The financial and managerial implications of herbicide resistance of annual ryegrass in the Central Swartland

By

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Declaration

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own original work, that I am the authorship owner thereof (unless to the extent explicitly otherwise stated) and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

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March 2018

Abstract

Food security is under increased pressure due to the demands set by a growing global population. Farming, the sector primarily responsible for food security, experiences this growing pressure directly. Because arable land is fixed in absolute terms, production levels of available arable land need to increase by optimising yields. To achieve optimal crop yields the yield reducing factors have to be identified and managed to limit impact on production.

Amongst the various yield limiting factors, one of the most important are weeds. This study focuses on winter cereal farming in the Central Swartland area of the Western Cape Province. In this area annual ryegrass has the most significant negative effect on production. This resulted in farmers becoming heavily reliant on the use of herbicides to effectively control ryegrass. This reliance on herbicides together with mal practises regarding the application of herbicides caused ryegrass to develop herbicide resistance.

Herbicide resistance can lead to an increase in the cost of weed control, a decrease in potential income, a reduction in the number of possible crops that can be produced and a decrease in the value of the land. There are various methods to manage and prevent herbicide resistance which are discussed in this study, but the primary conclusion is that various methods of control such as chemical, physical and biological control have to be integrated into a producer's complete weed management program.

The detrimental effect of herbicide resistant ryegrass on the profitability of a winter cereal farm in the Central Swartland are researched on a per hectare basis in this study and forms the central focus of this study. A well-known simulation model, the Resistance Integrated Management model (RIM model), is used to simulate three different scenarios. A multi group discussion was held to verify and validate the parameters and assumptions needed to use this model in the Central Swartland.

The three scenarios simulated in this study were: no resistance; known resistance (glyphosate and paraquat) and an unknown resistance (trifluralin). In both scenarios where resistance was simulated, a worst-case scenario was assumed, in other words zero percentage control. The gross margin per hectare for wheat monoculture (wheat-wheat-wheat-wheat) decrease from R2 488/ha to R329/ha after the effects of the resistance.

With exception of the wheat and medic rotation, the known resistance decreased the gross margin by a minimum of 15% over a ten year period for all the other crop rotations. The unknown resistance decreased some of the crop rotations' gross margins detrimentally, the wheat monoculture system decreased by 86% and the wheat-wheat-wheat-canola and wheat-wheat-wheat-legumes by 67% and 66% respectively. The wheat and canola rotation system were found to be the most profitable in both the no resistance and the known resistance scenarios. The wheat and medics rotation system achieved the highest level of control in all three scenarios as well as achieving the highest gross margin per hectare in the unknown resistance scenario.

Uittreksel

Voedselsekerheid is toenemend onder druk as gevolg van die eise wat ‘n groeiende wêreldbevolking stel. Hierdie druk word direk deur die landbousektor, primêr verantwoordelik vir die handhawing van voedselsekerheid, ervaar. Omdat bewerkbare landbougrond in absolute terme beperk is, is dit noodsaaklik dat produksie op beskikbare grond optimale opbrengste lewer. Ten einde optimale oeste te lewer moet die faktore wat opbrengste beperk geïdentifiseer en korrek bestuur word.

Die produksie van gewasse word deur verskeie faktore beperk waarvan gras onkruide een van die belangrikste is. Hierdie studie fokus op wintergraanverbouïng in die Sentrale Swartland van die Wes-Kaap Provinsie. In hierdie area het eenjarige raaigras die grootste negatiewe uitwerking op opbrengste. Die gevolg is dat landbouers toenemend steun op chemiese onkruiddoders in ‘n poging om raaigras te beheer. Die toenemende afhanklikheid van onkruiddoders tesame met die verkeerde toediening daarvan het gelei daartoe dat raaigras weerstandigheid teen onkruiddoders ontwikkel het.

Weerstand teen onkruiddoders mag lei tot ‘n toename in die koste van onkruidbeheer, ‘n verlies in potensiële inkomste, ‘n afname in die verskeidenheid gewasse wat verbou kan word asook ‘n afname in die waarde van die grond. Die verskeie metodes beskikbaar om weerstand teen onkruiddoders te bestuur en te voorkom word in hierdie studie bespreek. Die primêre gevolgtrekking is dat hierdie metodes, nl. chemiese, fisiese en biologiese kontrole, in ‘n produsent se bestuursprogram geïntegreer moet word ten einde ‘n volledige onkruidbeheerprogram te bewerkstellig.

Die skadelike gevolg van weerstandige raaigras op die winsgewendheid van ‘n wintergraan plaas in die Sentrale Swartland word op ‘n per hektaar basis nagevors en vorm die fokus van hierdie studie. ‘n Welbekende simulasie model, nl. die ‘Resistance Integrated Management model’ (RIM model) word gebruik om drie verskillende scenarios na te boots. ‘n Bespreking tussen verskeie rolspelers in die bedryf is gehou om die parameters en aannames nodig om die model in die Sentrale Swartland te gebruik, te verifieer en te bekragtig.

Die drie scenarios in hierdie studie gebruik, is: geen weerstand; bekende weerstand (glifosaat en paraquat); en ‘n onbekende weerstand (trifluralin). In beide scenarios waar weerstandigheid nageboots is, is die veronderstelling van weerstandigheid in die ergste graad, dus geen persentasie van kontrole, aanvaar. Die bruto marge per hektaar in die geval van koring monokultuur (koring-koring-koring-koring) het van R2 488/ha na R329/ha afgeneem as gevolg van die effek van weerstand.

Met uitsondering van die koring en medic rotasie, het bekende weerstandigheid bruto marges teen ‘n minimum van 15% oor ‘n tienjaar periode laat afneem in al die ander gewas rotasies wat bestudeer is. Onbekende weerstandigheid het sommige van die gewas rotasies se bruto marges uiters nadelig beïnvloed. Die koring monokultuur het ‘n afname van 86% getoon terwyl die koring-koring-koring-canola en die koring-koring-koring-peulgewasse afnames van onderskeidelik 67% en 66% getoon het. Die koring en canola rotasie was die mees winsgewende sisteem in beide die geen weerstand en die bekende weerstand scenarios. Die koring en medics rotasie het die hoogste vlak van kontrole in al drie scenarios getoon asook die hoogste bruto marge per hektaar in die geval van onbekende weerstand behaal.

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1. Chapter 1: Introduction

1.1 Background

In any weed population, there are single plants that are resistant to herbicides. These resistant plants can be as little as one or two but through constant use of herbicides it can quickly grow to make up a reasonable amount of the total weed population. Living organisms such as ryegrass, generally have sophisticated biological and biochemical adaptability. It was thus inevitable that biotypes of weed species that became resistant to herbicides would eventually evolve (Putwain, 1990).

Weed resistance was first identified in 1964 and currently there are more than 183 species that have been reported to be resistant against herbicides worldwide. Of that 183 species, eight species have been recorded in South Africa. These are: *Avena Fatua* (Wild Oat), *Lolium rigidum* (Rigid Ryegrass), *Amaranthus hybridus* (Smooth Pigweed), *Raphanus raphanistrum* (Wild Radish), *Phalaris minor* (Little seed Canary grass), *Stellaria media* (Common Chickweed), *Conyza bonariensis* (Hairy Fleabane) and *Plantago lanceolate* (Buckhorn Plantain). Five of these species have been recorded in the Western Cape alone (Heap, 2015). A population is defined as resistant when more than 20% of plants survive the herbicide application and as developing resistance when the survival range is between one to 20% (Owen *et al.* 2014). During the last four decades, farmers have come to rely heavily on the use of herbicides to control weeds whilst other methods of weed control, such as physical control, became less popular. While the focus on herbicides have been rewarding economically, several problems arose from this over-reliance on herbicides, the biggest probably being; weeds developing resistance against herbicides.

Ryegrass (Lolium spp.) is one of the most difficult, if not the most difficult, weed to control in cereals, orchards and vineyards in the Western Cape. It can be cross-pollinated and after a very short period of time the seeds start to germinate therefore, ryegrass is a species that develops resistance over a very short time span (Cairns & Eksteen, 2001). There has also been a discovery of paraquat resistance by ryegrass in the Western Cape and this gives reason for added significance, given that resistance to glyphosate have been found to be widespread in the Western Cape (Cairns & Eksteen, 2001). These two herbicide groups, account for more than 80% of all herbicides used in vines and deciduous fruit in the Western Cape. A study was done in 2007 in the Waveren valley near Tulbagh where it was discovered that ryegrass is resisting glyphosate and paraquat and during the course of that study resistance was found to be much more widespread than initially thought (Eksteen, 2007).

This resistance against herbicides have definitely had an enormous impact on the cost of weed control for farmers and have an influence on the type of methods farmers use to generally control weeds. While herbicides will always play a major role in the management of weeds an integration of systems and the combining of different methods of weed management will have to be considered in order to eliminate resistant and non-resistant weeds.

Herbicide resistance can have the following detrimental effects:

- Decrease in potential income;
- Increase in the cost of weed control;
- Decrease in the value of the land; and
- Reduction in the number of possible crops that can be produced.

These problems could be addressed by management aiming to prevent development of resistance, or by managing the problem if it already occurs. It is difficult, and expensive, to identify and develop new chemicals, these new chemicals take time to develop so that by the time it is ready for use, the weeds have already developed resistance against it (Britton, 2006). It is thus of utmost importance that farmers start considering integrated weed management systems. These systems may include physical, mechanical, chemical and biological methods. Whether management aims to prevent or contain resistance, it can be done through the following methods:

- Tillage practises;
- Rotation of herbicide groups and mixtures;
- Spraying herbicides at the rate as prescribed on the label on the recommended weed sizes;
- Rotational cropping;
- Higher crop seeding rates;
- Using grazing in a pasture phase of the rotation;
- Prevent seeds from entering the weed seedbank;
- Managing or destroying weed seeds during harvesting; and
- Prevent field-to-field distribution of weed seeds when harvesting etc.

However, farmers find a number of difficulties in their decision-making in terms of integrated weed management strategies such as:

- Strategies need to be evaluated over a longer period and not just for a single year;
- The farmers are unfamiliar and inexperienced with a number of the control options;
- The long-term impacts of multiple control options are difficult to predict;
- Some strategies have indirect, as well as direct costs; and
- There are a vast number of possible combinations of treatments to be considered.

This gave way to which a computerised decision support system could be especially valuable to farmers and farm advisors. This is why the RIM (Resistance and integrated management) model was developed. RIM is a decision support system that is designed to provide information and insights to farmers to help in their long-term decision-making about management of specifically annual ryegrass. RIM allows the user to simulate many different combinations of weed control treatments and observe their predicted impacts on ryegrass populations, crop yields and economic outcomes within a 10-year period (Pannel *et al.*, 2004).

1.2 Research problem and goals

1.2.1 Problem statement

Farmers' over reliance on herbicides to manage weeds have primarily contributed to a large number of weed populations evolving and building up resistance against herbicides. Five of the eight weed species that have been recorded to build up resistance against herbicides in South Africa are found in the Western Cape and all five weeds are found in the winter cereal production areas of the Western Cape. This resistance against herbicides will negatively impact farmers' profitability, because herbicides are one of the grain farmer's largest expenditures. Therefore, the impact of herbicide resistance on farmers' profitability has to be researched. Alternative ways to manage herbicide resistance in a profitable and sustainable manner need to be identified and assessed. The research question therefore is: "What is the impact of herbicide resistance on profitability and what alternative management strategies, besides chemical control, are options?"

1.2.2 Research questions

The research questions that have to be answered in this study are the following:

- Do herbicides play a significant enough role in a grain farmer's for him/her to consider looking in to it?
- What are the impacts of weed resistance in monetary terms?
- What are all the management options available to prevent or treat this herbicide resistance of weeds?

1.2.3 Primary objective

To measure the impact herbicide resistant ryegrass has on a grain farmer's profitability and to identify and assess profitable management options of dealing not only with ryegrass resistance but also with the annual ryegrass itself.

1.2.4 Secondary objectives

In the search of reaching the primary objective, a number of secondary objectives have to be met:

- Define herbicide resistance;
- Determine whether there is any resistance in the Western Cape and against which herbicides;
- A multi-disciplinary group discussion must be held with various experts, validating certain data in order to identify a realistic "typical paddock, typical crop rotations with their typical ryegrass control strategy" of a "typical farm" in the Central Swartland area.
- To adopt and verify the assumptions that are being used in the Australian RIM model so that it can be used in South Africa and the Central Swartland in particular.
- Apply the verified RIM model to calculate and determine the influence on profitability given different weed management options in grain producing farms of the Central Swartland.

1.3 Methodology of this study

The point of departure for this study is the fact that ryegrass is becoming more resistant causing its influence on winter cereal farming systems to become more apparent. The literature review will be used to define herbicide resistance and describe cases of resistant ryegrass that have been recorded in the Swartland region. An overview of the South African, Western Cape and Swartland's wheat industries serves to put the role of the Swartland's wheat industry in perspective in a provincial and national context. Various prolific wheat-producing areas of South Africa are compared to Australia. Due to insufficient research in South Africa, in terms of calculating the cost of herbicide resistance, focus is on a country such as Australia, for which the research has been done and actual numbers exist. This serves as a platform to form a relative idea in terms of the cost of herbicide resistance.

The study focuses on calculating the cost of herbicide resistance by using simulation modelling as the method in this study. The RIM-model developed in Australia by the University of Western Australia was updated by a panel of experts and applied to the Central Swartland region. A systems approach underlay the process of updating the model. It views the farm as a complex system with various different components influencing one another through a sequence of inter-relationships. A multi-disciplinary group discussion was held during which the combined ideas and opinions of experts from various disciplines were discussed. Each party gave input on specific assumptions of the model, relevant to their field of expertise. The model was updated through various other ongoing discussions with the various experts of the specific assumptions to improve the model's accuracy. A 'typical farm' with 'typical crop rotations' each with their 'typical ryegrass control strategy' of the Central Swartland was developed. The 'typical farm' values were obtained from data provided by agribusinesses in the area and was presented to the panel of experts and who validated them.

The 'typical farm' with the five most 'typical crop rotations' and their subsequent 'typical ryegrass control strategy' were simulated in the updated RIM-model, discussed and compared. This provided relatively accurate estimates of what the cost of herbicide resistance of ryegrass could be in the Central Swartland. These estimates were calculated on a per hectare-basis and also indicated the required level of control that are achieved if herbicide resistance should occur in these 'typical control strategies'.

1.4 Outline of the study

Chapter 1 gives background on the problem of herbicide resistance and states the problem that are to be researched in this study. Chapter 2 discuss annual ryegrass and show against which herbicides it already has developed resistance in the Swartland. A general overview of the South African, Western Cape and Swartland's wheat industry are provided to highlight the magnitude of the problem. A comparison between the most prolific industries of South Africa and Australia are made. The cost of herbicide resistance of ryegrass from an Australian perspective is discussed because of their experience of research and costs. A general idea of the cost of herbicide resistance is formed. This chapter concludes with a description of a framework that can be used to calculate the cost of weed management.

An overview of modelling and especially simulation modelling is discussed in Chapter 3. It is the method this study will follow in estimating the various effects of herbicide resistance on a typical farm in the Central Swartland. The RIM-model and all of its components is discussed in Chapter 4.

In Chapter 5, values and data of a 'typical farm' in the Central Swartland are simulated in the updated RIM-model. These values were obtained through a multi-disciplinary group discussion and ongoing personal interviews with experts of the various subjects. The various results and findings of the three different scenarios simulated in RIM are discussed and compared. The last chapter of this study then concludes with final remarks and recommendations that can be used for future studies.

2. Chapter 2: Literature review

2.1. Introduction

Chapter 1 discussed the purpose of this study and stated that the problem this project focus on is the financial implications of annual ryegrass resistance to herbicides on farm level.

Chapter 2 describe, in depth, the mechanism of herbicide resistance and against which herbicides resistance have been found in annual ryegrass in the Swartland region. An overview of the South African, Western Cape and the Swartland's wheat industry is provided in order to understand the magnitude and size of the mentioned industries. This overview gives an understanding of the total contribution of the Swartland in the Western Cape and the South African wheat context.

There are limited research and data regarding the economic impact of resistant ryegrass on the South African wheat industry. The impact of herbicide resistant ryegrass on the economy of wheat have been extensively studied in Western Australia, which have a similar climate to that of the Swartland. A comparison between the Australian and South African wheat industries are made, firstly to understand how the two industries differ in terms of volumes. Secondly, to understand their relative contributions towards the economy of the particular country. The cost of weeds in Australia, ryegrass in particular, are discussed and the cost of herbicide resistance. Again, due to limited research in South Africa, impacts are suggested based on Australia's figures. Comparing South Africa and Australia's wheat industries and costs of weeds, it paints a picture of the detrimental effects this resistance can have on South Africa if left unchecked and unmanaged. Lastly, a framework to measure or calculate the costs or impacts of weeds on an industry level is presented.

2.2. Description of *Lolium* spp.

In the context of this study, annual ryegrass will be used to refer to various hybrids and pure types of *Lolium multiflorum* (Italian ryegrass), *Lolium rigidum* (rigid ryegrass), *Lolium perenne* (perennial ryegrass) and *Lolium termulentum* (darnel). These occur in the different areas in the Swartland. Annual ryegrass are monocotyledonous plants belonging to the family Poaceae (Eksteen, 2007). These plants originated originally from the Mediterranean countries and have adapted very well to the agricultural areas of the Western Cape. There are some that is native to North America, Europe and temperate Asia. Similarities in vegetative, flower and seed features result in these grasses all being known as ryegrass (Britton, 2006).

"The adult plant of *L. rigidum* grows to a height of 15-60 cm. The plant is tufted and glabrous. The stems are erect or at first prostrate then ascending. The leaves are shiny beneath, smooth, flat and 2-6 mm broad. Sheaths are slightly swollen, especially that of the upper leaf" (Eksteen 2007).

Annual ryegrass (*Lolium* spp.) is a prolific seed producer. Under ideal conditions it can produce dense stands, up to 45 000 seeds per square meter. Annual ryegrass can rapidly achieve high seed densities (seed banks) and subsequent high seeding numbers at emergence. Even with good control in a crop, survivors can still tiller well and exploit the available space, resulting in high numbers of viable seed (Davidson, 1990). The major influence on rate of development of annual ryegrass appears to be the cold requirement (vernalisation) for flower initiation. A long photoperiod also hastens the rate of development both before and after flower initiation (Aitken, 1966). Aitken (1966) concluded that because of its short cold requirement and low critical photoperiod, annual ryegrass is well suited to a short and variable growing season.

Although annual ryegrass is not the most competitive plant in terms of procuring nutrients, once the numbers of the seed bank are high and the ryegrass becomes established early in the growing season of the crop, the damage is done. This ability of ryegrass plants to produce large numbers of tillers makes annual ryegrass a competitive weed and even a low density of plants can return a large number of seed to the seed bank (Eksteen 2007).

Lolium spp. is small seeded and is a shallow germinator that reproduces from seed only (Botha, 2001). The optimum temperature for germination is much lower for buried seeds (11º C in darkness compared to 27º C in light). This means that shallow buried seed will mostly germinate in autumn and early winter, when undisturbed conditions are most favourable for seedling survival. Peak germination occurs at the break-of-season, after the first rainfall that exceeds 20 mm. This usually results in 75 to 80 percent of germination for the season (Britton, 2006).

Annual ryegrass is a wind pollinated out-crosser, which, when coupled with its large genetic variability, contributes to its ability to rapidly adapt to a wide range of climatic and other factors such as break-of-season rains, cultivation practices and herbicide use. Herbicide susceptible plants can build resistance to a particular group of herbicides via pollen of resistant plants and the resistant seeds will produce resistant plants (Richter & Powles, 1993).

2.3. The mechanism of herbicide resistance

Weed resistance is the natural ability of some weed biotypes within a given weed population to survive a certain herbicide treatment that would, under normal conditions, effectively control that weed population (Herbicide Resistance Action Committee, 2015).

When high selection pressure is being exerted on a weed population for several years weed resistance often becomes a problem. This may be the result of several factors such as:

- ❖ repeated use of the same herbicide,
- ❖ herbicides are sprayed at a lower dosage than the prescribed rate,
- ❖ different herbicides used, but they all have the same mode of action; and
- ❖ Crop monoculture and improper cultivation practises (Herbicide Resistance Action Committee, 2015).

Farmers are always looking to minimize their costs and maximize their profits and the use of herbicides was the economically feasible option. As farmers wanted to make more profit, they shifted away from integrated methods to control weeds and relied solely on herbicides. This culminated over a period when conservation agricultural practices gained momentum. One of the foundations of conservation agriculture is minimum soil disturbance. This practise inevitably makes farmers more reliant on chemical control of weeds and this paved the way for weeds to develop resistance and become the problem that it is today.

2.3.1 Resistance of paraquat in annual ryegrass in the Western Cape

In South Africa paraquat were by far the most important herbicide for the control of annual weeds in orchards and vines since they came on the market in the mid 1960's. Paraquat is the name used in the industry for *N, N'-dimethyl-4, 4'-bipyridinium dichloride*. From the mid 1970's the bipyridylium herbicides were starting to be replaced by glyphosate and this has resulted in paraquat becoming less popular (Bradshaw *et al.*, 1997). Nevertheless, it is still extensively used and the total amount of paraquat sold annually continues to increase (Eksteen, 2007).

Some of the key characteristics of paraquat:

- It is fast-acting;
- It kills annual grasses as well as broad leaved weeds; and
- It is rain-fast which means it will not be washed away by rain.

There has been widespread resistance of ryegrass to paraquat reported in the Western Cape (Heap, 2015). The discovery of paraquat resistance in ryegrass takes on an added significance, given that resistance to glyphosate has also been found to be widespread in the Western Cape (Heap, 2015).

Paraquat and paraquat/diquat mixtures are very important herbicides for use in perennial crops. Anti-resistance practices need to be put in place to maintain the spread or even eradicate the existence of paraquat resistance. The use of products with an alternative mode of action to paraquat will have to be implemented to have any chance of success (Eksteen, 2007). According to the study done by Eksteen (2007) farmers in the Western Cape are running out of herbicidal options to control ryegrass and it has become very urgent that a solution is found for this fast-growing problem.

2.3.2 *Lolium* spp. resistance to glyphosate in annual and perennial crops in the Western Cape

Glyphosate is the world's most widely used herbicide (Eksteen, 2007). It is non-selective and controls a broad spectrum of weeds which includes broadleaf weeds as well as grass weeds and is commonly known as Roundup. There were reports of poor control of ryegrass with, non-selective herbicide, glyphosate in perennial crops (Cairns and Eksteen, 2001). These crops are of such a high value that it permits to large amounts of herbicide use and there are typically no to very little tillage on these lands. Glyphosate forms the backbone of a weed control program for perennial crops. The resistance of ryegrass against glyphosate is very significant in terms of weed management. In some areas, glyphosate have been used on a continuous basis since the introduction of the herbicide in the early

1970's. The product was thus overused and it resulted in a steady growth of resistant individual plants (Powles *et al.*, 1998).

According to Eksteen (2007) resistance to glyphosate can occur if there is persistent use of glyphosate, which is the case. The high level of resistance that was found in the ryegrass of the Western Cape is however surprising. The occurrence of resistance to glyphosate is very significant in terms of weed management in perennial crops. This limits options for weed control in these crops and poses a real threat to the winter cereal industry. Resistance in annual ryegrass is one of the most economically important examples of herbicide resistance in world agriculture (Powles *et al.*, 1997).

2.4. Overview of the South African, Western Cape and Swartland's wheat industries

2.4.1 Background

Wheat is one of the most important winter cereal grains grown in South Africa (Otto, 1990). The South African crop production environment is variable and wheat is grown as spring as well as a winter crop under irrigation, but mostly under dryland circumstances. The crop is produced mainly for human consumption, although small amounts that are not suitable for milling purposes are used as stock feed (Sartorius Von Bach and Van Zyl, 1994). The main wheat producing provinces of South Africa are the Western Cape, Free State and Northern Cape. Wheat also contributes up to 60% of the total seed market of all winter cereals, accounting for a potential 142 million rand in value (Jordaan, 2002).

South Africa has been a net importer of wheat for the past decade, as illustrated on Figure 2.1. Wheat imports have doubled over the last decade. Figure 2.1, illustrates that the amount being imported have increased significantly between 2013 and 2015 from just under 1,5 million tons to well over 2 million tons.

