom is evaluated understanding. It is the purpose and reason for doing things (Kambiz, 2017).

The first four categories deal with what has been or is known; thus, they relate to the past. It is only wisdom, the fifth category, which deals with the future, as it incorporates vision and design (Ackoff, 1989).

As described in the goal of this research project, the whole-farm concept and crop rotation systems require integration. A farm system is inherently complex and multifaceted. This means that research is done on various aspects of such systems, but from different perspectives and research specialisations. This tendency towards specialisation often leads to fragmentation of knowledge. A method is thus required that could integrate knowledge that may already exist but which might have become fragmented due to specialisation. Fields of research that are applicable to cereal and crop farming systems include agronomy, soil science, entomology, plant pathology, animal science, pasture science, mechanisation and agricultural economics.

2.4.1 The Delphi research model

This study made use of group discussions to validate information and to deepen understanding of the problem and possible solutions. Group discussions as a method for generating ideas started in advertising in the 1950s with rudimentary brainstorming (Thompson & Choi, 2006). The Delphi method and Idealised Design method are the two most prominent group discussion methods. The Delphi method was better suited to the goals and objectives of this study, as it does not start from a zero base with no constraints, as compared with the Idealised Design method (Ackoff et al., 2006).

The definition of the Delphi method has evolved since its inception back in the 1950s as a by-product of defence research. Project Delphi, an air force-sponsored Rand Corporation and Linstone and Turoff (1975) study, defined the Delphi method as follows:

> Delphi may be characterized as a method for structuring a group communication process so that the process is effective in allowing a group of individuals as a whole to deal with a complex problem.

The Delphi method was more recently defined by Skulmoski et al. (2007) as:

> The Delphi method is an iterative process to collect and distil the anonymous judgments of experts using a series of data collection and analysis techniques interspersed with feedback.

Commercial and smallholder farming has become more business orientated and less lifestyle orientated, which has resulted in modern-day farming shifting its central focus to whole-farm management and knowledge gathering (Du Toit, 2018). The Delphi method can be applied to a group of individuals from various specialised fields to increase interaction between parties. The Delphi method is well suited to aiding the deepening of the understanding of the problems, opportunities and solutions, and to developing forecasts (Skulmoski et al., 2007).

The Delphi process exists in two distinct forms, with the most common being the ‘paper-and-pencil’ version, also referred to as the ‘Delphi Exercise’, and the newer form called the ‘Delphi Conference’ (Linstone & Turoff, 1975). This study makes use of the paper-and-pencil version.

Usually, Delphi undergoes four distinct phases. The first is associated with exploring the topic under discussion, where individuals have an opportunity to contribute the information they feel is relevant. The second phase entails reaching an agreement or general understanding of how the group views the issue at hand. If there is substantial disagreement between the parties, they move on to the third phase. In this phase, the disagreement is explored to reveal the underlying reasons for the differences and then possibly to evaluate the differences. The fourth and last phase happens when all the information that was previously gathered has been initially analysed and the preliminary evaluations have been sent out for final feedback (Linstone & Turoff, 1975 & Hardaker et al., 2015).

For the Delphi method to be used successfully as a research technique, the following important features must be present: the anonymity of the participants should be guaranteed, iterations must be made with new relevant information being fed back in a controlled manner, and the opinions of the group members for a given response must be represented using statistics (Hoffmann, 2010 and Kenis, 1995).

The great degree of individuality and freedom that participants experience because of their anonymity is the biggest advantage of the Delphi method (Linstone & Turoff, 1975). Poorly designed questionnaires or below-par structured questions are some of the main problems associated with this method, and can result in skewed results (Hoffmann, 2010). For this study, the Delphi research method was used to validate the parameters and assumptions of a typical Goue Rûens farm budget model. A consensus was reached after the relevant agricultural role players and experts provided their valuable input. When building models that deal with complex problems, using the Delphi method allows for subjective information to be incorporated (Linstone & Turoff, 1975). The Delphi panel of experts as well as the valuable contributions made by each of them are given in Section 3.5.

2.4.2 Farm simulation modelling

A model can be defined as a simplification or abstracted representation of a limited part of reality, for a specific purpose, based on assumptions and data (Wilson & Morren, 1990). A model can also be seen as an analogy or description that helps to conceptualise something that usually cannot be perceived directly (McNickle & Daellenbach, 2005).

The behaviour of systems can be simulated by making use of models. Modelling is well established in the field of agricultural systems. Presently, the main focus of modelling efforts has been on understanding the relationships between individual system components and what drives the response of the system (McCown et al., 2006). Ever since its establishment, modelling has been a key part of systems analysis. Modelling agricultural systems is often done to improve knowledge of the systems (Swinton & Black, 2000).

The process of learning can be strengthened by making use of modelling. This process may be undertaken for various purposes, including:

- Improved communication of meaning and complexity,
- Searching for additional insights on system behaviour,
- Conveying the various relationships between individual components, and
- Evaluating alternative strategies (Kelly & Bywater, 2005).

One of the main reasons for constructing a farm model is to aid farmers in the decision-making process (Pannell et al., 2000). Numerous decisions are made by farmers against the backdrop of two key objectives. The first key objective of farmers is to stay in farming despite the various shocks that typify agriculture. Changes in policy and shocks in price and weather, as well as changes in technology and social conditions are some of the typical shocks that farmers face (Pannell et al., 2000). The second key objective of farmers is to increase their wealth over time.

Arriving at the correct big decision is the key to achieving both of these objectives. The big decisions entail the correct major tactical adjustments and those relating to the purchase of land, investment in machinery, and resource improvement (Kingwell et al., 1993 and Malcolm, 1994). Model types can be either descriptive or analytical, and are elaborated on in the sections that follow.

2.4.2.1 Descriptive models

In the systems approach, an essential first step is to describe the system; that is, to identify the boundaries, the component parts and their interactions. This description of the system may be in the form of mathematical equations, diagrams or text. Descriptive models are typically the outcome of observations of qualitative as well as quantitative data. Before advancing to further analysis, it is critical to have a sound understanding of the present state of the farm business. Constructing the model should be based on facts and observations in order to obtain a model that is an accurate reflection of reality. By nature, descriptive models should be current and historical (Kelly & Bywater, 2005).

2.4.2.2 Analytical models

In contrast to descriptive models, analytical models can also be predictive. Predictive models can be used to forecast the future behaviour of the system (Swinton & Black, 2000). Analytical models describe the cause-and-effect relationships between components of the system. The data used by analytical systems can be based on one of, or a combination of available historical farm-specific data and inputs from research or other industry-wide sources. These models are often used to gain an improved understanding of how a farm business has changed or could change over time, by comparing different years and contrasting similar farm types.

Traditionally, analytic models have been deterministic in design, but advances in computer hardware and software technology have made it possible to develop stochastic models as well (Kelly & Bywater, 2005).

2.4.3 Simulations

The purpose of the following section is to give an introductory overview of the concepts and techniques used in the simulation of agricultural systems (Peart & Curry, 1998). There are vast numbers of definitions and methods of modelling and simulations in the current literature. The definition by Johnson et al. (1977) is the one best suited to agriculture and also to this study. The process of modelling entails constructing a representation of a system, while simulation is the experimentation, by means of the constructed model, with the represented systems (Johnson et al., 1977).

Simulations thus imply that there is some kind of experimentation with the objective of representing or reproducing a certain relationship between components, people and objects in a real-world system. This can then be used to predict the most likely behaviour of the components, people or objects in the specific system (Strauss, 2005).

2.4.4 Farm budget models

The most widely used method of financial planning in farming systems is budgeting, where it is used as a non-optimising method to evaluate plans in both physical and financial terms (Hoffmann, 2010). Budgeting, in a sense, is only a planning aid because it does not involve drawing up a plan; rather, it merely evaluates a plan in financial and physical terms (Rehman & Dorward, 1984).

Budgeting models are based on the accounting system of the farm, and the purpose of these types of models is to describe the ongoing financial processes and relationships of the farm. This description should be done within a relatively simple framework of physical production of commodities (Csáki, 1976). The simple budgeting approach to farm planning has an advantage in that it enables consideration of all the significant characteristics of the particular farm business (Pannell et al., 2000). This is why whole-farm budget models are also applied in research. Their sophistication lies in the number of factors and relationships within a whole-farm system that can be accommodated.

In farm management, farmers understand the reality that it is better to solve the entire problem roughly than to try to solve a certain part of the problem outstandingly well (Pannell et al., 2000 and Malcolm, 1990).

Budgets can be a useful tool when used, with caution, alongside other relevant holistic methods to assess needs, aid planning and undertake participatory research and decision-making (Dorward et al., 1997). Planning entails considering the future, and explores, analyses and evaluates future possibilities, while diagnostic techniques analyse past events (Rehman & Dorward, 1984).

The budgeting process involves developing the physical details of a farming system in order to enable estimating the costs and returns that may be expected under the assumption that the particular farming system is put into operation (Nuthall, 2011). The popularity of budgets may be explained by their ease of use. Rather than imposing an analytical framework on the decision maker, budgeting aids a heuristic approach to decision-making (Rehman & Dorward, 1984). This allows for a decision to be made by comparing the alternatives.

Budgeting tools are suitable for most real-world situations. Except for the exclusion of risk, the nature of the real world has no simplifying assumptions. Budgeting is unrealistic in the sense that it assumes certainty with regard to input–output coefficients, and that both price and costs have fixed values. In an attempt to overcome this problem, analysts use conservative estimates, and the likely profit range is indicated by a range of parameter values. The conservative estimates could lead to lower-than-expected financial performance. These methods are not used to positively account for risk, but rather as a method for preventing over-optimistic estimates being made (Nuthall, 2011).

The advent of new technologies such as computer technology, the internet and other networks has changed the way budgets are done. This has led to the introduction of new dimensions that allow budgets to be used as tools for decision-making and dynamic planning. Budgets are no longer exclusively based on mathematics and can now also be classified as simulation models that are based on accounting principles and methods (Pannell, 1996 and Hoffmann, 2010).

2.4.5 Whole-farm budget

In essence, whole-farm budget models are simulation models that are normally developed using spreadsheet programs. Complex and sophisticated calculations are made within spreadsheet programs, and relationships can be expressed in a comparatively simple way. The ability of budget models to allow for detail, user-friendliness and adaptability is what makes them sophisticated (Keating & McCown, 2001).

Budgets are often used as a participatory research tool, and the main factors contributing to their use are outlined below:

- They are simple and easy to explain to parties of all education levels.
- Budgets have the ability to be based on any resources, not only financial resources.
- Budgets can accommodate a large number of variables and mathematical equations that are interrelated, but they do not necessarily have to contain these complex mathematical equations.
- The developers of the budget can decide on which performance indicators they find relevant (Dorward et al., 1997).

Whole-farm decision-making is very complex, and in order for outsiders to understand this complexity, it is important for them to have some way of analysing and understanding whole-farm issues.

Computer farm modelling falls into two broad categories, namely the simulation and optimization approaches to whole-farm modelling. Whole-farm budgets usually calculate profitability criteria, for instance, net farm income (NFI), internal rate of return on capital invested (IRR) and cash flow measures. This is achieved by incorporating physical as well as financial parameters into one model (Dillon & Hardaker, 1984). Another quantitative technique used in this type of budgeting is the optimisation of the whole-farm gross margin.

Obtaining a proper understanding of a system in order to later predict its behaviour, necessitates studying the system as a whole. Breaking the system down into smaller components and studying each component individually is likely to result in an underestimation of the system's interconnectedness, and hence and underestimation of the system itself (Sherwood, 2002).

Every farm owner has specific objectives in mind. These goals comprise both profit and non-profit targets, and they are a compromise between the various conflicting goals that exist within a farming business. The achievement of the goals and objectives of the farm owner can be attributed to the successful application of whole-farm management (Kelly & Bywater, 2005).

Farmers are, of necessity, decision makers and are confronted with a multitude of decisions on a daily basis. Some are small, quick and easy decisions with little to no impact if they turn out to be incorrect. Others are big and difficult, take longer to make, and have a bigger overall impact. These decisions are usually made under a lot of uncertainty. Farmers have to make these decisions with only partial information, and they thus need the skills and tools to cope with these situations of uncertainty.

The whole-farm-system approach can be used to assist farmers to improve their decision-making with regard to resource management, in terms of financial, physical and human resources. This will lead to them adopting the behaviours required to achieve their goals and objectives. Rather than describing and analysing only a single part of the system in isolation, the whole-farm system should be described and analysed to enable modelling of the particular system of interest.

2.4.6 Systems research

In order to manage the above-mentioned problem of complexity and the multifaceted nature of farms, a systems approach is required (Hoffmann & Kleynhans, 2011). When the whole is disassembled, it loses its essential properties, and the same applies to all of its parts.

The budget models used for this study measure profitability in terms of the internal rate of return on capital investment (IRR). A previous study done by Hoffmann and Kleynhans (2011) confirms that the IRR is suitable as a measure of the financial feasibility of a farming system. The IRR is a metric used in capital budgeting, and is probably the most broadly used sophisticated capital budgeting technique for estimating the profitability of potential investments. The IRR is a discount rate that makes the NPV of all cash flows from a particular project equal to zero. The IRR is measured as the compound annual rate of return that the farmer would receive if he invested in a specific project and gained the given cash inflows (Gitman, 2009).

2.4.7 Typical-farm approach as a profitability tool

The typical-farm approach can be used as a tool to evaluate the whole-farm profitability as well as the effect on farm-level profitability of changing variables (Hoffmann, 2010). The concept of a ‘typical farm’ originates from the ‘representative firm’ idea applied to agricultural economics, which was first used by F.F. Elliott in 1928 (Feuz & Skold, 1990).

This concept was widely used and later expanded by Feuz and Skold (1991) to ‘a model farm in a frequency distribution of farms in the same universe’. The typical farm concept is the ideal tool for collecting data because it is representative of a physical farm in homogenous production areas (Du Toit, 2018).

When establishing and modelling a typical farm, the inputs of producers and other stakeholders should be incorporated. Validation of the typical-farm model by experts from various relevant fields is vital (Hoffmann, 2010).

The purpose of a typical-farm model in the context of this research was to create a basis that could be used for comparing the anticipated financial outcomes of implementing the different crop rotations practiced at the Tygerhoek experimental farm on a whole-farm multi-period budget level.

2.5 The Southern Cape

The Western Cape can be divided into smaller, more homogeneous areas based on variations in climate, terrain and soil (Hoffmann, 2010). Expert groups were used to validate these homogeneous areas after consulting previous studies. In the process of identifying the homogeneous production areas, Hoffmann (2010) also emphasised the importance of considering certain characteristics such as farming practices, typical crop rotation systems, typical machine replacement policies and the affiliations the farmer has to agribusinesses.

In terms of grain production, the Western Cape can be divided into two broad regions: the Swartland and the Southern Cape (Strauss, 2013). The Southern Cape region, as identified by Hoffmann (2010), stretches from Botrivier to Riversdale, between the coastline and the Riviersonderend and Langeberg mountain ranges. Within the Southern Cape region, three homogeneous areas were identified; they are the Goue Rûens, the Middle Rûens, and the Heidelberg Vlakte. Refer to Annexure A for a map of these areas. The livestock component of a typical farm in the Southern Cape comprises mainly sheep. Pastures cultivated for the livestock include alfalfa and medics. Conservation agriculture principles are widely employed in the region, with only a small percentage of farmers still making use of conventional practices. The soil depth is a limiting factor, and farmers try to manage this resource the best they can. The focus of crop rotation systems is on improving the soil structure, with the aim of increasing moisture retention and the carbon concentration of the soil. This, in turn, leads to an increased yield potential of the soil and increased financial benefit to the farmer (Van Eeden et al., 2002).

Within the Southern Cape homogenous area, this study further narrowed its focus to the Goue Rûens, which is discussed in the following section.

2.5.1 *The Goue Rûens homogeneous area*

In order for farm models to be generally relatable to producers, a homogeneous production area has to be identified when constructing the models. For this study, the focus was on the Goue Rûens, within the Southern Cape region. The Goue Rûens forms a triangle stretching between Caledon, Bredasdorp and Riviersonderend. It has especially steep gradients relative to the Middle Rûens and Heidelberg Vlakte, which necessitates heavier machinery for soil cultivation and harvesting compared with the other homogenous areas in the Southern Cape. Refer to Annexure A for reference to the geographical area of the Goue Rûens.

2.5.1.1 Climatic characteristics of the Goue Rûens

The distinguishing factors with regard to separating the homogeneous regions of the Swartland from the Southern Cape on the basis of rainfall are both the total annual rainfall and the rainfall dispersion throughout the year. The Southern Cape area has a typical Mediterranean climate, with its characteristic winter rainfall and warm summers, but without a specific dry season (Peel et al., 2007). The Southern Cape receives its rain mainly in the winter months, but as one moves east, the prevalence of summer rain increases (Van Eeden et al., 2000). In a typical year, the Goue Rûens area receives 70% of its rain in the winter months and 30% in the summer months (Hoffmann, 2010).

The rainfall dispersion during the growing season is of more significance than the total amount of rainfall for that particular season, concerning the yield obtained by the farmer. This was confirmed by Hoffmann (2010) during his workshop discussions, with various examples of low yields per hectare achieved despite a relatively high total seasonal rainfall.

2.5.2 *The Tygerhoek experimental farm*

The Tygerhoek experimental farm (34° 09' 37.7"S 19° 54' 15.4"E) is located near the town of Riviersonderend in the Goue Rûens area, in the Southern Cape region of South Africa (Human, 2008).

The soils found in and around Tygerhoek are mostly shallow with a stony A-horizon that is rarely deeper than 30 cm, and the top soil is mostly a sandy loam, classified as a Glenrosa form with an Orthic A- on a Lithocutanic B-horizon (Mavicar al., 1997). These soil types are representative of the typical soils found in the Goue Rûens area.

The main cash crops produced in the surrounding area are wheat in rotation with barley, canola, lupins, medics and alfalfa. The lupins, medics and alfalfa are mainly used as pastures for livestock. Livestock in this region primarily consists of sheep.

Tygerhoek has an average annual rainfall of about 450 mm per year. Seventy percent of this falls in the autumn, winter and spring months (April to October) – the winter grain growing season – and thirty percent falls in the warm summer months (Vorster, 2015). The above-mentioned rainfall for Tygerhoek is representative of the Goue Rûens area.

The location, soils, climate and crops produced at the Tygerhoek experimental farm are representative of a typical farm in the Goue Rûens area, making the data from its research trials suitable for use in this study. How the data from the trials was obtained and the types of crop rotation systems in use at the Tygerhoek research farm are discussed in Section 3.2.

2.6 Conclusion

Chapter 1 highlights the current factors that lead to increased complexity and emphasises that there is a need for a tool to manage the increased complexity. Improved understanding of the complexities involved in farming systems can conceivably assist in simplifying decision-making environments. Complexity is inherent in farming systems, and therefore systems thinking is a suitable tool for managing the associated complexities.

The systems thinking approach is suitable in the management of complexity, and in some instances, is more effective than other approaches. Section 2.3 explains what a system is and how a systems approach can be used in farming to comprehend the complexity. The three main reasons for defining a farming system are, firstly, to describe the system in order to increase understanding of it. The second reason is to make improvements to the system. Finally, when goals or circumstances change, the system can be redesigned. The nine key elements from which the systems perspective emerges are defined, and reasons are given for why emphasis is placed on the principles of holism and boundaries. To summarise, holism defines a system as an entity that responds to the applied stimuli as a whole, with the whole being bigger than the sum of its individual parts, while boundaries are a way to identify the system being studied and are determined by the research question being asked.

The farm system is multifaceted and inherently complex, which means that research done on such systems stems from various different perspectives and research specialisations. The above-mentioned tendency towards specialisation leads to fragmentation and necessitates a method to integrate this fragmented knowledge. Expert knowledge from various fields was integrated by making use of group discussions, using the Delphi method. This method was also used to validate information and to deepen understanding of the problems and their possible solutions. A complex system can ideally be simulated and evaluated by using a model.

A farm model was constructed, with the main motivation being to aid farmers in the decision-making process. The systems thinking approach served as the conceptual basis for developing the whole-farm budget model. The typical-farm approach was used as a profitability tool, with ‘typical’ implying a farm that is most representative of a homogenous area, and to which most of the producers would thus be able to relate.

The Southern Cape and Goue Rûens areas are described in this chapter, and emphasis is placed on what makes these homogeneous areas unique, with rainfall dispersion being the biggest distinguishing factor. The Tygerhoek experimental trials site is located within the Goue Rûens, with climatic, soil and other relevant characteristics being representative of the Goue Rûens area. Because the trials are scientifically grounded, the data obtained from Tygerhoek is accurate and meaningful.