Figure 2.1: Import and Export of wheat in South Africa from 2006 to 2015 (Trademap, 2016)

2.4.2 Area planted

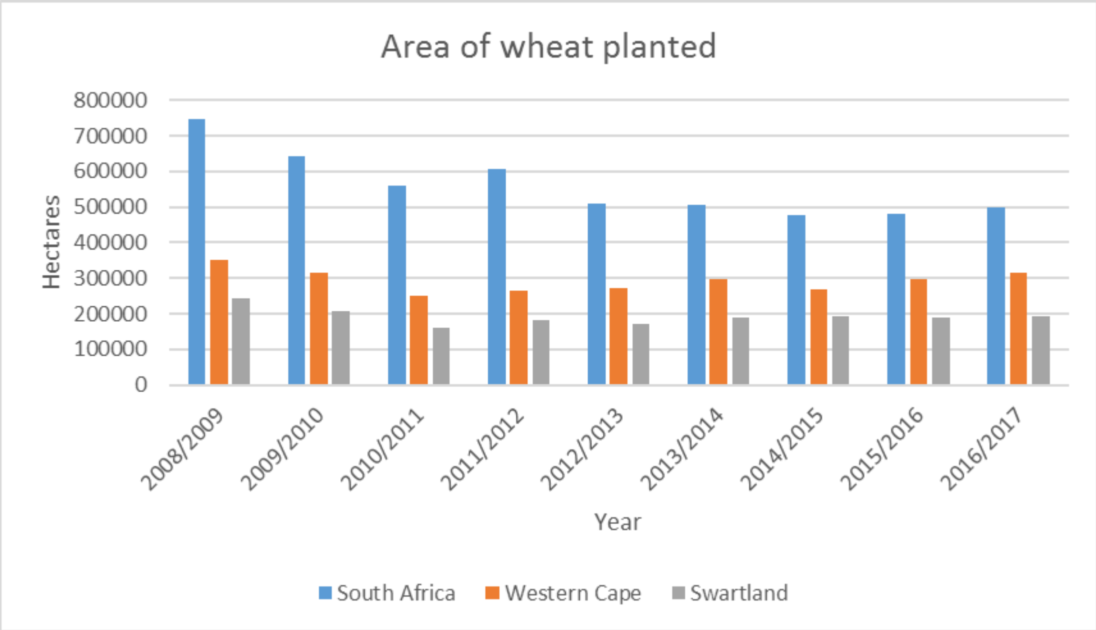


Figure 2.2: Total area of wheat planted in South Africa, Western Cape and Swartland from 2008-2017 (SAGIS, 2017).

South Africa

South Africa's total area of wheat planted reached a maximum of just less than 2 million hectares in 1988. The Free State playing a major role as almost half of South Africa's dryland wheat in terms of the total area of wheat planted were in the Free State. The government followed with an incentive for wheat farmers to plant alternative crops and convert their wheat fields to grazing pastures and a severe drought in 1992 contributed largely to the major drop in hectares' wheat planted during that period. This trend of a decline in wheat planted, continued long after the government incentives disappeared and resulted in only 70 000 hectares of wheat planted in the Free State in the year of 2014 compared to more than 1 million hectares in 1988 (BFAP, 2015).

From Figure 2.2 it's clear that the area planted under wheat in South Africa has decreased significantly. In a time-frame from 2008 to 2016 it went down from 748 000 ha to 498 150 ha. The main drivers of this decrease in wheat planted in South Africa was profitability, production risk, changing weather patterns and more profitable alternative crops.

Western Cape

Although South Africa's total area planted under wheat decreased almost by half, the Western Cape's area of wheat planted have remained relatively constant. South Africa's area planted decreased by 33% from 2008 until 2016 and in the same period the Western Cape's area contrastingly stayed the same. This is significant, because it is means that wheat farming in the Western Cape still makes sense economically. This is partly because of a lack of alternative crops for the Western Cape. Of all of the wheat planted in South Africa for the year of 2015 more than 60% were planted in the Western Cape. The same figure was only 37.5% in 2005, which shows how big of a role player the Western Cape have become in South Africa's wheat industry (SAGIS, 2017).

Swartland

The total area of wheat planted in the Swartland has remained constant from 2008-2016. In 2008, it was an extremely good year for wheat in terms of area planted. However, looking at the trend, it fluctuated around 180 000 hectares and the area planted shows only movement sideways.

2.4.3 Wheat Production

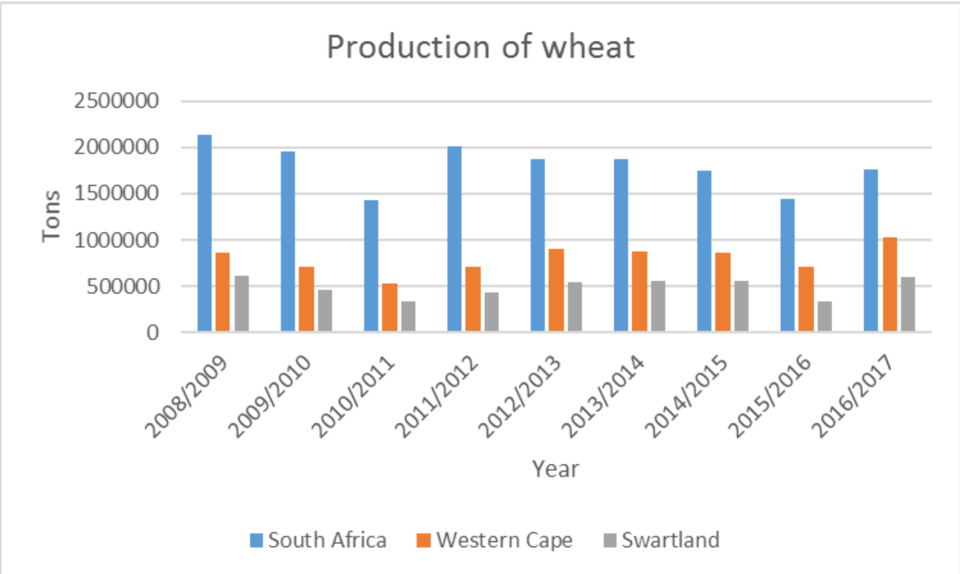


Figure 2.3: Total Production of wheat of South Africa, Western Cape and Swartland from 2008-2017 (SAGIS, 2017).

South Africa

South Africa's wheat production decreased by 8% between 2005 until 2015. During the same period the total area of wheat planted has decreased significantly. The yield per hectare, shown in Figure 2.4, increased significantly and compensated for the loss in area planted, this kept the production fluctuating between 2.1 million and 1.7 million tons from 2005 until 2016 (SAGIS 2017).

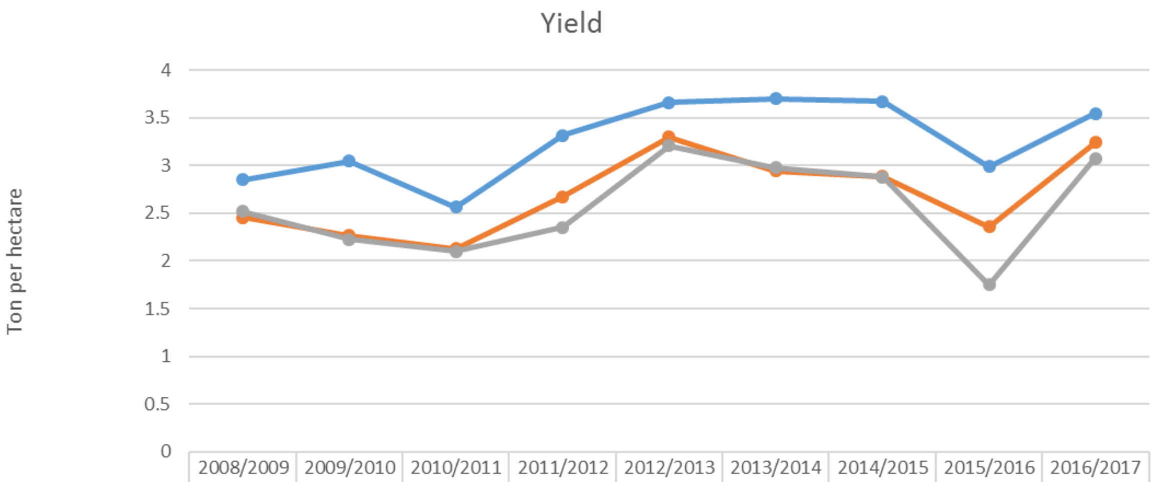
Western Cape

The Western Cape's production increased, as the yield per hectare increased from 2008 until 2016. It is interesting to note that in 2008 there was more wheat planted (approximately 34 467 hectares more) than in 2016 but due to the high yield in 2016 there was a lot more wheat produced in 2016 (approximately 161 623 tons more).

Swartland

The Swartland produced their most wheat over the last nine years since 2008. This is mostly due to the fact that in 2008 the most wheat was planted over the same period as well. The Swartland's production of wheat has fluctuated a lot over the past nine years. In 2008, just over 600 000 tons was produced and then two years later just over 330 000 tons. After a disappointing year in 2010, the production of wheat went up and stayed in the area of 500 000 tons. Except for 2015 when the Swartland experienced a severe drought, which can be seen in Figure 2.3.

2.4.4 Yield



	2008/2009	2009/2010	2010/2011	2011/2012	2012/2013	2013/2014	2014/2015	2015/2016	2016/2017
South Africa	2.848	3.047	2.562	3.316	3.658	3.699	3.672	2.987	3.546
Western Cape	2.457	2.267	2.129	2.67	3.3	2.944	2.883	2.358	3.238
Swartland	2.518	2.228	2.097	2.352	3.208	2.974	2.88	1.75	3.072

Figure 2.4: Yields of South Africa, Western Cape and Swartland from 2008-2017 (SAGIS, 2017).

2.4.5 Conclusion

The Western Cape is seen as the breadbasket of South Africa because of the total area of wheat planted in the province. This is highlighted by the fact that from 2006 until 2016, 48% of the total area of wheat planted in South Africa was in the Western Cape. The province also accounted for 40.82% of the total amount of wheat that was harvested in South Africa over the same period of time (SAGIS, 2017). The Western Cape have become a much bigger role player relatively in South Africa's wheat industry since 2006, because it contributes over 60% of the total area planted and 57.8% of its wheat production for 2016. This indicates that wheat is still a profitable industry in the Western Cape.

Two areas, namely the Overberg and the Swartland, make up the majority share of wheat produced in the Western Cape. Over the last nine years the Swartland averaged 65.7% of all the wheat planted and 61.7% of all the wheat produced in the Western Cape. Over the same period but in terms of a South African outlook the Swartland averaged 34.8% from the total area of wheat planted in South

Africa and averaged 27.2% of the total of wheat produced in South Africa. According to these statistics, the Swartland is the biggest producing area of wheat in the Western Cape and the Western Cape being the biggest wheat producing province in South Africa. It shows the importance of the Swartland in a national context.

2.5. A Comparison between the wheat industry of South Africa and Australia

2.5.1 Production overview

Australia have been consistently producing more than 20 million tons of wheat each year for the past six years. This accounts for more or less 3% of the annual global wheat production each year (Trademap, 2016). Annually around 80% of Australia's wheat is exported due to its relatively small domestic demand. Australia is the third largest exporter of wheat, Canada being first and USA second, with Australia having 11.4% share of total global wheat exports (Trademap, 2016). Wheat is a significant contributor to the Australian economy and generates more than 3 billion US dollars annually. South Africa's wheat production is around 1.5 million tons a year. South Africa is a net importer of wheat due to its large domestic demand and domestic supply being insufficient. The reason for this comparison between South Africa and Australia is that both have similar climates and the main reason is to analyse how competitive South Africa is in terms of its wheat industry, against a big global role player such as Australia.

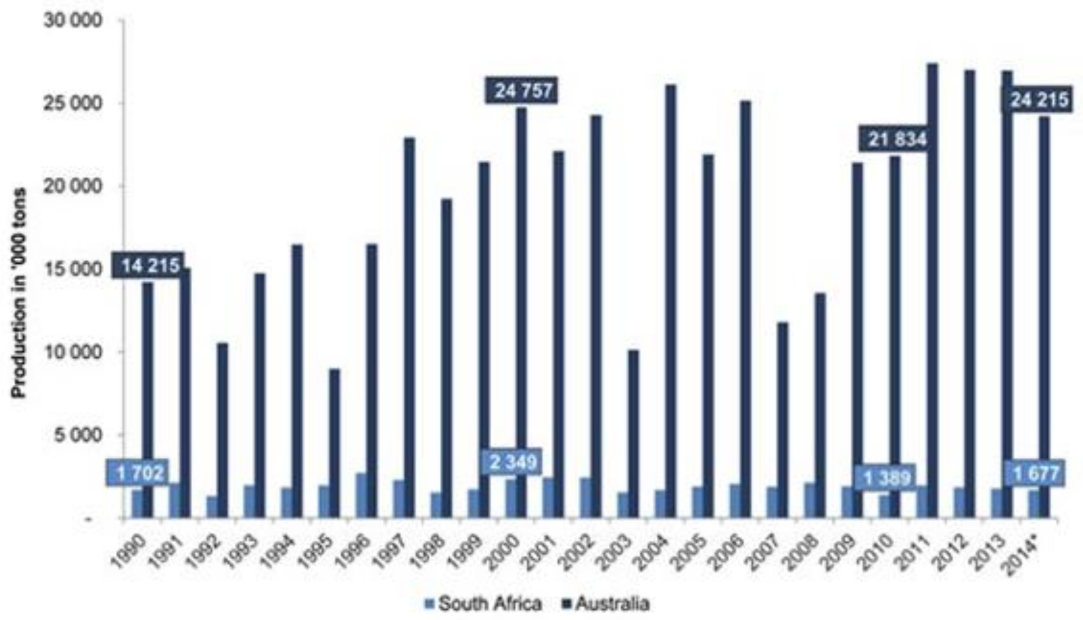


Figure 2.5: Production of South African wheat versus Australia (BFAP, 2015)

2.5.2 Area

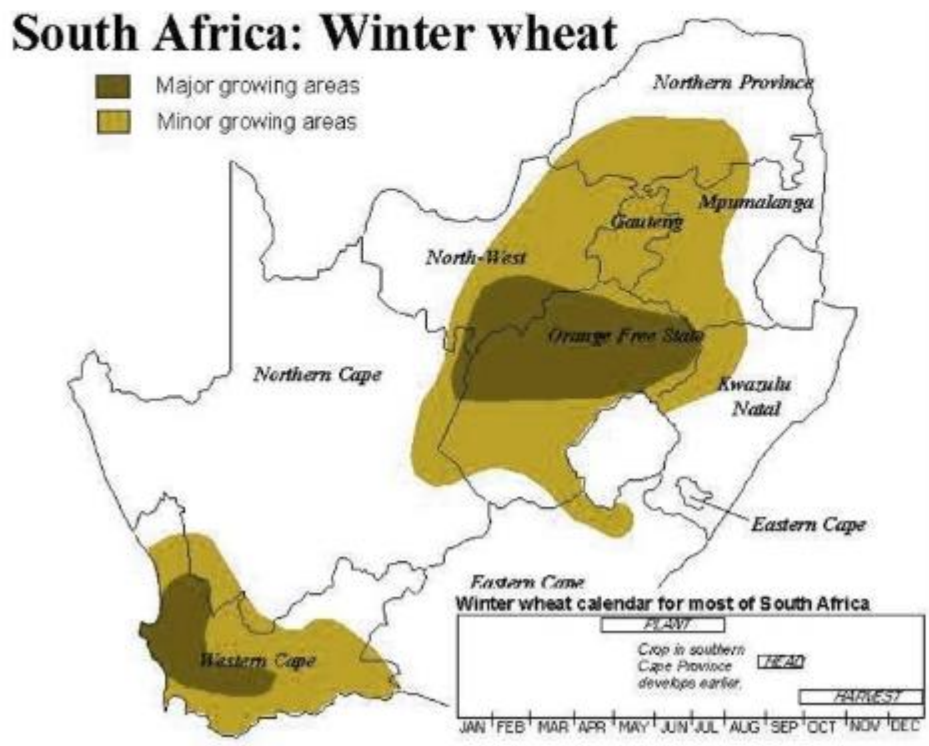


Figure 2.6: South Africa's wheat producing areas.

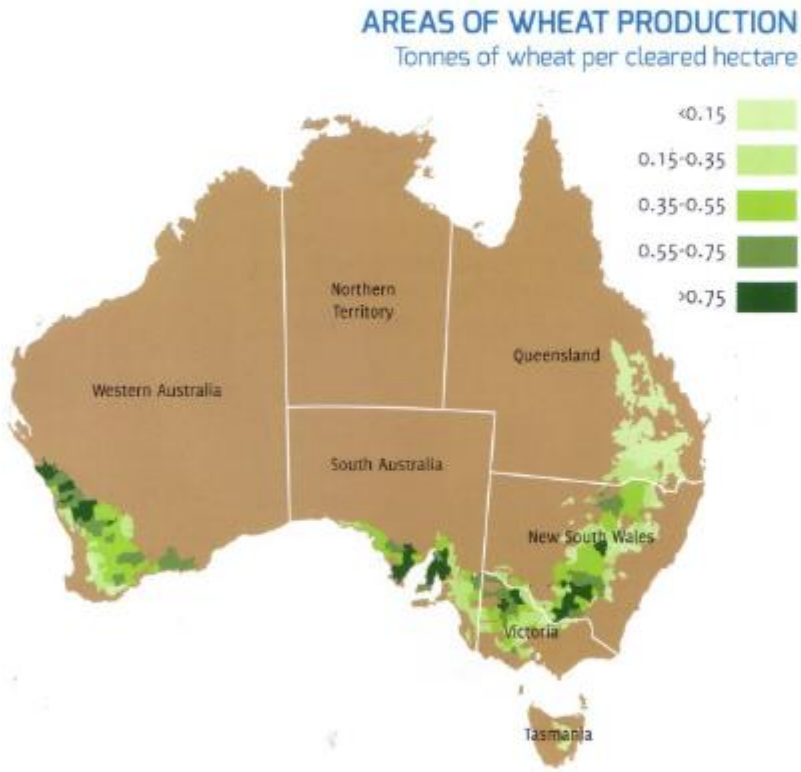


Figure 2.7: Australia's wheat producing areas.

South Africa's main wheat producing areas are the Western Cape, Northern Cape and Free State. In Australia it is New South Wales, Victoria, Southwest of Western Australia and the South Coast of South Australia. South Africa produced 1.75 million tons of wheat under 476 570 hectares while Australia produced 23.6 million tons on 13.81 million hectares in 2014 (SAGIS and BFAP, 2015). Australia uses more land for the production of wheat than South Africa because over the last 20 years Australia have never planted less than 10 million hectares of wheat. Comparatively South Africa haven't planted more than 1 million hectares of wheat in the last 16 years. South Africa's wheat producing have also declined from 934 000 hectares in 2000 to 476 570 in 2014 whilst Australia's area increased from 12.14 million hectares in 2000 to 13.81 million hectares in 2014 (BFAP, 2015)

2.5.3 Yield

South Africa and Australia's yield trend was more or less equal from 1990 until 2000 except for Australia's drop in 1995. Since 2000 South Africa have definitely outperformed Australia in terms of yields (BFAP, 2014). The drought, that occurred Australia during 2006, is evident in Figure 2.8 and it was mainly responsible for this drop in yield per hectare. South Africa's wheat yield per hectare have increased consistently from 2000 until 2014 while Australia haven't really experienced growth for the same period, it fluctuated a lot but over the whole ten years it moved in a straight line.

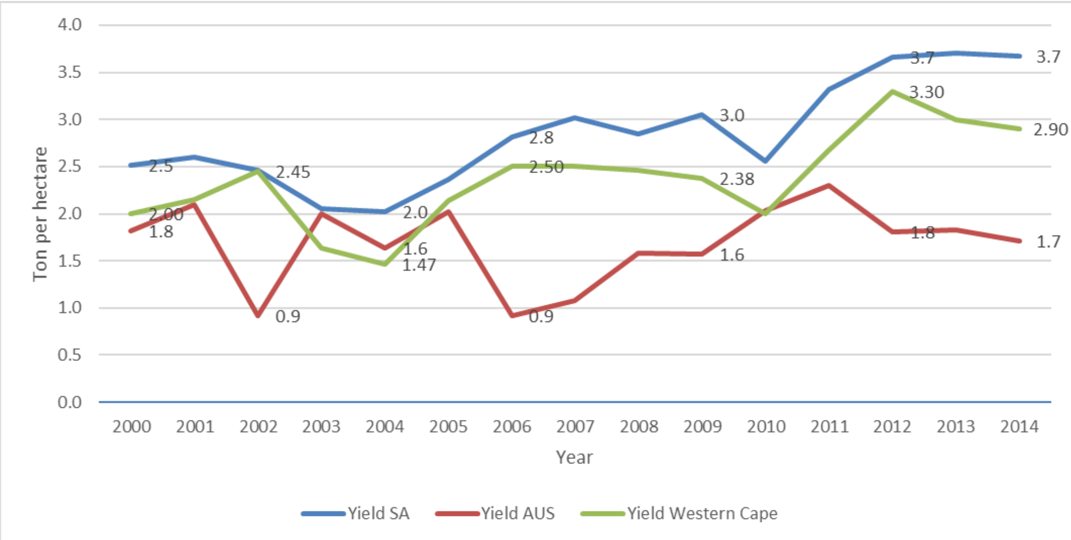


Figure 2.8: Yield comparisons of wheat for SA, AUS and Western Cape from 2000 until 2014 (SAGIS and Australian bureau of census and statistics, 2015)

2.5.4 Wheat price, costs and gross margins

The wheat price that South African producers received is higher than those of their Australian counterparts. This is mainly due to the fact that South African wheat attracts an import price that is higher than the export price of Australian wheat (BFAP, 2015).

In a study done by BFAP in 2015 a comparison was made between various main wheat-growing areas in Australia and South Africa. The Australian areas were the Western Australian Wheat Belt and the Western Australian South Coast and the South African regions were the: Overberg and the Eastern Free State. The data that was used in this study are as follows:

- Australia - Average between 2009 until 2013
- South Africa – Overberg: average between 2008-2013 and Eastern Free State: average between 2012-2013.

In terms of the cost structure which consists of: fertilizer, seed, plant protection, contractor and diesel costs, both of the South African regions were outperformed by their Australian counterparts. The contractor and diesel costs in both South African regions were significantly higher than that of the Australian regions.

The total establishment cost per hectare in US dollars are as follows: Western Australia's South Coast (261$) showed many similarities with the Eastern Free State (276$) in terms of cost structure. Thus Overberg's total establishment cost per hectare was much higher than the rest at 361 US dollars per hectare while the Australian wheat belt was the lowest at 199 US dollars per hectare.

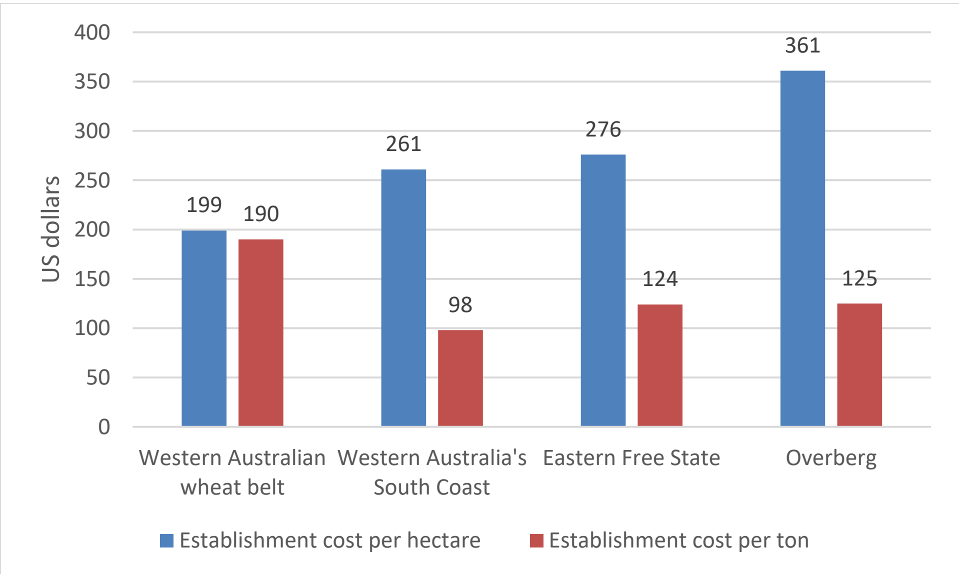


Figure 2.9: Establishment costs per hectare of wheat and establishment costs per ton of wheat in US Dollars for South Africa and Australia (BFAP, 2015).

The cost per ton of wheat produced gives a different picture because the yield per hectare are taken into account and the regions did as follows (US dollars per ton of wheat produced):

1. Western Australia's South Coast – 98$
2. Eastern Free State – 124$

3. Overberg – 125$

4. Western Australian Wheat Belt – 190$

It is evident that Western Australia's South Coast produces wheat the most efficiently amongst these regions followed by the Eastern Free State, the Overberg and the Western Australian Wheat Belt. The low yields of the Australian Wheat Belt increased the cost per ton dramatically.