Chapter 3

The process of implementing whole-farm models from crop rotation data

3.1 Introduction

The systems approach and its importance as a tool for managing the complexities associated with whole-farm systems, and the use of models as a method to integrate knowledge are discussed in Chapter 2.

The main objective of this research project was to evaluate the whole-farm long-term financial implications of each evaluated crop rotation system. Chapter 3 consists of an outline and comprehensive discussion of the Tygerhoek crop rotation trial, and a financial analysis of the trial data.

This chapter aims to provide an understanding of the process of moving from the Tygerhoek crop rotation trials to a whole-farm-level budget model. The methods used to capture crop and livestock data from the trial are also discussed. The typical-farm concept and the justifications for using it in this study are explained. The process of converting the trial data to whole-farm financial budgets is explained with reference to the input, calculation and output components. This formulation includes a per-hectare financial analysis of the crop rotation systems from trial data.

How the experts on the Delphi panel were identified and the contributions they made are highlighted. This chapter concludes with an explanation of the three pillars of conservation agriculture, with a focus on crop rotation. This focus is highlighted and the corresponding potential agronomical and financial benefits of it are explained.

3.2 Tygerhoek crop rotation trials layout

The Tygerhoek crop rotations trials form part of a large project. It is one of three research sites associated with the main project. The reason for not including the other two research sites is that they test long-rotation systems, while Tygerhoek is the only research site that focuses on short-rotation systems. Section 2.5 provides a more thorough description of where the Tygerhoek experimental trials site is located within the Goue Rûens and the distinguishing characteristics of the Goue Rûens homogenous area.

The two main reasons for initiating the main project were the following. First, the lack of knowledge and understanding of both the short- and long-rotation crop systems in the Southern Cape. The knowledge gained could subsequently be used to improve the biological and financial sustainability of crop production systems in this area. Second, there was a lack of understanding of the mechanisms of both the internal and external economic and biological factors within these production systems, which support sustainable production. The project team for the Tygerhoek crop rotation trial consists of Dr Johann Strauss, Professor MB Hardy and Willie Langenhoven of the Western Cape Department of Agriculture.

The aim of the trial conducted on Tygerhoek was to determine the financial sustainability of short- and long-rotation crop and pasture production systems in the Southern Cape. In order to accommodate commodity price fluctuations and inter-annual climatic effects on crop yields, all phases of each rotation are present in each year at the Tygerhoek trial site.

The trial was started in 2002 and consists of a randomised block design experimental layout, using two replicas of each rotation system in each year. For example, in 2017 there were six camps dedicated to System 2a (PPW – Pasture, Pasture, Wheat): two different camps dedicated to wheat, two different camps for the first pasture rotation, and two for the second pasture rotation.

During the pasture phase of the crop–pasture rotation system, the allocated camp size was two hectares. System Category 5 is the only system category that does not include any pastures. In order to obtain reliable ewe and lamb performance data, an area that is large enough to carry the number of sheep must be provided. Two hectares is sufficient to satisfy this requirement. In the cropping year, the pasture camps are subdivided into smaller sub-camps to accommodate the cropping phase of the cycle.

3.2.1 Tygerhoek research data

The most important characteristic of any successful experiment is relevant and reliable data that is captured and processed in a scientific way in order to make a positive contribution to future research (Hardaker et al., 2015 and Leedy & Ormrod, 2005).

The data used in this study was obtained from trials conducted on the Tygerhoek experimental farm. The trial was started, and is currently managed by the Directorate Plant Sciences, Western Cape Department of Agriculture. The raw data is captured at the farm and transferred to Microsoft Excel. This is an electronic data capturing tool widely used as a means of capturing raw data. This Excel database consists of a spreadsheet-based, gross margin program. There is a separate data set from each year from 2002 to 2017. These spreadsheet-based gross margin data sets form the basis of the typical whole-farm multi-period budget model. The raw data as well as the gross margin budgets were used as the basis for my assumptions about the typical production activities and their associated costs.

The research data from the Tygerhoek crop rotation trials was captured in a scientific way to ensure its reliability and accuracy with respect to the Goue Rûens homogeneous area. All factors that influence crop production are included in the trials' comprehensive record-keeping system. The trial layout ensures that the systems are comparable, and its design neutralises variable factors such as soil type, gradients, weed prevalence and wind direction.

The data sets from 2002 to 2017 each contain a detailed gross margin for each of the camps within the rotation systems. These data sets also contained the various crop rotation and yields achieved in a particular year on a specific trial plot. The relevant prices of inputs and outputs for each year are also available.

For each year, all the allocable variable input costs per hectare, direct and indirect, and gross income per hectare for each crop, as well as for the sheep component of each rotation system, are recorded in detail in the data sets.

In order to analyse the cost component of production and the relative gross margins of the various crop rotation systems, the data had to be organised into a single Excel workbook. All the calculations made for gross production value, and gross margin were based on an identical process. Real interest rates were used for all cash flows and profitability calculations in order to capture the effect of inflation.

3.2.2 Gross production value

Three separate budgets were compiled for each crop within each crop rotation system, for good, average and poor yields. Each year within the multi-period budget was labelled ‘good’, ‘average’ or ‘poor’. Of course the sequence of good, average and poor years in terms of yield is completely unpredictable for the budget period of the next 20 years. In order to overcome this challenge, the number and sequence of good, average and poor yields were composed from historical rainfall distribution pattern data obtained from a weather station on the experimental site – see Annexure C for a yearly and seasonal rainfall summary. The number of each of the good, average and poor years was validated by the Delphi panel of experts.

The gross production values were calculated by taking the corresponding good, average and poor yields and multiplying them by the hectares allocated to the specific crop, and then multiplying that figure by the price of the corresponding output.

3.2.3 Variable costs

Variable costs were divided into directly allocable variable costs, which included, on the crop side: fertiliser, weed control, pest control, fungicide, fuel, lime, seed, contractors, repairs and maintenance. On the livestock side, this included: feed purchased, pasture cost, veterinary costs, shearing costs, transport and packaging, as well as indirectly allocable costs.

The directly allocable variable costs are the actual prices paid for the products and services at the date that they were supplied to the trial site. These prices were gathered in such a manner as to give the most accurate representation possible of the typical farm in the Goue Rûens homogeneous area.

Indirectly allocable variable costs are the energy costs, which are based on the average cost price of diesel per litre for the period April to October, as supplied by the Automobile Association for that year. Fuel and repairs and maintenance costs are based on data obtained from the *Guide to Machinery costs* for the actual machinery and implements used on the experimental site for that year (DAFF, 2016).

3.2.4 Gross margin

The gross margin of the various enterprises was calculated by matching the gross margins according to good, average or poor yields per hectare with the good, average or poor rainfall of each year. The selected gross margin per hectare was multiplied by the total number of hectares of the particular crop within the whole-farm system. The number of hectares allocated to each crop was determined by the total cultivated area in hectares and the crop rotation system implemented. The sum of all the gross margins for the different crops gives the total farm gross margin.

3.2.5 Fixed cost

The annual fixed cost used in this model is typical for the Goue Rûens area and was determined by a study conducted by Hoffmann (2010), and adapted and verified with the help of the Delphi panel of experts to ensure that the cost was relevant for this study. The fixed cost was included as a whole and was not broken down into its constituent components because the model was based on a typical framework. Owner's remuneration was included as a fixed cost in the model. Usually, fixed costs include fuel and maintenance on general farm vehicles, banking and accountant's fees, fixed improvements and maintenance on fixed improvements, permanent labour, insurance, licences, and administration costs, and provision was made for any unexpected costs that may have arisen.

3.3 Crop rotation systems at Tygerhoek

There are four different categories of crop rotation systems at Tygerhoek that were compared in this study. The different systems were thus grouped into Categories 2, 3, 4 and 5. Within each of these categories there was a different number of crop rotation systems; for example, Category 2 had Systems 2a, 2b and 2c. There was a total of 13 systems at the Tygerhoek research trial that were used in this study.

The system in Category 1 consisted of only alfalfa as a pasture and could not be considered as part of a rotation system and was only included at the Tygerhoek experimental farm trial site for comparative purposes. This system was discontinued at the end of 2013, and thus System 1 was not considered as part of this study, for the above-mentioned reasons.

The categories of systems were grouped together according to the ratio of pastures to crops. Systems Category 2 consists of a pasture to crop ratio of 67% annual legume pasture to 33% cash crops, with three different rotation systems being included in this category. Systems Category 3 consists of a pasture to crop ratio of 50% annual legume pasture to 50% cash crops, with alternating years of crops and pastures. Four different rotation systems were included in Systems Category 3. Systems Category 4 consists of a pasture to crop ratio of 50% annual legume pasture to 50% cash crops, which is the same as Systems Category 3 but differs from it in that two consecutive years of crops are followed by two consecutive years of pastures. Four different rotation systems were included in Systems Category 4. Systems Category 5 consists of 100% cash crops with the two different continuous cash crop rotation systems included in this category.

In order to ensure that the Tygerhoek trial is managed successfully, experts from various fields, ranging from soil scientists, agronomists and farmers to agricultural economists are involved. This also helps when constructing a farm model based on the crop trials, as it enables the subsequent simulation to be as similar as possible to the real farm environment and practices followed by farmers (Hoffmann, 2010).

Below, the four main categories of systems are described and the systems included are described in more detail.

System 2 – 67% annual legume pasture:33% crops

There were three different rotations from Systems Category 2 that were included in this study, and all of the crop rotations had two consecutive years of pastures followed by one year of crops:

- 2a – PPW (Pasture, Pasture, Wheat)
- 2b – PPO (Pasture, Pasture, Oats)
- 2c – PPB (Pasture, Pasture, Barley)

System 3 – 50% annual legume pastures:50% crops

There were four different rotations from Systems Category 3 that were included in this study, and all of the crop rotations had alternating years of crops and pastures:

- 3a – PWPW (Pasture, Wheat, Pasture, Wheat)
- 3b – PWPO (Pasture, Wheat, Pasture, Oats)
- 3c – PWPB (Pasture, Wheat, Pasture, Barley)
- 3d – PWPC (Pasture, Wheat, Pasture, Canola)

System 4 – 50% annual legume pastures:50% crops

There were four different rotations from Systems Category 4 that were included in this study, and all of the crop rotations had two consecutive years of crops followed by two consecutive years of pastures:

- 4a – PPWW (Pasture, Pasture, Wheat, Wheat)
- 4b – PPOW (Pasture, Pasture, Oats, Wheat)
- 4c – PPWB (Pasture, Pasture, Wheat, Barley)
- 4d – PPCW (Pasture, Pasture, Canola, Wheat)

System 5 – 100% crops

There were two different rotations from Systems Category 5 that were included in this study, and both had continuous crop sequences with no pastures in either of the systems:

- 5a – WCWL (Wheat, Canola, Wheat, Lupines)
- 5b – WBCWBL (Wheat, Barley, Canola, Wheat, Barley, Lupines)

3.4 Structure of farm-level budget model

The farm-level budget was constructed to evaluate the effect that different crop rotation systems and, as a result, the different machinery replacement schedules had on the financial performance of the typical farm in the Goue Rûens, measured in terms of IRR. The Tygerhoek gross margin trial budgets were adapted to be scaled up to farm-level budgets in order to build a model and eventually simulate a typical farm in the Goue Rûens area.

For this purpose, a whole-farm multi-period budget model was developed for each of the different cropping systems. Each of the two-hectare systems was scaled up to a 'real' farm size in order to compare the systems with each other in 'real' farm financial terms. This meant, for example, that System 2a was scaled up to a 2000-hectare fully-operational farm with a machinery replacement schedule and fixed costs.

The factors influencing the financial performance of a farm can be divided into exogenous factors and manageable factors, the latter of which to some extent can be controlled by management. Exogenous factors are those that are beyond the control of individuals or groups of producers and are typically determined by the market and macro environment.

The focus of the following section is on the factors that can be managed or influenced in order to improve the financial performance of the farm. The potential impact of these factors on the profitability of a typical farm was established by developing whole-farm, multi-period budget models. This farm-level budget model allowed for the comparison of alternative crop rotation systems from the Tygerhoek trials. Spreadsheet programs, like Microsoft Excel, are generally used when computer-based farm-level budget models are developed, as is the case in this study. The financial implications or future outputs are calculated on the basis of assumptions, inputs and other relevant factors.

After developing a whole-farm multi-period budget, the model is used first to calculate the initial financial position of the typical farm. Second, it is used to compare the financial implications of alternative production systems.

The biggest criticism against budget models is that, unlike mathematical models, they cannot identify an optimum outcome. Rather, this type of budget model is used to find the best alternative among a selection of outcomes. The second criticism is that budgeting as a simulation technique requires the modeller to have an in-depth understanding of the systems being modelled. Thus, the model developed for this study was validated by the Delphi panel of experts to ensure that it was understood sufficiently enough. Budget models should be treated as a management aid rather than as rigid, or fixed, plans (Blignaut et al., 2000).

3.4.1 Structure

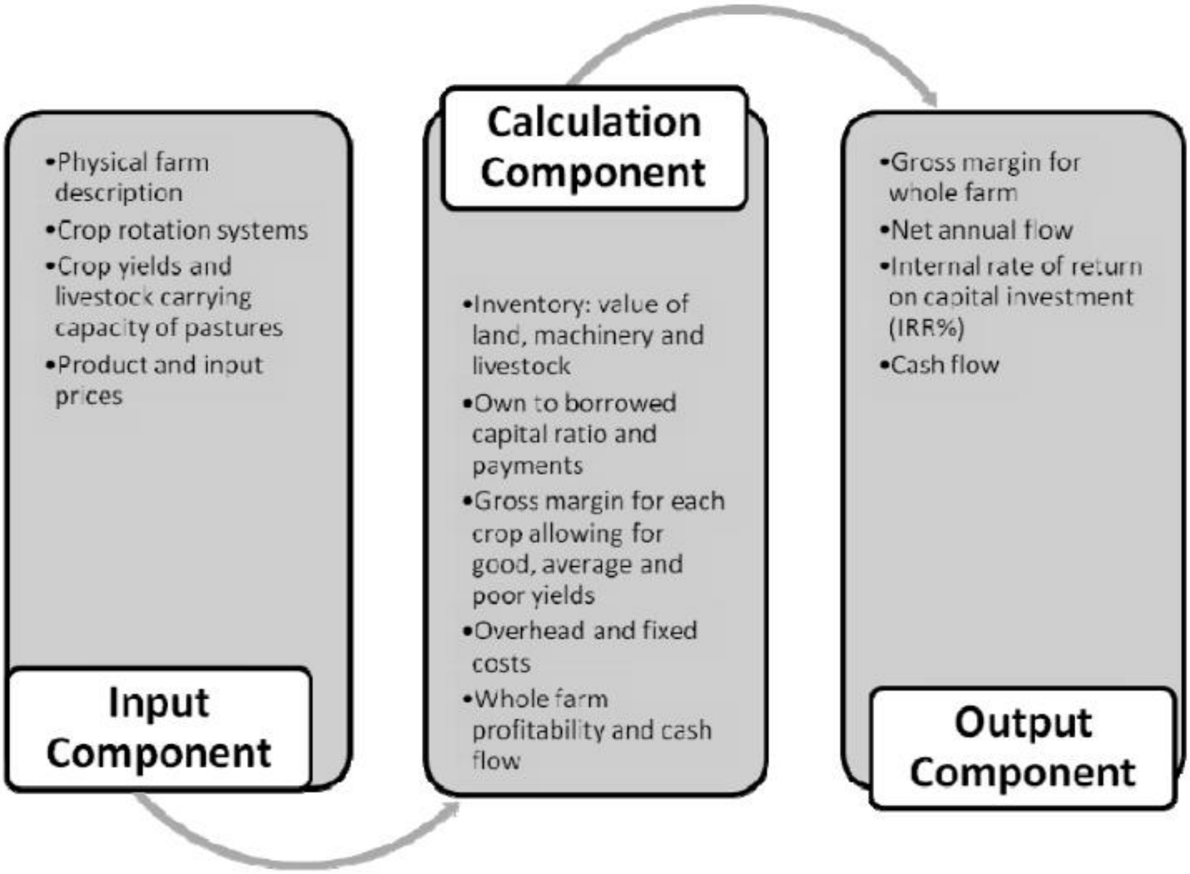

Figure 1: A graphic representation of the components of the whole-farm multi-period budget model

Source: Hoffmann & Kleynhans (2011)

The aim of this section was to transform the trial data in its agronomical form into financial data for it to be used for comparison. This needed to be done from a whole-farm perspective, to ensure that the effects of crop sequence alteration on other aspects of the farm were captured. Despite the criticism mentioned in the previous section concerning the budget model in farm management, it still has value and is continually used in research and decision-making. The farm-level budget model's ability to address the associated complexities is one of the major reasons for its continued use. It is better for the farmer to roughly solve the whole problem than to solve a certain part of the problem outstandingly well (Malcolm, 1990).

The associated complexities were incorporated and addressed by developing whole-farm, multi-period budget models. The structure of the development of the calculations is graphically illustrated in **Error! Not a valid bookmark self-reference.**, which breaks it down into three components, namely input, calculation and output, with each component consisting of various subcomponents (Hoffmann, 2010). Some of these subcomponents are more relevant than others regarding their influence on the financial performance of the farm, measured in terms of IRR, and are discussed in depth in the sections that follow.

3.4.1.1 Input component

The input component consists of factors that can be adapted, which in turn have an immediate impact on the output component, and thus also on the financial performance of the farm. The most important parts of this component as it relates to this study are the description of the physical farm and the crop rotation systems.

The description of the physical farm is elaborated on later in this section, while the various crop rotation systems are discussed above in section 3.3. Yield assumptions, land use patterns, and input and output prices are further noteworthy parts of the input component. The combination of the above-mentioned parts provides data that outlines the parameters of the farm-level budget model.

3.4.1.2 Calculation component

In order to ensure the validity of the model, the calculation component applies standard and established accounting principles. This component consists of a wide range of calculations, and everything from the various input parts is interconnected to produce a valid output, according to the accounting principles, in the form of a profitability criterion, such as IRR.

The importance of the calculation component is attributable to two main reasons. Firstly, mechanisation and tillage processes have to be simulated accurately. In this study, different crop rotation systems have different types and amounts of mechanisation requirements, depending on the type of crop and the land utilisation allocated to each crop. A machinery replacement schedule is incorporated in the Excel models to ensure that the process of accurately simulating the criteria are met. The machinery and equipment required and used for planting, soil preparation and harvesting are the most expensive machinery and equipment categories.

Secondly, all the physical and biological factors and their interrelationships must be structured in the format of standard accounting principles in order to obtain financial results that are universally comparable, for example, gross margin at the crop enterprise level. Furthermore, processed data should be presented as an IRR applicable to a whole-farm profitability level.

The variability of climatic conditions over time was also accounted for by adjusting the gross margin accordingly for each crop, and this data was then categorised into good, average and poor yields. The method and reasons for incorporating the variability of climatic conditions are explained in section 3.2.

3.4.1.3 Output component

The output component consists of financial indicators such as whole-farm profitability and affordability of borrowed capital, which are measured in terms of the farm's expected cash flows.

This model's whole-farm profitability output was expressed as an internal rate of return on capital. The model was constructed to simulate a farm over a 20-year production cycle. The reason for the long time frame was to provide ample time for the rotation effect of the crops to be observed, as well as to capture the effect that machinery replacement has on the IRR. The IRR is the financial measure used to compare the different crop rotation systems with each other.

For all the cash flow and profitability calculations, this model used real interest rates to incorporate the effects of inflation. The output components' financial impact is further explained in section 3.4.3, on farm profitability.

3.4.2 Typical farm

Obtaining accurate farm-level data is one of the challenges researchers face when conducting farm-level research. The ideal tool for data collection in this regard is the typical-farm concept, because it is a representation of actual farms in a homogenous area (Feuz & Skold, 1990). The trial data from Tygerhoek was collected in a scientific manner, which helped to model the typical farm currently in the Goue Rûens.

Feuz and Skold (1990) define a typical farm as a model farm in a frequency distribution of farms in the same universe. It is vital to incorporate producer and other stakeholder inputs into the process of establishing and modelling the typical farm. The aim of the typical-farm concept is to make a basis available that is relatable to farmers in a particular homogeneous area.

The typical farm used by this study is described in physical and financial terms by making use of Excel spreadsheets. Within these spreadsheets, an inventory and a description of the farm are outlined. The inventory presents the land and fixed improvement values, as well as moveable assets in the form of machinery and equipment. All of the above-mentioned factors vary with the size of the farm and the type of rotation system used. General assumptions as well as yield and carrying capacity norms are discussed in section 4.3.

The concept of an average farm's physical composition is its total area divided by its number of farm units. This could mean that an average farm is financially representative, but that it is not representative of any particular group of farmers. The typical farm is used instead because it gives the most frequently occurring farm in the identified homogenous area but does not include the misleading effect of outliers. The physical assumptions about the structure of the typical farm found in the Goue Rûens area of the Southern Cape were adapted from a study by Hoffmann (2010). These assumptions were validated through the Delphi panel of experts to verify that the assumptions made were still valid for this study. The Delphi panel of experts made minor adjustments to the assumptions and these were incorporated into the farm model.

The typical-farm model was developed with the objective of serving as a relatable model for farmers of a typical farm in the Goue Rûens homogenous area. Typical does not refer to an average farm in an area. In statistical terms it refers to the modus of a typical farm in a particular area; in other words, the farm that one is most likely to come across in the Goue Rûens area. The typical farm's physical and financial profile was established, and is further explained in the following sections.

The typical farming system in the Southern Cape consist of 54.4% cash crops and 45.6% pastures for livestock. The land use patterns for the typical farm in the Southern Cape are given in Table 3 under the assumption that 20% of the farm is under System 1, 40% is under System 2, and the remaining 40% is under System 3.

3.4.2.1 Physical farm description

Farm size forms the basis that determines various aspects of the farm description and is the first important assumption that is made regarding the description of the physical farm (Hoffmann, 2010).

Other relevant components of the description of the physical farm include its land use patterns and the layout of its machinery and equipment. Furthermore, the land use patterns determine the crop and livestock layout, stocking rates, expected yield and the employment of labour.

The importance of farm size was taken into account when developing the model, and the above-mentioned interconnectedness of the factors was programmed into the model so that a change in farm size would influence all other relevant connected factors. The model should be dynamic. For example, a change in farm size should automatically adapt the mechanisation requirements.

In a sense, farm size is a limiting factor, and the only way to overcome this is by increasing the yield or decreasing costs. Thus, the importance of crop rotation and the financial effect it has on the farm is explained and further emphasised in section 3.4.1. These and other physical parameters influence the financial performance, which is elaborated on in the following section.

3.4.2.2 Financial description of the farm

The physical extent of the farm is expressed in financial terms through the financial description of the farm. The financial description of the farm is presented in the form of an inventory, or asset register, which state the value of each item. Typical-farm inventory, or asset registers, include short-, medium- and long-term assets, such as land, fixed improvements, equipment, machinery and livestock. All of the above-mentioned assets are interconnected, and depend on the physical size of the farm. Altering the physical size of the farm will result in automatic adjustment of all the assets.

The initial assumptions of the above-mentioned variables were adapted from a study by Hoffmann (2010), and from study group research done by a local agribusiness (Schutte, 2018). The above-mentioned variables were combined into one model, and all the assumptions made in the model were validated by the carefully selected Delphi panel of experts.

The parameters and assumptions in this model are not fixed, and can be adjusted to create alternative scenarios to test the effect on profitability of altering parameters or assumptions.

3.4.3 Farm profitability

The output calculations, which measure the expected profitability for this research project, were measured in terms of the internal rate of return on capital investment (IRR). The net present value (NPV) calculation is another measure of expected profitability, but the IRR was better suited to this project. Both the IRR and NPV measures are generally-accepted criteria for measuring the performance of a capital investment project over the long term (Hoffmann, 2010).

For each of the rotation systems, a whole-farm multi-period budget was developed to calculate the expected profitability in terms of IRR. The budget model's calculations were done with respect to a 20-year period. The two main reasons for the long time period were to capture the nature of the crop rotation systems and to allow for the replacement of machinery and equipment to be taken into account in the budget.

3.4.3.1 Net present value

The net present value (NPV) is the sum of all the individual outflows and inflows of cash related to the investment, with each of the individual cash flows discounted to its present value: thus, where time equals 0.

The formula used to calculate NPV is given below:

$$NPV = \text{Present value of future cash flows } (CF_t) - \text{Initial investment required } (CF_0)$$

One of the main challenges when calculating NPV is determining the appropriate discount rate to use when computing the present value of the expected cash flows. For this reason, the NPV is better suited to comparing two investments with different amounts of initial capital. Since all of the different crop rotations are simulated with the same typical-farm model and the same initial capital investment as their basis, the IRR was a better suited measure of profitability for this study.

3.4.3.2 Internal rate of return on capital investment

The internal rate of return (IRR) on capital investment is "a measure of the growth generated by the cash flows, as a percentage return on the initial capital investment" (Hoffmann, 2010). What this indicates is that if one were to set an interest rate (used in calculating the NPV) that would result in a zero NPV, this interest rate would be the IRR.

The profitability for each of the typical whole-farm budget models was measured in terms of IRR. The IRR measure was more suitable for this study because the impact of the different strategies and crop rotations on whole-farm profitability was better measured by the IRR, while the NPV was better suited to comparing projects where the size of the initial investment differed.

3.5 Delphi

The Delphi method for research is presented in detail in section 2.4. The method relies on individuals completing a questionnaire, only to expand on the points of view where they differed significantly from the group's results. Opposing views of individuals were then gathered and sent out for review by the panel of experts, and consensus was reached that was most representative of the area and the typical farm in the Goue Rûens. The Delphi method provides individuals with anonymity, resulting in a high degree of individuality and freedom, while providing a platform that allows for the gathering of subjective information to be incorporated into models and simulations (Linstone & Turoff, 1975).

3.5.1 The Delphi panel of experts

It is important to consider the objectives and criteria of the research project when compiling a panel of experts. The main focus areas of this research project were in the following fields: agricultural economics, crop production and rotation, livestock production, and practical farming. The Delphi panel of experts comprised individuals who were well acquainted with the Goue Rûens area and who specialised in the fields mentioned above.

The Delphi panel of experts consisted of the following members:

- Dr Johann Strauss**:** Senior scientist in sustainable cropping systems at the Department of Agriculture, Government of the Western Cape (Directorate Plant Sciences: Research and Technology Development, Western Cape Department of Agriculture).
- Dr Willem Hoffmann: Agricultural Economist and lecturer at the University of Stellenbosch (M.Agric and PhD focussed on crop rotation systems in the Southern Cape).
- Dr George De Kock: Veterinarian with extensive knowledge of livestock systems in the Southern Cape as well as being a farmer in the Goue Rûens.
- Pierre Laubscher: Farmer in Bredasdorp.
- Pieter Blom: Extension officer at a local agribusiness in Swellendam.
- Pieter Streicher: Farmer in the Goue Rûens.
- Willie Langenhoven**:** Directorate Plant Sciences: Research and Technology Development, Western Cape Department of Agriculture.

3.5.2 Contributions made by the panel of experts

The contributions of the producers, scientists and other participating role players ensured that the typical farm was simulated as accurately as possible. Producers contributed mainly to the description of the physical aspects of the typical farm, and the rotation systems and mechanisation needs associated with each system. They also helped to identify factors that were particularly influential regarding farm-level profitability and identify other assumptions such as land prices, stocking rates, average overhead cost per hectare, and capital replacement schedules.

The scientists contributed by adding their knowledge of the input–output relationships as well as the interrelatedness of the crop and livestock systems and the affect it has on the whole farm. They also assisted with quantifying the expected sensitivity of certain variables on whole-farm output levels. Valuable input was also received from scientists in the construction phase of the model, where they assisted with clarifying the sustainability of certain crops within the crop rotation systems. For example, the reason canola was not included more regularly in crop rotations systems is that the effect of black stem in canola limits production to once in four years on a particular field.

The contributions made by agricultural economists were primarily related to farm profitability and the factors that influence it. The process and importance of the transformation of physical biological data into financial data was also valuable knowledge contributed by the agricultural economists.

The gap that is often found between researchers and producers was bridged by the contributions made by various producers and other experts. Knowledge regarding the latest technological innovations and their costs was contributed by technical experts in the group discussions.

3.6 Conservation agriculture

The concept of conservation agriculture encapsulates three fundamental principles: minimum soil disturbance, maximum soil cover and diversified crop rotation systems. The aim of combining these three practices is to reduce soil degradation and improve soil health. Less soil degradation will lead to more sustainable long-term farming practices and financial benefits in the form of reduced input costs and improved yields. Conservation agriculture can also be seen as the amalgamation of several sustainable agricultural practices.

Conservation agriculture can be practised under almost any circumstances, including various soil and weather conditions and are not limited by the location or farm size (Friedrich et al., 2012).

In order to obtain optimal results, all three of the above-mentioned practices should be combined and applied simultaneously. The focus of this research project was on crop rotation systems, but all three of the fundamental principles were applied in the trials tested on the Tygerhoek experimental farm. The amount of soil cover and the extent of soil disturbance remained constant between all the camps at the Tygerhoek trial, with only the crop rotation strategy varying between the camps. Thus, the emphasis of this research project was not on what the financial benefits of conservation agriculture as a whole are, but rather on which crop rotation system within the practice of conservation agriculture has the highest financial benefit for the farmer.

Conservation agriculture was popularised in the dust bowl of the United States of America as a result of losses in soil productivity due to soil degradation resulting from erosion and compaction. This was not the first time the concept emerged, but it was described and popularised from this point onwards (FAO, 2015). Some of the main reasons why farmers implement conservation agriculture practices are lower production costs, increased total yield and yield quality, and improved weed management (Strauss, 2018).

3.6.1. Minimum soil disturbance

Aggressive mechanical ploughing leads to soil degradation, because of the high rates of soil carbon loss, disruption of soil biology, and erosion by wind and rain (Reicosky, 2015). By making use of conservation tillage, minimum soil disturbance can be achieved.

Minimum or reduced tillage is described by Darby (2011) as being a tilling practice where the ploughing frequency is kept to a minimum compared with other more conventional tillage practices.

Broadly, the concept of conservation tillage includes three ploughing methods. These are minimum tillage, direct drilling and zero tillage (ARC, 2014 and Baker et al., 2002). The optimal conservation tillage method is zero tillage, but is not viable for every farmer.

3.6.2. Maximum soil cover

Soil cover includes cover by plant stubble after harvest and cover by cover crops while the crop is growing. Crop residue and cover crops increase water infiltration and reduce soil erosion by wind and water (Reicosky, 2015).

This is done to increase soil moisture retention by putting a metaphorical blanket over the soil to protect it from direct exposure to sunlight. Soil moisture stimulates the degradation of organic materials and has an enriching effect on the soil (ARC, 2014). This protection also lowers soil temperature, which in turn prevents the destruction of organisms in the soil.

Livestock – sheep in this research study – are allowed to graze on the crop residue, but only up to the point where 50% of the soil cover remains before planting the next season's crops.

3.6.3. Crop rotation

Crop rotation refers to the cultivation of different crops alternating on a particular section of land. There should preferably be as many different crops as possible in a year on the particular section of land, with the aim of at least three different crops in a rotation and the inclusion of cover crops to keep the soil covered. Monoculture should be avoided because it depletes plant-specific nutrients in the soil, which must then be added back by means of chemical fertilisers.

In order to make conservation agriculture more feasible, crop rotation, as a management tool can be used, as it minimises risk by employing better production and increased cost-efficient inputs (ARC, 2014; FAO, 2016 and Hobbs et al., 2008). Including legumes in a cereal grain rotation system has the beneficial effect of decreasing the amount of additional nitrogen required for the subsequent grain crop (McEwen et al., 1989).

Ideally, all of the above-mentioned principles of conservation agriculture should be applied simultaneously in order to acquire the maximum benefit. It is important to note that because of the variety of biological factors there is no single best crop rotation system. Through examining all of the factors, producers must develop or adapt a crop rotation system that fits into their particular farming systems (ARC, 2014).

The goal of crop rotation systems is to improve the soil structure, with the aim of increasing moisture retention and the carbon concentration of the soil. This in turn leads to an increased yield potential of the soil and an increased financial benefit for the farmer (Van Eeden et al., 2002).

The financial and enhanced sustainable land use benefits of crop rotation systems have been well documented and are explained in the following section.

3.6.3.1 The benefits of crop rotation

The main financial benefit of implementing crop rotation within conservation agriculture is reduced input costs, as previously mentioned. Benefits also include, but are not limited to, lower input cost of, for example, using less diesel, fertiliser and weed and pest control.

The costs of fuel and for the maintenance of machinery and equipment are reduced, which stem from the reduced use of tractors and other implements to prepare the soil for planting, which also results in less labour being required. More time becomes available for the farmer and labourers to focus on other, more important aspects of the farm.

The agronomic benefits observed from implementing crop rotation are the following, which translate into financial benefits for the farmer.

- Enhanced soil fertility
- Yield of subsequent crops is positively affected
- Crop protection due to breaking disease cycles
- Reduced herbicide resistance in crops
- Mechanisation utilised over longer periods

The financial benefits of implementing crop rotation originating from the above-mentioned agronomic benefits include reduced input costs, time and labour, and reduced maintenance costs of machines as a result of being used less.

3.7 Conclusion

Chapter 3 presents a comprehensive outline and discussion of the Tygerhoek crop rotation trial and a financial analysis of the trial data. The differences between the crop rotation system categories lie mainly in the pasture to cash crop ratios. These rotation systems are scientifically evaluated at the Tygerhoek experimental farm. The challenge was to apply the agronomical data generated during the experimental trials and translate it into financial implications at the whole-farm-level. A whole-farm budget model was constructed to capture the different trials and to show the simulated financial performance as though each crop rotation system were implemented on the same farm.

The model was designed to be interactive in terms of how agronomical data is transformed into financial data, through its input, calculation and output components. The process of moving from the Tygerhoek crop rotation trials to a whole-farm-level budget model is described. The construction of, and reasons why the typical-farm concept was suitable for this study lie in the need to accommodate all facets of implementing the system at the whole-farm-level.

The Delphi panel of experts were identified and their contributions are outlined in section 3.5. The final section of this chapter presents the three pillars of conservation agriculture, after which the potential agronomical and financial benefits of implementing crop rotation practices are explained.

Chapter 4

Results and findings

4.1 Introduction

The previous chapter introduces the methods used to capture data and the process of formulating the trial data as whole-farm financial budgets, and this is explained through the input, calculation and output components. The scientifically generated crop rotation trial data needed to be applied to evaluating the financial performance of each system. This also needed to be incorporated into the whole-farm system.

The main objective of this research project was to evaluate the whole-farm long-term financial implications of each evaluated crop rotation system within the Goue Rûens area. This chapter provides an evaluation of each crop rotation system in terms of its whole-farm financial implications, with the main concern being long-term profitability. The core benefit of crop rotation is the carry-over effect of certain crops on the crop in the following year. Therefore, the systems need to be evaluated over the longer term in order to capture these interrelationships. To incorporate the systems into the whole farm budget correctly necessitates integrating specialised knowledge.

This chapter starts by presenting and explaining the Tygerhoek trial data results up to the level of the gross margin. The following section explains how the Tygerhoek trial data for each system was integrated into a whole-farm-level model based on the conceptual typical farm. The mechanism for constructing the typical-farm model for the Goue Rûens area is explained. The starting point for evaluating the expected financial performance of the systems on the whole-farm-level is the expected IRR. For each of the different rotation systems, a separate model was developed based on the parameters of the typical-farm model.

This chapter concludes with a section on the different scenarios developed to test the possible future outcomes of changes to the systems, with a focus on the expected effects on financial performance, measured in IRR. These changes are made by changing one of the variables and observing the change in expected IRR.

4.2 Trial results

This section presents the Tygerhoek trial results from an agronomic study obtained from the Tygerhoek experimental farm, and shows how these results compare on a gross margin level. This is the trial data before it was used on a typical whole-farm-level. The crop rotation trial data from Tygerhoek serves as the foundation, which was later used to simulate 13 different crop rotation systems that could be implemented on the typical farm to evaluate and compare profitability. The trial data and the differences between the 13 systems, as well as the reasons why each of the individual systems was selected are discussed in section 3.3.

4.2.1 Gross production value

The gross production value of crops is calculated by multiplying the amount of output per hectare, or yield, with the price obtained for the specific commodity. This approach is one of the core characteristics of crop rotation systems. The sequence of crops within the cropping system has certain implications on the yield of the following crops. These yield effects can be due to nitrogen fixation, as in the case of alfalfa or lupines. They can also be due to the suppression of soil-borne diseases and weeds, in combination with an improved soil structure, as is the case with crops following the year after canola.

The yields were recorded in a scientific way to ensure that the data was accurate. The prices of the products for the trial data were obtained from farmers and local businesses to ensure that they were representative of the Goue Rûens area. This implied that the prices were similar to what farmers received for their crops and paid for their inputs, on average.

The gross production value for each system is determined by the sum of all the gross production values of all the separate enterprises that form part of a particular system.

4.2.2 Variable costs

Variable costs can be further divided into directly and indirectly allocable costs. These typically comprise fertiliser, chemicals such as herbicide and pesticides, and other inputs for contract services. The prices for these inputs and services were obtained from farmers and local businesses to ensure that they were representative of the Goue Rûens area. The amounts of chemicals and fertilisers applied depend on the different camps and crops cultivated each year. The systems are managed as closely as possible to the norms and standards that farmers in the area follow. There are annual technical committee meetings before the planting season, which include producers from the area, who contribute towards information on the application of seeding and its rates for the crop rotation trials at Tygerhoek. This is in order to mimic the farming practices in the area as closely as possible so that producers can relate to the outcome of the trial results.

The input prices were obtained in a similar fashion to the prices for the products and represent typical prices in the Goue Rûens area. These are the actual prices paid for products and services at the date of use at the trial site. The prices were comparable with those a typical farmer would pay. The cost figures were thus the input quantity as measured during the trials multiplied by the input price per individual input.

Figure 2 shows the historical average total cost per hectare for each of the 13 different rotation systems evaluated at the Tygerhoek experimental farm.

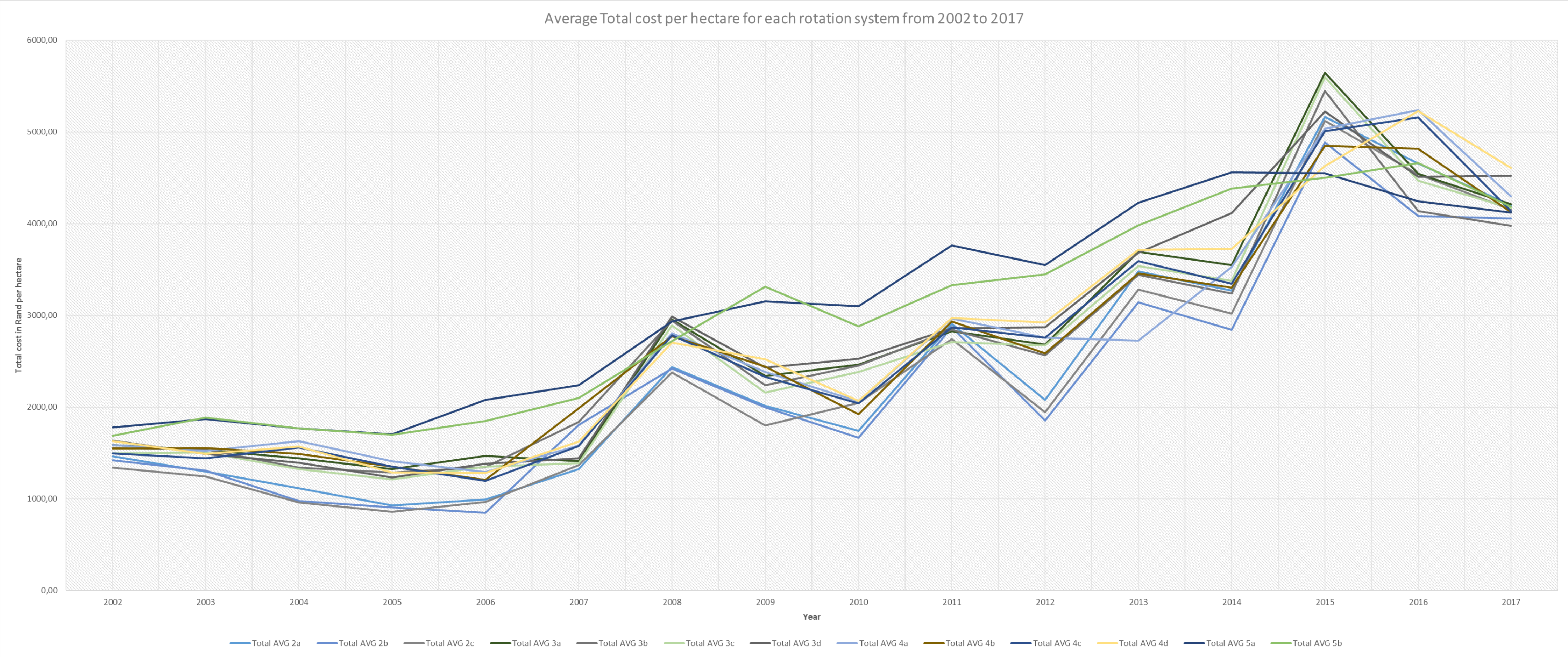

Figure 2: Average total cost per hectare for each rotation system at the Tygerhoek experimental farm

4.2.3 *Gross margin*

Table 1: System 3a (PWPW) gross margin per hectare for 2017

System	**3a – 1**	**3a – 2**	**3a – 2**	**3a – 1**	**3a – 1 Average**	**3a – 2 Average**
Camp no.	2,5	8,3	15,7	21,7		
Crop	Pastures	Wheat	Wheat	Pastures	Pastures	Wheat
Gross income	R10 599	R8 365	R8 365	R10 004	R10 301	R8 365
Allocable variable costs	R3 579	R4 392	R4 392	R3 568	R3 574	R4 392
Gross margin above all allocable costs	R7 019	R3 972	R3 972	R6 436	R6 728	R3 972

All gross margin calculations were done on a per-hectare basis. Using the results from Table 1, the average gross margin used in the whole-farm multi-period model for System 3a was thus R5 350 per hectare, being the average of R6 728 and R3 972.