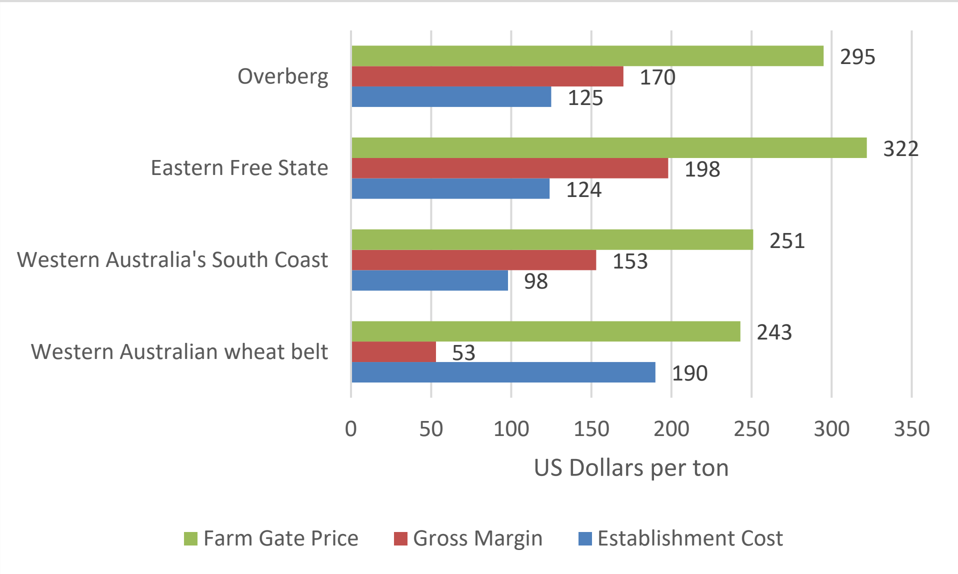


Figure 2.10: Farm gate price in US$ per ton of wheat for various wheat producing areas in South Africa and Australia (BFAP, 2015).

Both of the South African regions can compete against their Australian rivals in terms of the costs to produce a ton of wheat. The South African producers enjoys a higher gross margin due to higher output prices that is a result of the import parity status of South African wheat. However, even though South African producers enjoy higher margins the reality is that the magnitude of Australia's wheat industry gives a comparative advantage over South Africa. Wheat producers in Australia have economies of scale which is much more beneficial than South Africa's higher margins. In 2011 Australia had 29 786 wheat producers with an average farm size of 453 hectares while in South Africa only 3 925 farmers produced wheat with an average farm size of 154 hectares. Each Australian farmer produced more than twice the amount of wheat their South African counterpart produced in 2011, thus Australian wheat producers can spread their overhead costs over much larger units of output resulting in more profit (BFAP, 2015).

2.7.5 Conclusion

It is evident that a small producer of wheat, such as South Africa, can compete against a bigger global role player, such as Australia. In some instances, such as gross margin, yield per hectare and farm gate price South Africa even outperformed Australia. However, sheer size of the Australian wheat industry and of their farms enables them to spread their overhead costs over more tons of wheat making their farms achieve a comparative advantage over South African farms.

2.6. The cost of weeds an Australian perspective

Weeds are recognised as a major problem in the South African as well as the Australian grain industry. Weeds have various negative impacts on the economics of the industry and profitability of a farm because it reduces yield, contaminates the crop and creates a cost to manage it. The weed challenge faced by farmers is also constantly evolving with changes in weed types and even some of their characteristics such as herbicide resistance, which requires an ongoing adaptation of management strategies (Llewellyn et al, 2016).

In a study done by Jones et al. (2003) the financial cost of weeds in seven field crops in Australia was AU$ 1, 182 million for the year 1998-1999. The main contributors to this amount were herbicides (AU$571 million), the competitive effects of residual weeds (AU$ 380 million), tillage (AU$ 206 million) and weed contamination (AU$ 25 million).

A recent study done by Llewellyn et al. (2016) showed that the total cost of weeds to Australian grain growers is estimated at $3, 318 million (US dollars). That consists of total yield revenue loss ($745 million) and the total cost of the management of weeds ($2, 573 million). Some of the key findings of that study was that ryegrass remains the major weed, in terms of the cost of herbicide resistance. The cost of ryegrass is more than all of the other forms of resistance combined. Herbicide resistance was estimated to cost $187 million in additional herbicide treatment costs, over and above the extra costs of using integrated weed management practises.

2.7. A framework to measure or calculate the impact of weeds on an industry level

The costs regarding the impact of weeds can easily be misinterpreted. The direct costs, such as the cost of the herbicide and the labour, that is used to apply herbicides are relevant, but they only form part of the impact weeds have on total cost. Opportunity costs that arise such as losses in production, losses in value of output and even losses in labour productivity due to a weed invasion are very important and have significant effects on the farm and the industry as a whole and should not be underestimated (Sinden *et al*., 2004).

Sinden *et al. (2004)*, showed there was a framework to measure these problematic impacts of weeds that would incorporate both the expenditure on weed control (*E*) and the loss in production (*L)*. Figure 2.11 uses a loss-expenditure frontier (L_1L_2) that shows how much the weed loss change due to changes in different levels of control costs. Losses would be at their maximum where there is no control while losses will be at a minimum where control is at a maximum. Crop production such as wheat production is depicted in the Central of the frontier (X_C) where there are substantial losses and substantial control costs. X_H would be an example of an industry such as horticulture, which typically involves high control costs and low production losses per hectare due to weeds. X_L presents an example of an industry such as livestock and land used for grazing where the control costs are low and the production losses per hectare are high due to the impact of weeds.

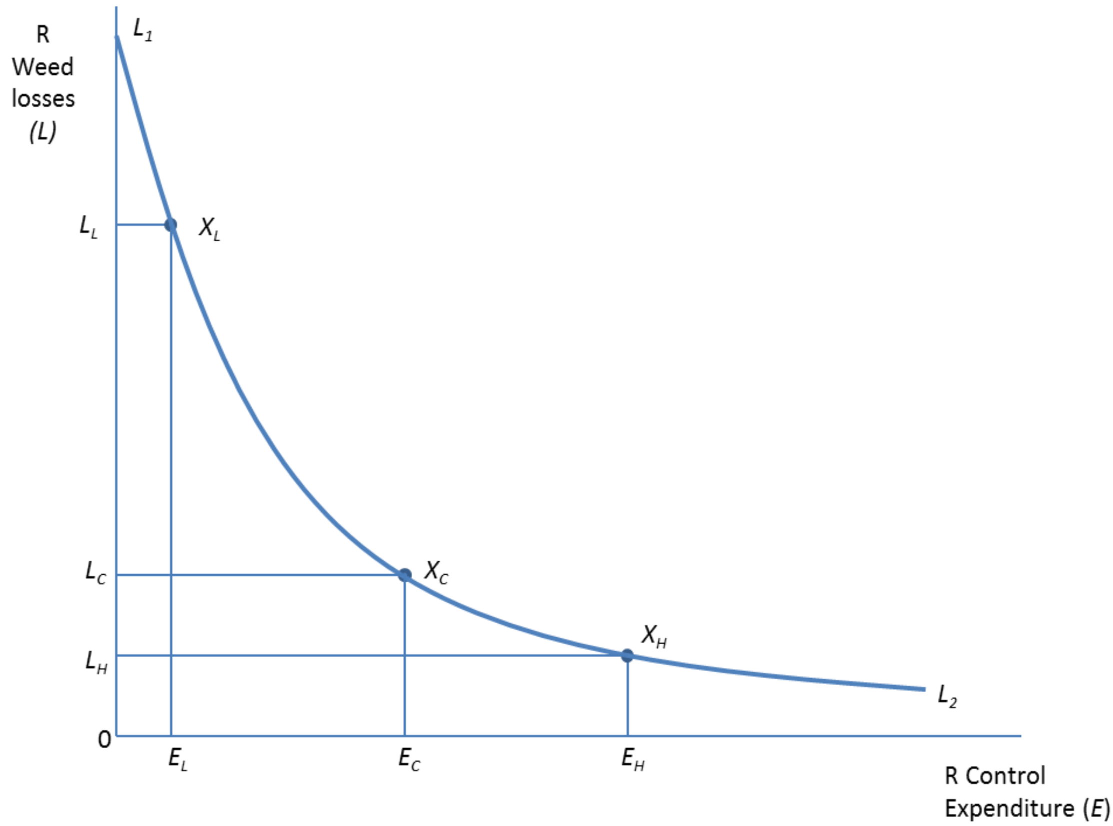


Figure 2.11: Economic impacts of a weed invasion (Sinden et al., 2004)

The total cost of the impact (*C*) can be defined as:

Total cost of the impact (*C*) = Total expenditure (*E*) + Total losses (*L*)

Weed management can be thought of as a choice of between different levels of *E* and *L,* because, for example, the higher the expenditure (*E*) the lower the losses (*L*) and vice versa, if successful control could be established. Herbicide resistance of weeds influence this choice between *E* and *L* because, if resistance should occur, the more the expenditure the lower the losses will not be necessarily true.

2.7.1 The Welfare impact of weeds

Considering the measurement of the weed impact, should be regarded as a loss in economic welfare. This approach measures the effects of weeds upon producers and consumers within an industry such as the wheat industry and it includes the direct and indirect financial costs within the calculations. This approach aggregates all the weed impacts for the various functional groups of weeds in industry-focussed estimates of economic surplus.

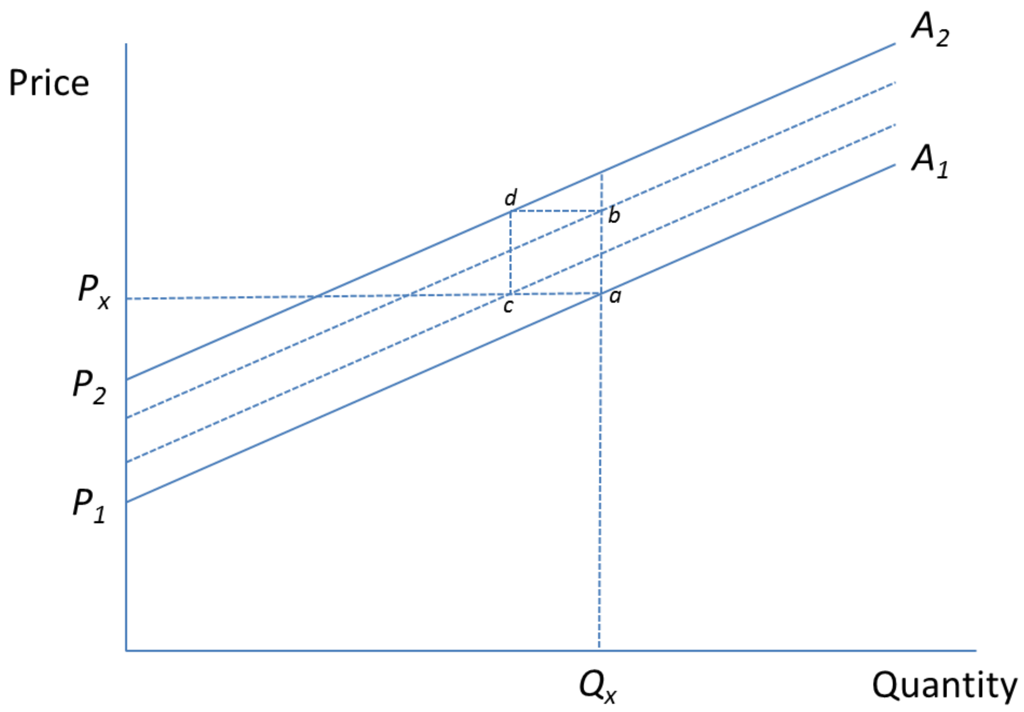


Figure 2.12: Impacts of a weed invasion through changes in expenditure (E) and losses (L) on a commodity supply function.

Figure 2.12 demonstrates how a weed invasion affects the economic surplus of an industry such as wheat. The basic supply function is just the amount or quantity that producers would supply at different price levels, and for this example, its interpreted as the cost of production. The invasion of weeds has two major impacts upon wheat production namely:

a) The variable costs of production increases because of the increasing usage of herbicides, tillage and other methods to control weeds. This means that the cost to produce a single level of output will increase and will shift the supply function upwards and therefor the more units of output produced the more the cost of control will be. This upward shift is demonstrated by moving from point "*a*" to "*b*". To produce the same quantity (Q_x) it now costs more due to the impact of weeds and this effect is known as the expenditure (*E*) effect.

b) The competitive effects of weeds lead to a yield loss. Due to increased competition from weeds for water and nutrients the yield of crops tend to decrease. This means that for a given cost of production there is a lower level or quantity of output. This is known as the loss effect (*L*) and is represented by the leftward shift of the supply function, moving from "*a*" to "*c*" for a certain cost of production (P_x).

The shift of the supply function from "A_1" to "A_2" or moving from point "*a*" to point "*b*" in Figure 2.12 demonstrates the combined effects of the expenditure (*E*) and loss (*L*) effects of weeds. This is also the total cost of weeds (*C=E+L*). It is important to note that this upward shift of the supply function reduces the welfare of both the consumers and producers. The consumers lose because the supply have decreased and price have increased for the same product and therefor they now consume less although they are paying more to do so. Producers lose when the decrease in production is greater than the increase in market price.

2.7.2 Financial cost of weeds and herbicides

The financial cost in this section refers to the direct costs of control in monetary terms. This consist of the actual cost of the herbicide, the cost of labour and vehicles to apply it. To calculate or demonstrate the impact weeds have on a farm, in terms of a financial impact, a production function could be used to better explain or demonstrate it. The crop output, for example grain yield, is determined by the quantity of fixed and variable inputs into the production process, represented algebraically by the production function.

The production function is as follows:

$$Y = f\,(V, F)$$

The (Y) is the yield or the output of the crop, while the (V) represents the variable production inputs such as labour, fuel, water and fertilizer, lastly (F) represents fixed production inputs such as depreciation, pests, soil type.

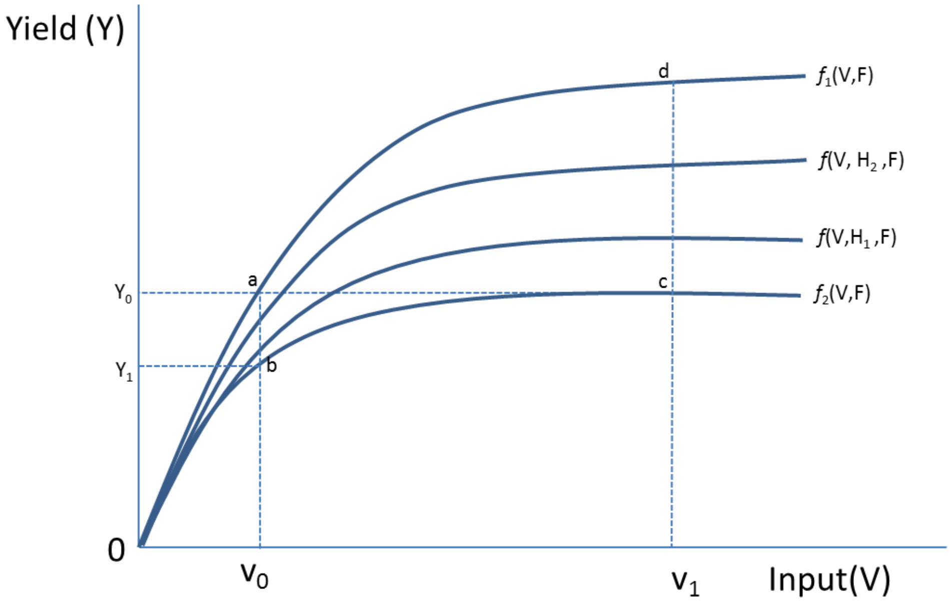


Figure 2.13: The effects of weeds and herbicides on a production function

Weeds reduce the yield (Y) of this function for any given level of yield (Y) as can be seen by Figure 2.13, where f_1 (V, F) is weed-free and f_2 (V, F) is with weeds. It is important to note that the loss due to weeds is a relationship and not a constant value and that the chance of a totally weed-free crop field is very rare to none (Jones *et al*., 2005). The loss under high input-high output point "*c"* to point "d" is more than that of low input-low output point "*a*" to point "*b*" production. This loss, associated with weeds, can also be expressed by the difference between "Y_0" and "Y_1" because this shows the difference in output for a weed-free and a "with-weeds" production system. The financial cost of weeds can also be demonstrated by looking at the output levels of "*a*" and "*b*". To demonstrate this difference, note the difference between "V_1" and "V_0". This indicates the extra inputs for the "with-weeds *b"* that are needed to reach the same output level the weed-free system reached at "*a*".

Input variables such as herbicides that are specifically for weed control extends the production framework as follows:

$$Y = f\,(V, H, F)$$

"*H*" is herbicides which is a type of weed control input and by increasing this input that control weeds, the production losses that weeds create will reduce significantly and result in higher levels of output for a given level of other production inputs "*V*" and "*F*". This effect can be seen in Figure 13 where *f* (V, H_1, F) and *f* (V, H_2, F) represents increasing levels of weed control and "H_2" is bigger than "H_1".

2.8 Conclusion

Annual ryegrass can rapidly achieve high seed densities and high seeding numbers at emergence. Even with good control in a crop, survivors can still tiller well and exploit the available space, resulting in a strong seedbed. Once a seedbank with high numbers of seed are reached, the damage is done and is it very difficult to get rid of the ryegrass and seedbank.

It was found that ryegrass have already evolved resistance against paraquat and glyphosate in the Western Cape as well as the Swartland. This resistance developed mainly due to farmers looking to maximise profits by over-relying on herbicides to control weed populations. Various factors played a role in the development of resistance, such as farmers spraying herbicides at a lower dosage than the prescribed rate, repeated use of the same herbicide, repeated use of herbicides with the same mode of action and reduced use of integration methods such as crop rotation.

South Africa consumes all of its domestic produced wheat and is therefore dependent on the domestic wheat industry. South Africa's wheat industry has decreased in hectares planted. In 1988, there were just less than 2 million hectares planted in comparison to last year (2016) when 498 150 hectares were planted. This can be attributed to various factors such as increased production risks, due to changing weather patterns, more profitable alternative crops or profitability as a whole. Production also decreased. South Africa's yield per hectare has increased well over the last nine years.

The Western Cape's production and hectares of wheat planted haven't significantly increased or decreased over the last nine years. However, with the South African industry as a whole declining and the Western Cape production staying the same, the Western Cape has further established itself as the major role player in South Africa's wheat industry. So much so that of all the wheat planted in South

Africa in 2016, just over 60% was planted in the Western Cape alone and the province produced just under 60% of the country's wheat in that same year. The Swartland makes up the majority share of the Western Cape's wheat industry. Over the last nine years (2008-2016), of all the wheat that was planted in the Western Cape, 65% was planted in the Swartland and it produced just more than 60% of the province's wheat. The fact that the Swartland makes up around a 60% share of the wheat industry of the largest contributing province emphasizes its role in the South African wheat industry.

South Africa produced 1.75 million tons of wheat on 476 570 hectares while Australia produced 23.6 million tons on 13.81 million hectares in 2014. Although this means that Australia's industry dwarves South Africa's industry, in that same year South Africa produced a yield of two tons per hectare more than that of Australia. South Africa have been consistently producing greater yields than Australia since 2000 (SAGIS and Australian bureau of census and statistics 2015).

Research on wheat and ryegrass in particular have extensively been done in Australia. It showed that the total cost of weeds to Australian grain growers is estimated at $3, 318 million that consists of; total yield revenue loss ($745 million) and the total cost of the management of weeds ($2, 573 million). Some of the key findings of that study was that ryegrass remains the major weed in terms of the cost of herbicide resistance, with the cost of resistant ryegrass being more than all of the other forms of resistance combined.

Chapter 2 then finally creates a picture of how big the Australian wheat industry are and by looking at the figures of the cost of weeds in a relative way it can be used to create an idea of how big of a problem resistant ryegrass can become in South Africa and the Western Cape. This study will then look to determine the cost of varying levels of ryegrass and resistant ryegrass on a typical wheat farmer's profitability in the Central Swartland.

3. Chapter 3: Introduction to systems approach theory and farm simulation models

3.1 Introducion

Chapter 2 gave an overview of the overall Western Cape wheat industry and highlighted the fact that ryegrass have developed resistance against glyphosate and paraquat. These two chemicals typically form the backbone of a wheat farmer's chemical weed management strategy. Therefore, resistance has severe economic consequences for wheat farmers. Other concerns modern day farmers' face, include: rapid urbanization, pollution, climate change, exhaustion of natural resources and unequal distribution of food and income to name but a few (Knott, 2015).

The world population keeps on growing at a rapid rate, thus the demand for food is increasing rapidly. To cope with the expected growth of the world's population and the subsequent food demand, over the next 40 years, more wheat and maize need to be produced than the world has produced over the last 500 years. To meet this demand the main solution will be to increase yields of crops, because there are absolute limits to arable land. This attitude of "doing the most with what we have" leads to further intensification and specialization of farming practises. In turn, it adds to the complexity of the productive, environmental and socially interconnected problems that already exists in agriculture. The way to solve these complex problems involves the development and application of unifying, trans-disciplinary and innovative solutions (Rodriguez and Sadras, 2011).

To solve some of these complex problems, a traditional (annalistic) scientific approach is generally used. The main goal of such an approach is to break the complex problem down to small, individual, components which can then be solved individually with greater ease. However, the analytical approach can only be applied to problems where there are no inter-relationships between different individual components in a system. Analysis also require that all the components have to be in a linear relationship. This paper as well as agriculture in general considers that there are too many individual components, with limits in linearity. To try to understand a single component and then comprehend the different interrelated impacts of various components is insufficient (Hirooka, 2010).

To solve complex problems in complex systems a common method used is that is of a multi-disciplinary approach. A multi-disciplinary approach integrates different fields of specialized knowledge in order to solve different complex problems within a larger system. This paved the way for using a "systems approach" through models and simulations on computers (Hirooka, 2010). This means that a system can be studied experimentally because it can be modelled. Real life situations can be mimicked through simulations and models, to test possible future impacts that different components have on the system as a whole (Knott, 2015).

The management of ryegrass, in wheat producing farms, can be considered as a complex system, because there are so many different factors that are important. Each has various different effects, such as; initial weed seedbank density, chemical management strategy, different crop rotations, seedbank management strategy etc. In this study, each component will not be studied individually, but the focus will be on how different ryegrass management strategies affects profitability on a typical wheat farm in the Central Swartland over a 10-year time period.

3.2 Systems approach theory in agriculture

The basic principle of general system theory is to study the relationships between different objects, whether their relationship might be linear or non-linear. This implies that an object within a system can be studied accurately by focusing on its environment, and factors that influence this object's behaviour and environment (Strauss, 2005).

Research methods and techniques used by researchers in the early 1900's could not accommodate the increasing complexity of agricultural systems and this led to the development of Farming Systems Research (Schiere et al., 2004). Prior to this development, researchers used a method where a problem was broken into smaller individual components. These smaller individual components can then be studied individually. This method is based on a reductionist approach and is the traditional scientific approach mentioned earlier. The two assumptions for this approach to work are:

- There are no inter relationships between different components; and
- If there should be a relationship between different components, it must be linear (Hirooka, 2010).

This reductionist approach has limited capabilities, because as soon as the system's components shows a non-linear relationship becomes too complex. In agriculture, there are very few systems where different components do not influence each other, and henceforth other approaches and ways of thinking had to be explored. This led to the development of a more holistic approach towards agricultural systems (Knott, 2015). To incorporate these non-linear relationships between different components in system approaches, models on computers became very useful.

Considering the topic for this study, it involves various interrelated systems, such as; economic systems, chemical systems, biological systems and mechanical systems. Each one of these systems also consists of many interrelated components, such as; input prices, planting dates, product prices, chemical and mechanical options, fertilizer and different rotational options. An overview of simulation models, that can comprehend all of these different systems within an agricultural system, is subsequently presented.

3.3 Modelling

The word modelling is described as: "building a representation of a system" (Johnson et al.,1977). Therefor modelling can be used to develop accurate representations of various systems of the real world and for the purposes of this study, a component of a real-world farm.

Farms are complex systems and usually cover large amounts of land. It is inefficient in terms of time and money to conduct field research, when these complex systems are to be studied (Knott, 2015). This is where models, such as computerised versions of real farms become useful. It is important that the right assumptions be applied to these computerised models, because they are usually fixed and present the difference between different models. Models allow for the experimentation with numerous different inputs, that in turn, allows for different possible outcomes. These outcomes can be analysed, in order to understand the various different effects, the various different inputs have on the system and each other. Models can also be developed in such a way that the results of the different inputs can be compared with actual data (Hoffmann, 2010).

Models are helpful tools that producers can use to provide insight into certain problems as well as more information around certain pending decisions. It allows producers to consider possible outcomes according to the various decisions they make. A model could then assist in the producer making a better decision, depending on the function of the particular model. One of the key attributes required of a successful model to be used in practise, is simplicity. The model must be developed in such a way that the producer understands the various assumptions and what they are aiming to achieve with the use of a particular model (Doyle, 1990).