The gross margin was calculated by subtracting the total variable cost from the gross production value. Essentially, it represents the profit margin above production cost, calculated as directly allocable variable cost plus indirectly allocable variable cost.

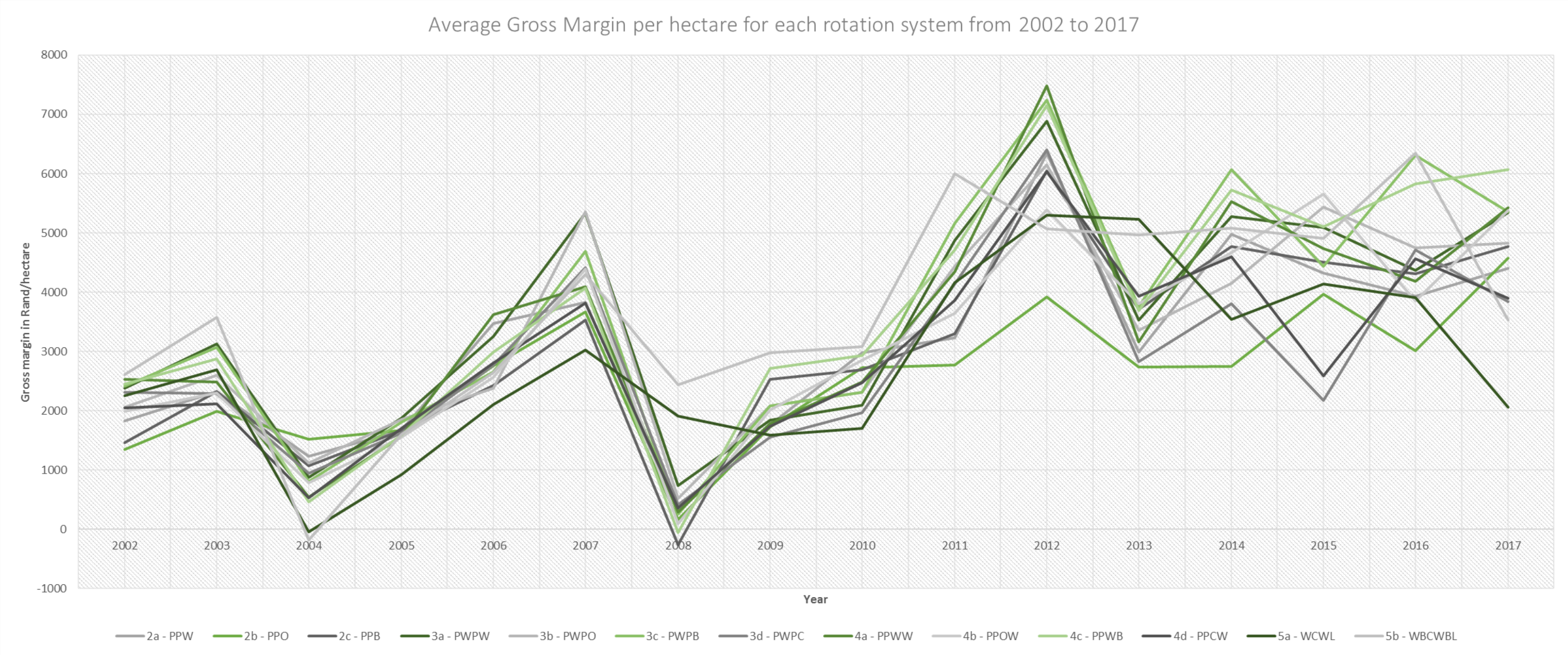

Figure 3: The average gross margin per hectare for each of the rotation systems from 2002 to 2017

The benefit of the rotation effect, as mentioned in section 3.4.1, can clearly be seen across most of the systems, with a general upwards trend. The dips and spikes observed in Figure 3 correspond with good and bad rainfall years, or years where the amount of rainfall was sufficient but the timing and rainfall dispersion were not. It is well known that rainfall dispersion throughout the year is as important, if not more important, than total annual rainfall. Refer to Annexure C for historical rainfall patterns.

Table 2 provides the average gross margin per hectare for each of the individual systems from the trial results for 2017. This was also the gross margin used to develop the particular whole-farm multi-period model, by replacing the gross margin of the typical farm and making adjustments to the capital replacement structure.

For example, System 2a comprises two pasture rotations and one wheat rotation. The two camps with the pastures were averaged. Next, the corresponding wheat camps were also averaged separately. The average of the two wheat camps in that rotation is R5 150, while the average for the first pasture rotation in that system is R3 972, and R4 146 for the second. If the three rotations within System 2a are averaged out, an average gross margin per hectare of R4 408 is obtained. This assumes that the whole-farm multi-period budget model's farm was split into three camps of equal size, one with wheat and two with pasture.

Table 2: Average gross margin per hectare for each system for 2017

Crop rotation system	**Average GM per Ha**
2a – PPW	R4 407,99
2b – PPO	R4 573,54
2c – PPB	R4 770,91
3a – PWPW	R5 349,95
3b – PWPO	R4 832,05
3c – PWPB	R5 354,14
3d – PWPC	R3 835,46
4a – PPWW	R5 422,60
4b – PPOW	R5 383,40
4c – PPWB	R6 067,11
4d – PPCW	R3 898,56

5a – WCWL	R2 062,66
5b – WBCWBL	R3 535,77

4.3 The typical farm

This section explains how the typical whole-farm multi-period budget model was developed for the Goue Rûens area and concludes with the typical farm's expected IRR under current systems, as evaluated in the Tygerhoek crop rotation trials. The typical-farm model was developed from study group data, as discussed in section 3.4.2. The expert group was thus included in both the development and validation of the model's structure.

The typical-farm model was developed using Microsoft Excel, a spreadsheet program. The model comprises various interlinked spreadsheets and equations that strive to simulate the interrelatedness of the whole farm on a multi-period scale. The main advantage of spreadsheets is that the data can easily be separated from the calculations. This allowed for the financial impact of changes at the whole-farm-level to be instantly recalculated if a change was made. This is necessary to adhere to the systems nature of the farm. Various components need to be integrated simultaneously, including the sequencing of crops in the crop rotation system, the infrastructure requirements for each system, the effect of rainfall variability, and the impact of the livestock factor on the total farm. The interrelatedness of the system requires that changes in any component need to reflect the effects on the other components. In this instance, for example, a change in the crop sequence of the system would instantly show the impact on livestock numbers as well as the associated infrastructure requirement.

4.3.1 Farm size and crop rotation systems

After feedback was received and reviewed from the Delphi panel of experts, an agreement was reached that the typical farm size in the Goue Rûens area was 2500 hectares, with a land value of R70 000 per hectare. The above-mentioned land value excluded fixed improvements. This brought the total land value of a typical farm to R175 000 000. The assumption was made that no additional land was rented and that the farm was financed entirely with own capital.

The typical farm in the Goue Rûens area had 90% cultivatable land (2250 ha), with the remaining 10% of non-cultivatable land (250 ha) usually comprising roads, steep slopes, wet areas and areas used for buildings and housing. The assumption was made that there was no price distinction between cultivatable and non-cultivatable land. The expert group agreed that the assumption could be made that camps in the same crop rotation system could be divided into the same size.

The land use patterns of the three different crop rotation systems applied on the typical farm are shown in Table 3, where the 2250 ha of cultivatable land was divided according to the specified ratios.

Table 3: Land use patterns of different systems for the typical farm

System divided	**% allocated to system**	**Ha allocated to system**
System 1	20%	**450**
System 2	40%	**900**
System 3	40%	**900**
Total	**100%**	**2250**

The crop allocation, year of rotation and hectares allocated to each crop for each of these systems are given in Table 4, Table 5 and Table 6.

Table 4: System 1 crop allocation

Crop	**Year of rotation**	**Ha allocated**
Alfalfa pastures	1	45,00
Alfalfa pastures	2	45,00
Alfalfa pastures	3	45,00
Alfalfa pastures	4	45,00
Alfalfa pastures	5	45,00
Wheat	6	45,00
Barley	7	45,00

Canola	8	45,00
Wheat	9	45,00
Barley	10	45,00
Total: Pastures		**225**
Total: Crops		**225**

Table 5: System 2 crop allocation

Crop	**Year of rotation**	**Ha allocated**
Alfalfa pastures	1	69,23
Alfalfa pastures	2	69,23
Alfalfa pastures	3	69,23
Alfalfa pastures	4	69,23
Alfalfa pastures	5	69,23
Alfalfa pastures	6	69,23
Wheat	7	69,23
Barley	8	69,23
Barley	9	69,23
Canola	10	69,23
Wheat	11	69,23
Barley / Alfalfa pastures	12	69,23
Oats	13	69,23
Total: Pastures		**415,4**
Total: Crops		**484,6**

Table 6: System 3 crop allocation

Crop	**Year of rotation**	**Ha allocated**
Alfalfa pastures	1	64,29
Alfalfa pastures	2	64,29
Alfalfa pastures	3	64,29
Alfalfa pastures	4	64,29
Alfalfa pastures	5	64,29
Alfalfa pastures	6	64,29
Wheat	7	64,29
Barley	8	64,29
Canola	9	64,29
Wheat	10	64,29
Barley	11	64,29
Lupines	12	64,29
Wheat	13	64,29
Barley / Alfalfa pastures	14	64,29
Total: Pastures		**385,7**
Total: Crops		**514,3**

The land use patterns for the typical farm in the Southern Cape is given in Table 7, under the assumption that 20% of the farm was under System 1, 40% under System 2, and the remaining 40% under System 3. The typical farm had a crop to pasture ratio of 54.4 to 45.6. That means that the cultivated area of the farm was planted with 45.6% pastures and 54.4% cash crops.

Table 7: Land use patterns for the typical farm in the Southern Cape

Crop	**Ha allocated to crop**	**% of usable land**
Wheat	421,32	18,73%
Barley	490,55	21,80%
Canola	178,52	7,93%
Oats	69,23	3,08%
Lupines	64,29	2,86%
Alfalfa pastures	1026,10	45,60%
Total	**2250**	**100%**

4.3.2 Capital requirement

The capital requirement for a typical farm can be divided into three main components. They are land and fixed improvements, machinery and livestock. The inventory of the farm can also be seen as a register of the capital required for the optimal functioning of the typical farm.

The capital requirement in terms of land is discussed in the previous section, and the total land value of a typical farm is R175 000 000. Table 8 describes the fixed improvements needed for a typical farm in the Goue Rûens area. The total value of land and fixed improvements combined is R177 940 000.

Table 8: Fixed improvements of a typical Goue Rûens farm

Description	**Total Value**
Farm houses	R900 000
Labourer’s houses	R720 000
Sheds for general storage and offices	R420 000
Sheep shearing shed	R120 000
Livestock water systems	R300 000
Fencing	R480 000
Total: Fixed improvements	**R2 940 000**

The total value of the machinery required for a typical farm in the Goue Rûens area is shown in Table 9, and was based on best practices. The size of the typical farm will determine the size and capacity for the machinery required, as well as the maintenance and replacement schedule. A machinery replacement period of 12 years was used, as recommended by the Delphi panel of experts. The assumed age at the start of the budgeting period was derived with the assistance of an officer from the local agribusinesses and was presented to the expert group for validation.

Table 9: Total value of machinery and mechanisation for a typical Goue Rûens farm

Description of machinery and mechanisation	**Total Value**
Tractors	R4 476 998
Harvesters	R4 197 500
Wind mowers ('platsnyers')	R2 998 913
Planters	R1 788 308
Ground cultivation implements	R67 629
Other implements	R2 834 709
Vehicles	R1 159 478
Trailers	R170 967
Total value of machinery and mechanisation	**R17 523 534**

Table 10 shows the total number and value of livestock for a typical farm in the Goue Rûens area. The Tygerhoek trial data served as a starting point for the value (rand per SSU) of livestock when the data was presented to the Delphi panel of experts. The Delphi panel of experts gave their input, which was combined with local agribusiness data. The data provided by local agribusiness was obtained from group studies done with producers in the region on a regular basis. The number of livestock was determined by a stocking rate of 2,8 ewes per hectare and the total pastures available for them.

Table 10: Total value of livestock for a typical Goue Rûens farm

Description of animal	**Amount**	**R per SSU**	**Total value**
Rams	86	7000	R603 346
Breeding ewes	2873	2200	R6 320 769
Replacement ewes	479	1500	R718 269
Lambs	2203	1000	R2 202 692
Total Livestock	**5641**		**R9 845 077**

4.3.3 Gross margin

Gross margins were calculated for each of the cash crops, pastures and livestock branches of the typical farm. The final gross margins were verified by the Delphi panel of experts. Certain members of the panel made a proposal that the input cost of alfalfa was too high on an annual basis, and that the cost suggested to the panel was likely the once-off cost of establishing a new alfalfa field. A suggestion was made that the costs should be divided by five to obtain a more representative cost. The suggestion was presented to the panel and the panel agreed that this would be a valid alteration. No further alterations to the gross margins were suggested by the panel.

Each of the individual gross margins was calculated on a per-hectare basis, by subtracting the directly allocable variable costs and the indirectly allocable variable costs of production from the gross production value. The gross margin obtained was then multiplied by the amount of land allocated to each of the individual crops or pastures to obtain the whole-farm gross margin.

Table 11: Total gross margin for good, average, and poor seasons for each crop and livestock system for a typical farm in the Goue Rûens on a per-hectare and whole-farm basis

Crop	**Good year**		**Average year**		**Poor year**	
	R/farm	**R/ha**	**R/farm**	**R/ha**	**R/farm**	**R/ha**
Barley	R2 772 487	R5 652	R2 217 990	R4 521	R1 663 492	R3 391
Wheat	R1 950 411	R4 630	R1 560 328	R3 703	R1 170 246	R2 778
Canola	R411 031	R2 302	R328 825	R1 842	R246 618	R1 381
Oats	R241 633	R3 490	R193 306	R2 792	R144 980	R2 094
Lupines	R6 563	R102	R5 250	R82	R3 938	R61
Sheep on pastures	R1 904 989	R1 857	R1 523 991	R1 485	R1 142 993	R1 114

The data used for calculating the gross margins used in Table 11 was obtained from study group data from a local agribusiness, and to ensure the validity of the data, it was verified by the Delphi panel of experts. To obtain the total gross margin, measured in rands per farm, the rands per hectare from Table 11 were multiplied by the hectares allocated to each crop in Table 7 to get the gross margin for the whole typical farm.

The effect that rainfall variations have on crop yield were simulated by adding good, average and poor years to the model. To obtain the gross margin for good, average and poor years, the gross margin in the table above was multiplied by 100% for good, 80% for average and 60% for poor years. The frequency of good, average and poor years remained the same for the multi-period long-term budget used for the different crop rotations. Refer to section 3.2.2, where the effects of rainfall dispersion on yields are discussed.

4.3.4 Overhead and fixed costs

The overhead and fixed costs generally vary between farms, with the same crops, in the same production area, and normally include costs independent of production scale or the amount of output.

The overhead and fixed costs applied in the typical-farm model were obtained from study group results, and the Delphi panel of experts verified the typical overhead and fixed costs on a per-hectare basis that were representative of the typical farm in the Goue Rûens.

The overhead costs were estimated by the panel of experts to be R1 523/ha. They consisted of, among others, permanent labour, maintenance on fixed improvements, banking fees, and management costs (other than the owner's remuneration). Miscellaneous costs, referred to in Table 12, are generally the costs that differ between farms, and include: insurance, licences for equipment, electricity and admin fees.

Table 12: Total overhead and fixed costs per hectare

Overhead and fixed costs	**Rands per hectare**
Management	R65
Permanent labour	R411
Miscellaneous costs	R741
Maintenance on fixed improvements	R247
Banking fees	R19
Consultation fees	R40
Total	**R1 523**

4.3.5 Internal rate of return

The farm profitability was measured over a 20-year budgeting period, by making use of a budget model. The typical farm was identified, described and constructed to serve as a basis for comparison of the various systems that were evaluated as part of the Tygerhoek crop rotation trials. Thus, in effect, there was thus a separate multi-period budget for each system. Each budget showed the expected financial performance of the system if implemented on the identified typical farm at a whole-farm-level.

The typical farm in the Goue Rûens had an IRR of -0.20%. (The multi-period budget model for this typical farm is shown in Annexure F.)

4.4 Systems comparison at the farm-level

This section explains how the Tygerhoek trial data, discussed in section 4.2, for each system was incorporated into the typical-farm model to construct the whole-farm multi-period budget. For each of the different rotation systems, a separate model was developed, to demonstrate the expected financial performance if implemented based on the typical-farm model.

The effect of 'running' the trial data at the gross margin level can be shown by using the typical-farm whole-farm budget model. The construction of a whole-farm budget model is based on the physical properties of the typical farm to allow for the assessment of the impact of alterations to the physical-biological factors on the expected financial performance. The validity of the model used was strengthened by its adherence to standard accounting principles.

4.4.1 Capital requirement

During the study, the results for each of the different systems were presented to the Delphi panel of experts. The panel suggested that the machinery requirement remain constant for all of the systems. This was a surprise, because farmers tend to change their machinery if the ratio of crop to pasture changes by more than 10%, and the first item of machinery they make changes to is the size or number of harvesters. The same question was posed to the farmers in a previous study by Hoffmann (2010). The farmers explained that even if the amount of hectares they needed to harvest decreased, they would still not decrease the number or size of their harvesting machines. The reason was mainly for insurance against strong winds that could reduce or destroy yields towards the end of the harvesting season. Decreasing the amount of days spent harvesting, by using the same number or size of harvesting machines with fewer hectares could prevent these crop losses. The other possible reason for not changing the machinery ratio could be the tardiness of farmers in adapting to change: although it is technically possible to make the necessary changes, most of the farmers do not.

This model was designed to accommodate adaptations to the capital requirements for the different crop rotation systems. However, on the recommendations of the members of the Delphi panel of experts, this function was not adopted, as they were risk averse towards crop losses and thus would rather have owned or bought more expensive harvesting machinery. On their recommendations, the machinery for all the systems was kept the same. System 5 was an exception because there was no livestock component, and the whole system comprised only cash crops. For this reason, the capital requirement was modified for Systems 5a and 5b.

4.4.2 IRR results at whole-farm-level

The typical-farm model serves as a basis for comparison in this study. In order to compare the different rotation systems with each other at a whole-farm multi-period level, a separate model had to be constructed for each system. The gross margin of the typical farm was replaced by the whole-farm gross margin for the trial results for each separate system. This gross margin was then multiplied by the number of cultivatable hectares. The assumption was thus made that the farm could be divided into camps of equal size as it was in the trial. The capital requirement for each system was also adapted or kept the same according to the recommendations of the Delphi panel of experts.

In order to fully comprehend the effects that the rotation effect has and also the effect of the capital replacement schedule, it is vital that the budget model be the multi-period type. This is to allow for the effects of the crop rotations to reflect the risk in terms of rainfall dispersion and for machine replacement cycles to be incorporated.

The financial output, measured in profitability (IRR), is impacted by the changes in the input data, and is best understood within a systems context. This is because a change in one input will result in a series of interrelated changes and events that will impact the financial performance of the budget model.

Rainfall and rainfall dispersion during the growing season are key determinants of yield potential in the Goue Rûens area. The shallowness of the soil limits its moisture retention ability and increases the importance of relatively even rainfall distribution throughout the growing season. For this reason there was a relatively strong variance between years and a clear difference between years in terms of yield potential. The years were labelled by the producers as good, average or poor measured in terms of potential yield, as determined by rainfall dispersion. The prevalence of these years was relatively certain; however, the sequence was difficult to predict. This is a common phenomenon for all Mediterranean climate areas. The assumption was made for the typical-farm model that there would be four good years, four bad years and twelve average years in a 20-year cycle. This assumption was made on the basis of historical rainfall data, and was confirmed by the Delphi panel of experts as being representative. A good year was seen as a year when 100% of the gross margin was obtained. An average year was a year when 80% of the gross margin was obtained, while a bad year was a year when only 60% of the gross margin was obtained.

This model was developed in Microsoft Excel, a spreadsheet-based program. The model comprised various interlinked sheets and equations that replicate the interrelatedness of the whole farm on a multi-period scale.

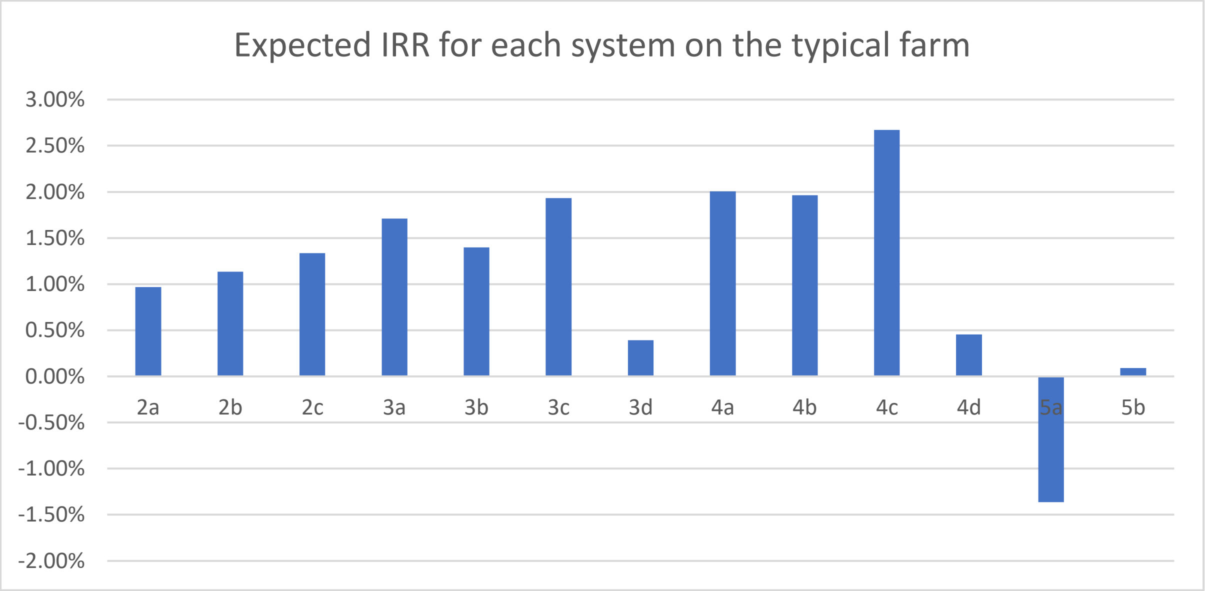

Figure 4: The expected internal rate of return (IRR) for each system that forms part of the Tygerhoek crop rotation trials, as incorporated on the typical farm

The IRR was calculated by discounting all the capital flows. These flows comprised a big initial outflow at the beginning of the first year, in respect of the capital investment needed. Then there were some inflows from the income generated by the crops and livestock sold in years one to twenty. These were followed by a big inflow reflecting when the capital is sold at the end of the 20-year multi-period term.

Systems 2c, 3c and 4c showed the highest expected IRR in their respective categories, and were the systems that included a barley sequence. Barley had the highest gross margin per hectare on average.

Systems 3d, 4d and 5a had the lowest returns in each of their respective categories and were the only systems with canola as part of the rotation. Canola has a relatively low gross margin on average, but its advantage lies in its crop rotation effects.

Wheat was expected to have a relatively higher IRR, but within some systems, wheat outperformed oats at the gross margin, while in others, oats outperformed wheat.

Systems Category 5 showed the lowest total expected IRR. This system included both canola and lupines. Lupines have a relative low gross margin. System 5b showed a relatively better expected IRR than system 5a, because it included two rotations of barley. Barley had the highest gross margin, because the malt barley produced in the Goue Rûens area is of a relatively high quality (Hoffmann, 2010). This could be the reason why barley systems performed better than other systems.

Canola and lupines have a positive effect on the soil nutrient content, which is beneficial for the crops following canola and lupines in the crop rotation cycle. This increases the yield of the crop in the following year. The increased yield, and thus increased income, from the following crop, usually wheat or barley, is then only attributed to that next specific crop in the rotation system. Thus, some of the increase in income gained from cultivating canola or lupines should theoretically be subtracted from the crop, usually wheat or barley, following them in the rotation system and be added to the canola or lupines from the previous year. Unfortunately, it is challenging to reallocate income generated from crops grown in different years. That is why it is important not to view the system in terms of its individual parts but rather to take a holistic view of the system. It is also important to have a holistic view of how the system fits into the farm, given a certain capital replacement schedule. Thus, the importance of the systems approach used in this study is emphasised.

4.5 Scenarios tested

Up to this point, the whole-farm multi-period budget was used only to study the future, with the assumption of current trends and other assumptions remaining the same. The possible future is, unfortunately, not as predictable as one would like it to be. Possible futures can be explored by making use of scenario development and sensitivity analysis. These developments and analysis could assist in our understanding of how the possible future might unfold, by altering some of the variables and inputs or assumptions. Another way of understanding scenario development and sensitivity analysis is that we are looking at the future in a suppositious, ‘what might happen’ way, rather than looking at it as a hypothetical ‘what will happen’ scenario (IFR, 2013).

4.5.1 Altering gross margin scenarios

Altering some of the variables or inputs and assumptions will have an influence on the model, and this influence can be measured in terms of the financial sensitivity of the whole-farm profitability. The financial sensitivity of the different systems was analysed through a sensitivity analysis of the gross margin for wheat and through a sensitivity analysis of the gross margin for barley. The reason the sensitivity analysis was done with respect to wheat and barley was because they contribute the most to the total farm gross margin.

The gross margin as a whole was increased under the assumption that the combination of yield and price received for the product would increase.

With respect to the above, relative change was calculated using the following formula:

*Relative Change = (Final value – Initial value) / Initial value * 100%*

Table 13: Gross margin scenario 1: adjusting wheat gross margin upwards

		Wheat 10% up		**Wheat 20% up**	
	Initial state	**SensAna 1.1**		**SensAna 1.2**	
System	**IRR**	**IRR**	**Relative Δ**	**IRR**	**Relative Δ**
2a	0,94%	1,11%	18,09%	1,28%	36,18%
3a	1,66%	1,86%	12,17%	2,06%	24,38%
3b	1,36%	1,46%	7,24%	1,55%	14,49%
3c	1,88%	1,98%	5,28%	2,07%	10,57%
3d	0,38%	0,48%	25,46%	0,57%	50,95%
4a	1,94%	2,22%	14,03%	2,49%	28,12%
4b	1,91%	2,08%	9,10%	2,25%	18,23%

4c	2,59%	2,69%	3,87%	2,79%	7,75%
4d	0,44%	0,48%	9,50%	0,53%	19,01%
5a	-1,32%	-1,26%	-5,02%	-1,19%	-10,04%
5b	0,09%	0,26%	192,91%	0,43%	386,33%

Table 14: Gross margin scenario 1: adjusting wheat gross margin downwards

		Wheat 10% down		**Wheat 20% down**	
	Initial state	**SensAna 1.3**		**SensAna 1.4**	
System	**IRR**	**IRR**	**Relative Δ**	**IRR**	**Relative Δ**
2a	0,94%	0,77%	-17,76%	0,61%	-35,47%
3a	1,66%	1,46%	-12,13%	1,26%	-24,23%
3b	1,36%	1,26%	-7,23%	1,16%	-14,44%
3c	1,88%	1,78%	-5,27%	1,68%	-10,54%
3d	0,38%	0,28%	-25,42%	0,19%	-50,80%
4a	1,94%	1,67%	-13,96%	1,40%	-27,86%
4b	1,91%	1,73%	-9,08%	1,56%	-18,13%
4c	2,59%	2,49%	-3,87%	2,39%	-7,72%
4d	0,44%	0,40%	-9,49%	0,36%	-18,98%
5a	-1,32%	-1,39%	5,02%	-1,46%	10,03%
5b	0,09%	-0,08%	-192,42%	-0,25%	-384,36%

Table 15: Gross margin scenario 2: adjusting barley gross margin upwards

		Barley 10% up		**Barley 20% up**	
	Initial state	**SensAna 2.1**		**SensAna 2.2**	
System	**IRR**	**IRR**	**Relative Δ**	**IRR**	**Relative Δ**
2c	1,30%	1,43%	10,09%	1,56%	20,21%
3c	1,88%	1,98%	5,28%	2,07%	10,57%
4c	2,59%	2,78%	7,46%	2,98%	14,94%
5b	0,09%	0,31%	245,55%	0,53%	491,92%

Table 16: Gross margin scenario 2: adjusting barley gross margin downwards

		Barley 10% down		**Barley 20% down**	
	Initial state	**SensAna 2.3**		**SensAna 2.4**	
System	**IRR**	**IRR**	**Relative Δ**	**IRR**	**Relative Δ**
2c	1,30%	1,17%	-10,07%	1,04%	-20,12%
3c	1,88%	1,78%	-5,27%	1,68%	-10,54%
4c	2,59%	2,40%	-7,43%	2,21%	-14,84%
5b	0,09%	-0,13%	-244,76%	-0,35%	-488,74%

4.5.2 Sensitivity of farm profitability to changes in climate

The following section focuses on the sensitivity of farm profitability to climate fluctuations. The two scenarios developed for this study are based on external factors over which producers have no control. Climate change researchers predict that the weather patterns are changing and will continue to do so in the future. Although there is no clear consensus that temperatures will rise, one thing climate researchers agree on is that the weather will become more extreme. This suggests that the number of droughts and floods will not necessarily increase, but the severity of droughts and floods will likely increase.

For the first scenario, the amount of good, average and poor years stayed the same, but the percentage yield deviated further than the assumption made for the typical farm by the group of experts. Scenario C1.1, for example, has a 10% change at the extremes, which means that the good yield factor changed from 100% to 110%, the average remained the same at 80%, and the poor yield factor decreased from 60% to 50%.

Scenario C1.1 – 10% change at extremes

Scenario C1.2 – 20% change at extremes

Scenario C1.3 – 30% change at extremes

Scenario C1.4 – 40% change at extremes

Table 17: Climate scenario 1: changing the intensity of production years at the extremes, C1.1 and C1.2

	Initial state	**Scenario C1.1**		**Scenario C1.2**	
System	**IRR**	**IRR**	**Relative Δ**	**IRR**	**Relative Δ**
2a	0,94%	0,95%	0,55%	0,95%	1,11%
2b	1,10%	1,11%	0,57%	1,12%	1,15%
2c	1,30%	1,31%	0,60%	1,31%	1,21%
3a	1,66%	1,67%	0,70%	1,68%	1,40%
3b	1,36%	1,37%	0,61%	1,37%	1,23%
3c	1,88%	1,89%	0,69%	1,90%	1,38%
3d	0,38%	0,38%	0,47%	0,38%	0,95%
4a	1,94%	1,96%	0,70%	1,97%	1,40%
4b	1,91%	1,92%	0,69%	1,93%	1,39%
4c	2,59%	2,61%	0,79%	2,63%	1,60%
4d	0,44%	0,44%	0,48%	0,45%	0,96%
5a	-1,32%	-1,33%	0,24%	-1,33%	0,48%
5b	0,09%	0,09%	0,43%	0,09%	0,87%

Table 18: Climate scenario 1: changing the intensity of production years at the extremes, C1.3 and C1.4

	Initial state	**Scenario C1.3**		**Scenario C1.4**	
System	**IRR**	**IRR**	**Relative Δ**	**IRR**	**Relative Δ**
2a	0,94%	0,96%	1,67%	0,96%	2,24%
2b	1,10%	1,12%	1,74%	1,13%	2,33%
2c	1,30%	1,32%	1,83%	1,33%	2,45%
3a	1,66%	1,70%	2,12%	1,71%	2,85%
3b	1,36%	1,38%	1,85%	1,39%	2,49%
3c	1,88%	1,92%	2,09%	1,93%	2,80%
3d	0,38%	0,39%	1,43%	0,39%	1,91%
4a	1,94%	1,99%	2,12%	2,00%	2,85%
4b	1,91%	1,95%	2,10%	1,96%	2,82%
4c	2,59%	2,65%	2,42%	2,68%	3,26%
4d	0,44%	0,45%	1,45%	0,45%	1,95%
5a	-1,32%	-1,33%	0,73%	-1,34%	0,97%
5b	0,09%	0,09%	1,30%	0,09%	1,75%

Scenario 2 takes into consideration the possibilities that temperatures could rise or fall. This is simulated by changing the number of average rainfall years and then changing them either to poor or good years. This implies that the yield factor stays at 100% for good years, 80% for average years and 60% for poor years, but that instead of there being twelve average years, there will now be only ten for Scenarios C2.1 and C2.2, and eight for Scenario C2.3, with average years being diverted to poor or good years.

Scenario C2.1, for example, would have six poor years instead of four, and ten average years instead of twelve, while the number of good years stays the same.

Scenario C2.1 – 2 average years becomes 2 poor years

Scenario C2.2 – 2 average years becomes 2 good years

Scenario C2.3 – 4 average years becomes 2 poor years and 2 good years.

Table 19: Climate scenario 2: changing the number of average rainfall years to either poor or good years

	Initial state	**Scenario C2.1**		**Scenario C2.2**		**Scenario C2.3**	
System	**IRR**	**IRR**	**Relative Δ**	**IRR**	**Relative Δ**	**IRR**	**Relative Δ**
2a	0,94%	0,84%	-11,09%	1,05%	11,42%	0,95%	0,69%
2b	1,10%	1,00%	-9,77%	1,21%	10,11%	1,11%	0,71%
2c	1,30%	1,19%	-8,61%	1,41%	8,98%	1,31%	0,74%
3a	1,66%	1,53%	-7,63%	1,79%	8,06%	1,67%	0,84%
3b	1,36%	1,24%	-8,32%	1,48%	8,69%	1,37%	0,75%
3c	1,88%	1,75%	-6,57%	2,01%	6,99%	1,89%	0,82%
3d	0,38%	0,29%	-24,24%	0,47%	24,49%	0,38%	0,60%
4a	1,94%	1,82%	-6,41%	2,08%	6,84%	1,96%	0,83%
4b	1,91%	1,78%	-6,50%	2,04%	6,92%	1,92%	0,82%
4c	2,59%	2,45%	-5,27%	2,74%	5,76%	2,62%	0,91%
4d	0,44%	0,35%	-21,18%	0,54%	21,44%	0,44%	0,61%
5a	-1,32%	-1,38%	3,91%	-1,28%	-3,73%	-1,33%	0,33%
5b	0,09%	0,00%	-96,28%	0,17%	96,28%	0,09%	0,56%

4.6 Conclusion

The point of departure for this research project was the trial data results from the Tygerhoek experimental farm. This was available up to the level of the gross margin per camp, which in a specific year represents a crop. The data for each system was integrated into a whole-farm-level model and implemented on the typical farm for the Goue Rûens. The goal of this research project was to illustrate how the systems were compared at a farm-level. A separate whole-farm multi-period model was developed for each of the different rotation systems and was based on the parameters identified in the typical-farm model. The dynamics of the models allow for the incorporation of complexity and various interrelated variables, all within a whole-farm systems context. The models were developed on a multi-period scale to allow for incorporating the crop rotation effect and for the mechanisation changes to be observed. The final section of this chapter presents different scenarios that tested the possible future outcomes of changes made to the system. Scenarios for a change in gross margin as well as for climate fluctuations were modelled. Focus was placed on the financial performance of the relevant systems, measured in terms of IRR.

The beneficial financial effects of crop rotations can be observed in the general upwards trend in Figure 3. Climatic conditions had an overriding effect on the production of all crops and pastures in the trials. The significant effect that rainfall and rainfall dispersion have on crop yield can also be observed in Figure 3. It is noticeable that all the systems dip and peak together, to a certain extent, in the same production year, correlating with the changes in the extreme climatic conditions.

Farm-level multi-period budget modelling was found to be a suitable way to evaluate crop rotation systems in terms of the financial performance of the farm system. A farm-level financial model incorporates crop rotation systems well, by ensuring the integration of physical, biological and financial factors, and by presenting the results in a standardised format that most famers can easily understand.

The method of modelling the impact of various crop systems at a typical-farm-level was successful, although not without challenges. The fact that the Tygerhoek crop rotation trial data was scientifically generated was reassuring for the participating experts, who as a result, could trust in the data and models presented to them. The data for the typical farm was challenging to gather. This could be due to using the Delphi method, rather than using a group discussion.

The typical farm in the Goue Rûens area had an IRR of -0.20%, which was very low. It is very surprising that the IRR is negative. In addition, the possible reasons for it being so low could be one or both of the following two factors. The producers that described the typical farm were always more conservative when they presented their yield and price data to the study groups. The other reason could have been that the crop trials were managed more intensely, and thus were presenting more positive data. Crop trials could theoretically get more and faster attention to problems and challenges that arise compared with those of large-scale farms. It is also important to note that the concept of a typical farm includes the poorer performing farms as well. Therefore, this result does not imply that the average farmer in the Goue Rûens area is losing money. The study group data used also includes the poorest performing farms, which could also have been a reason for the low expected returns.

Systems 2c, 3c and 4c show the highest expected IRRs in their respective systems categories, with System 4c having the highest overall IRR of 2.59%. Systems 3d, 4d and 5a had the lowest returns in each of their respective systems categories, with System 5a having the lowest IRR overall at -1.32%. Systems Category 5 produced the lowest expected total IRR. This system included both canola and lupines. Lupines had a relatively low gross margin, while canola's benefits were not observed in its gross margins. System 5b showed a better expected IRR than System 5a, because it includes two rotations of barley.

The range of IRRs for the different crop rotation systems on a whole-farm multi-period level was relatively narrow, and there was no system that significantly outperforms any other one. From this we can conclude that the crop rotation systems in the Southern Cape were well established, as farmers had been implementing and perfecting this practice for quite a while. However, some systems performed relatively better or worse than others.

Chapter 5

Conclusion, summary and recommendations

5.1 Conclusion

The world's population is expected to increase to 10.9 billion by 2100 and consequently to cause an increased demand for food. To produce enough food for the projected increased population and the shifts in food consumption, world food production will have to increase. This will place increasing pressure on natural resources, and will most likely lead to environmental problems. These challenges create a need for improved crop production systems. Conservation agriculture is identified as an available solution to these resource demand problems. Conservation farming principles are being tested in the crop rotation trials at Tygerhoek farm to simulate potential winter cereal crop systems for the Goue Rûens area. The data generated from these trials shows positive contributions to crop yields and soil health. A remaining challenge is to assess the expected financial outcome of these systems. To provide this fuller financial context to the implications of different crop systems, a whole-farm financial evaluation of crop rotation practices is required. The research question this study aimed to answer is: What are the whole-farm long-term financial implications of the evaluated crop rotation systems within the Goue Rûens area? To answer this question required understanding the agronomical dimension and making a financial evaluation of each individual system. To understand the implications within the whole-farm context required describing and modelling a typical farm that could serve as a basis for comparison. Evaluating each crop rotation system in terms of whole-farm financial implications was undertaken by running the crop trial results through the model.

Complexity is inherent in farming systems, and systems thinking is a suitable tool to manage the associated complexities. Improved understanding of the complexities involved in farming systems can conceivably assist in simplifying decision-making environments.