3.3.1 Approaches to modelling

The purpose of the model will determine the approach of the model. There are two main approaches to modelling, they are; a normative or a positive approach. The difference between these two approaches lies, in the aim of the model. It can either describe what would be “preferred” to happen and what “does” actually happen (Hoffmann, 2010). A normative approach answers questions such as “what ought to be?” and “what is the optimal solution?” while a positive approach is more concerned with “what does happen, what will happen, and what did happen?”.

Normative approaches provide a perspective on economics that reflects normative judgements or opinionated reactions toward economic projects, statements and scenarios. This approach relies heavily on value judgements and economic statements that present “what ought to be” rather than facts and cause-and-effect statements (Buysse et al., 2007). This focus on optimisation and not describing facts, but can also be seen as a disadvantage. Normative approaches tend to be more prescriptive in a sense that it prescribes solutions. With regards to modelling, optimization models can typically be considered "normative" because their objective is to find the best or optimal solution. The uses of a normative approach to modelling can be divided into four subclasses:

1. Prescription of solutions;
2. Prediction of consequences;
3. Demonstration of sensitivity; and
4. Solution of systems and equations (Buysse et al., 2007).

A positive approach focuses on causes and effects, behavioural relationships and facts involved in the particular system. It is objective and fact based. The outcome of a model with a positive approach do not have to be "correct" but the model must be open for testing and can then be approved or disapproved. Positive models are descriptive and are not interested in the desired outcome (Shakun, 1972). A positive economic approach follows a more scientific approach than a normative approach. The process of a typical positive approach is described in the following steps:

1. Create a hypothesis;
2. Gather data and research to support the hypothesis;
3. Test the hypothesis;
4. Make predictions or forecasts according to the results found; and lastly
5. Make recommendations.

Positive simulation models that are used in the agriculture industry are built on statistical descriptions of historically proven interrelationships (Hoffmann, 2010). These models are used to assess the impact or effect of certain specific variables or parameters on predetermined criteria, for instance, sustainability. A lot of these models allows the user to have a major role in the outcome, due to many options and inputs not being fixed, and must be supplied by the user. The modeller, and user, must thus have a good understanding of the interrelations of the systems and parameters.

3.3.2 Simulation modelling

To simulate means to reproduce, imitate, to appear similar (Pereira, 1987). The art of simulating has been consciously and unconsciously done throughout the ages. From the origin of civilization, man had to struggle to survive, using simulations of real future events to be ready for any life event. Simulation is, therefore, an analogy with the reality, and is common in many areas. A good example of simulation is an athlete who simulates racing conditions while training to be well prepared for the actual race. In agriculture, simulation is important because it enables users to “forecast” the results of certain management options, given certain assumptions and parameters (Wu et al., 1996).

Model is a word that admits several connotations, among which the following can be mentioned:

- Representation of some entity; and
- A simple description of a system used to explain it, or to perform calculations (Crowther, 1995).

It is noticeable, based on the above definitions, that simulation models can be a prototype, a simplified representation, as well as an abstraction of a reality (system).

Simulation is normally done with mathematical models, but can also be done with other quantitative methods. The aim of simulation is to predict the likely response between different objects within the specific system (Strauss, 2005). Simulation enables users and researchers to evaluate systems with the help of modern computer technology, without disrupting the actual physical system. This can also be viewed as the main advantage of simulation models, because it enables users to evaluate outcomes of different variables without actual observation of the outcome within the physical system. With this method, outcomes of different variables can be evaluated timelier and at much lower costs (Hoffmann, 2010).

The different components of simulation models include:

- Various assumptions that consist of different definitions in order to set boundaries for the model in terms of feasibility, area and time;
- Known relationships and dependencies between assumptions (Brenner & Werker, 2007).

The main advantages of simulation models as a research and decision-making tool include:

- It can be used to compress a time frame, a simulation model run on a computer system can be used to investigate quickly the effects of a change in a real-life situation that take place over several years;
- It has wide applicability, they can deal with a wide range of questions;
- It can be used to study complex systems that would otherwise be too difficult to investigate;
- It is easy to perform "What-if" analyses;
- It allows experimentation of real systems without using real systems or disrupting them;
- It supports a trial-and-error learning process by allowing exploration of alternative management strategies at a very low cost (Cros et al., 2004); and
- It might be the only method applicable to situations that cannot be observed (Hoffmann, 2010).

The main disadvantages of simulations models as a research and decision-making tool include:

- The building of simulation models is expensive;
- Sometimes the results can be difficult to interpret due to the fact that these models allow for many different combinations of variables and conditions;
- Every user need to have a good understanding of the assumptions that are in the model and this process may be time consuming;
- They are not optimization models, therefor does not identify the "best" or "optimal" solution; and

- Human behaviour is difficult to simulate and to incorporate in simulation models (Hoffmann, 2010).

Simulation models have been used in farming system research for a long time. The last decades have seen the development of simulation models that are largely integrated. The use of simulation methods in agriculture began in the late 1960's, motivated by the need to integrate research results. The increase in computational capacity and the development of user-friendly programming software, both played important roles in making the diffusion of simulation models in farming system research possible. Simulation models that are used in agriculture allows for detailed, farm-level, specifications and considerations within flexible structures (Weersink et al., 2002). The use of simulation models on farms can lead to "new" information regarding management options for producers and this reduces uncertainty. Simulation models can therefore be used to create a platform from which producers can ''test" new management options. Simulation models that are used in agriculture are particularly useful in livestock growth models, yield models, crop growth models and crop response models (Hoffmann, 2010).

In the case of this study a computerised simulation model that was developed in Australia have been customized so that it can be used for the Swartland region in the Western Cape. The original model was developed in such a way that it can be applied to different regions other than the Australian Wheatbelt, certain assumptions just had to be customized by experts. This customized simulation model is then used to simulate different effects of different levels of ryegrass plants, herbicide resistance and seed densities on farmer's profitability in the Central Swartland region.

3.4 Whole-farm model and a "typical farm"

Farmers continuously try to protect their farms against possible risks such as price fluctuations, changing climatic conditions, diseases etc. Therefore, to mitigate these risks they diversify their farm. This diversification can come in various forms such as different enterprises, different planting dates, farming in different areas etc. Agriculture is therefore ever increasing in complexity and are best analysed within a systems approach (Knott, 2015). Changes in a single component will impact other components and thus affect the farming system as a whole. Therefor if a farm should be analysed it would be generally better if the study is conducted in a whole-farm context (Hardaker et al., 2004). In this study, the focus is on the financial implications of ryegrass on a whole-farm level.

3.4.1 Typical farm

The "typical farm" serves as a template or basis of normality as a representative farm in the same area. The "typical farm model" within a whole-farm approach is used more generally because of the importance of relationships between variables within systems (Knott, 2015). The aim with this technique is to compare farms with a "normal farm" in the area not the best or the worst just the "typical farm" which is most common. This criterion of identifying a "typical farm" are; profitability, management quality, access to markets, farm size, cropping systems and cultivation practises (Hoffmann, 2010). This "typical farm" then represents what a group of farmers would normally do within the same area.

It is important to note that a typical farm model is established and developed by incorporating the knowledge of producers and agribusinesses within a homogenous area. Thus, it is important that experts, such as, scientists, economists and producers validate the assumptions and parameters that make up the typical farm model.

The important characteristic of "typical farms" is that the resource base and the technological constraints are typical and are not the average of a group of farms (Feuz and Skold, 1990). Three important issues need to be considered when creating a set of "typical farms" they are:

1. Justification for the farm type;
2. Criteria for stratification; and
3. Desired level of detail.

Agriculture is very diverse in many areas with a large variety of farms in certain areas. To attempt to model all of the different types of farms would be costly; therefore, a “typical farm” approach is useful.

The typical- whole-farm-approach can be used to assess the impact that certain changes in variables or management decisions have on the profitability of the farm as a whole. This model can be used to compare certain outcomes, due to specific changes in managerial decisions, such as different crop rotations and the effects of each crop rotation on profitability. This typical whole-farm model is only just a simulation model, and not an optimization model, so therefore it does not find the “optimal” solution. It must thus not be used to direct managerial decisions. It provides insight into the possible outcome of a decision and thus lead to better decision-making. The purpose of using a typical farm model in this research is to provide a basis of comparison for the expected impacts of specific scenarios (Knott, 2015).

Agriculture is complex as mentioned earlier, because there is diversity due to many factors that each play a specific role. Different actions will have different effects on camps on the same farm that differ from one another in terms of soil fertility etc. The idiosyncratic nature of farms means the impact of the exact change in a variable will not have the exact outcome on a different farm. The typical whole-farm model focuses on the impacts of trends, strategies and policy options on farm-level profitability (Hoffmann, 2010).

3.4.2 Multi-expert group discussion

Process

Understanding a wheat farm system requires knowledge of numerous disciplines or areas of specialization, such as agronomy, soil science, agricultural economy, plant pathology, animal science, entomology, marketing and people skills (Hoffman, 2010). In order to bridge the gap between these different disciplines, a group discussion consisting of experts from each of these disciplines can be used. This discussion allows each participant to share an expert opinion with other experts from within the farming sector. This in turns allows the integration and sharing of different expert opinions from different disciplines and facets of farming, to better understand the farming system as a whole. This method is also used to determine what the impact of a certain change of a certain variable would be on the farm as a whole. This is especially valuable when setting assumptions that will be used in a whole-farm model, and thus a multi-group discussion works ideally as a research method for the purpose of this study.

The discussion

The multi-group discussion took place on the 16th of February 2017 at the department of Agricultural Economics of Stellenbosch University. Each participant was given a summary of the topics that were to be discussed. Each one of the participants was able to voice his/her opinion to which everyone else had the chance of responding to if they felt it was relevant. The main goals of the discussion were:

- Determine if the RIM model can be made applicable to the Swartland;
- Verify the assumptions and parameters used in the RIM model;
- Determine the five most common crop rotations of the Swartland; and
- Develop typical ryegrass control strategies for each crop rotation.

In preparation for the discussions numerous personal interviews with experts were held and the discussion reached consensus speedily and all of the objectives were reached. One of the key findings of the discussion was that medics must be built into the model. It is widely used as a pasture crop in crop rotation systems of the Central Swartland, especially to control ryegrass. The discussion was followed up by more personal interviews with various experts.

The panel

The list of experts present at the discussion was:

- ❖ Dr. Willem Hoffmann – Agricultural economist at the University of Stellenbosch;
- ❖ Dr. Johann Strauss – Plant scientist at the Department of Agriculture: Western Cape and coordinator of the long-term crop rotation trial at Langgewens;

- Dr. PJ Pieterse – Agronomist at the University of Stellenbosch;
- Mr. Dirk van Eeden – Herbicide specialist from Inteligro; and
- Mr. CH Basson – Producer and researcher on crop rotation systems.

3.5 Conclusions

Farm systems consist of numerous components that have linear and non-linear relationships, making farming a complex system. In the past, a reductionist approach was used, whereby these systems were broken down into smaller individual components that were then studied individually. An increase in complexity and non-linear relationships between some of these components made the use of the reductionist approach inefficient. This led to an increase of the use of modelling as a tool to better understand farming systems. Modelling is more of an expansionist approach.

Modelling is described as building a representation of a system, in this case a real-world farm. Models allow for the experimentation of different inputs that leads to different outcomes. This provides more insight for producers concerning decision-making. Modelling is done, within a certain approach. This approach can either be normative "what is the optimal solution" or positive "what does happen", "what will happen" and "what did happen" depending on the purpose of the model. For the purpose of this study and the model that are being used, a positive approach is followed.

There are various types of models but the type used in this study is a simulation model. Simulation models are representation of reality as well as an abstraction of a reality (system). Simulation enables users and researchers to evaluate systems with the help of modern day technology, without disrupting the physical system. The aim of simulation is to predict the likely response between different objects, within the specific system. Simulation models create a platform from which producers can "test" new management options. Producers can "run" the option through the simulation model and determine what the likely outcome of this option will be.

The purpose of this study is to assess the financial effects of ryegrass and herbicide resistant ryegrass within different management strategies to control ryegrass on whole-farm level in the Central Swartland. A typical whole-farm simulation model is used with a focus on controlling ryegrass. The "typical farm" serve as a template or basis of normality as a representative farm in the same area. The "typical farm" with the five most "typical crop rotation systems", each with their own "typical ryegrass control strategy" is simulated. In the RIM-model data and parameters were obtained through the multi-group discussion and personal interviews. The aim with this approach is to compare farms with "a normal farm" in the area and not the best or worst, but the "typical farm".

4. Chapter 4: The RIM model

4.1 Introduction

The previous chapter explained agriculture as a complex system and that a systems approach should be followed if farming, as a whole were, to be studied. Chapter 3 also explained the many different aspects of farming and the interrelatedness of various components.

The purpose of this study is to look at a single component, ryegrass, and the effect of herbicide resistant ryegrass and how it influences profitability on a whole-farm level in the Swartland. To analyse the impact of this single component on the system (farm) as a whole, a simulation model will be used. The simulation model used in this project is known as the Ryegrass Integrated Management, or RIM model.

The objectives of this section are to describe the RIM model that was formulated in 2004, to define its key assumptions, and to describe the various components of RIM, which includes the economic, agronomic and biological components. The differences and changes between the 2004 model and the model used in this research project are discussed.

4.1.1 Overview of the 2004 RIM model

In Australia, just like in South Africa, farmers rely heavily on herbicides for weed control (Sinden, 2000). Therefore, it came as no surprise that herbicide resistance became a problem. Annual Ryegrass (Lolium rigidum), which has long been the most important economically debilitating weed occurring in field crops in Southern Australia presents the world's most severe example of herbicide resistance (Doole, 2008). Annual Ryegrass has multiple types of resistance, which mean it is resistant to various modes of actions of different herbicides including types that have not yet been applied to weeds.

This type of resistance has led to farmers' inability to maintain weed control with the use of herbicides, and they had to introduce alternative methods of control. This led Australian farmers to adopt diverse combinations of weed control methods and emphasizing the concept of Integrated Weed Management (IWM). Integrated weed management is often difficult for farmers to understand etc. so a computerised decision support system could be of exceptional value to farmers and advisors (Pannel *et al.*, 2004). This led to the development of the Resistance Integrated Management (RIM) model.

RIM is a dynamic simulation model that is deterministic and integrates economic, biological and agronomic components. The model includes 500 parameters (agronomic, biological and economic) that can be adjusted by users. It can be used in Microsoft Excel®.

RIM is a decision support system that allows the user to simulate many combinations of weed control treatments on different levels of ryegrass prevalence and observe their predicted impacts on ryegrass populations, crop yields and economic outcomes. The user can specify whether the ryegrass population in the field is resistant to each herbicide group, or how many applications of herbicides from each group are available before resistance will develop. A wide variety of non-herbicide weed treatment options are included, so that as herbicides are losing their effectiveness, the best substitute treatments can be identified.

The enterprise options available for users to select are wheat, barley, canola, lupineees, ''volunteer'' pasture (consisting of a mixture of grasses, legumes and other species), subterranean clover pasture (*Trifolium subterrameum*), and cadiz seradella pasture (*Ornithopus sativus*). The user may select any one of these above-mentioned options in any agriculturally feasible sequence. There are inter-year impacts of one enterprise on another, depending on the sequence selected. For example, a cereal crop grown after a legume crop or pasture benefits from a higher yield and a reduced requirement for nitrogen fertilizer (Pannell, 1998).

4.2 Dynamics of the 2004 RIM model

4.2.1 Weed population dynamics

In RIM, the year is divided into seven distinctive periods:

1. First rains of the growing season which allow crop planting;
2. Seeding to ten days later;
3. 11-20 days after seeding;
4. Up to time of post-emergence herbicide application;
5. Post-emergence spraying to mid spring;
6. Mid spring to harvest; and
7. Harvest to opening rains of the next season.

The model operates according to these steps, rather than on a daily or weekly timeframe. This was accepted, as there is a lack of evidence for a finer division for most elements of the model. Farmers understand the purpose this way and accepted it (Pannell *et al.*, 2004). The number of weeds and weed seeds in the soil are recorded at the end of each of these seven periods. Factors that influence these recordings are the following:

- ❖ Seed production per plant;
- ❖ Initial weed seed density in the soil;

- Timing of weed seed germination relative to the crop. Later germinating weeds produce fewer seeds per plant due to more competition;
- Natural mortality of weeds and seeds;
- Impacts of weed and crop densities on seed production per plant; and
- The effectiveness of treatments to reduce weeds or seeds.

4.2.2 Competition between weeds and crops

Competitive relations between crop and weed plants do not rely solely on species characteristics. Relative time of emergence, for instance, is an important determinant of competitive ability, as an early emergence generates an improved access to the available resources (Powles & Walsh, 2007). Various techniques can be used to improve the competitiveness of the crop, such as increased seeding rate, seed priming, breeding and row placement of fertilizer to improve the chances of the crop to absorb the fertilizer. The competitive ability of a crop and of ryegrass, will affect the yield of the crop. This is because the level of this ability can, or cannot, benefit the crop naturally against weeds, because if its competitive ability is strong, then it will be affected less by weeds and vice versa. To calculate the effect of this competition on the crop yield, RIM uses the following equation:

$$Y = \frac{(P_o + a)}{P_o} \times \frac{P_1}{a + P_1 + (k \times W)} \times M + (1 - M)$$

Where Y is the yield of the crop, P_o is a standard crop density, P_1 is the actual crop density, W is the density of the weeds surviving all the treatments. M presents the maximum proportion of grain yield lost at very high weed densities, a is a constant that depends on the crop, and k is a constant reflecting the competitiveness of the weed on the particular crop. For wheat in competition with annual ryegrass, the default values are as follows: P_o = 100, M = 0.6, a = 5 and k = 0.33 (based on the results of Pannel & Gill, 1994).

4.2.3 Crop-related variables

The following crop-related variables are represented in the model:

- ❖ Yield boosts for cereals after legumes, canola or a pasture;
- ❖ Standard weed-free yields for crops after a break of at least three years without a legume;
- ❖ Yield effects on crops by green manuring and swathing;
- ❖ Yield effects from disease in short rotations;
- ❖ Seeding rates;
- ❖ Savings in nitrogen fertilizer following lupinees and pasture;
- ❖ Impacts of delayed seeding on yield;
- ❖ Parameters of the competition function; and
- ❖ Phytotoxic effects of herbicides and some physical control measures on each crop.

4.2.4 Pasture-related variables

RIM does not include detailed simulation of the population dynamics for each possible pasture species. The biological impacts of a pasture phase on ryegrass populations are there for represented in a relatively simple way. For each type of pasture, the impact on ryegrass seed density under standard and high intensity grazing conditions is specified (Table 4.1) based on the advice of pasture scientists at the Department of Agriculture of Western Australia (Pannel *et al.*, 2004). In the second or third consecutive year of pasture the standard reduction in weed seeds is greater because the non-ryegrass plants of the pasture are denser and more competitive at these stages.

Table 4.1: Reduction in number of ryegrass plants setting seed as a result of grazing.

	Pasture type		
	Sub-clover	**Cadiz Serradella**	**Mixed**
Standard grazing intensity			
First year of pasture	50	30	30
Second consecutive year of pasture	70	40	40
Third consecutive year of pasture	80	60	60
High grazing intensity			
First year of pasture	87	82	82
Second consecutive year of pasture	92	85	85
Third consecutive year of pasture	95	90	90

Source: Pannel *et al.* (2004).

4.2.5 Herbicide Resistance

All of the different herbicides that can be used in RIM are summarised in Table 4.2. Each herbicide is allocated to a particular group, based on the mechanism by which it controls weeds. All herbicides within a group are assumed to have the same resistance status. RIM does not simulate the population genetics of resistance development. Instead, the user can specify the number of applications available for each herbicide group prior to the onset of resistance. If ryegrass is fully resistant to a particular herbicide group, the limit for that group is set to zero. The onset of high-level resistance is usually rapid and the number of herbicide applications required to invoke resistance is reasonably predictable, and well known. This simplified approach to representing resistance development in RIM is found to be effective for the types of management problems the model is used to address. Farmers accepted this, because they understand the mechanism (Pannel *et al*., 2004).

4.2.6 Weed management options

RIM can simulate a total of 35 different weed treatment options illustrated in Table 4.2. There are four respective groups: non-selective herbicides (five), selective herbicides (11), non-herbicide treatments (16) and three user-defined treatments. Non-selective herbicides kill all actively growing vegetation (grass as well as broadleaf weeds) either by contact or by a systemic mode of action (method by which the chemical is transported throughout the plant). A common example is Round-Up (Glyphosate) which is used to kill all existing unwanted vegetation growing in a poorly managed landscape before planting seeds or mature crops. A selective herbicide kills only certain targeted plants (as specified on the product label) and does not damage other plants (Baker & Percival, 1991). The non-herbicide treatments are based on physical or ecological approaches. They include the following:

Pre-seeding weed management options

- Delayed seeding with a non-selective herbicide application: Delaying crop seeding enables a much greater number of annual weeds to emerge. This allows the farmer to control weeds before the seed of the crop are on the field and to use a non-selective herbicide to which weeds have not built up that much resistance (Powles and Walsh, 2007). There are concerns of using just glyphosate as the non-selective herbicide due to increasing development of resistance against it, by weeds. This is why the “double knockdown” approach is being recommended. It entails the use of glyphosate first and one to seven days later do a follow-up by using paraquat (Neve *et al.*, 2003). The combination of these two techniques have a ryegrass mortality rate of 100% (Pannel *et al.*, 2004).
- Green manure: This involves the ploughing of a growing crop, or pasture, into the soil prior to the weeds setting seed. This is an effective method of weed control, assumed to prevent 98% of ryegrass seed production (Pannel *et al*., 2004). However, if a crop is not harvested, it involves a substantial sacrifice in revenue.
- Cultivation and delayed planting: Cultivation is used to stimulate germination and to uproot and kill unwanted plants. Shallow soil cultivation is the method available in RIM. A delay between the cultivation and seeding is necessary to allow the weeds to germinate, the longer the delay the more weeds germinate. This however shortens the growing season of the crop and there is thus a yield penalty. In RIM, planting can be delayed by 10 days (wheat yield penalty = 5%) or 20 days = 10% yield penalty.

<u>Weed management options while seeding</u>

- High crop seeding rates: Increasing the density of wheat plants from 100 to 160 plants/m^2 or of lupinee plants from 40 to 66 plants/m^2 provides increased competition against weeds, increasing crop yields, reducing weed growth and reduces its ability to produce seed. This increased seeding rate consistently led to higher grain yields without reducing the size of the kernel (Anderson *et al.*, 2004). The seeding rate of wheat in Western Australia was increased by 50% (it went from 60 to 90 kg/ha) for the period of 1994 to 2004 and this was driven by herbicide resistance as well as yield advantages (Owen *et al.* 2005).

In-Crop weed management options

- Swathing: This involves cutting the crop while still green and laying it on the ground. Once dry, it is harvested. Swathing can reduce harvest losses of grain, and help managing moisture content of barley grain. It also provides a modest reduction in ryegrass seed production by cutting off ryegrass plant heads before they set seed. RIM includes seed reductions of 25% for swathing of barley, and 20% for canola and lupine.

Post-Crop maturity weed management options

- Burn crop stubble or pasture residues: This is probably one of the oldest methods to destroy weed seeds. This strategy involves burning the residues remaining after a harvest or grazing. The effectiveness of stubble burning increases when weed seeds are exposed to high temperatures over long periods of time, however stubble burning produces high temperatures but only for short durations of time. Therefore, the effectiveness of burning depends on the amount of fuel (residue) and type of fuel (Chitty and Walsh, 2003). If harvest residues were concentrated into narrow windrows the residues will burn at higher temperatures, for longer periods of time, improving the effectiveness of this method. The burning of concentrated windrows can also help reducing the risk of erosion. In RIM the standard kill rate for ryegrass seed from a burn is 30% following crops or 20% following pastures (Pannel *et al.*, 2004).
- Cut weeds for hay or silage: This strategy requires acting before the weeds set seed. Both options are specified in RIM with a follow-up application. The assumed ryegrass kill rate is 95-98% (Pannel *et al.*, 2004). The problem with this strategy is that some of the seed of weeds such as ryegrass is small and may be missed or fall of in the process of making hay.

- Grazing: Sheep help to control ryegrass by eating ryegrass seed over the summer months and eating the ryegrass plants in the pasture. Ryegrass mortality depends on pasture type, length of the pasture phase, and grazing intensity. All of these factors are selected by the user. The mortality rates can be seen in Table 4.2.
- Header trails: Instead of the residues being distributed over the width of the header path, it is possible to concentrate them in a band behind the harvester for more effective burning later. The assumed weed control rate from burning is then increased to 50-63%.
- Mowing: A mower is used to cut the tops of the weeds prior to setting seed. This treatment, plus a follow-up application of glyphosate, is assumed to give 95% weed control (Pannel *et al.*, 2004).
- Seed catching: The catching of weed seeds during the harvest operation is an effective means of reducing weed seed input into the seedbank of crop-production fields (Powles and Walsh, 2007). It is estimated that 75% or more of the ryegrass present at harvest passes through the harvester. Around five of farmers are experimenting with seed catching equipment, which collects all the seed and chaff from the harvester's top sieve into a cart towed behind the harvester. In RIM, the control rate of seed catching is set at 60–68%. The observed kill range in field trials is 40–80%.