The systems thinking approach is suitable in the study of complex systems, and in some instances, it is more effective than other approaches. Section 2.3 explains what a system is and how a systems approach can be used in farming to address complexity. The three main reasons for defining a farming system are first, to describe a system in order to increase understanding of it; second, when the system is understood, to make improvements to it; third, to enable the system to be redesigned in case the goals or circumstances change. The nine key elements from which the systems perspective emerged are defined, with the emphasis being on the principles of holism and boundaries. Holism is defined as a system that responds to applied stimuli as a whole, with the whole being greater than the sum of its parts, while boundaries are a way to identify the system being studied and are based on the research question being asked.

The farm system is multifaceted and inherently complex, which means that research done on such systems stems from various different perspectives within fields of research specialisation. This tendency towards above-mentioned specialisation leads to fragmentation, and requires a method to integrate the existing fragmented knowledge. Expert knowledge from various fields was integrated by making use of a group of experts, using the Delphi method. This method was also used to validate information and to deepen understanding of the systems and their implementation at the farm-level. The Delphi method was successful as a tool for incorporating knowledge and for verifying data, but it presented some challenges. The respondents took very long to reply to the questionnaires, and they needed to be reminded to return their feedback.

A complex system can ideally be simulated and evaluated by making use of a model. A model is a relatively inexpensive representation of a real system, which mimics the farming system in physical and biological as well as socio-economic terms. A farm model was constructed with one of the main reasons being to aid farmers in the decision-making process. The systems thinking approach served as a basis for developing the whole-farm budget models. The typical-farm approach was used as a profitability tool, with 'typical' implying the farm that is most representative of farms in a homogenous area, so that most of the producers would be able to relate to it.

The Southern Cape and Goue Rûens areas are explained in terms of what makes these homogeneous areas well-suited to winter cereal crop production. Rainfall dispersion is the biggest distinguishing factor that affects crop yields in this area. Long-term precipitation trends show that the region is getting less rain, and rainfall during the rainy season is erratic and unpredictable. The Tygerhoek experimental trials site is located within the Goue Rûens, with the climatic, soil and other relevant characteristics being representative of the Goue Rûens area. Accurate and meaningful data was obtained from Tygerhoek, as the trials are scientifically grounded.

There are four different categories of crop rotation systems at Tygerhoek that were compared in this study. The different systems were thus grouped as Category 2, 3, 4 or 5. Within each of these categories there were different numbers of crop rotation systems. For example, Category 2 comprised Systems 2a, 2b and 2c. There were 13 systems from the Tygerhoek research trial that were used in this study.

To integrate the crop rotation systems within a farm structure required modelling a farm in financial terms. The whole-farm perspective was necessary to understand the wider effects of system changes. A longer-term perspective was required to capture the interrelationships between crops over time. To this end, a whole-farm multi-period budget model was constructed. The point of departure remained the scientifically-generated trial data, and the implications were evaluated at the whole-farm-level, using a budget simulation model. Budget models have the advantage that they can accommodate vast numbers of components and interrelationships within a spreadsheet program. The model transforms agronomical data into financial information through input, calculation and output components. The process of upscaling the Tygerhoek crop rotation trial data to whole-farm-level financial outcomes required a systematic process. This process included analysis of the trial results; identification of a typical farm that served as a basis for comparison and that producers could relate to; model construction; model use, by running each system through the farm model; and sensitivity testing.

To ensure accuracy, experts in winter cereal production systems contributed to the process of designing and testing the model. The Delphi panel of experts were identified, and their contributions were valuable in terms of the design and validation of both the structure of the farm model and the process of dealing with the trial data.

The trial results data from the Tygerhoek experimental farm was available at the gross margin level. The data for each system was integrated into a whole-farm-level model based on the parameters for the typical farm. A typical-farm model was developed for the Goue Rûens area, and the financial outcomes were measured in terms of IRR. A separate whole-farm multi-period model was developed for each of the crop rotation systems, based on the parameters identified in the typical-farm model. The dynamics of the models allowed for the incorporation of complexity and various interrelated variables all within a whole-farm systems context. The models were developed at a multi-period scale to allow for incorporation of the crop rotation effect and for the mechanisation changes to be observed. Different scenarios that tested the possible future outcomes of changes made to the system were developed. Scenarios for changes in gross margin and changes in climate fluctuations were modelled. The focus was placed on the financial performance of the identified systems, measured in terms of IRR.

The financial effects of crop rotations show, in general, upwards trends in terms of profitability. Climatic conditions had an overriding effect on the production of all crops and pastures in the trials. The significant effect that rainfall and rainfall dispersion have on crop yield can be observed in Figure 3, where it can be observed that all the systems dip and peak together, to a certain extent, in the same production year, correlating with extreme climatic conditions.

Farm-level multi-period budget modelling proved to be a suitable way for evaluating and comparing crop rotation systems with each other. A farm-level financial model incorporates crop rotation systems sufficiently by ensuring integration of the physical, biological and financial factors, and by presenting the results in a standardised format, to which most famers can easily relate. The method applied in this study was successful, although challenging. The fact that the Tygerhoek crop rotation trial data was scientifically generated enabled the farmers to trust the data and models presented to them. The data for the typical farm was challenging to gather, which could have been the result of using the Delphi method, rather than a group discussion.

The typical farm in the Goue Rûens area had an IRR of -0.20%, which was very low, and it was surprising that the IRR was negative. The possible reasons for the IRR being so low could have been one or both of the following two factors. The sizes of the farms in the Goue Rûens combined with the relatively high land prices result in a high investment requirement for purchasing land, which consequently has the effect of reducing the IRR. The producers who helped to define the typical farm, are usually more conservative when they present their yield and price data to study groups. The other possible reasons could be that the crop trials were managed more intensely, and thus were presenting more positive data. Crop trials could theoretically get more and faster attention to problems and challenges when compared with large-scale farms. It is also important to note that the concept of a typical farm includes the poorer-performing farms as well. Thus, this did not imply that the average farmer was losing money in the Goue Rûens area. Study group data also included the poorest performing farms, which could have been another reason for the low expected returns.

Systems 2c, 3c and 4c showed the highest expected IRRs in their respective system categories, with System 4c having the highest overall IRR, of 2.59%. Systems 3d, 4d and 5a had the lowest returns in each of their respective system categories, with System 5a having the overall lowest IRR, at -1.32%. Systems Category 5 gave the lowest total expected IRR. This system included both canola and lupines. Lupines has a relatively low gross margin, while canola's benefits were not observed in canola's respective gross margins. System 5b gave a relatively better expected IRR than System 5a, because it had two rotations of barley included.

The range of the IRRs for the different crop rotation systems at a whole-farm multi-period level was relatively narrow, and there was no system that significantly outperformed any other system. From this we could conclude that the crop rotation systems in the Southern Cape were well established, as farmers had been implementing and perfecting this practice for quite some time. However, some system performed relatively better or worse than others.

5.2 Summary

Chapter 1 states that the main objective of this research project was to evaluate the whole-farm long-term financial implications of each evaluated crop rotation system within the Goue Rûens area. The main objective was placed within the context of how it related to addressing the challenges identified, of an increasing global population, increasing demand for calories, and the need for more sustainable farming practices. These challenges have led to the need for improved crop production systems, and conservation agriculture has been identified as a potential solution to these problems. In order to achieve the primary goal of this study, the following secondary goals were set: to agronomically describe and financially analyse each system involved, to identify and describe a typical farm that could serve as a basis for comparison, and to evaluate each crop rotation system in terms of its whole-farm financial implications. The research question was stated as What are the whole-farm long-term financial implications of each evaluated crop rotation system within the Goue Rûens area? The systems approach served as the basis in this study to integrate fragmented knowledge and to accommodate the inherent complexity of farming systems. The scientific foundation of this study lies in the systems approach. A whole-farm multi-period budget model approach was used to evaluate the financial implications of each identified crop rotation system. Financial modelling, as a method, was successful in achieving the research goal. Chapter 1 also highlights the current factors that lead to increased complexity. In the study emphasis was placed on the need for a tool that could assist with managing the increased complexity. Complexity is inherent in farming systems, and systems thinking is a suitable tool for managing the associated complexities. The Delphi method was used to ensure that the measures used for comparison in this study were validated measures.

Chapter 2 provides a literature review and research methodology that places emphasis on the importance of knowledge integration when constructing whole-farm multi-period budget models. Chapter 2 consists of four sections that aim to explain the research methodology followed in this study, as well as the relevant literature. Complexity is defined in order to put into perspective the reasons for using the proposed methodology. The systems approach and systems thinking within farming systems is also described as an academic foundation for complex research in the area of systems research. How the Delphi method was used to gather and validate the data is explained. The use of the typical-farm approach as well as the building blocks of a whole-farm multi-period budget model are also explained. Chapter 2 concludes with an brief overview of where the Goue Rûens is located and the key differentiating characteristics of this identified homogeneous area.

Chapter 3 presents a comprehensive outline and discussion of the Tygerhoek crop rotation trial layout, how the research data was gathered, and what each of the individual crop rotation systems comprised. The difference between the crop rotation system categories is explained, and each of the rotations used for this study is identified and described at the gross margin level. The methods used to capture crop and livestock data from the trial are also discussed. Accurate and meaningful data was obtained from Tygerhoek, as the trials are scientifically grounded. The construction of the farm-level budget model and its underlying components is described with the goal of measuring farm profitability within a typical-farm context. The workings of the model, in the sense of how agronomical data was transformed into financial data through input, calculation and output components, is also explained. The Delphi panel of experts is identified and their contributions outlined. Chapter 3 concludes with a section presenting the three pillars of conservation agriculture, after which the potential agronomical and financial benefits of implementing the crop rotation pillar practices are explained.

Chapter 4 presents the results and findings of this research project, and describes the principles and process of applying both the typical farm and whole-farm multi-period budget models. Section 4.3 explains how the typical-farm-model was developed for the Goue Rûens area, with a separate model having been developed for each of the different rotation systems, based on the parameters of the typical-farm model. The dynamics of the models allow for the incorporation of complexity and various interrelated variables all within a whole-farm systems context. The models were developed on a multi-period scale to allow for the incorporation of the crop rotation effect and for the mechanisation changes to be observed. Different scenarios that tested the possible future outcomes of changes made to the system are presented. Scenarios for changes in gross margin as well as for changes in climate fluctuations were modelled, with the focus being on the financial performance of the systems involved, measured in terms of IRR.

The beneficial financial effects of crop rotations, in general, can be observed in the general upwards trend in Figure 3. The typical farm in the Goue Rûens area has an IRR of -0.20% compared with System 4c, which has the highest overall IRR of 2.59% of all the crop rotation systems. Systems Category 5 gave the lowest total expected IRR, with System 5a having the overall lowest IRR of all the crop rotation systems, at -1.32%. The range of the IRRs for the crop rotation systems at the whole-farm multi-period level was relatively narrow, and there was no system that significantly outperformed any other system. The objective of this study was achieved, and it found that implementing crop rotation System 4c produced increased long-term financial benefits.

5.3 Recommendations

The main research objective of this research project was to evaluate the whole-farm long-term financial implications of each identified crop rotation system within the Goue Rûens area. The crop rotation systems consisted of cash crops and livestock grazing on pastures. This study placed significant emphasis on the interactions between the crops. It is recommended that the optimisation of the livestock component of the aforementioned systems and the interaction it has with crops be studied in more depth within the systems context.

The rotation systems as implemented on Tygerhoek were evaluated. However, there might potentially be additional crops available to cultivate in the area, that when placed in rotation systems present greater benefits in terms of crop yields and soil health.

It is recommended that future trials conducted at the Tygerhoek experimental farm be focused on a regenerative farming approach and on the viability of this practice in the Southern Cape region. Regenerative farming is already feasible in the USA, but no long-term scientific trials have been conducted in the Western Cape, which is needed before such a practice can be recommended to farmers in this particular area.

The Delphi technique was challenging to use because of the participants taking long to reply and the need for constant reminders for them to do so, but this challenge could be overcome by using group discussions instead, as a validation method. Group discussions may have the added benefit of stimulating creativity among participants, leading to more insightful suggestions.

The secondary objective of this study was to evaluate the systems, and the scope of the evaluation could be increased by using stochastic modelling with the existing models. This could be done to observe the financial effects of price fluctuations on a system. The problematic nature of implementing stochastic models on top of these models, if the main goal was to rank systems, would be that it would be superfluous. Running all the systems through the same stochastic model would most likely present the same sequence of rankings as those obtained in this study. The only difference would be that the rankings would be more accurate. Stochastic modelling is useful when studying systems in isolation, as it can provide a risk profile for a particular system. The risk profile obtained for the system concerned would produce valuable additional information.

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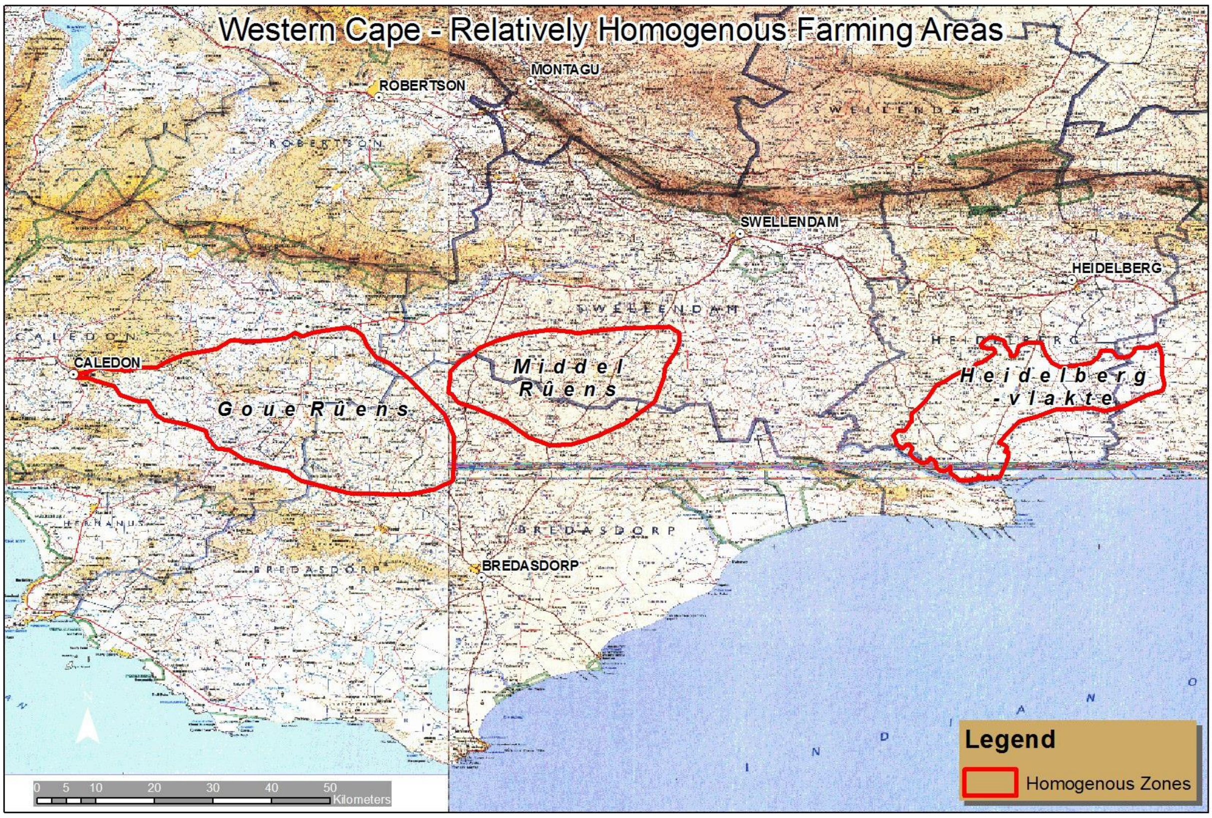
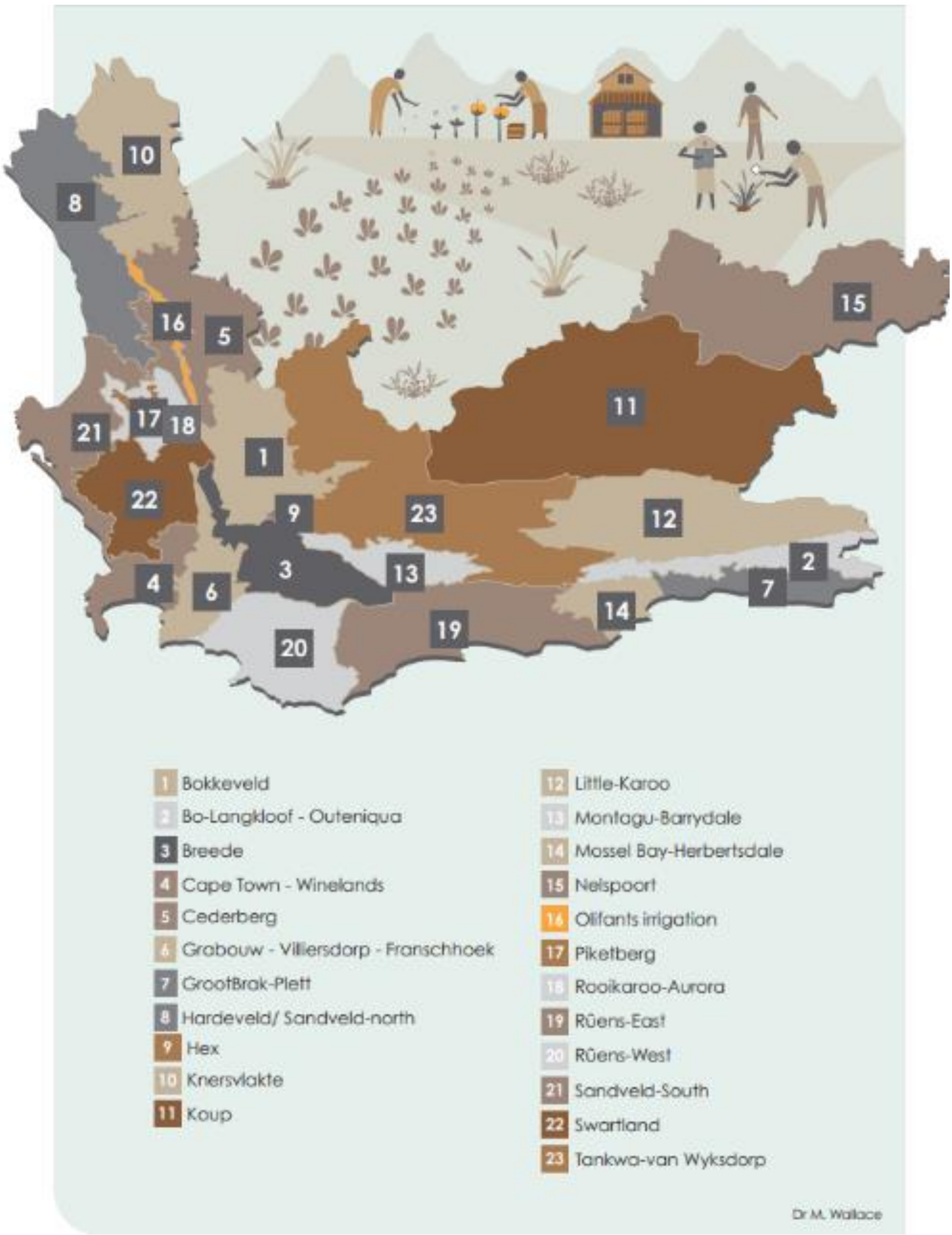
APPENDICES

Annexure A: Map indicating the homogenous farming areas of the Southern Cape



Source: Hoffmann, 2010

Annexure B: Map indicating the homogenous farming areas of the Western Cape



Source: Green Agri, Western Cape Climate Change-Response Framework 2016

Annexure C: Tygerhoek rainfall (mm) 2002-2017

Tygerhoek rainfall (mm) 2002-2017

	2002	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**Average**
January	87,90	58,40	7,00	68,20	77,00	4,30	41,00	12,70	4,55	20,77	9,64	10,67	200,90	24,13	39,70	37,10	44,00
February	26,80	0,00	1,00	17,40	33,20	13,50	45,30	32,24	38,60	57,38	14,66	34,99	31,48	31,72	33,30	10,30	26,37
March	4,40	0,00	14,40	22,40	42,00	11,60	26,00	4,56	68,56	26,41	61,19	31,46	38,81	12,69	51,30	6,60	26,40
April	31,00	32,00	29,80	186,20	77,40	21,60	46,10	31,49	25,36	28,65	85,84	32,99	64,45	2,90	15,80	16,80	45,52
May	63,20	36,80	1,80	42,20	44,40	31,30	7,60	21,57	45,16	89,09	39,83	45,18	32,24	0,00	1,70	14,50	32,29
June	48,50	14,60	16,60	54,60	24,20	22,80	36,10	79,96	74,07	80,46	136,52	81,97	110,19	91,19	42,00	39,30	59,57
July	72,80	11,20	17,60	3,30	83,80	35,70	51,80	73,06	59,40	53,51	78,14	45,67	20,79	0,00	105,70	43,10	47,22
August	44,00	16,20	6,60	26,30	83,30	11,70	36,10	24,86	24,86	52,54	54,09	111,68	10,61	42,30	29,80	63,20	39,88
September	50,80	24,00	65,60	0,00	8,40	9,50	37,70	37,05	32,23	2,53	25,08	14,68	64,98	85,90	73,50	26,00	34,87
October	20,60	25,20	75,60	1,40	16,20	28,90	95,00	54,31	42,09	25,63	117,40	84,75	25,62	31,20	24,60		44,57
November	19,40	4,20	231,20	54,20	18,20	206,40	81,93	0,75	58,66	75,41	11,64	173,67	47,72	36,20	10,10		68,65
December	13,20	296,00	236,40	7,20	17,20	72,40	73,65	11,92	24,32	0,28	14,72	3,56	25,34	0,41	21,00		54,51
Total (year)	482,60	518,60	703,60	483,40	525,30	469,70	578,28	384,47	497,86	512,66	648,75	671,27	673,13	358,64	448,50	256,90	513,35
Total Apr-Sept	310,30	134,80	138,00	312,60	321,50	132,60	215,40	267,99	261,08	306,78	419,50	332,17	303,26	222,29	268,50	202,90	259,35
Total summer	172,30	383,80	565,60	170,80	203,80	337,10	362,88	116,48	236,78	205,88	229,25	339,10	369,87	136,35	180,00	54,00	254,00

Source: Tygerhoek crop rotation trial data.

Annexure D: Summary of the identified systems Gross Margin and IRR

System	2a	2b	2c	3a	3b	3c	3d	4a	4b	4c	4d	5a	5b
Average GM per Ha	R4 407,99	R4 573,54	R4 770,91	R5 349,95	R4 832,05	R5 354,14	R3 835,46	R5 422,60	R5 383,40	R6 067,11	R3 898,56	R2 062,66	R3 535,77
Total farm GM	R9 917 984,32	R10 290 474,29	R10 734 552,99	R12 037 398,49	R10 872 117,28	R12 046 816,08	R8 629 785,28	R12 200 851,18	R12 112 660,66	R13 651 002,98	R8 771 753,58	R4 640 983,79	R7 955 484,16
Total overhead costs	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00
Net farm income	R6 491 774,32	R6 864 264,29	R7 308 342,99	R8 611 188,49	R7 445 907,28	R8 620 606,08	R5 203 575,28	R8 774 641,18	R8 686 450,66	R10 224 792,98	R5 345 543,58	R1 214 773,79	R4 529 274,16
Total factor costs	R500 000,00	R500 000,00	R500 000,00	R500 000,00	R500 000,00	R500 000,00	R500 000,00	R500 000,00	R500 000,00	R500 000,00	R500 000,00	R500 000,00	R500 000,00
Farm profit	R5 991 774,32	R6 364 264,29	R6 808 342,99	R8 111 188,49	R6 945 907,28	R8 120 606,08	R4 703 575,28	R8 274 641,18	R8 186 450,66	R9 724 792,98	R4 845 543,58	R714 773,79	R4 029 274,16
IRR	**0,94%**	**1,10%**	**1,30%**	**1,66%**	**1,36%**	**1,88%**	**0,38%**	**1,94%**	**1,91%**	**2,59%**	**0,44%**	**-1,32%**	**0,09%**

Annexure E: Gross Margin calculations from Tygerhoek

GROSS MARGIN & MARGIN ABOVE SPECIFIED COSTS:							
Crop:	**Barley**			**Date:**	**05-Dec-17**		
				YEAR	**2017**		
Counrty:	**SA**						
Province:	**Western Cape**						
Location:	**Tygerhoek**						
Comment:	**Southern Cape crop rotation trials**						
Camp:	22,4	**System:**	**4c**	**Pastures-Wheat-Barley-Pastures**			
		Unit	**Price/unit Rand**	**Quantity**	**R per ha**	**R/yield unit**	Code:
Gross Income							
Product income:							
Barley							
Barley Malt		ton	3650,00	3,147	11486,55	3650,00	107
Marketing cost:							
Gross income minus marketing cost					**11486,55**	**3650,00**	
ALLOCATABLE VARIABLE COSTS:					**3449,46**	**1096,11**	
Directly Allocatable Variable Costs:					**3019,67**	**959,54**	
Pre Harvest Cost:					**2806,81**	**891,90**	
Plant material:							
Seed							
S 9		kg	6,90	65,000	448,50	142,52	201
Fertilizer:							
U Plant 31 S		t	6219,00	0,100	621,90	197,62	300
#N/A		#N/A	#N/A		0,00	0,00	
#N/A		#N/A	#N/A		0,00	0,00	
#N/A		#N/A	#N/A		0,00	0,00	
#N/A		#N/A	#N/A		0,00	0,00	
#N/A		#N/A	#N/A		0,00	0,00	
#N/A		#N/A	#N/A		0,00	0,00	
#N/A		#N/A	#N/A		0,00	0,00	
#N/A		#N/A	#N/A		0,00	0,00	
#N/A		#N/A	#N/A		0,00	0,00	
Lime & manure:							
#N/A		#N/A	#N/A		0,00	0,00	
Weed Control:							
Erase2.5L2.4D.5LBoxer3LDifflan.2L		Per ha	692,90	1,000	692,90	220,18	406
Aurora25gBrush-off4gMCPA.5LBladbuff.125LW		Per ha	179,06	1,000	179,06	56,90	401
#N/A		#N/A	#N/A		0,00	0,00	
#N/A		#N/A	#N/A		0,00	0,00	
#N/A		#N/A	#N/A		0,00	0,00	
#N/A		#N/A	#N/A		0,00	0,00	
#N/A		#N/A	#N/A		0,00	0,00	
#N/A		#N/A	#N/A		0,00	0,00	
Pest Control:							
Mospilan		gram	0,65	50,000	32,25	10,25	426
Dimet		liter	64,00	0,750	48,00	15,25	427
#N/A		#N/A	#N/A		0,00	0,00	
#N/A		#N/A	#N/A		0,00	0,00	
#N/A		#N/A	#N/A		0,00	0,00	
#N/A		#N/A	#N/A		0,00	0,00	
#N/A		#N/A	#N/A		0,00	0,00	
Fungicide control:							
Acanto.3L,Prosaro.4L		Per ha	419,20	1,000	419,20	133,21	423
Abacus		liter	365,00	1,000	365,00	115,98	424
#N/A		#N/A	#N/A		0,00	0,00	
#N/A		#N/A	#N/A		0,00	0,00	
#N/A		#N/A	#N/A		0,00	0,00	
Contractors:							
#N/A		#N/A	#N/A		0,00	0,00	
#N/A		#N/A	#N/A		0,00	0,00	
#N/A		#N/A	#N/A		0,00	0,00	
Lime spread:							
#N/A		#N/A	#N/A		0,00	0,00	
Harvest cost:					212,86	67,64	
Grain							
Transport		ton	67,64	3,147	212,86	67,64	
MARGIN ABOVE DIRECTLY ALLOCATABLE COSTS:					**8466,88**	**2690,46**	
In Directly Allocatable costs:					**429,79**	**136,57**	
PRE HARVEST COST:					**273,37**	**86,87**	
Energy					153,12	48,65	
Repairs and Maintenance					116,45	37,00	
Tyres					3,81	1,21	
HARVEST COST:					**156,41**	**49,70**	
Energy					77,05	24,48	
Repairs and maintenance					78,59	24,97	
Tyres					0,77	0,25	
TOTAL PRE HARVEST COSTS					**3080,18**	**978,77**	
TOTAL HARVEST COSTS					**369,27**	**117,34**	
GROSS MARGIN ABOVE ALL ALLOCATABLE COSTS:					**8037,09**	**2553,89**	

Annexure F: Multi-period budget model for the typical farm in the Goue Rûens over a 20 year calculation period

Yield potential based on the rainfall distribution												Multi period budget for the typical farm in the Goue Rûens										
1	Good	100,00%																				
2	Average	80,00%																				
3	Poor	60,00%																				
Year			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Yearly allocation (good, average, poor)			1	1	2	3	2	1	2	3	2	3	1	2	2	2	2	2	2	3	2	2	
Gross margin																							
Cash crop	Ha																						
Wheat	421,32	R1 950 410,57	R1 950 410,57	R1 950 410,57	R1 560 328,46	R1 170 246,34	R1 560 328,46	R1 950 410,57	R1 560 328,46	R1 170 246,34	R1 560 328,46	R1 170 246,34	R1 950 410,57	R1 560 328,46	R1 560 328,46	R1 560 328,46	R1 560 328,46	R1 560 328,46	R1 560 328,46	R1 170 246,34	R1 560 328,46	R1 560 328,46	
Barley	490,55	R2 772 487,38	R2 772 487,38	R2 772 487,38	R2 217 989,91	R1 663 492,43	R2 217 989,91	R2 772 487,38	R2 217 989,91	R1 663 492,43	R2 217 989,91	R1 663 492,43	R2 772 487,38	R2 217 989,91	R2 217 989,91	R2 217 989,91	R2 217 989,91	R2 217 989,91	R2 217 989,91	R1 663 492,43	R2 217 989,91	R2 217 989,91	
Canola	178,52	R411 030,63	R411 030,63	R411 030,63	R328 824,51	R246 618,38	R328 824,51	R411 030,63	R328 824,51	R246 618,38	R328 824,51	R246 618,38	R411 030,63	R328 824,51	R328 824,51	R328 824,51	R328 824,51	R328 824,51	R328 824,51	R246 618,38	R328 824,51	R328 824,51	
Triticale	0,00	R0,00	R0,00	R0,00	R0,00	R0,00	R0,00	R0,00	R0,00	R0,00	R0,00	R0,00	R0,00	R0,00	R0,00	R0,00	R0,00	R0,00	R0,00	R0,00	R0,00	R0,00	
Oats	69,23	R241 632,69	R241 632,69	R241 632,69	R193 306,15	R144 979,62	R193 306,15	R241 632,69	R193 306,15	R144 979,62	R193 306,15	R144 979,62	R241 632,69	R193 306,15	R193 306,15	R193 306,15	R193 306,15	R193 306,15	R193 306,15	R144 979,62	R193 306,15	R193 306,15	
Lupins	64,29	R6 562,93	R6 562,93	R6 562,93	R5 250,34	R3 937,76	R5 250,34	R6 562,93	R5 250,34	R3 937,76	R5 250,34	R3 937,76	R6 562,93	R5 250,34	R5 250,34	R5 250,34	R5 250,34	R5 250,34	R5 250,34	R3 937,76	R5 250,34	R5 250,34	
Alfalfa	1026,10	R1 904 988,54	R1 904 988,54	R1 904 988,54	R1 523 990,83	R1 142 993,12	R1 523 990,83	R1 904 988,54	R1 523 990,83	R1 142 993,12	R1 523 990,83	R1 142 993,12	R1 904 988,54	R1 523 990,83	R1 523 990,83	R1 523 990,83	R1 523 990,83	R1 523 990,83	R1 523 990,83	R1 142 993,12	R1 523 990,83	R1 523 990,83	
Capital sold			R0,00	R77 864,58	R73 096,88	R148 944,17	R534 200,67	R156 184,38	R248 376,04	R299 293,63	R834 037,50	R219 094,17	R157 837,50	R0,00	R0,00	R77 864,58	R73 096,88	R148 944,17	R782 576,71	R156 184,38	R0,00	R299 293,63	
Whole-farm gross margin	**2250,00**		**R7 287 112,75**	**R7 364 977,33**	**R5 902 787,07**	**R4 521 211,81**	**R6 363 890,86**	**R7 443 297,12**	**R6 078 066,24**	**R4 671 561,27**	**R6 663 727,70**	**R4 591 361,81**	**R7 444 950,25**	**R5 829 690,20**	**R5 829 690,20**	**R5 907 554,78**	**R5 902 787,07**	**R5 978 634,36**	**R6 612 266,90**	**R4 528 452,02**	**R5 829 690,20**	**R6 128 983,82**	
Yearly overhead and fixed costs																							
Total yearly overhead costs		R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	
Margin after fixed and overhead costs			**3860902,75**	**3938767,33**	**2476577,07**	**1095001,81**	**2937680,86**	**4017087,12**	**2651856,24**	**1245351,27**	**3237517,70**	**1165151,81**	**4018740,25**	**2403480,20**	**2403480,20**	**2481344,78**	**2476577,07**	**2552424,36**	**3186056,90**	**1102242,02**	**2403480,20**	**2702773,82**	
Owners wage			**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	
Foreign factor cost																							
Management			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Total foreign factor cost			**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	
Margin after foreign factor cost			**3860902,75**	**3938767,33**	**2476577,07**	**1095001,81**	**2937680,86**	**4017087,12**	**2651856,24**	**1245351,27**	**3237517,70**	**1165151,81**	**4018740,25**	**2403480,20**	**2403480,20**	**2481344,78**	**2476577,07**	**2552424,36**	**3186056,90**	**1102242,02**	**2403480,20**	**2702773,82**	
Capital flow																							
																							Resale value
Long term																							
Land and fixed improvements			175000000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	175000000
Intermediate capital	Age																						
Tractors (Kw)																							
240	4		2730483,33	0	0	0	0	0	0	0	4095725	0	0	0	0	0	0	0	0	0	0	0	341310,42
125	8		630391,67	0	0	0	1891175	0	0	0	0	0	0	0	0	0	0	0	1891175	0	0	0	1418381,25
100	7		576197,92	0	0	0	0	1382875	0	0	0	0	0	0	0	0	0	0	0	1382875	0	0	1152395,83
100	9		345718,75	0	0	1382875	0	0	0	0	0	0	0	0	0	0	0	1382875	0	0	0	0	921916,67
75	11		77864,58	934375	0	0	0	0	0	0	0	0	0	0	0	934375	0	0	0	0	0	0	467187,50
60	10		116341,67	0	698050	0	0	0	0	0	0	0	0	0	0	0	698050	0	0	0	0	0	407195,83
Harvesters (Kw)																							
201	4		2798333,33	0	0	0	0	0	0	0	4197500	0	0	0	0	0	0	0	0	0	0	0	349791,67
201	8		1399166,67	0	0	0	4197500	0	0	0	0	0	0	0	0	0	0	0	4197500	0	0	0	3148125,00
Wind mowers (with a head)																							
Windmower : 15 feet, 4.57m	2		1578375,00	0	0	0	0	0	0	0	0	0	1894050	0	0	0	0	0	0	0	0	0	473512,50
Windmower : 15 feet, 4.57m	3		1420537,50	0	0	0	0	0	0	0	0	1894050	0	0	0	0	0	0	0	0	0	0	315675,00
Wind mowers																							
Minimum tillage wheat planter- 12,3 m (air pressure seeder)	4		1788307,50	0	0	0	0	0	2980512,5	0	0	0	0	0	0	0	0	0	2980512,5	0	0	0	-894153,75
Deep cultivation implement	5		67629,33	0	0	0	0	0	0	115936	0	0	0	0	0	0	0	0	0	0	0	115936	0,00
Other implements																							
Crop sprayer 24m boomspray - max 3000 L Tank	5		619011,46	0	0	0	0	0	0	1061162,5	0	0	0	0	0	0	0	0	0	0	0	1061162,5	0,00
Fertilizer spreader - Double disc (1500 L) - precision	4		327558,33	0	0	0	0	0	0	0	491337,5	0	0	0	0	0	0	0	0	0	0	0	40944,79
Fertilizer spreader - Double disc (1500 L) - precision	7		204723,96	0	0	0	0	491337,5	0	0	0	0	0	0	0	0	0	0	0	491337,5	0	0	409447,92
Screen	8		107244,33	0	0	0	321733	0	0	0	0	0	0	0	0	0	0	0	321733	0	0	0	241299,75
Baler - Large square baler (120 X 70) (Standard)	5		1408414,58	0	0	0	0	0	0	2414425	0	0	0	0	0	0	0	0	0	0	0	2414425	0,00
Water carrier / firefighting	3		167756,25	0	0	0	0	0	0	0	0	223675	0	0	0	0	0	0	0	0	0	0	37279,17
Vehicles																							
Truck - 7 ton	4		696516,67	0	0	0	0	0	0	0	1044775	0	0	0	0	0	0	0	0	0	0	0	87064,58
Hilux 2.8 GD-6 Xtra Cab Raider	3		383553,75	0	0	0	0	0	0	0	0	511405	0	0	0	0	0	0	0	0	0	0	85234,17
Hilux 2.4 GD	9		79407,50	0	0	317630	0	0	0	0	0	0	0	0	0	0	0	317630	0	0	0	0	211753,33
Trailers																							
Four-wheeledtrailer - 10 ton	4		119408,33	0	0	0	0	0	0	0	179112,5	0	0	0	0	0	0	0	0	0	0	0	14926,04
Four-wheeledtrailer - 10 ton	10		29852,08	0	179112,5	0	0	0	0	0	0	0	0	0	0	0	179112,5	0	0	0	0	0	104482,29
Loaders - front end loaders	9		21706,25	0	0	86825	0	0	0	0	0	0	0	0	0	0	0	86825	0	0	0	0	57883,33
Total intermediate capital:			17694501	934375	877163	1787330	6410408	1874213	2980513	3591524	10008450	2629130	1894050	0	0	934375	877163	1787330	9390921	1874213	0	3591524	9391653
Livestock			9845077																				9845077
Total Capital flow			202539578	934375	877163	1787330	6410408	1874213	2980513	3591524	10008450	2629130	1894050	0	0	934375	877163	1787330	9390921	1874213	0	3591524	194236730
Net annual flow			-198678674,93	3004392,33	1599414,57	-692328,19	-3472727,14	2142874,62	-328656,26	-2346172,23	-6770932,30	-1463978,19	2124690,25	2403480,20	2403480,20	1546969,78	1599414,57	765094,36	-6204863,60	-771970,48	2403480,20	193347980,54	
IRR	-0,20%																						

Annexure G: Multi-period budget model for System 2a over a 20 year calculation period