Table 4.2: Management options in RIM (2004 version)

Nr.	Treatment	Type	Kill percentage
1	Knockdown option 1 Glyphosate (Group M)	Non-selective herbicide	97

2	Knockdown option 2-paraquat (Group L)	Non-selective herbicide	97
3	Double knockdown option (Group M+L)	Non-selective herbicide	100
4	Trifuralin (Group D)	Selective herbicide	70
5	Simazine pre-emergence (Group C)	Selective herbicide	75 (canola)
6	Attrazine pre-emergence (Group C)	Selective herbicide	75 (canola)
7	Chlorsulfron pre-emergence (Group B)	Selective herbicide	85
8	Use high crop seeding rate	Biological treatment	
9	Seed at first chance (default)	Biological treatment	5
10	Tickle, wait 10 days, seed	Biological treatment	5
11	Tickle, wait 20 days, seed	Biological treatment	5
12	Simazine post-emergence (Group C)	Selective herbicide	75
13	Atrazine post-emergence (Group C)	Selective herbicide	75
14	Chlorsulfron post-emergence (Group B)	Selective herbicide	30
15	Dicloflop (Group A)	Selective herbicide	95
16	Fluazifop (Group A)	Selective herbicide	95 (canola)
17	Clethodim (Group A)	Selective herbicide	95 (canola)
18	Other Dim for lupinees or canola (Group A)	Selective herbicide	90 (canola)
19	Other selective herbicide	Selective herbicide	User specified
20	Grazing	Biological treatment	See table 1
21	High intensity grazing winter/spring	Biological treatment	See text
22	Glyphosate top pasture (Group M)	Non- selective herbicide	85 (pasture)
23	Paraquat top lupinees/pasture (Group L)	Non- selective herbicide	85 (pasture)
24	Green manure	Biological treatment	98
25	Cut for hay, then glyphosate (Group M)	Biological treatment	95
26	Cut for silage, then glyphosate (Group M)	Biological treatment	98
27	Swathe	Biological treatment	20 (canola)
28	Mow pasture	Biological treatment	98 (pasture)
29	User defined option A (spring)	Biological treatment	User specified
30	Seed catch- burn dumps	Biological treatment	60
31	Seed catch- total burn	Biological treatment	68
32	Windrow-burn window	Biological treatment	50
33	Windrow- total burn	Biological treatment	63
34	Burn crop stubble or pasture residues	Biological treatment	30
35	User defined option B (at or after harvest)	Biological treatment	User specified

Source: (Pannel *et al.*, 2004)

4.2.7 Financial Implications

RIM allows users to examine the potential for long-term benefits from short-term economic, or financial, sacrifices. The question of whether a preventative strategy is economically feasible in the long run depends on various factors. These include the cost of the strategy, its impact on weeds, prices of outputs and the initial weed seed density. The standard approach used by economists and financial analysts to assess long-term investment choices involves “discounting”, which allows all costs and benefits to be expressed in the equivalent of their present-day value (Robinson and Barry, 1996). The costs and benefits of all strategies of interest are discounted and summed to determine the net present value (NPV), and the preferred strategy is that with the highest NPV.

If the discount rate used is the bank interest rate, then this process is equivalent to identifying the strategy which would result in the highest bank balance at the end of the period. Assuming that all income is deposited in the bank account and accumulates interest, and all costs are withdrawn from the bank account and reduce the amount of interest earned. This “final bank balance” approach is the method used in RIM, based by default on a nominal interest rate of 8%. When calculating the final bank balance, the following factors have to be taken into account:

a) Tax is paid on interest earned. The tax system is represented simply, because there is so much variability between farmers in their tax arrangements. RIM allows the user to specify a single marginal tax rate (by default, 21%), which should be the rate of tax that would be paid on any additional income earned above current income.
b) The inflation rate on sale prices in agriculture has historically been lower than the inflation rate on input purchase prices. In RIM, the default settings for the inflation rates on crop product prices (1%) and sheep product prices (0.5%) are lower than the assumed inflation rate on input costs (3%).

c) Yields increase over time. This is hard to predict, but over the long term it is significant. In RIM, the standard annual rate of yield increases is set to 1.0% for crops and 0.5% for sheep products (per hectare, not per sheep).

4.2.8 Limitations

RIM does not calculate the “best” strategy automatically; users evaluate strategies using experimentation in the form of trial and error. The model also does not take year-to-year variations in weather, potential yield or herbicide performance into account. However, yields do vary from year to year due to the sequence of crops and pastures selected, the level of weed competition, and the effects of different weed control strategies. Climatic conditions do not rule out any of the treatment options (Pannel *et al*., 2004). Users can self-impose constraints on the use of different treatments.

Another limitation of the RIM model is that it only represents a single field and that some strategies might involve changes in machinery or livestock management that have impacts at the whole-farm level. Similarly, RIM makes particular assumptions about the way that investments in machinery are financed (repayments at a constant nominal rate over eight years). Farmers may need to further consider whole-farm cash flow implications of strategies outside of RIM before adopting decisions.

Although considerable effort was spent on data collection, there are still areas where the available information could be strengthened. For example, it would be helpful to improve information on the benefits of some weed control methods, and aspects of weed population dynamics. A related issue is the variation in biological and economic parameters between farms. The values included in the standard version of RIM are representative of a typical farm in a region of Western Australia, but need adjusting for other farm types and for other regions (Pannel *et al*., 2004). Users can readily alter the parameter values to suit their particular situation.

4.3 The new upgraded version of the RIM model

RIM is still used in countries such as Australia, Spain and the Philippines, mostly as a research tool at universities. RIM remained a useful tool to illustrate and measure different effects of different weed management strategies on farm profitability. Some consultants still run RIM workshops with farmers to raise awareness of herbicide resistance and consequently, RIM needed to be upgraded, which was done in 2013 (Lacoste *et al*., 2014). This upgraded version of RIM focused on:

- Being more user friendly;
- Use current and newly developed farming practises and prices;
- Include new farming technologies with regards to herbicide resistance; and
- Made it easier to update so that the prices and conclusions stay realistic.

In the next section, these new updates of the new RIM model will be discussed.

4.3.1 Changes in the interface and programming

Interface

The new RIM model has a brand-new interface that consists of a four-step progression setup. This include; define paddock, build strategy, compare results and lastly export these results so that they can be studied in full. Microsoft Excel is still the platform and the new interface allows for much better navigation and improved error handling offer some interface protection.

User inputs

Inputs were minimized in such a manner that only the most important 100 parameters from a total of 600 parameters are required to be changed to the user's liking for the program to function. Similar variables are grouped together under a single entry which makes it easier for the user to modify his/her inputs while the program is asking more straightforward questions at the same time. Various user inputs can also be saved as a particular strategy, which enables the user to load older saved strategies and to compare these different strategies with one another.

Outputs

The graphs that show the user's results are now directly underneath the strategy table which enables the user to observe different effects of different strategies much quicker and easier. Maximum values for ryegrass have also been set at approximately 3000 plants/m^2 and at 9000 seeds/m^2. Other additional outputs include: ryegrass control expenses assigned to chemical, mechanical, competition, income breakdown by enterprise type, ryegrass population dynamics, rotational effects and the ryegrass burden on yields. It also allows these outputs of different strategies to be compared as mentioned earlier.

4.3.2 Contents revision

Updating Options

The major changes of all the options and enterprises are summarized in the table 4.

Table 4.3: major changes from the 2004 version of RIM.

Category: Enterprises	**Number of available options**	**Major change from RIM 2004**
Crops	4	Generic crops, undefined legume
Pastures	3	Generic pastures, fodder adjustments
Field operations		
Timing of seeding	4	Addition of dry seeding
Soil preparation	2	Addition of mouldboard ploughing
Establishment system	2	Germination pattern adjustments

Crop seeding rates	2	Modification of different seeding rates
Pre-seeding herbicides	2	User-defined applicability to enterprises
PRE-herbicide	5	New options
POST herbicide	5	New options
Crop sacrifice	5	For the first time, a crop can be sacrificed
Late season spray/swathing	3	
Grazing	2	Removed ryegrass biomass contribution
Harvest weed seed control	6	Three new options
User-defined options	4	Addition of two options

Source: (Lacoste et al., 2014)

Updating parameters

All the parameters were revised by experts and default values were selected to best represent assumptions that are based on dominant conditions in the dryland cropping systems of the Australian Southern wheat belt.

4.3.3 Key differences from the original version

Components that are removed

The 20-year horizon was changed to 10 years, because it improves the model's accuracy and decreases prediction uncertainty. The resistance component of RIM was removed because it leads to misinterpretations such as the idea that resistance evolution solely depends on the number of applications of an herbicide (Lacoste *et al., 2014).* However, the model was constructed in such a way that the user can now determine against which herbicides ryegrass developed resistance.

Broadened assumptions and increased flexibility which allows for wider applicability

RIM workshop surveys indicated that users required extended new or updated options and crops (Lacoste *et al*., 2014). The new RIM version accommodated many of these requests, such as; swathing possibilities, mouldboard ploughing and environmental effects. Most options were made more applicable by increasing compatibilities, for instance, some options became a possibility. Even an uncommon practise in Australia such as swathing. Mowing was also made possible for all enterprises.

Emphasizing user's choices

The new RIM model allows the user more freedom. A user can now decide what option is applicable and logical and therefor cater for a wider range of situations. For example, the user must determine the efficacy of various herbicides.

Simplifying the framework

By simplifying RIM, the process of updating, adapting and maintenance was simplified. The components that did not affect the quality of outputs were either removed or simplified. The parameters that influenced the economic outcomes the most, such as; weed seed density, grain prices and yields were emphasized in the interface. The assumption to replace the initial weed seedbank with the initial plant densities was made due to difficulty in predicting and estimating the initial weed seedbank densities (Doole, 2008).

Specific changes to certain options

There were two major additions to the establishment options. They were; the inclusion of dry seeding and mouldboard ploughing. Spring options also incurred a few changes such as; allowing all enterprises to be sacrificed, sprayed and a variable was added into the ryegrass seed production equation to cater for the impact of a nonselective late-season herbicide on the fertility of ryegrass survivors (Lacoste *et al*., 2014). Harvest options that were changed was the inclusion of new parameters such as residue removal costs and baling income.

Prices and costs

The prices and costs of various options and parameters were updated to ensure outputs are more realistic. Updating should be done on a yearly basis to ensure realistic outcomes.

4.3.4 Changes that had to be made to the RIM model for it to be used in the Swartland of South Africa

Prices and costs

Firstly, for the model to be applied to areas such as the Swartland and other areas in South Africa all of the model's economic values had to be changed from US dollars to South African Rand.

Updating parameters

All of the parameters were revised by experts and professionals with particular knowledge of the Swartland. Default values were developed through these multi-disciplinary discussion and interviews with experts from the Central Swartland. This was done to prevent the user from being overwhelmed by all of the options and parameters that need customising when the program is used for the first time. It serves as a template of what the parameter "should" be or the average practise, the same with the options.

Updating assumptions

Various assumptions were changed due to the fact that the difference between these two regions, the Swartland and Western Australian Wheatbelt. For example, in the Western Australian Wheatbelt model there are no yield benefit when you plant canola after legumes, whilst in the Swartland the yield benefit is anywhere in the region of 20-30%. The maximum ryegrass density also had to be increased due to farmers of the Swartland being able to carry on farming with more ryegrass plants in their fields than farmers of Australia.

Changing options

Due to the popularity of medics as a pasture in the Swartland's rotation, it was decided to rather have medics as an option for a pasture in place of subterranean clover.

Correcting errors

There were a few errors with regards to the selection of data to be calculated in formulas and these errors have been corrected. Throughout the process each parameter and assumption were checked and verified as applicable to the South African conditions. The prices were easily adapted, but the effect of systems on yields needed to be clarified by expert discussions.

4.4 Conclusion

In Chapter 3 the theory and dynamics of a systems approach and modelling was discussed. Chapter 4 focuses on using an actual simulation model and describes the various aspects and components of the model in detail.

RIM is a useful tool for analysing and evaluating the agricultural, economical and biological performance of different long-term weed management systems. Through various simulations, RIM allows users to test the impact or effect(s) of different weed management methods/strategies on ryegrass numbers and most importantly farm or crop profitability. With these simulations, farmers also avoid the risk of failure, because RIM allows them to simulate different scenarios which means that they do not have to experiment with these methods on their actual farm.

The model enables users to construct different scenarios for up to 10 years. One can observe the different effects of these varying levels of ryegrass plant, and seed densities on crop yields and economics, on a per hectare basis. The long-term scenarios allow the user to incorporate rotational effects as well as yield advantages. There are seven enterprises and over 40 management options to choose from for the users' simulations.

5. Chapter 5: Financial Implications of herbicide resistance of annual ryegrass on a typical farm in the Central Swartland.

5.1 Introduction

This chapter will briefly discuss the different crops used in the different crop rotation systems on a "typical farm" in the Central Swartland. Then a look at the strategy to control ryegrass on a "typical farm" in the Central Swartland will be discussed. "Typical values" for a "typical paddock" were then obtained through various processes that included; a multi-disciplinary group discussion, values received from an agribusiness and numerous personal interviews with experts in the area. A "Typical chemical strategy" for each of the crop rotations in the Central Swartland were also obtained from the previously mentioned discussions and interviews. Due to a lack of data and research being done on the topic in the Swartland region some of the assumptions used in the RIM model were not changed. The panel agreed that where no data or research was available for the Central Swartland, assumptions would be based on the data from the Western Australian Grain belt due to the credible similarities between the two regions.

The values of the "typical paddock", "typical crop rotations" each with their particular "typical chemical strategy" in the Central Swartland were then simulated in the RIM simulation model. This was done to demonstrate and witness the effects of ryegrass on the profitability of different crop rotations systems with their particular chemical strategy on a "typical farm" in the Central Swartland. Two scenarios were developed, the first being where ryegrass developed resistance against glyphosate and paraquat, and the second, where ryegrass developed resistance against glyphosate, paraquat and trifluralin. These different scenarios demonstrate the effect and severity of herbicide resistant ryegrass on the profitability of a typical wheat farm in the Central Swartland.

A previous study (Eksteen, 2007) found resistance against glyphosate and paraquat in the Swartland region and providing valuable data for this study. This is a real threat that farmers are facing in the

Swartland region and have to deal with. A scenario of resistance against another important herbicide, such as trifluralin, is simulated to demonstrate the seriousness of herbicide resistance and what "could" happen if farmers are not made aware of the severity of the effects of herbicide resistance on farming profitability and sustainability. Resistance against trifluralin have been found in Australia (Broster, Koetz and Wu, 20011). This needs to be brought under the South African grain farmer's attention in order to avoid the same fate.

The results of the different crop-rotations and strategies of a particular scenario are discussed and compared. These results give a sense of what could happen should this particular rotation and control strategy be implemented on a "typical farm" in the Central Swartland. The comparisons are primarily done, on profitability and the level of ryegrass control that can be achieved by following the particular rotation, with its particular control strategy. The comparisons enable a thorough look at the differences between the various cop-rotations and strategies. Using figures and tables in the following chapter, the trends of profitability and the amount of ryegrass are demonstrated and the way each of these factors influence one another.

5.2 Fixed assumptions of the typical farm in the Central Swartland

5.2.1 Farm size and investment

The RIM-model assumes that the farm being modelled is already financed and equipped with all the equipment necessary to produce wheat. This include equipment, such as; a planter, harvester, sprayer etc. The user can specify the particular size of the farm. The size of the farm plays a role in the machinery repayments. It is used to calculate the repayments, if a narrow windrow chute, Harrington seed destructor, chaff cart or bale direct system is purchased. However, none of these methods or machines is used extensively in the Swartland. Therefore, the size of the farm option is of no interest for the simulations that are done in this study. The calculations are based on one-hectare units.

5.2.2 Establishment Costs

As mentioned earlier RIM assumes that the farm being modelled is equipped with all the necessary equipment and machinery to produce wheat. The different establishment costs that can be customized are seeding (including cleaning, dressing, inoculum etc.), fertiliser, fertiliser after legumes and additional costs.

The seeding cost of a typical Swartland wheat farm consist of two parts, purchased seed and producer's stock. The purchased seed are seed bought in the particular year to be planted and the producer's stock is seed that remained from the previous year that the farmer opted to hold back for planting material. The seeding costs of wheat consist of 71% purchased seed and 29% producer's stock. The wheat seed that are being used for this study is SST 027. Canola TT are used in the Central Swartland. Canola TT are triazine tolerant, which means that various triazine herbicides can be used without affecting the canola. All of the canola seed are assumed as purchased. The legumes' seed consists of 33% purchased seed and the remaining 67% of the seed are used from the producer's stock. All of the seed used to establish a medic pasture are purchased. The seeding costs for the same crop in different areas of the Swartland will differ. For example; wheat for the Central Swartland will differ from the cost of seeds for the Southern Swartland, because of different seeding rates. The user can also change these seeding rates in the "More Options" option.

The fertilizer application differs from crop to crop due to different nutritional requirements of each crop. The main fertilizers components given to wheat and canola in the Swartland are nitrogen, sulphur, phosphate and potassium. Medics and legumes only need phosphate and a little nitrogen. The different rates and prices of each of these macronutrients can be seen in annexure A.

The “additional costs” component consists of insecticides, fungicides, contract work, gypsum and lime, insurance and planting cost. The costs of this component differ between different crops in the Swartland due to different nutritional requirements, yields etc. of the particular crop. The different rate and price of each of these components are illustrated in Annexure A.

5.2.3 Prices and Yields

The information on prices and yields were obtained from a well-established agribusiness specialising in financing production costs for farmers in the Swartland region. Prices and yields for these simulations were obtained from the budget of 2016 for the Central Swartland region. It is assumed that the yields reflect a normal year in terms of rainfall and weed free conditions. The user can only specify the yield for the first year of the 10-year cycle. For the following years various yield benefits and penalties apply influencing the yield of a particular crop. RIM does not allow the user to see the particular yield of a given year unless the program is unlocked. The rate of increase of potential crop yield is 1% per year.

The prices used in the model and simulations are farm gate prices. This means that the transport differential, marketing and handling costs at silos have all been deducted; the complete breakdown can be seen in annexure A. The inflation rate of crop and sheep prices are 1% and 0.5% per year respectively. The inflation rate of input prices is 3% per year.

5.2.4 Control Options

The different control options that are included in RIM are discussed in Chapter 4. The various herbicides to control ryegrass that are used in this simulation on a typical farm in the Central Swartland are shown in Table 5.1:

Table 5.1: Different herbicides used in the various simulations for this study.

Retail name	Active ingredient	Chemical class	Classification group (HRAC)
Knockdown herbicides:			
Round-up Turbo 450	Glyphosate	Glycine	Group G
Ciplaquat	Paraquat	Bipyridylium	Group D
Pre-emergent herbicides:			
Triflurex 480 EC + Sustain	Trifluralin	Dinitroaniline	Group K1
Wrestler(Boxer) 800 EC	Prosulfocarb	Thiocarbamate	Group N
Sakura 850 WG	Pyroxasulfone		Group K3
Kerb 500 WP	Propyzamide	Benzamide	Group K1
Simazol SC	Simazine	Triazine	Group C1
Post-emergent herbicides:			
Axial 45 EC	Pinoxaden	Phenylpyrazoline 'DEN'	Group A
Monitor 75 WG	Sulfosulfuron	Sulfonylurea	Group B
Simanex 500 SC	Simazine	Triazine	Group C1
Aramo 50	Tepraloxydim	Cyclohexanone	Group A
Vega 240 EC	Clethodim	Cyclohexanedione 'DIMs'	Group A

This list, with their efficacy and cost per hectare according to each herbicide, are also shown in Annexure A. The herbicides used in these simulations what a "typical" producer in the Central Swartland and what is "typically" used to control only ryegrass. Another method of control used in the simulations is topping which is a late season application of a non-selective herbicide. Then there is also an early "autumn tickle" that can be done by pulling a few tyres over the bare paddock or last season's stubble stimulating weed germination, particularly ryegrass a, resulting in a denser first flush of weeds. A spray action with a non-selective herbicide such as Roundup is followed. Other methods of control in weed management strategies include increased competition through high seeding rates of the crop, such as wheat, and lastly grazing by sheep in the pasture phases.

5.2.5 Other options

The seeding rate of the different crops and pastures for the 2016 budgets were provided by local agribusinesses in the area. The harvest index and the percentage of fodder yield, relative to the harvest index, are derived from the data and results founded in Western Australia (Lacoste, 2013).

The yield benefits for canola and all other cereals, following legumes, are derived from data provided by Langgewens experimental farm which is situated in the Central Swartland. Over the past 20 years, trials have been done at Langgewens farm on crop rotation systems with the input of local producers to reflect farming practises as accurately as possible. Legumes increase soil fertility and improve nitrogen levels in the soil. This benefits the crops planted the following year according to the rotational cycle. The benefit of mouldboard ploughing is 5% provided by the Australian data used in this study (Lacoste, 2013).

All the various yield penalties and mechanical control of ryegrass data and percentages are from Australian data, due to insufficient research on the topic in South Africa. Various experts supported the use of Australian data as it accurately reflects the conditions of the Swartland.

For pastures, the Australian data was used, but only after it was validated by the multi-group discussion and a few changes had to be made to some of the stocking rates.

5.2.6 Machinery costs

The maintenance, fuel consumption and price per litre entries are all from farmer study group budget information received from an agribusiness. The model includes the purchase of a narrow windrow chute, Harrington seed destructor, chaff cart and a bale direct system. However, none of these machines are used extensively in the Swartland. The loan repayments and interest rate on the loan are therefor also not really applicable.

5.2.7 Other costs

This segment contains the costs of using a mouldboard plough, mowing pasture and swathing. None of these options is used extensively in the Swartland and will not be used in the simulations of a typical farm of the Swartland. In Australia, the mouldboard plough has been found to remove 100% of ryegrass plants and 99% of the seedbank which makes it a good mechanism to control ryegrass, but as it contradicts the ideals of conservation agriculture it is not widely used.

5.3 Weed control strategies of a typical farm in the Swartland

5.3.1 The different crop rotations in the weed management strategies.

Wheat is the most commonly grown winter cereal crop in the Swartland. Farmers do not practise wheat monoculture anymore except on the rare occasion. The reason farmers planted wheat in the past is that it made economic sense due to wheat's high income per hectare (high yield x high price). In more recent times farmers have adopted crop rotation strategies due to a number of reasons discussed below. This means that wheat monoculture is not as popular as it used to be and farmers rotate now between different crops over a certain amount of years. This depends on how long the rotation strategy is. The reasons discussed below:

- To manage weeds. In wheat monoculture, the same herbicides are applied year after year, subsequently allowing the weeds, such as ryegrass, to develop resistance against these herbicides. Once weeds have developed resistance, the farmer has to deal with the problem over a number of years, due to the amount of time it takes to develop herbicides with new modes of action. Crop rotation allows the spray of certain grass leaf herbicides in a broad leaf crop, that would not be sprayed in wheat or any other grass leaf crop. These grass leaf herbicides are cheaper than grass leaf herbicides that are used in a grass leaf crop. The technology, and time required to develop a grass leaf herbicide that can be used in a grass leaf crop, is more and consequently cost much more. This is due to the grass leaf crop and grass leaf weed being genetically relatively similar. The change in herbicides due to the rotation also prolongs the herbicide's usage and the time it takes for weeds to develop resistance against it.
- The rotation of crops also mitigates the risk of a farmer in terms of price of the particular crop. Diversification allows the farmer to sell different crops in the same year (If the farm is divided into different crop rotations). Thus, if the price for a certain crop is low the other crop can buffer income.

- Wheat monoculture depletes the soil of its resources and minerals.
- A broad leaf crop in a wheat rotation helps to stop the spread of fungal and bacterial diseases present in the soil. Grass weeds are often hosts of a particular disease and it is easier to isolate and chemically treat the disease in a broad leaf crop than, in a grass crop.
- Certain crops such as legumes benefits the soil in terms of nitrogen fixation resulting in better yields for the crop planted in the next rotational phase.

Therefor crop rotations are mainly implemented to increase yields, lower input costs, make more profit and to farm more sustainable.

According to various professionals, agribusinesses and the multi-disciplinary group discussion the main crop rotations for the Central Swartland are as follows:

- Wheat-Wheat-Wheat-Canola (W-W-W-C);
- Wheat-Medics-Wheat-Medics (W-M-W-M);
- Wheat-Wheat-Wheat-Wheat (W-W-W-W);
- Wheat-Wheat-Wheat-Legumes (W-W-W-L);
- Wheat-Canola-Wheat-Legumes (W-C-W-L).

Table 5.2 illustrates the five most "typical" crop rotations of the Central Swartland. They are simulated in a 10-year time frame in the RIM-model on a continuous basis.

Table 5.2: Different crop rotations and their share of the total area planted (Group study of an agribusiness 2016).

Crop Rotation	Percentage of area planted
W-W-W-C	37%
W-M-W-M	18%

W-W-W-W	12.4%
W-W-W-L	6%
W-C-W-L	2.5%
Other	25.1%

5.3.1 The different crops in the weed management strategies

Although other crops such as canola are now commonly used in crop rotations in the Swartland, wheat remains the basis of all the rotations. Here are the crops that are used in the crop rotations of this study:

- Wheat (W), produced mainly for human consumption is still the most common crop produced in the Central Swartland (Knott, 2015). For good reason, it makes economic sense to cultivate wheat due to its potential high gross margin. The most crop rotations are aimed to increase the yield of wheat, whether it is a short or long-term goal.
- Canola (C) can be used as animal feed due to its high protein and low fibre content or the oil, extracted from the seed, can be used in the food industry. Canola unlike wheat is a broadleaf crop. Grass leaf weeds and diseases can be treated effectively in this crop phase. Another advantage of using canola in a crop rotation, is that it enhances the yield of the wheat planted the following year.
- Medics (M) are part of the clover family and extensively used as a pasture phase in crop rotation systems in the Central Swartland. This pasture phase allows livestock production, which are predominately sheep in the Central Swartland. Clover and medics being broadleaf crops offers the same benefits as canola and legumes in terms of agrochemicals. Medics also have significant yield benefits if wheat were to be planted after the medics' phase.

- The legumes (L) used in this study are sweet (narrow leaf) lupines, *Lupineeus angustifolius*, and it is a broad leaf crop. It has the same agrochemical benefits as canola and medics. After a year of lupines, the yield of wheat shows a significant increase, due to the nitration fixation effects of legumes. This effect can also lower the fertiliser costs of the year following the legume year. Lupines can be used as grazing, due to high protein content in the seeds.

Lastly the model also include barley, Cadiz French serradella and a voluntary pasture (not planting a crop on the paddock but instead leaving it bare for livestock to graze on) as rotational options but none of these are used extensively on a 'typical farm' in the Central Swartland.

5.4 Different ryegrass management strategies

The different strategies used by typical farmers in the Central Swartland to manage ryegrass will be explained according to the various crop rotations, each with their own particular ryegrass control strategy. Due to the various benefits of conservation agriculture such as increased yields, improved soil moisture retention, reduced input costs, improved soil structure and reduced erosion the typical farmer in the Central Swartland have adopted a no-till establishment system. No-tillage means that soil disturbance is minimized through tillage in terms of ploughing or through other types of field cultivators.

The seeding rates of all the crops in all the strategies are standard except for wheat monoculture in which the seeding rate is high at 125kg/ha. This is done to give wheat a competitive advantage over ryegrass in terms of nutrient absorption.

5.4.1 W-W-W-C

Time of planting

In this strategy for eight of the 10 years in total, dry planting will occur. This means that farmers plant before the opening rains. Early planting benefits are early germinating crops and therefore more competition for nutrients with ryegrass. However, this means a higher risk if erosion should occur.

In the fifth and ninth year planting is delayed, this means planting will take place one to two weeks after the first rains. When planting is delayed, shallow cultivation or a tickle may be done in autumn. This stimulates weed germination enabling more ryegrass to establish at the same time (so that the first flush of weeds is denser), which are then followed by a spray of a non-selective herbicide. This is done to effectively control more weeds with the knockdown herbicide.

Pre-emergent herbicides

The two pre-emergent herbicides that are predominately used in wheat on a typical farm in the Central Swartland are Sakura 850 W and Trifluralex 480 EC. Trifluralex is sprayed with Sustain because Sustain improves the retention of trifluralin by the root zone of weeds such as ryegrass and prevents evaporation and UV damage of trifluralin. The efficacy of trifluralin is subsequently improved. Sakura and Trifluralin alternate throughout the 10-year period and neither Sakura nor Trifluralin is used for three consecutive years, in order to avoid herbicide resistance.

Simazol SC is used to control ryegrass in the canola years of the strategy. This is where a broadleaf crop in the rotation has a significant benefit, because herbicides that control grass weeds in broadleaf crops are cheaper than herbicides that control grassweeds in a grass crop, such as wheat. As indicated in Paragraph 5.3.1 such herbicides are expensive due to the levels of specialisation needed to develop.

Post-emergent herbicides

Axial is used in the first and sixth year of the strategy in wheat as a post-emergent herbicide. Vega 240 EC and Simanex 500 SC are used in the canola years of the strategy.

Other methods of controlling ryegrass in this strategy

Topping are done in the canola years of the rotation, which means a late spray of a non-selective herbicide. Table 5.3 presents the full strategy.

Table 5.3: Ryegrass control strategy in a wheat and canola crop rotation system.

W-W-W-C										
Year:	**Yr 1**	**Yr 2**	**Yr 3**	**Yr 4**	**Yr 5**	**Yr 6**	**Yr 7**	**Yr 8**	**Yr 9**	**Yr 10**
Enterprise:	Wheat	Wheat	Wheat	Canola	Wheat	Wheat	Wheat	Canola	Wheat	Wheat
Time of sowing	Dry	Dry	Dry	Dry	Delayed	Dry	Dry	Dry	Delayed	Dry
Soil preparation					Tickle				Tickle	
Knock-down / Double-knock					Round-up Turbo				Round-up Turbo	
Pre-emergent herbicide	Sakura 850 W	Sakura 850 W	Trifluralin	Simazol SC	Trifluralin	Trifluralin	Sakura 850 W	Simazol SC	Trifluralin	Trifluralin
Establishment system	No-till	No-till	No-till	No-till	No-till	No-till	No-till	No-till	No-till	No-till
Crop seeding rate	Standard	Standard	Standard	Standard	Standard	Standard	Standard	Standard	Standard	Standard
Post-emergent herbicide 1	Axial			Vega 240 EC		Axial		Vega 240 EC		
Post-emergent herbicide 2				Simanex 500 SC				Simanex 500 SC		
Post-emergent herbicide 3										
Grazing intensity										
Spring options				Topping				Topping		
- Swathe										
- Others										
Harvest options - Crops										
Harvest options - Others										

5.4.2 W-M-W-M

Time of planting

The wheat is dry-planted each year. Medics however are established in the second year of the strategy and will emerge in the years when no wheat is planted. Medics are also dry-planted.

Pre-emergent herbicides

Sakura 850 W and Trifluralex 480 EC + Sustain are alternated, with none of these herbicides being sprayed for three or more consecutive years. In the first, or establishment year of medics, Trifluralex 480 EC + Sustain are sprayed and then not again in the medics' phase of the strategy.

Post-emergent herbicides

In the second year of wheat and third year of the strategy Axial are sprayed. Vega 240 EC are sprayed every year on medics.

Other methods of controlling ryegrass in this strategy

Livestock (sheep) are used in the medic years of this strategy to control ryegrass through grazing. The stocking rate of sheep is high at a dry sheep equivalent of three animals per hectare. Through intensive grazing the ryegrass control will be more efficient than the standard stocking rate. Lastly, this strategy allows for a late season topping during every medics year. The full detail of this strategy is presented in Table 5.4.

Table 5.4: Ryegrass control strategy in a wheat and medic crop rotation system.

W-M-W-M										
Year:	**Yr 1**	**Yr 2**	**Yr 3**	**Yr 4**	**Yr 5**	**Yr 6**	**Yr 7**	**Yr 8**	**Yr 9**	**Yr 10**
Enterprise:	Wheat	Medics	Wheat	Medics	Wheat	Medics	Wheat	Medics	Wheat	Medics
Time of sowing	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry	Dry
Soil preparation										
Knock-down / Double-knock										
Pre-emergent herbicide	Sakura 850 W	Trifluralin	Trifluralin		Sakura 850 W		Sakura 850 W		Trifluralin	
Establishment system	No-till	No-till	No-till	No-till	No-till	No-till	No-till	No-till	No-till	No-till
Crop seeding rate	Standard	Standard	Standard		Standard		Standard		Standard	
Post-emergent herbicide 1		Vega 240 EC	Axial	Vega 240 EC		Vega 240 EC		Vega 240 EC		Vega 240 EC
Post-emergent herbicide 2										
Post-emergent herbicide 3										
Grazing intensity		High		High		High		High		High
Spring options		Topping		Topping		Topping		Topping		Topping
- Swathe										
- Others										
Harvest options - Crops										
Harvest options - Others										

5.4.3 W-W-W-W

Time of planting

Every year the wheat is dry-planted except for the third and seventh year, which are delayed and followed by a tickle and a spray of Round-up Turbo.

Pre-emergent herbicides

This strategy alternates between Sakura 850 W and Trifluralex 480 EC + Sustain.

Post-emergent herbicides

In this strategy, a post-emergent herbicide is sprayed every third year. Axial are sprayed in the third and ninth year while Monitor 75 W are sprayed in the sixth year.

Other methods of controlling ryegrass

Wheat is planted at a high seed rate (125kg/ha) every year for increased competition with ryegrass. Table 5.5 presents the detail of this strategy.

Table 5.5: Ryegrass control strategy in a wheat monoculture system.

W-W-W-W										
Choose enterprise	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 6	Yr 7	Yr 8	Yr 9	Yr 10
and control options:	Wheat	Wheat	Wheat	Wheat	Wheat	Wheat	Wheat	Wheat	Wheat	Wheat
Time of sowing	Dry	Dry	Delayed	Dry	Dry	Dry	Delayed	Dry	Dry	Dry
Soil preparation			Tickle				Tickle			
Knock-down / Double-knock			Round-up Turbo				Round-up Turbo			
Pre-emergent herbicide	Trifluralin	Sakura 850 W	Trifluralin	Sakura 850 W	Sakura 850 W	Trifluralin	Sakura 850 W	Sakura 850 W	Trifluralin	Trifluralin
Establishment system	No-till	No-till	No-till	No-till	No-till	No-till	No-till	No-till	No-till	No-till
Crop seeding rate	High	High	High	High	High	High	High	High	High	High
Post-emergent herbicide 1			Axial			Monitor 75 W			Axial	
Post-emergent herbicide 2										
Post-emergent herbicide 3										
Grazing intensity										
Spring options										
- Swathe										
- Others										
Harvest options - Crops										
Harvest options - Others										

5.4.4 W-W-W-L

Time of planting

The wheat and legumes of this strategy are predominantly planted dry, except for wheat following a year of legumes. The fifth and ninth year of this strategy, wheat planting is delayed in order to perform a tickle and spray Round-up turbo to control ryegrass.

Pre-emergent herbicides

Sakura 850 W and Trifluralex 480 EC + Sustain are used to control ryegrass in this strategy while Simazol SC is used to control ryegrass in the legumes.

Post-emergent herbicides

Axial is sprayed in the third year of the strategy while Vega 240 EC is sprayed every year legumes are planted.

Other methods of control

A late season topping are used in the legume years. Table 5.6 show the full detail for this strategy.

Table 5.6: Ryegrass control strategy in a wheat and legume crop rotation system.

W-W-W-L										
Year:	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 6	Yr 7	Yr 8	Yr 9	Yr 10
Enterprise:	Wheat	Wheat	Wheat	Legume	Wheat	Wheat	Wheat	Legume	Wheat	Wheat
Time of sowing	Dry	Dry	Dry	Dry	Delayed	Dry	Dry	Dry	Delayed	Dry
Soil preparation					Tickle				Tickle	
Knock-down / Double-knock					Round-up Turbo				Round-up Turbo	
Pre-emergent herbicide	Sakura 850 W	Sakura 850 W	Trifluralin	Simazol SC	Trifluralin	Trifluralin	Sakura 850 W	Simazol SC	Trifluralin	Trifluralin
Establishment system	No-till	No-till	No-till	No-till	No-till	No-till	No-till	No-till	No-till	No-till
Crop seeding rate	Standard	Standard	Standard	Standard	Standard	Standard	Standard	Standard	Standard	Standard
Post-emergent herbicide 1			Axial	Vega 240 EC				Vega 240 EC		
Post-emergent herbicide 2										
Post-emergent herbicide 3										
Grazing intensity										
Spring options				Topping				Topping		
- Swathe										
- Others										
Harvest options - Crops										
Harvest options - Others										

5.4.5 W-C-W-L

Time of planting

All of the crops are planted dry except in the years following canola when the wheat are delayed so that a tickle can be performed and Round-up Turbo is sprayed.

Pre-emergent herbicides

Trifluralex 480 EC + Sustain are used in wheat phases and Simazol SC is used in the canola and legume phases. However, trifluralin and Sustain are used in the sixth year of the strategy when canola is planted.

Post-emergent herbicides

Axial is used in the ninth year on the wheat and Vega 240 EC is used every year on canola and legumes.

Other methods of control

A late season topping is done in every year that canola or legumes are planted. The full details for this strategy are presented in table 5.7.

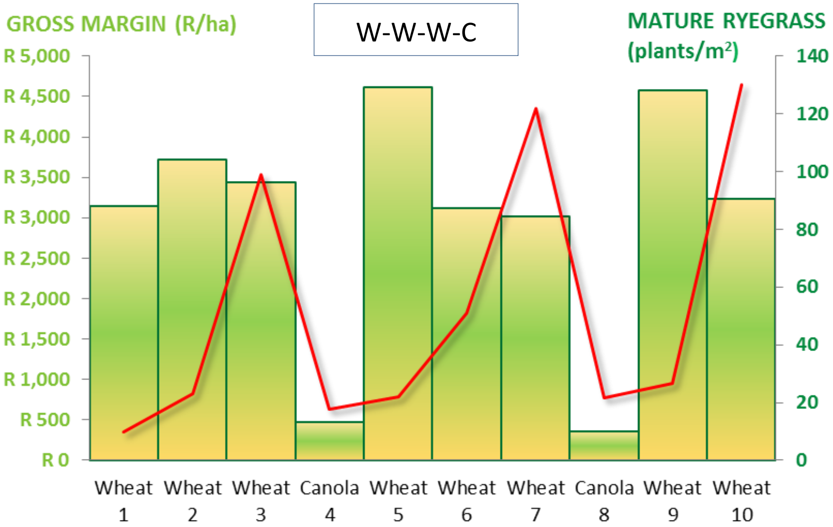
Table 5.7: ryegrass control strategy in a wheat, canola and legume crop rotation system.

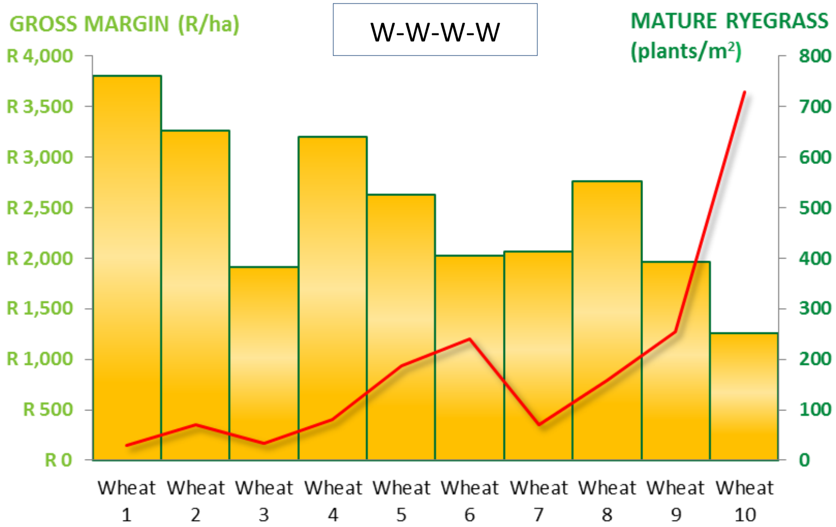
W-C-W-L										
Year:	Yr 1	Yr 2	Yr 3	Yr 4	Yr 5	Yr 6	Yr 7	Yr 8	Yr 9	Yr 10
Enterprise:	Wheat	Canola	Wheat	Legume	Wheat	Canola	Wheat	Legume	Wheat	Canola
Time of sowing	Dry	Dry	Delayed	Dry	Dry	Dry	Delayed	Dry	Dry	Dry
Soil preparation			Tickle				Tickle			
Knock-down / Double-knock			Round-up Turbo				Round-up Turbo			
Pre-emergent herbicide	Sakura 850 W	Simazol SC	Trifluralin	Simazol SC	Sakura 850 W	Trifluralin	Sakura 850 W	Simazol SC	Trifluralin	Simazol SC
Establishment system	No-till	No-till	No-till	No-till	No-till	No-till	No-till	No-till	No-till	No-till
Crop seeding rate	Standard	Standard	Standard	Standard	Standard	Standard	Standard	Standard	Standard	Standard
Post-emergent herbicide 1		Vega 240 EC		Vega 240 EC		Vega 240 EC		Vega 240 EC	Axial	Vega 240 EC
Post-emergent herbicide 2										
Post-emergent herbicide 3										
Grazing intensity										
Spring options		Topping		Topping		Topping		Topping		Topping
- Swathe										
- Others										
Harvest options - Crops										
Harvest options - Others										

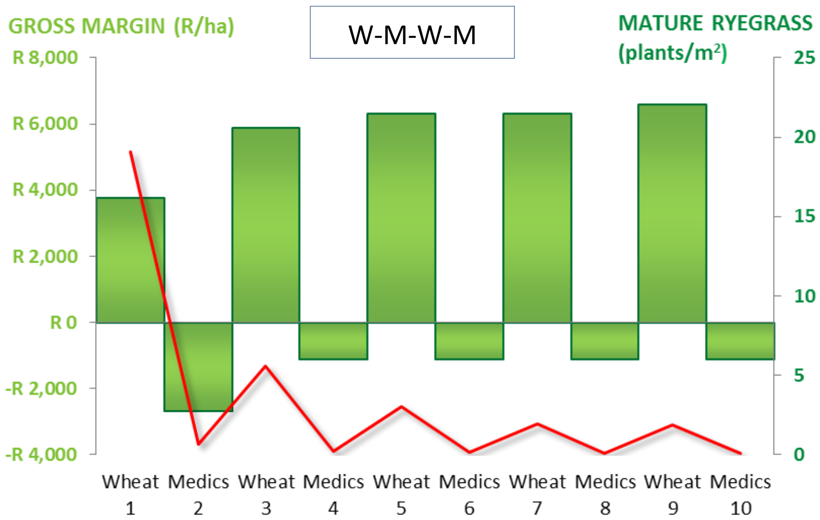
5.5 Financial implications of ryegrass and herbicide resistance on a typical farm in the Central Swartland.

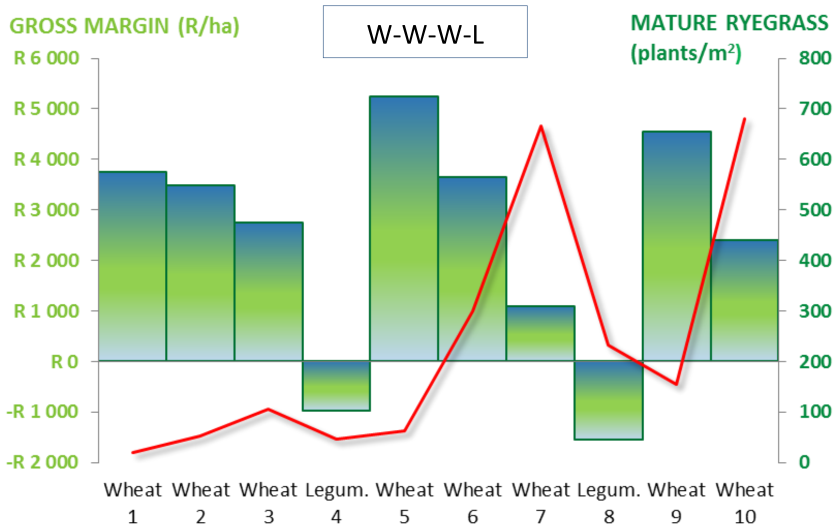
In the next section, the effect of ryegrass on the profitability of a typical farm in the Central Swartland will be discussed. It is assumed that the same ryegrass density is present in each of the different crop rotations as well as different crop strategies. Then the effect of resistance against glyphosate and paraquat will be demonstrated. Lastly if resistance to trifluralin should be prevalent, the effects thereof will also be demonstrated. In all three of the scenario's simulated a "worst-case scenario" approach was used in terms of resistance, in other words a zero-percentage control.

5.5.1 Starting weed density at two ryegrass plants per square meter last spring









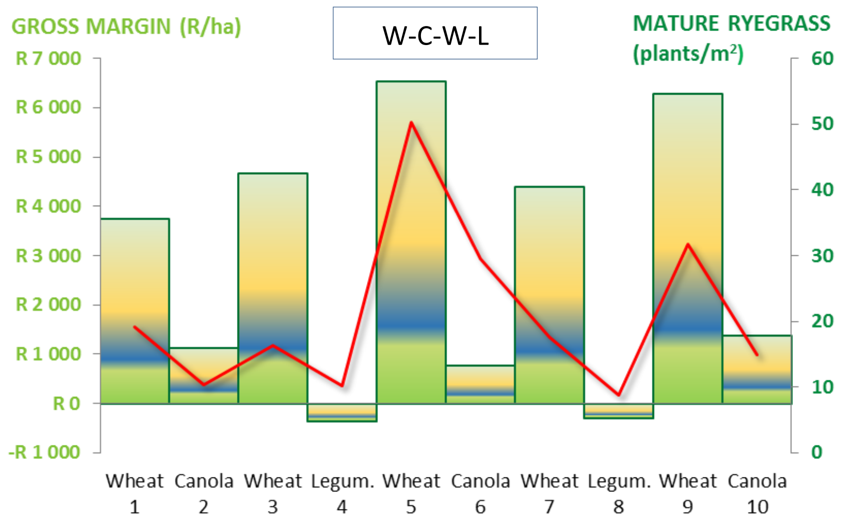


Figure 5.5.1: The effect different numbers of ryegrass plants (line) have on the annual gross margin (columns) of different crop rotations over a 10-year period.

5.5.1.1 Wheat and canola rotation

5.5.1.1.1 Biological discussion

Table 5.8 illustrates the ryegrass population dynamics in a wheat and canola rotation system of 10 years.

Crop	Wheat 1	Wheat 2	Wheat 3	Canola 4	Wheat 5	Wheat 6	Wheat 7	Canola 8	Wheat 9	Wheat 10
Ryegrass plants per m^2										
First chance to seed	5	6	17	67	15	18	32	82	19	22
10 days after break	10	12	50	175	46	54	63	215	56	65
20 days after break	14	16	74	256	13	80	87	314	15	97
Time for post-emergence spraying	15	19	87	298	17	94	99	366	20	114
Early spring	10	23	99	71	22	51	122	87	27	130
Mature ryegrass setting seed (Sept.)	10	23	99	18	22	51	122	22	27	130
Seeds in the soil										
Seeds in the soil at the start of the season	100	121	339	1342	308	368	639	1648	375	446
Seeds in the soil at the end of the season	121	339	1342	308	368	639	1648	375	446	1720

Prior to the first year of wheat, there were two ryegrass plants per square meter during springtime. These plants seeded and the seedbank started to grow. As little as two plants per square meter produced a seedbank of 100 seeds per square meter. Five percent of the 100 seeds will then have germinated by the time wheat is planted. After the opening rains or break of the season, another 35% percent of the ryegrass seeds that are currently in the seedbank will germinate. The first flush of weeds will be well established by then and Sakura 850 W is sprayed as a pre-emergent herbicide to control ryegrass. This spray of Sakura 850 W reduces the number of ryegrass plants from 42 plants per square meter to 10. The reason why some ryegrass plants survive this application is that Sakura 850 W has a 95% efficacy rate together with a decrease in the efficiency of the pre-emergent herbicide due to dry seeding. This decreased efficacy of the pre-emergent herbicide during dry-seeding, is due to UV light damage and the impaired retention capabilities of the roots compared to when seeding is delayed and the ryegrass had a little more time to grow.

At the time of post-emergence spraying in the first year of the rotation there are 15 plants per square meter due to seeds still germinating after the spraying of the pre-emergent herbicide. Axial is then sprayed as the post-emergence herbicide, with a 60% efficacy rate, that results in 10 ryegrass plants surviving to reach maturity and set seed. The reason the surviving ryegrass plants was not eliminated from 15 down to six plants is that there were still some seed that germinated after the post-emergence herbicide was sprayed. The 10 surviving ryegrass plants produced a total of 182 seeds per square meter, but due to the natural mortality rate of the ryegrass seed only 121 seeds per square meter are present in the soil by next autumn.

Years two and three of the rotation’s ryegrass control strategy are similar to the first year, except that no post-emergence herbicide are sprayed. In the third year of the rotation Trifluralin is alternated with Sakura 850 W as a pre-emergent herbicide. The increase of ryegrass plants and seed per square meter from the first year of the rotation until the end of the third year ranges between 10 to 99 plants setting seed and 121 to 1342 seeds in the soil. This is an increase of 890% plants per square meter and an increase of 1009% seeds per square meter in the space of three years.