Multi period budget for System 2a

Yield potential based on the rainfall distribution																							
1	Good	100,00%																					
2	Average	80,00%																					
3	Poor	60,00%																					
Year			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Yearly allocation (good, average, poor)			1	1	2	3	2	1	2	3	2	3	1	2	2	2	2	2	2	3	2	2	
Gross margin per Ha farm	**Ha**																						
R4 407,99	2250	R 9 917 984,32	R9 917 984,32	R9 917 984,32	R7 934 387,45	R5 950 790,59	R7 934 387,45	R9 917 984,32	R7 934 387,45	R5 950 790,59	R7 934 387,45	R5 950 790,59	R9 917 984,32	R7 934 387,45	R7 934 387,45	R7 934 387,45	R7 934 387,45	R7 934 387,45	R7 934 387,45	R5 950 790,59	R7 934 387,45	R7 934 387,45	
Capital sold			0,00	77864,58	73096,88	148944,17	534200,67	156184,38	248376,04	299293,63	834037,50	219094,17	157837,50	0,00	0,00	77864,58	73096,88	148944,17	782576,71	156184,38	0,00	299293,63	
Whole-farm gross margin			**9917984,32**	**9995848,90**	**8007484,33**	**6099734,76**	**8468588,12**	**10074168,69**	**8182763,49**	**6250084,21**	**8768424,95**	**6169884,76**	**10075821,82**	**7934387,45**	**7934387,45**	**8012252,04**	**8007484,33**	**8083331,62**	**8716964,16**	**6106974,96**	**7934387,45**	**8233681,08**	
Yearly overhead and fixed costs																							
Total yearly overhead costs		R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	
Margin after fixed and overhead costs			**6491774,32**	**6569638,90**	**4581274,33**	**2673524,76**	**5042378,12**	**6647958,69**	**4756553,49**	**2823874,21**	**5342214,95**	**2743674,76**	**6649611,82**	**4508177,45**	**4508177,45**	**4586042,04**	**4581274,33**	**4657121,62**	**5290754,16**	**2680764,96**	**4508177,45**	**4807471,08**	
Owners wage			**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	
Foreign factor cost																							
Management			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Total foreign factor cost			**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	
Margin after foreign factor cost			**6491774,32**	**6569638,90**	**4581274,33**	**2673524,76**	**5042378,12**	**6647958,69**	**4756553,49**	**2823874,21**	**5342214,95**	**2743674,76**	**6649611,82**	**4508177,45**	**4508177,45**	**4586042,04**	**4581274,33**	**4657121,62**	**5290754,16**	**2680764,96**	**4508177,45**	**4807471,08**	
Capital flow																							
																							Resale value
Long term																							
Land and fixed improvements			175000000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	175000000
Intermediate capital	Age																						
Tractors (Kw)																							
240	4		2730483,33	0	0	0	0	0	0	0	4095725	0	0	0	0	0	0	0	0	0	0	0	341310,42
125	8		630391,67	0	0	0	1891175	0	0	0	0	0	0	0	0	0	0	0	1891175	0	0	0	1418381,25
100	7		576197,92	0	0	0	0	1382875	0	0	0	0	0	0	0	0	0	0	0	1382875	0	0	1152395,83
100	9		345718,75	0	0	1382875	0	0	0	0	0	0	0	0	0	0	0	1382875	0	0	0	0	921916,67
75	11		77864,58	934375	0	0	0	0	0	0	0	0	0	0	0	934375	0	0	0	0	0	0	467187,50
60	10		116341,67	0	698050	0	0	0	0	0	0	0	0	0	0	0	698050	0	0	0	0	0	407195,83
Harvesters (Kw)																							
201	4		2798333,33	0	0	0	0	0	0	0	4197500	0	0	0	0	0	0	0	0	0	0	0	349791,67
201	8		1399166,67	0	0	0	4197500	0	0	0	0	0	0	0	0	0	0	0	4197500	0	0	0	3148125,00
Wind mowers (with a head)																							
Windmower : 15 feet, 4.57m	2		1578375,00	0	0	0	0	0	0	0	0	0	1894050	0	0	0	0	0	0	0	0	0	473512,50
Windmower : 15 feet, 4.57m	3		1420537,50	0	0	0	0	0	0	0	0	1894050	0	0	0	0	0	0	0	0	0	0	315675,00
Wind mowers																							
Minimum tillage wheat planter- 12,3 m (air pressure seeder)	4		1788307,50	0	0	0	0	0	2980512,5	0	0	0	0	0	0	0	0	0	2980512,5	0	0	0	-894153,75
Deep cultivation implement	5		67629,33	0	0	0	0	0	0	115936	0	0	0	0	0	0	0	0	0	0	0	115936	0,00
Other implements																							
Crop sprayer 24m boomspray - max 3000 L Tank	5		619011,46	0	0	0	0	0	0	1061162,5	0	0	0	0	0	0	0	0	0	0	0	1061162,5	0,00
Fertilizer spreader - Double disc (1500 L) - precision	4		327558,33	0	0	0	0	0	0	0	491337,5	0	0	0	0	0	0	0	0	0	0	0	40944,79
Fertilizer spreader - Double disc (1500 L) - precision	7		204723,96	0	0	0	0	491337,5	0	0	0	0	0	0	0	0	0	0	0	491337,5	0	0	409447,92
Screen	8		107244,33	0	0	0	321733	0	0	0	0	0	0	0	0	0	0	0	321733	0	0	0	241299,75
Baler - Large square baler (120 X 70) (Standard)	5		1408414,58	0	0	0	0	0	0	2414425	0	0	0	0	0	0	0	0	0	0	0	2414425	0,00
Water carrier / firefighting	3		167756,25	0	0	0	0	0	0	0	0	223675	0	0	0	0	0	0	0	0	0	0	37279,17
Vehicles																							
Truck - 7 ton	4		696516,67	0	0	0	0	0	0	0	1044775	0	0	0	0	0	0	0	0	0	0	0	87064,58
Hilux 2.8 GD-6 Xtra Cab Raider	3		383553,75	0	0	0	0	0	0	0	0	511405	0	0	0	0	0	0	0	0	0	0	85234,17
Hilux 2.4 GD	9		79407,50	0	0	317630	0	0	0	0	0	0	0	0	0	0	0	317630	0	0	0	0	211753,33
Trailers																							
Four-wheeledtrailer - 10 ton	4		119408,33	0	0	0	0	0	0	0	179112,5	0	0	0	0	0	0	0	0	0	0	0	14926,04
Four-wheeledtrailer - 10 ton	10		29852,08	0	179112,5	0	0	0	0	0	0	0	0	0	0	0	179112,5	0	0	0	0	0	104482,29
Loaders - front end loaders	9		21706,25	0	0	86825	0	0	0	0	0	0	0	0	0	0	0	86825	0	0	0	0	57883,33
Total intermediate capital:			17694501	934375	877163	1787330	6410408	1874213	2980513	3591524	10008450	2629130	1894050	0	0	934375	877163	1787330	9390921	1874213	0	3591524	9391653
Livestock			9845077																				9845077
Total Capital flow			202539578	934375	877163	1787330	6410408	1874213	2980513	3591524	10008450	2629130	1894050	0	0	934375	877163	1787330	9390921	1874213	0	3591524	194236730
Net annual flow			-196047803,36	5635263,90	3704111,83	886194,76	-1368029,88	4773746,19	1776040,99	-767649,29	-4666235,05	114544,76	4755561,82	4508177,45	4508177,45	3651667,04	3704111,83	2869791,62	-4100166,34	806552,46	4508177,45	195452677,79	
IRR	0,94%																						

Annexure H: Multi-period budget model for System 3b over a 20 year calculation period

Multi period budget for System 3b

Yield potential based on the rainfall distribution																						
1	**Good**	100,00%																				
2	**Average**	80,00%																				
3	**Poor**	60,00%																				
Year			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Yearly allocation (good, average, poor)			1	1	2	3	2	1	2	3	2	3	1	2	2	2	2	2	2	3	2	2	
Gross margin per Ha farm	Ha																						
R4 832,05	2250	R 10 872 117,28	R10 872 117,28	R10 872 117,28	R8 697 693,82	R6 523 270,37	R8 697 693,82	R10 872 117,28	R8 697 693,82	R6 523 270,37	R8 697 693,82	R6 523 270,37	R10 872 117,28	R8 697 693,82	R8 697 693,82	R8 697 693,82	R8 697 693,82	R8 697 693,82	R8 697 693,82	R6 523 270,37	R8 697 693,82	R8 697 693,82	
Capital sold			0,00	77864,58	73096,88	148944,17	534200,67	156184,38	248376,04	299293,63	834037,50	219094,17	157837,50	0,00	0,00	77864,58	73096,88	148944,17	782576,71	156184,38	0,00	299293,63	
Whole-farm gross margin			**10872117,28**	**10949981,86**	**8770790,70**	**6672214,53**	**9231894,49**	**11028301,65**	**8946069,87**	**6822563,99**	**9531731,32**	**6742364,53**	**11029954,78**	**8697693,82**	**8697693,82**	**8775558,41**	**8770790,70**	**8846637,99**	**9480270,53**	**6679454,74**	**8697693,82**	**8996987,45**	
Yearly overhead and fixed costs																							
Total yearly overhead costs		R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	
Margin after fixed and overhead costs			**7445907,28**	**7523771,86**	**5344580,70**	**3246004,53**	**5805684,49**	**7602091,65**	**5519859,87**	**3396353,99**	**6105521,32**	**3316154,53**	**7603744,78**	**5271483,82**	**5271483,82**	**5349348,41**	**5344580,70**	**5420427,99**	**6054060,53**	**3253244,74**	**5271483,82**	**5570777,45**	
Owners wage			**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	
Foreign factor cost																							
Management			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Total foreign factor cost			**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	
Margin after foreign factor cost			**7445907,28**	**7523771,86**	**5344580,70**	**3246004,53**	**5805684,49**	**7602091,65**	**5519859,87**	**3396353,99**	**6105521,32**	**3316154,53**	**7603744,78**	**5271483,82**	**5271483,82**	**5349348,41**	**5344580,70**	**5420427,99**	**6054060,53**	**3253244,74**	**5271483,82**	**5570777,45**	
Capital flow																							**Resale value**
Long term																							
Land and fixed improvements			175000000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	175000000
Intermediate capital	Age																						
Tractors (Kw)																							
240	4		2730483,33	0	0	0	0	0	0	0	4095725	0	0	0	0	0	0	0	0	0	0	0	341310,42
125	8		630391,67	0	0	0	1891175	0	0	0	0	0	0	0	0	0	0	0	1891175	0	0	0	1418381,25
100	7		576197,92	0	0	0	0	1382875	0	0	0	0	0	0	0	0	0	0	0	1382875	0	0	1152395,83
100	9		345718,75	0	0	1382875	0	0	0	0	0	0	0	0	0	0	0	1382875	0	0	0	0	921916,67
75	11		77864,58	934375	0	0	0	0	0	0	0	0	0	0	0	934375	0	0	0	0	0	0	467187,50
60	10		116341,67	0	698050	0	0	0	0	0	0	0	0	0	0	0	698050	0	0	0	0	0	407195,83
Harvesters (Kw)																							
201	4		2798333,33	0	0	0	0	0	0	0	4197500	0	0	0	0	0	0	0	0	0	0	0	349791,67
201	8		1399166,67	0	0	0	4197500	0	0	0	0	0	0	0	0	0	0	0	4197500	0	0	0	3148125,00
Wind mowers (with a head)																							
Windmower : 15 feet, 4.57m	2		1578375,00	0	0	0	0	0	0	0	0	0	1894050	0	0	0	0	0	0	0	0	0	473512,50
Windmower : 15 feet, 4.57m	3		1420537,50	0	0	0	0	0	0	0	0	1894050	0	0	0	0	0	0	0	0	0	0	315675,00
Wind mowers																							
Minimum tillage wheat planter- 12,3 m (air pressure seeder)	4		1788307,50	0	0	0	0	0	2980512,5	0	0	0	0	0	0	0	0	0	2980512,5	0	0	0	-894153,75
Deep cultivation implement	5		67629,33	0	0	0	0	0	0	115936	0	0	0	0	0	0	0	0	0	0	0	115936	0,00
Other implements																							
Crop sprayer 24m boomspray - max 3000 L Tank	5		619011,46	0	0	0	0	0	0	1061162,5	0	0	0	0	0	0	0	0	0	0	0	1061162,5	0,00
Fertilizer spreader - Double disc (1500 L) - precision	4		327558,33	0	0	0	0	0	0	0	491337,5	0	0	0	0	0	0	0	0	0	0	0	40944,79
Fertilizer spreader - Double disc (1500 L) - precision	7		204723,96	0	0	0	0	491337,5	0	0	0	0	0	0	0	0	0	0	0	491337,5	0	0	409447,92
Screen	8		107244,33	0	0	0	321733	0	0	0	0	0	0	0	0	0	0	0	321733	0	0	0	241299,75
Baler - Large square baler (120 X 70) (Standard)	5		1408414,58	0	0	0	0	0	0	2414425	0	0	0	0	0	0	0	0	0	0	0	2414425	0,00
Water carrier / firefighting	3		167756,25	0	0	0	0	0	0	0	0	223675	0	0	0	0	0	0	0	0	0	0	37279,17
Vehicles																							
Truck - 7 ton	4		696516,67	0	0	0	0	0	0	0	1044775	0	0	0	0	0	0	0	0	0	0	0	87064,58
Hilux 2.8 GD-6 Xtra Cab Raider	3		383553,75	0	0	0	0	0	0	0	0	511405	0	0	0	0	0	0	0	0	0	0	85234,17
Hilux 2.4 GD	9		79407,50	0	0	317630	0	0	0	0	0	0	0	0	0	0	0	317630	0	0	0	0	211753,33
Trailers																							
Four-wheeledtrailer - 10 ton	4		119408,33	0	0	0	0	0	0	0	179112,5	0	0	0	0	0	0	0	0	0	0	0	14926,04
Four-wheeledtrailer - 10 ton	10		29852,08	0	179112,5	0	0	0	0	0	0	0	0	0	0	0	179112,5	0	0	0	0	0	104482,29
Loaders - front end loaders	9		21706,25	0	0	86825	0	0	0	0	0	0	0	0	0	0	0	86825	0	0	0	0	57883,33
Total intermediate capital:			17694501	934375	877163	1787330	6410408	1874213	2980513	3591524	10008450	2629130	1894050	0	0	934375	877163	1787330	9390921	1874213	0	3591524	9391653
Livestock			9845077																				9845077
Total Capital flow			202539578	934375	877163	1787330	6410408	1874213	2980513	3591524	10008450	2629130	1894050	0	0	934375	877163	1787330	9390921	1874213	0	3591524	194236730
Net annual flow			-195093670,39	6589396,86	4467418,20	1458674,53	-604723,51	5727879,15	2539347,37	-195169,51	-3902928,68	687024,53	5709694,78	5271483,82	5271483,82	4414973,41	4467418,20	3633097,99	-3336859,97	1379032,24	5271483,82	196215984,16	
IRR	1,36%																						

Annexure I: Multi-period budget model for System 4c over a 20 year calculation period

Yield potential based on the rainfall distribution												Multi period budget for System 4c										
1	**Good**	100,00%																				
2	**Average**	80,00%																				
3	**Poor**	60,00%																				
Year			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Yearly allocation (good, average, poor)			1	1	2	3	2	1	2	3	2	3	1	2	2	2	2	2	2	3	2	2	
Gross margin per Ha farm	**Ha**																						
R6 067,11	2250	R 13 651 002,98	R13 651 002,98	R13 651 002,98	R10 920 802,38	R8 190 601,79	R10 920 802,38	R13 651 002,98	R10 920 802,38	R8 190 601,79	R10 920 802,38	R8 190 601,79	R13 651 002,98	R10 920 802,38	R10 920 802,38	R10 920 802,38	R10 920 802,38	R10 920 802,38	R10 920 802,38	R8 190 601,79	R10 920 802,38	R10 920 802,38	
Capital sold			0,00	77864,58	73096,88	148944,17	534200,67	156184,38	248376,04	299293,63	834037,50	219094,17	157837,50	0,00	0,00	77864,58	73096,88	148944,17	782576,71	156184,38	0,00	299293,63	
Whole-farm gross margin			**13651002,98**	**13728867,56**	**10993899,26**	**8339545,95**	**11455003,05**	**13807187,35**	**11169178,42**	**8489895,41**	**11754839,88**	**8409695,95**	**13808840,48**	**10920802,38**	**10920802,38**	**10998666,96**	**10993899,26**	**11069746,55**	**11703379,09**	**8346786,16**	**10920802,38**	**11220096,01**	
Yearly overhead and fixed costs																							
Total yearly overhead costs		R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	R3 426 210,00	
Margin after fixed and overhead costs			**10224792,98**	**10302657,56**	**7567689,26**	**4913335,95**	**8028793,05**	**10380977,35**	**7742968,42**	**5063685,41**	**8328629,88**	**4983485,95**	**10382630,48**	**7494592,38**	**7494592,38**	**7572456,96**	**7567689,26**	**7643536,55**	**8277169,09**	**4920576,16**	**7494592,38**	**7793886,01**	
Owners wage			**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	**500000,00**	
Foreign factor cost																							
Management			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Total foreign factor cost			**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	
Margin after foreign factor cost			**10224792,98**	**10302657,56**	**7567689,26**	**4913335,95**	**8028793,05**	**10380977,35**	**7742968,42**	**5063685,41**	**8328629,88**	**4983485,95**	**10382630,48**	**7494592,38**	**7494592,38**	**7572456,96**	**7567689,26**	**7643536,55**	**8277169,09**	**4920576,16**	**7494592,38**	**7793886,01**	
Capital flow																							**Resale value**
Long term																							
Land and fixed improvements			175000000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	175000000
Intermediate capital	Age																						
Tractors (Kw)																							
240	4		2730483,33	0	0	0	0	0	0	0	4095725	0	0	0	0	0	0	0	0	0	0	0	341310,42
125	8		630391,67	0	0	0	1891175	0	0	0	0	0	0	0	0	0	0	0	1891175	0	0	0	1418381,25
100	7		576197,92	0	0	0	0	1382875	0	0	0	0	0	0	0	0	0	0	0	1382875	0	0	1152395,83
100	9		345718,75	0	0	1382875	0	0	0	0	0	0	0	0	0	0	0	1382875	0	0	0	0	921916,67
75	11		77864,58	934375	0	0	0	0	0	0	0	0	0	0	0	934375	0	0	0	0	0	0	467187,50
60	10		116341,67	0	698050	0	0	0	0	0	0	0	0	0	0	0	698050	0	0	0	0	0	407195,83
Harvesters (Kw)																							
201	4		2798333,33	0	0	0	0	0	0	0	4197500	0	0	0	0	0	0	0	0	0	0	0	349791,67
201	8		1399166,67	0	0	0	4197500	0	0	0	0	0	0	0	0	0	0	0	4197500	0	0	0	3148125,00
Wind mowers (with a head)																							
Windmower : 15 feet, 4.57m	2		1578375,00	0	0	0	0	0	0	0	0	0	1894050	0	0	0	0	0	0	0	0	0	473512,50
Windmower : 15 feet, 4.57m	3		1420537,50	0	0	0	0	0	0	0	0	1894050	0	0	0	0	0	0	0	0	0	0	315675,00
Wind mowers																							
Minimum tillage wheat planter- 12,3 m (air pressure seeder)	4		1788307,50	0	0	0	0	0	2980512,5	0	0	0	0	0	0	0	0	0	2980512,5	0	0	0	-894153,75
Deep cultivation implement	5		67629,33	0	0	0	0	0	0	115936	0	0	0	0	0	0	0	0	0	0	0	115936	0,00
Other implements																							
Crop sprayer 24m boomspray - max 3000 L Tank	5		619011,46	0	0	0	0	0	0	1061162,5	0	0	0	0	0	0	0	0	0	0	0	1061162,5	0,00
Fertilizer spreader - Double disc (1500 L) - precision	4		327558,33	0	0	0	0	0	0	0	491337,5	0	0	0	0	0	0	0	0	0	0	0	40944,79
Fertilizer spreader - Double disc (1500 L) - precision	7		204723,96	0	0	0	0	491337,5	0	0	0	0	0	0	0	0	0	0	0	491337,5	0	0	409447,92
Screen	8		107244,33	0	0	0	321733	0	0	0	0	0	0	0	0	0	0	0	321733	0	0	0	241299,75
Baler - Large square baler (120 X 70) (Standard)	5		1408414,58	0	0	0	0	0	0	2414425	0	0	0	0	0	0	0	0	0	0	0	2414425	0,00
Water carrier / firefighting	3		167756,25	0	0	0	0	0	0	0	0	223675	0	0	0	0	0	0	0	0	0	0	37279,17
Vehicles																							
Truck - 7 ton	4		696516,67	0	0	0	0	0	0	0	1044775	0	0	0	0	0	0	0	0	0	0	0	87064,58
Hilux 2.8 GD-6 Xtra Cab Raider	3		383553,75	0	0	0	0	0	0	0	0	511405	0	0	0	0	0	0	0	0	0	0	85234,17
Hilux 2.4 GD	9		79407,50	0	0	317630	0	0	0	0	0	0	0	0	0	0	0	317630	0	0	0	0	211753,33
Trailers																							
Four-wheeledtrailer - 10 ton	4		119408,33	0	0	0	0	0	0	0	179112,5	0	0	0	0	0	0	0	0	0	0	0	14926,04
Four-wheeledtrailer - 10 ton	10		29852,08	0	179112,5	0	0	0	0	0	0	0	0	0	0	0	179112,5	0	0	0	0	0	104482,29
Loaders - front end loaders	9		21706,25	0	0	86825	0	0	0	0	0	0	0	0	0	0	0	86825	0	0	0	0	57883,33
Total intermediate capital:			17694501	934375	877163	1787330	6410408	1874213	2980513	3591524	10008450	2629130	1894050	0	0	934375	877163	1787330	9390921	1874213	0	3591524	9391653
Livestock			9845077																				9845077
Total Capital flow			202539578	934375	877163	1787330	6410408	1874213	2980513	3591524	10008450	2629130	1894050	0	0	934375	877163	1787330	9390921	1874213	0	3591524	194236730
Net annual flow			-192314784,70	9368282,56	6690526,76	3126005,95	1618385,05	8506764,85	4762455,92	1472161,91	-1679820,12	2354355,95	8488580,48	7494592,38	7494592,38	6638081,96	6690526,76	5856206,55	-1113751,41	3046363,66	7494592,38	198439092,72	
IRR	2,59%																						