In the fourth year of the rotation, which is the first-year canola will be planted, the ryegrass numbers are starting to become a serious problem, with more than 60 plants per square meter, before the canola are even planted. At the same time, there are more than 1 200 ryegrass seed per square meter in the seedbank waiting to germinate. By the time a post-emergence herbicide can be sprayed the ryegrass numbers have increased to 298, the pre-emergent herbicide (Simazol AC) decreased the numbers from 972 down to the 298 there are currently.

In the canola year of the rotation two different post-emergence herbicides are sprayed. This is because of the high number of ryegrass plants and it is imperative to try and stop any ryegrass plants setting seed. Vega 240 EC and Simanex 500 SC are used as post-emergence herbicides, with a combined control percentage of 92%. If none of the post-emergence herbicides were used there would have been 346 ryegrass plants per square meter as opposed to the 71 plants after the post emergence sprayings. The final method of control in the fourth year of this rotation is topping which is a late season application of a non-selective herbicide. Topping brings the number of ryegrass plants down from 71 to 18, setting seed at the end of the season. The end result of this canola year, which is used as a year during which revenue is sacrificed in order to control ryegrass, is that ryegrass have decreased in numbers from 99 to 18 plants per square meter and 1 342 to 308 seeds per square meter from the start of the year until the end of the year. If canola was not planted in the fourth year of this rotation and another year of dry-seeded wheat, with a pre-and post-emergent herbicide spraying followed, the mature ryegrass setting seed would have been 186 plants per square meter. This is a difference of 168 plants per square meter, which emphasizes the importance of canola in the rotation and the control it brings combined with the applicable herbicides.

In the fifth year of the rotation the planting of wheat is delayed and a tickle is performed to stimulate ryegrass germination. Therefore, the first flush of ryegrass will be much denser in terms of plants per square meter, so that the administration of a knockdown herbicide such as glyphosate is more effective. When a tickle is not performed, 35% of the ryegrass seeds in the soil would germinate 10 days after the break (first rains) but with a successful tickle that number increases to 55%. In the fifth year of this rotation, the ryegrass numbers increase from 18 to 22 plants per square meter and 308 to 368 seeds per square meter.

From the first to the fifth year, the ryegrass numbers have increased from 10 to 22 ryegrass plants per square meter setting seed and 121 to 368 seeds per square meter in the soil. The next five years of the rotation follows the same control strategy as the previous five years. In this wheat and canola rotation the ryegrass numbers at the end of the first year was 10 plants per square meter and 121 seeds per square meter and after 10 years the numbers are 130 plants per square meter and 1 720 seeds per square meter in the soil.

5.5.1.1.2 Economic discussion

Table 5.9 presents the financial implications of ryegrass in the wheat and canola rotation.

Crop	Wheat 1	Wheat 2	Wheat 3	Canola 4	Wheat 5	Wheat 6	Wheat 7	Canola 8	Wheat 9	Wheat 10
Mature ryegrass plants setting seed (per m^2)	10	23	99	18	22	51	122	22	27	130
Seeds in soil at the end of the season (per m^2	121	339	1342	308	368	639	1648	375	446	1720
Gross margin (R/ha)	3142	3714	3433	475	4620	3116	3018	353	4578	3239
Average annual gross margin over 10 years	2969									

In the first year of wheat of the rotation this yield is penalised by six percent due to phytotoxicity (toxic damage to crops due to the spray of herbicides) and two percent for not swathing. The early planting however benefits the yield of the wheat by five percent thus the wheat yield for the first year is 2.77 tons per hectare. The wheat yield is 100% weed free and achieve a gross production value of R 8 793 per hectare.

The non-weed control costs of the first year is R 4 601 per hectare. This non-weed control costs per hectare consists of the no-till seeding (R 200), harvest (R 279), fertiliser (R 2 277), seed (R 734) and additional costs (R 1 111) which include the insurance, gypsum, insecticides, contract work and planting cost. The non-weed control costs remained constant for wheat every year, throughout the 10 years of the rotation.

The weed control costs of the first year consists fully of herbicides at a price of R 1050 per hectare. Sakura 850 W and Axial are sprayed, which are both expensive herbicides.

A gross margin of R 3 142 per hectare is achieved for the first year. In the next year the gross margin increases to R 3 714 per hectare. This is mainly due to the cutback on herbicide costs (only one herbicide is sprayed during the entire year). The third year the gross margin decreases to R 3 433.This decrease is primarily caused by ryegrass numbers starting to affect the yield of the crop. The yield decreased by 200 kilograms per hectare due to ryegrass.

In the fourth year of the rotation, canola is planted for the first time. Canola has a lower yield than wheat due to a number of reasons and this “low yield” makes it extremely sensitive to high ryegrass numbers. This sensitivity is emphasized by the fact that it has the lowest tolerance for competition against ryegrass in comparison to wheat, barley and legumes. The yield of canola decreases in this year from 1.3 tons per hectare to 1.02 tons per hectare, due to the weed burden. The gross production value of canola in the fourth year of the rotation is R 6 215 per hectare, supported by a relative high price. The non-weed control costs are similar to wheat at R 4 606 per hectare and the weed control costs consists completely out of herbicides. Simazol SC is sprayed as a pre-emergent herbicide and Simanex 500 EC and Vega 200 EC are sprayed as post-emergent herbicides. The weed control cost accumulates to R 1 044 per hectare. The gross margin for the fourth year of this rotation is R 475 per hectare.

In the following year after canola, wheat is again planted. Canola has several benefits for the following wheat crop including healthier root systems and it decrease the occurrence of root diseases. This benefits the yield of wheat by 23%. Therefore, in the fifth year of this rotation, the wheat yield is 3.13 tons per hectare and the yield is 99% weed free due to the level of control of ryegrass in the previous year. The gross production value is R 9 858 per hectare which is also the highest of the 10-year rotation. The weed control methods are mechanical, due to the tickle performed. The gross margin for the fifth year is R 4 620 per hectare.

The rotation repeats itself to complete the 10-year period. The only difference during the second five years is a slight decline in yield as the ryegrass numbers gradually increases. The average gross margin for this rotation over the 10-year cycle is R 2 962 per hectare.

If canola was not included in this rotation not only for the higher probability of root sickness that could occur, the average annual gross margin would have decreased to R 1 826 per hectare. This is an average annual drop of more than R 1 000 per hectare. Thus, the benefits that canola has in terms of future revenue due to yield benefits, healthy roots and ryegrass control outweighs the sacrifice in revenue that given year. This is one of the main reasons why farmers use canola as a "break-crop".

5.5.1.2 Wheat monoculture

5.5.1.2.1 Biological discussion

Table 5.10 illustrates the ryegrass numbers per square meter at various stages of a 10-year wheat monoculture rotation.

Crop	Wheat 1	Wheat 2	Wheat 3	Wheat 4	Wheat 5	Wheat 6	Wheat 7	Wheat 8	Wheat 9	Wheat 10
Ryegrass plants per m^2										
First chance to seed	5	18	43	21	49	106	114	42	92	125
10 days after break	15	36	128	41	97	312	170	82	270	366
20 days after break	22	49	35	57	133	464	26	113	402	546
Time for post-emergence spraying	26	56	47	65	151	544	34	129	471	640
Early spring	29	70	33	80	187	240	71	159	255	730
Mature ryegrass setting seed (Sept.)	29	70	33	80	187	240	71	159	255	730
Seeds in the soil										
Seeds in the soil at the start of the season	100	365	861	419	980	2130	2276	832	1843	2502
Seeds in the soil at the end of the season	365	861	419	980	2130	2276	832	1843	2502	6018

Prior to the first year of the wheat monoculture system there were two ryegrass plants per square meter that seeded and produced a seedbank of 100 seeds per square meter. Five percent of the 100 seeds will germinate by the time wheat are planted. After the opening rains, 35% of the seed currently in the seedbank will germinate. Trifluralin is then sprayed as a pre-emergent herbicide and the ryegrass plants decrease from 37 to 15 plants per square meter, 10 days after the break (first rains). The difference between the ryegrass numbers, at this stage, for "wheat and canola rotation" and the “wheat monoculture” are primarily caused by the difference in efficacy rates between Trifluralex and Sakura.

In a wheat monoculture rotation, the seeding rate remains constant at 125 kg/ha every year instead of a standard rate of 100 kg/ha. This increases the competition between wheat and ryegrass for nutrients in the soil and positively affects the control of ryegrass.

For the first year, the ryegrass plants per square meter increased from five plants to 29 plants setting seed with only trifluralin and increased seeding rates used as methods of controlling ryegrass.

In the second year of this rotation, only a pre-emergent herbicide is applied and an increased seeding rate used as methods of controlling ryegrass. The mature ryegrass setting seed increased from 29 to 70 plants per square meter from the end of the first year until the end of the second year of this system.

In the third year, there is an increased focus on eliminating and controlling ryegrass. A tickle action increases the germination of the first flush of weeds. Round-up Turbo is then sprayed as a knockdown herbicide. With a pre-emergent spray of Trifluralex, only three percent of weeds survive ten days after the break. The tickle plus the knockdown and the pre-emergent herbicide decreases the number of ryegrass plants from 517 to 35 plants per square meter 20 days after the break. The main reason for ryegrass plants still remaining in the paddock is that the seed still available in the seedbank which germinate after the tickle and spray of the pre-emergent herbicide. This year sees an intense focus on controlling ryegrass using various methods used to control ryegrass such as; dry-seeding, high seeding rates, tickle, and a knockdown, pre-emergent and post-emergent herbicide application. These methods decreased the number of ryegrass plants from 70 to 33 plants per square meter setting seed. If none of these methods were used the number of mature ryegrass plants setting seed would increase from 70 to 654 per square meter. This illustrates the importance of intense ryegrass control with a diversification of methods during year 3 of the rotation.

For years 4 and 5, only a pre-emergent herbicide is sprayed. In year six a pre-emergent as well as a post-emergent herbicide are sprayed. From year three until the end of year six, the ryegrass numbers increased from 33 to 240 plants per square meter and seed increased from 419 to 2276 seed per square meter.

In year seven, aggressive actions are applied to decrease the amount of ryegrass plants in the paddock. A tickle action, followed by a knockdown herbicide is sprayed followed by a pre-emergent herbicide. Only five percent of weeds survive the pre-emergent herbicide sprays, but of the ryegrass seed still in the seedbank 30% will germinate after the pre-emergent herbicide is sprayed. Almost 71 ryegrass plants per square meter will still set seed.

The last three years of the rotation, the number of ryegrass plants and seed per square meter increase exponentially. This is due to the number of seed in the seedbank and each year increasing numbers of ryegrass plants survive and set seed.

Over the space of ten years where wheat is planted continuously, the number of ryegrass plants increased from 29 to 730 plants per square meter setting seed. The seed in the seedbank increased from 365 to 6038 seed per square meter.

5.5.1.2.2 Economic results

Table 5.11 presents the financial implications of ryegrass on a wheat monoculture system.

Crop	Wheat 1	Wheat 2	Wheat 3	Wheat 4	Wheat 5	Wheat 6	Wheat 7	Wheat 8	Wheat 9	Wheat 10
Mature ryegrass plants setting seed (per m^2)	29	70	33	80	187	240	71	159	255	730
Seeds in soil at the end of the season (per m^2)	365	861	419	980	2130	2276	832	1843	2502	6018
Gross margin (R/ha)	3803	3265	1907	3202	2624	2029	2067	2763	1959	1263
Average annual gross margin over 10 years	2488									

The yield of the first year of wheat is 99% weed free with a gross production value of R 8 887 per hectare. The non-weed control costs are R 4 601, and the weed control cost is R 483 consisting of herbicides (R 300) and an increased seeding rate (R183) to increase competition. A gross margin of R 3 803 per hectare is achieved for the first year of wheat. The second year of the rotation the gross margin drops by R 538 per hectare which are caused primarily by an increasing weed burden.

The third year, the yield of the wheat suffers various penalties, namely for not swathing, phytotoxicity and for late planting. These penalties accumulate to a yield loss of 11%. The yield is reduced from 2.8 to 2.49 ton per hectare. Non-weed control costs remained constant. The weed control increased from R 753 to R 1 301. This lowers the gross margin to R 1 907 per hectare. This sacrifice in revenue to eliminate ryegrass in this particular year is justified by the gross margins in following years. Without this intensive control to curb ryegrass numbers escalating, the gross margin would be less than R 1 000 per hectare in two years’ time and ryegrass numbers would be more than 500 mature plants per square meter setting seed.

The gross margin of the fourth and fifth year recovers to R 3 202 and R 2 624 per hectare respectively, due to the increase in yields. The weed control costs decrease and further improved the gross margin. From Table 5.11 it can be seen that the gross margin per hectare decrease gradually as the numbers of ryegrass plants and seeds increase. The wheat monoculture achieved an average annual gross margin of R 2 488 per hectare over the ten years.

5.5.1.3 Wheat and medics rotation

5.5.1.3.1 Biological discussion

In the first year of the wheat and medic rotation, there are 100 seeds per square meter in the seedbank due to the two ryegrass plants that seeded. The wheat is planted dry and only a pre-emergent herbicide is sprayed as a method of weed control for the first year. The ryegrass numbers increase from two ryegrass plants per square meter setting seed in the previous year to 19 plants per square meter setting seed at the end of the first year.

Table 5.12 illustrates the ryegrass population dynamics of a 10-year wheat and medic rotation system.

Crop	Wheat 1	Medics 2	Wheat 3	Medics 4	Wheat 5	Medics 6	Wheat 7	Medics 8	Wheat 9	Medics 10
Ryegrass plants per m^2										
First chance to seed	5	14	2	4	1	3	1	2	1	3
10 days after break	10	41	6	23	2	18	2	14	2	17
20 days after break	14	61	9	39	3	30	2	24	3	28
Time for post-emergence spraying	15	72	10	47	3	36	2	28	3	33
Early spring	19	46	6	25	4	19	3	15	3	18
Mature ryegrass setting seed (Sept.)	19	1	6	0	4	0	3	0	3	0
Seeds in the soil										
Seeds in the soil at the start of the season	100	281	41	73	16	46	10	29	6	27
Seeds in the soil at the end of the season	281	41	73	20	56	15	44	12	52	14

In the second year of this rotation, medics are established. The ryegrass numbers gradually increase throughout the year until the time for post-emergence spraying. Vega 240 EC is sprayed and the ryegrass numbers decrease from 72 plants to 46 plants per square meter. The number of ryegrass plants is decimated by the time they reach maturity. Of the 46 plants only 10% survive due to the late season topping and of that 10 percent only 15% survive after the sheep grazing. After this late season extermination of ryegrass only one ryegrass plant per square meter set seed.

All the wheat in this rotation is dry-planted. Every year of wheat, there are either Sakura or Trifluralin sprayed as a pre-emergent herbicide, to control ryegrass. Axial is sprayed in year three providing intensive control of ryegrass at the start of this rotation. At the end of year three, six plants per square meter set seed.

Year four of the rotation is a medics year. Medics will not be planted again because it was established earlier in the rotation. The following years of medics have the same effective control strategies. It consists of a post-emergent herbicide (Vega 240 EC), topping and lastly high intensity grazing by sheep.

The ryegrass plants setting seed at the end of the first year was 19 plants per square meter, and at the end of the 10-year period, that number is down to zero plants per square meter. The seeds in the seedbank decreased from 281 seeds per square meter to 14 seeds per square meter.

5.5.1.3.2 Economic discussion

Table 5.13 illustrates the economic significance of ryegrass in a wheat-medic rotation system.

Crop	Wheat 1	Medics 2	Wheat 3	Medics 4	Wheat 5	Medics 6	Wheat 7	Medics 8	Wheat 9	Medics 10
Mature ryegrass plants setting seed (per m^2)	19	1	6	0	4	0	3	0	3	0
Seeds in soil at the end of the season (per m^2)	281	41	73	20	56	15	44	12	52	14
Gross margin (R/ha)	3748	-2673	5868	-899	6301	-899	6301	-899	6571	-899
Average annual gross margin over 10 years	2252									

The gross margin of the first year of this rotation is R 3 748 per hectare. The second year of the rotation and the first year of medics, the gross margin decreases significantly where the medics is used as a pasture for sheep to graze on. The only revenue for the years of medics in this rotation is derived from the sheep component. When using medics in a rotation, the first year will be used to establish the medics and in the following years, it will re-establish without requiring planting, unless it is sprayed with an herbicide that kills it. The gross production value for medics is the gross margin for a dry sheep equivalent times the stocking rate and for the first year that is R 873 (R 291*3). The non-weed control is R 2 681 which is high for medics because it is the year in which it is being established. The weed control cost is R 867 and consists of a pre-emergent and post- emergent herbicide and topping. The gross margin for the first year of medics is R -2 673 per hectare.

The year following medics, the wheat yield is boosted to 3.5 ton per hectare due to the benefits of medics, such as nitrogen fixation in the soil. The gross production value of the wheat is R 11 035 per hectare. The yield of wheat is also 100% weed free. The non-weed control costs are normally R 4 601 per hectare, but due to the nitrogen fixation of the medics, a saving on fertiliser can occur. The non-weed control costs are only R 4 387 per hectare. The weed control costs are R 780 per hectare returning a gross margin of R 5 868 per hectare.

In the fourth year, medics do not have to be planted because it was established in the second year of the rotation. Therefore, a saving of R 1475 is expected. The gross margin is R -899 per hectare, which is still negative but it is an improvement on the year it was established.

For this rotation system a gross margin is expected every other year. Wheat is consistently benefitting from the yield benefits of the medics in the previous year of the rotation. The average annual gross margin over the 10-year period for this rotation is R 2 252.

5.5.1.4 Wheat and legume rotation

5.5.1.4.1 Biological discussion

Table 5.14 shows the ryegrass numbers per square meter at various stages of a 10-year wheat and legume rotation.

Crop	Wheat 1	Wheat 2	Wheat 3	Legum. 4	Wheat 5	Wheat 6	Wheat 7	Legum. 8	Wheat 9	Wheat 10
Ryegrass plants per m^2										
First chance to seed	5	14	38	64	45	51	175	316	110	117
10 days after break	10	28	112	167	133	150	346	827	328	342
20 days after break	14	38	167	244	37	224	473	1206	90	509
Time for post-emergence spraying	15	43	196	284	49	263	540	1405	120	596
Early spring	19	54	106	188	63	300	666	931	156	681
Mature ryegrass setting seed (Sept.)	19	54	106	47	63	300	666	233	156	681
Seeds in the soil										
Seeds in the soil at the start of the season	100	281	765	1280	894	1027	3493	6330	2196	2333
Seeds in the soil at the end of the season	281	765	1280	894	1027	3493	6330	2196	2333	6279

The first year of wheat in this particular rotation share the same strategy as the first year of wheat in the wheat and medic rotation. Thus, at the end of the first year 19 plants per square meter will set seed. The second year follows precisely the same ryegrass control strategy as the first. The amount of ryegrass plants setting seed have now increased to 54 plants per square meter. The third year of the strategy sees the change from Sakura to Trifluralin as a pre-emergent herbicide. Axial is sprayed this year as a post-emergent herbicide and decreases the ryegrass plants setting seed from 203 to 106 plants per square meter.

The first year of legumes follows a similar strategy to canola, with Simazol AC being sprayed as a pre-emergent herbicide. Vega 240 EC is applied as a post-emergent herbicide and then followed by a late season topping. These three methods of control decrease the amount of ryegrass setting seed at the end of the year from 972 to 47 plants per square meter.

The fifth year of the rotation and the first year after legumes, the seeding of wheat is delayed to perform a tickle action and spray a knockdown herbicide. At the end of this year there is an increase of just 16 plants per square meter from the previous year, setting seed.

Years six and seven entail two consecutive wheat crops. This is followed by one year of legumes followed by two consecutive years of wheat. In this strategy, the years of legumes and delayed seeding of wheat are the years in which the control of ryegrass is at an optimal level. Over this 10-year crop rotation sequence the amount of seeds in the seedbank increased from 281 seeds to 6 279 seeds per square meter. The mature ryegrass plants setting seed have increased from 19 to 681 plants per square meter.

5.5.1.4.2 Economic discussion

Table 5.15 illustrates the financial implications of ryegrass on a wheat and legume rotation system of 10 years.

Crop	Wheat 1	Wheat 2	Wheat 3	Legume 4	Wheat 5	Wheat 6	Wheat 7	Legume 8	Wheat 9	Wheat 10
Mature ryegrass plants setting seed (per m^2)	19	54	106	47	63	300	666	233	156	681
Seeds in soil at the end of the season (per m^2)	281	765	1280	894	1027	3493	6330	2196	2333	6279
Gross margin (R/ha)	3748	3479	2744	-974	5236	3646	1086	-1555	4548	2402
Average annual gross margin	2436									

The first two years of the rotation the gross production value of exceeds R 8 500 per hectare. Due to the burden of ryegrass in the third year the gross production value decreases to R 8 125 per hectare.

Combined with the cost of the post-emergent herbicide, the annual gross margin decreases by R 1 004 per hectare from year one to year three.

The gross production value for the first year of legumes is R 2 191 per hectare which is substantially less than that of wheat. The reason for this relative low gross production value compared to wheat is the 1.7 ton per hectare yield difference and the higher price of wheat. In this simulation the yield of the legumes is decreased from 1.1 down to 0.71 ton per hectare. This means that only a 66% portion of the legume yield is ryegrass free. The weed control costs are R 777 per hectare. This cost consists of a pre-emergent, post-emergent herbicide and a late season topping. The non-weed control costs are R 2 388 per hectare which is considerably lower than the same cost for wheat and canola. The cost of fertilization is significantly lower than the fertilization costs of wheat, canola and barley. The fertilization for wheat, barley and canola are all higher than R 2 000 per hectare, while the cost for legumes is R 309 per hectare. This low cost of fertilization for legumes is due to its own ability to produce nitrogen and improve the health of the soil. The very low gross production value of legumes is then responsible for the annual gross margin of R -974 per hectare.

The wheat that is planted after the year of legumes benefits significantly in terms of yield due to improved soil health. In the first year after legumes the wheat yield increased from 2.8 to 3.6 ton per hectare. Due to the weed burden and yield penalties of 10% that are caused by phytotoxicity, late planting and for not swathing, the actual yield is decreased to 3.17 ton per hectare. The gross production value of wheat after the first year of legumes is R 10 047 per hectare due to this increase in yield. The weed control costs are R 638 per hectare and the non-weed control costs are R 4 174 per hectare. The non-weed control cost has been decreased by R 427 per hectare due to a saving in nitrogen fertilizer that are caused by the nitrogen fixation of the legumes in the previous year. The annual gross margin for the fifth year is R 5 236 per hectare.

The second consecutive year of wheat after the legumes still benefits in terms of yield because of the impact the legumes had on the soil and the wheat yield averages at 3.2 ton per hectare. The yield benefit of early planting (5%) cancels out the yield penalties for not swathing (2%) and phytotoxicity (2%). The ryegrass is starting to influence the yield of the wheat negatively because of the weed burden. The weed burden caused by the ryegrass decrease the wheat yield to 2.6 ton per hectare. The gross production value for the sixth year of this rotation is R 8 404 per hectare. The weed control costs are R 300 per hectare and the non-weed control cost are R 4 458 per hectare. There is a saving of R 142 per hectare in terms of nitrogen caused by the legumes planted two years previously in the rotation. The annual gross margin for this year is R 3 646 per hectare.

Wheat is planted again in the seventh year of the rotation, which is the last of the three consecutive years of wheat. The annual gross margin for this year is R 1 086 per hectare. This decline in annual gross margin is primarily caused by the weed burden of the ryegrass. The yield is decreased from 2.8 to 1.97 ton per hectare as a result of the high ryegrass numbers in the crop.

During the eighth year of this rotation ryegrass amounts to a very high number and negatively affects the yield. The legume yield is 0.5 ton per hectare, and the annual gross margin is R -1 555 per hectare.

The only reason the annual gross margins of the years' nine and ten of this rotation remain high. This is because of the yield benefits of the legumes that were planted in the eighth year. An average annual gross margin of R 2 436 per hectare is achieved over the ten years.

5.5.1.5 Wheat, canola and legume rotation

5.5.1.5.1 Biological discussion

Table 5.16 presents the population dynamics of ryegrass in a wheat, canola and legume rotation system

Crop	Wheat 1	Canola 2	Wheat 3	Legum. 4	Wheat 5	Canola 6	Wheat 7	Legum. 8	Wheat 9	Canola 10
Ryegrass plants per m^2										
First chance to seed	5	14	12	14	13	36	28	12	11	20
10 days after break	10	37	35	36	26	105	42	31	33	53
20 days after break	14	53	9	53	36	157	6	45	50	77
Time for post-emergence spraying	15	62	13	62	41	184	8	53	58	89
Early spring	19	41	16	41	50	118	18	35	32	59
Mature ryegrass setting seed (Sept.)	19	10	16	10	50	29	18	9	32	15
Seeds in the soil										
Seeds in the soil at the start of the season	100	281	231	277	263	719	565	238	229	403
Seeds in the soil at the end of the season	281	231	277	263	719	565	238	229	403	320

Wheat is planted in the first year. At the end of the first year 19 ryegrass plants per square meter set seed. The second year of the rotation canola is dry-planted with a 100% chance of weeds surviving 20 days after the break of the season. The first time weed control is introduced in the second year, is when the pre-emergent herbicide, Simazol SC, is sprayed. This pre-emergent have an 85% efficacy rate but due to the dry-planting of canola the efficacy drops by 10% and thus only having a 75% rate of control. Vega 240 EC is sprayed as a post-emergent herbicide and the second year's control strategy ends with a late season topping. The topping plays a critical role in this strategy, as it decreases the ryegrass plants from 41 in early spring to only 10 plants per square meter setting seed. The second year of the rotation reduces the ryegrass setting seed, at the end of the year, by 9 plants per square meter and the seeds by 50 seeds per square meter, in the seedbank from the previous year.

In the third-year wheat planting is delayed and a tickle action is performed in order to stimulate ryegrass germination. This tickle causes a 20% increase in ryegrass germinating 10 days after the break of the season. The knockdown herbicide is sprayed and a pre-emergent herbicide is sprayed after that. This decreases the number of weeds, surviving 20 days after the break, from 50 to nine plants per square meter.

Legumes are dry-planted in the fourth year. the key component of control in this year is the late season topping. The ryegrass plants increase steadily in numbers throughout the year in spite of a pre-and post-herbicide being sprayed. Ryegrass numbers increase until the late season topping in spring when the ryegrass plants are decreased from 41 plants in early spring to only 10 plants per square meter setting seed.

The remaining six years of the rotation will continue as; Wheat-Canola-Wheat-Legumes. The same cropping sequence with exactly the same weed control strategies in terms of herbicides being sprayed, Time of planting etc. The last two years are canola and wheat that follow the same weed control strategies as earlier in the cropping system.

The ryegrass numbers decreased in this rotation of wheat, canola and legumes from 19 plants to 15 plants per square meter setting seed, but the amount of seeds in the soil increased from 281 to 320 seeds per square meter over the 10-year period.

5.5.1.5.2 Economic discussion

Table 5.17 presents the financial implications of ryegrass on a wheat, canola and legume rotation system.

Crop	Wheat 1	Canola 2	Wheat 3	Legume 4	Wheat 5	Canola 6	Wheat 7	Legume 8	Wheat 9	Canola 10
Mature ryegrass plants setting seed (per m^2)	19	10	16	10	50	29	18	9	32	15
Seeds in soil at the end of the season (per m^2)	281	231	277	263	719	565	238	229	403	320
Gross margin (R/ha)	3748	1132	4670	-356	6533	768	4388	-313	6281	1370
Average annual gross margin over 10 years	2822									

The first year of wheat shows an annual gross margin of R 3 748 per hectare. This is more or less a "normal" gross margin for weed-free wheat with no significant yield benefits or penalties affecting the gross margin.

The next year canola is planted as a "break-crop". This paddock is relatively weed-free this year and a positive annual gross margin of R 1 132 is achieved.

In the third-year wheat planting is delayed and suffer a 10% yield penalty due to the late planting, phytotoxicity and for not swathing. The yield of the wheat is 3.12 ton per hectare. This results in a gross production value of R 9 906 per hectare and a gross margin of R 4 670 per hectare for the third year.

Legumes are dry-planted in the fourth year of the rotation. The ryegrass decreases the yield of the legumes from 1.1 to 0.9 ton per hectare. A gross production value of R 2 808 per hectare is achieved. The weed control costs are at R 777 per hectare and the non-weed control costs are at a low R 2 388 per hectare. This is due to the nitrogen fixation abilities of legumes as mentioned earlier. An annual gross margin of R -356 per hectare are achieved.

Wheat is then planted after the legumes and will experience significant yield benefits which are expected in the year after legumes were planted. The yield of 3.7 ton per hectare is adapted to 3.6 ton per hectare because of the weed burden. Gross production value is R 11 276 per hectare due to the high yield. Only a pre-emergent chemical is sprayed and the non-weed control costs are low due to the fertilization savings caused by the previous years' legumes. A gross margin of R 6 533 per hectare is achieved.

The rotation then continues with the same sequence of crops through the 10 years. A relatively high gross margin in the wheat phases and low gross margins in the canola phases is expected. Comparatively low gross margins are achieved in the legume phases. An average annual gross margin of R 2 855 per hectare is achieved with this crop rotation.

5.5.1.6 Discussion

All of the rotations start with a low number of ryegrass plants setting seed in the year previous to the first year of the rotation, approximately two plants per square meter. The seedbank builds up quickly from only a few plants required to set seed. As ryegrass plants survive and set seed, the number of seedlings increase exponentially in the following year.

In the wheat and canola rotation, the ryegrass numbers build up rapidly during the wheat phases. The gross margin decreases as the ryegrass numbers and the total weed burden increase. After three consecutive years of wheat during which relatively "good" gross margins are achieved a canola year is brought into the rotation to curb this increase of ryegrass numbers. Canola is used as a "break-crop" with the added benefit of also improving soil health. The canola year is justified with the high gross margin of wheat the following year. This is due to the yield benefits and the level of ryegrass control possible during the canola year.

In wheat monoculture, the "delayed" years are the years that best control the ryegrass. In these delayed years revenue is sacrificed in exchange for better ryegrass control and, therefore, ensuring better future revenue. If these years were also dry-seeded after eight years, a negative gross margin would have been experienced. This rotation that consists of wheat for 10 consecutive wheat years is not a very effective strategy to control ryegrass on a profitable and sustainable basis as demonstrated by Figure 13. The ryegrass numbers proof this, after the first year 29 plants per square meter set seed and after 10 years that number increased to 730 plants per square meter. The gross margin also decreased from R 3 803 to R 1 263 per hectare over the 10-year period.

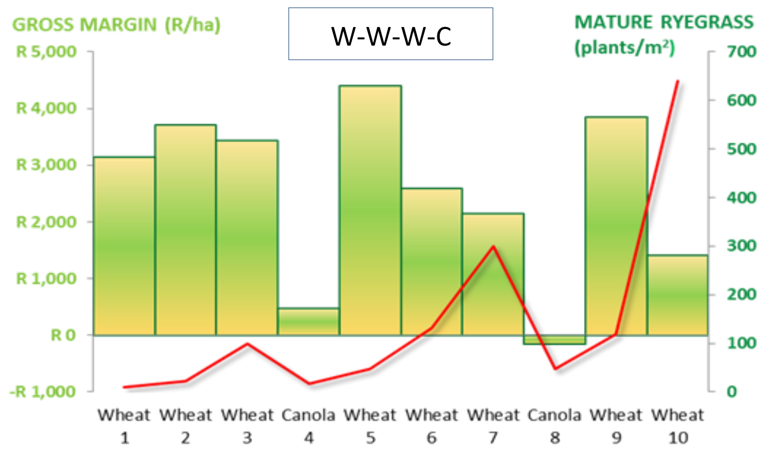
The wheat and medic rotation system control the ryegrass numbers well. The ryegrass plants setting seed are decreased from 19 plants in the first year to zero plants per square meter setting seed after 10 years. The average annual gross margin is, however the lowest of the five rotations, and this is mainly due to the low income from sheep in the medic years. If the stocking rates can be increased the gross margin in the medic years would improve. The gross margins achieved in the years of wheat in this rotation are the highest out of all of the strategies. This is mainly due to the high level of ryegrass control combined with the yield boost resulting from the medics.

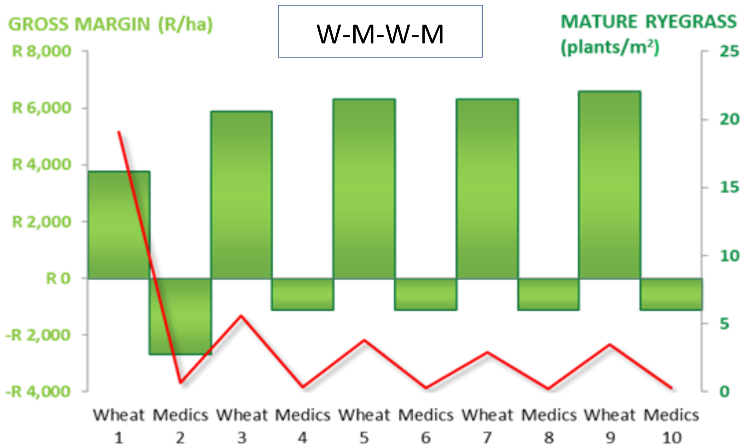
The wheat and legume rotation show many similarities to the wheat and canola rotation. The legume years, as with the canola years, are seen as years in which revenue is sacrificed to control ryegrass. However, the weed control in the wheat and legume rotation compares poorly to the level of control achieved in the wheat and canola rotation. However, the gross margin in the wheat and legume year is buffered by the yield benefits caused by legumes plus the savings in fertilizer. Without this benefit, the weed burden would overshadow the gross margins for the last few years of this rotation.

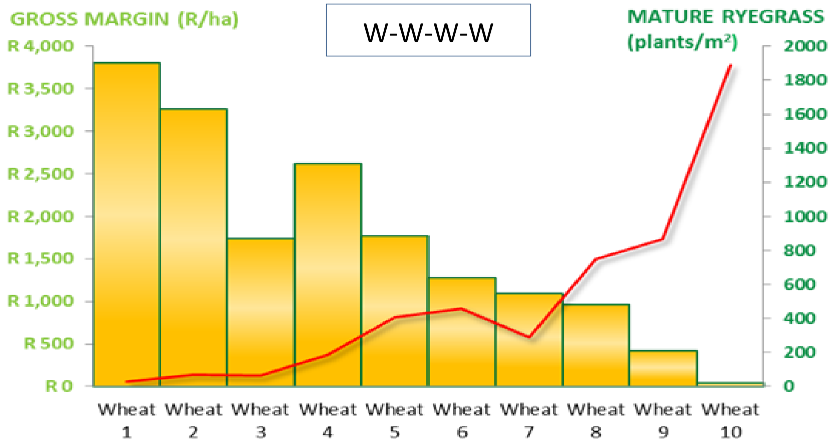
Lastly, the wheat, canola and legume rotation controls ryegrass the second best of these five rotations in terms of eliminating ryegrass. It is second only after the wheat and canola rotation in terms of highest average annual gross margin over the 10-year period.

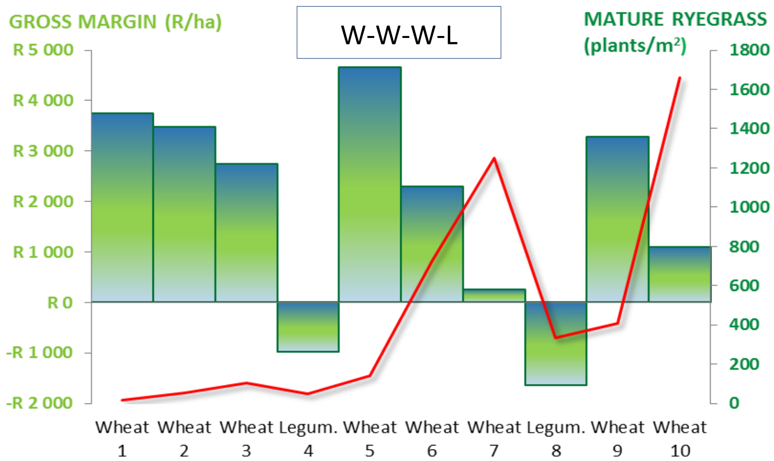
5.5.2 Glyphosate and paraquat resistance

There are already glyphosate and paraquat resistance found in the Western Cape (Eksteen, 2007). The same rotation and control strategy of a "typical" wheat farmer is simulated in the RIM model with the exception of the assumption that glyphosate and paraquat have a zero-percentage control (worst-case scenario).









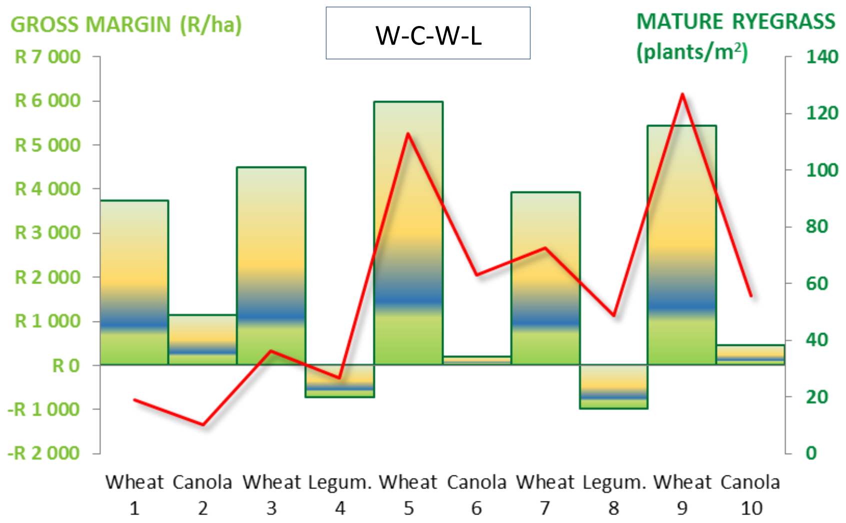


Figure 5.5.2: The effect glyphosate and paraquat resistance have on different numbers of ryegrass plants (line) and the effect this have on the annual gross margin (columns) of different crop rotations over a 10-year period.

5.5.2.1 Discussion

In the canola and wheat rotation, the main effect of this resistance against glyphosate can be seen in the fifth and ninth year. In these two years the planting of wheat is delayed so that a tickle action can be performed, followed by a knockdown herbicide (Round-up Turbo). Before ryegrass developed resistance against glyphosate, the number of weeds surviving past day 10 after the break was a mere 3% compared to the current 60%. Without resistance after the fifth year, 22 plants per square meter would set seed, with this resistance that figure increase to 48. More importantly, the seeds in the soil increased from 368 to 955 seeds per square meter. The glyphosate and paraquat resistance only have an effect from the fifth year onwards because glyphosate (Round-up Turbo) is sprayed in the fifth year for the first time. The resistance decreases the average annual gross margin over the last six years from R 3 154 per hectare to R2 370 per hectare per year. This is an average loss of R 784 per hectare per year. However, ryegrass numbers increase exponentially as more ryegrass plants survive and set seed therefor the loss in the fifth (R 228 per ha) and sixth year (R 531 per ha) The loss in the ninth (R 727 per ha) and tenth year (R 1 826 per ha) is the highest.

In the wheat monoculture rotation, the resistance of ryegrass against glyphosate and paraquat have the biggest effect on profitability out of all the rotations. The annual gross margin and the amount of ryegrass plants show an inverse relationship. Resistance has an effect from the second year of the rotation, due to Round-up Turbo being sprayed as a knockdown-herbicide after the tickle action. In the wheat and canola rotation when the planting of wheat is delayed, the percentage of ryegrass plants surviving 10 days after the break increase from three percent to 60%. The average annual gross margin over the 10-year period decrease from R 2 488 to R 1 699 per hectare. The average annual gross margin over the last five years decrease from R 2 016 to R 760 per hectare. The ryegrass numbers increase rapidly to 1 892 plants per square meter setting seed and results in an excess of 9 000 seeds per square meter in the soil. Without the resistant factor, the figures for the same rotation at the end of the 10-year cycle would be 730 mature ryegrass plants per square meter setting seed and 6 038 seeds per square meter in the seedbank.

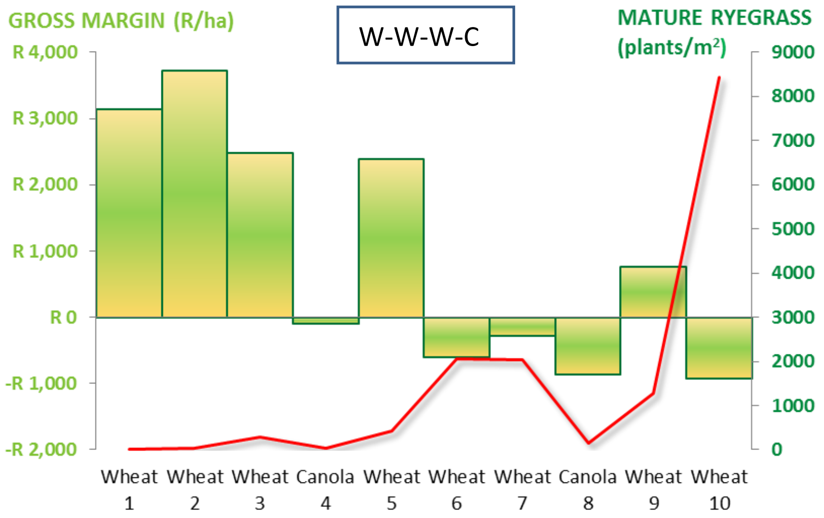
The wheat and medic rotation experience no changes in profitability or control due to glyphosate not being sprayed in the rotation.

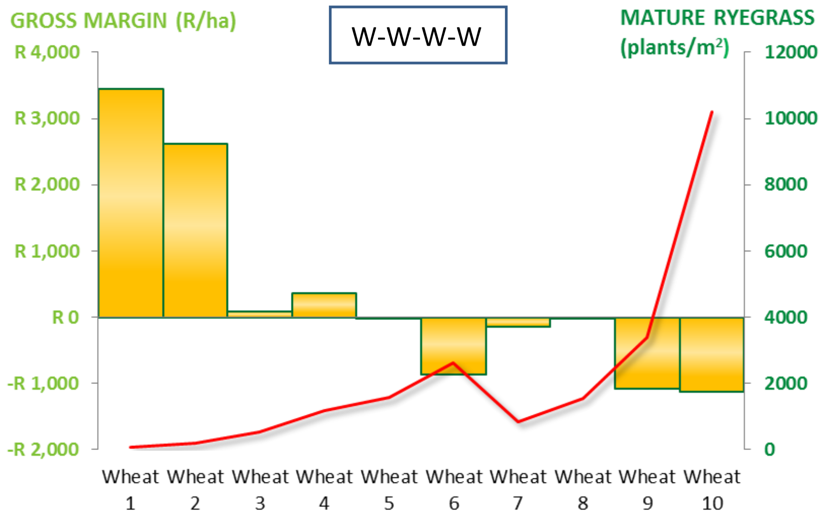
In the wheat and legume rotation, the first year this resistance has an effect is in the fifth year when the knockdown herbicide is applied. The glyphosate and paraquat resistance decrease the average annual gross margin of the last six years by R 899 per hectare. This effect gets exponentially bigger as the number of seeds in the soil increase and from the fifth year onwards, the seeds in the soil are consistently more than 1000 seeds per square meter. For the last two years of the rotation this resistance decreased the annual gross margin by R 2 278 and R 1347 per hectare per year respectively. The average annual gross margin over the 10-year period was R 2 436 per hectare and after resistance it is R 1 897 per hectare. The only reason that the latter years in this rotation have a positive value is due to the yield benefits of the legume phases in the rotation.

The wheat, canola and legume rotation does not seem to be affected greatly by the resistance due to the high level of control in the rotation. Glyphosate are sprayed twice in the rotation, in the third and seventh year. The average annual gross margin over the 10-year period was R 2 822 per hectare per year before the resistance and after the resistance it is R 2 391 per hectare. The ryegrass plants setting seed at the end of the tenth year were 15 plants per square meter and after the resistance factor, there are 56 plants per square meter. The number of seed in the soil also increased, from 320 seed per square meter to 452.

5.5.3 Glyphosate, paraquat and trifluralin resistance

To demonstrate the severity of herbicide resistance, a simulation where ryegrass has developed resistance against a popular herbicide such as Trifluralin is simulated. In South Africa, there are none reported cases of ryegrass developing resistance against trifluralin (2017). However, in Australia there are numerous cases (Broster, Koetz and Wu, 2011). The simulations will demonstrate the effect of a "known" resistance (glyphosate) and an "unknown" resistance (trifluralin) on ryegrass numbers as well as annual gross margins of "typical" Central Swartland crop rotations.





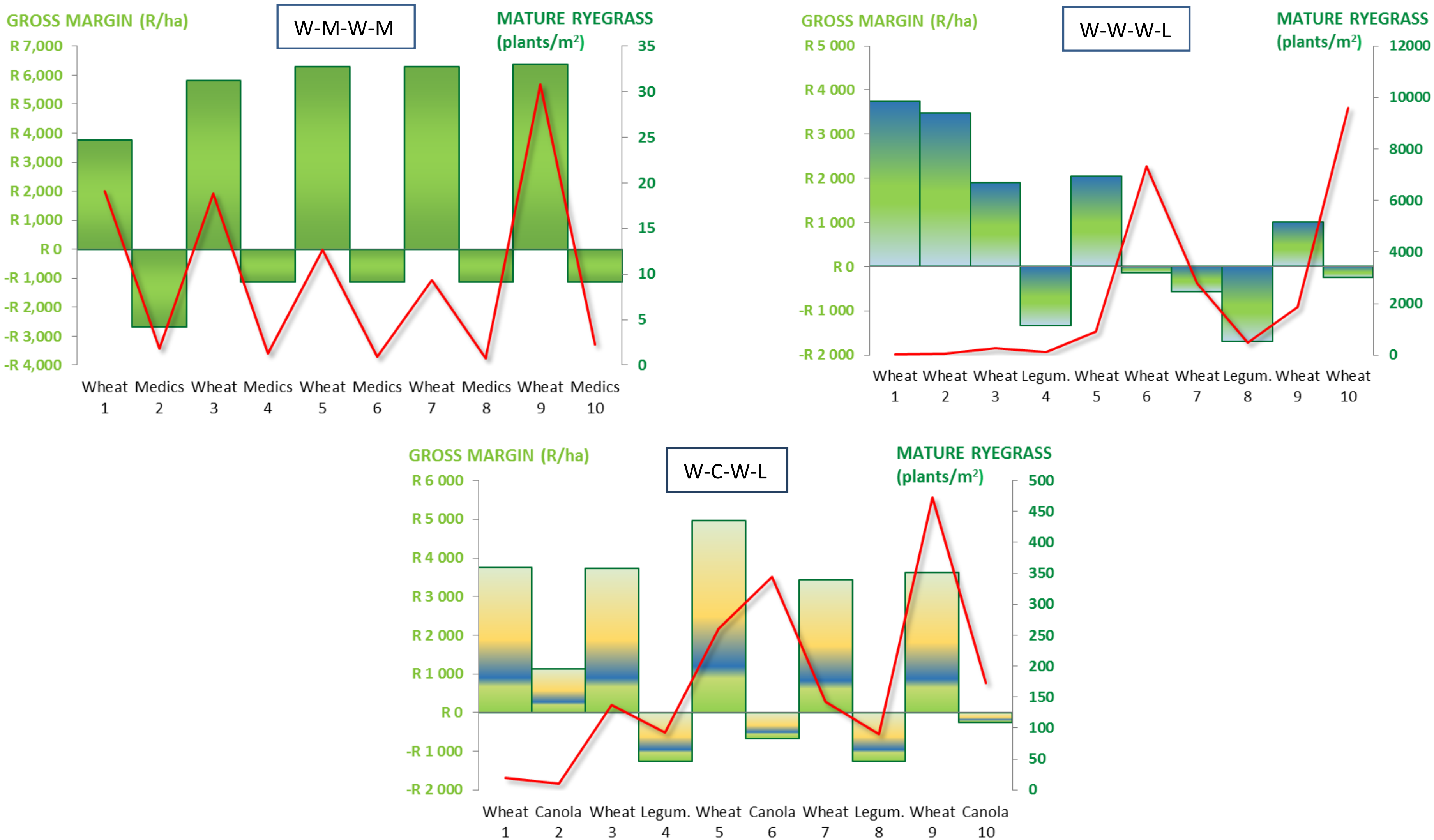


Figure 5.5.3: The effect glyphosate, paraquat and trifluralin resistance have on different numbers of ryegrass plants (line) and the effect this have on the annual gross margin (columns) of different crop rotations over a 10-year period.

5.5.3.1 Discussion

The effect of resistance against paraquat, glyphosate and Trifluralin will only have an effect once one of these mentioned herbicides is sprayed.

In the wheat and canola rotation Trifluralin is sprayed in the third year of the rotation. Resistance against Trifluralin will have an effect from year three onwards to the end of the rotation. The canola crop that is planted in the fourth year as the "break-crop" eliminates a lot of ryegrass. From the 282 plants that seeded the previous year, only 43 plants per square meter will seed at the end of the canola year. Because of the sheer amount of seed in the seedbank left over from the previous year, the canola year cannot deplete all the seed in the seedbank. In the next year, when the seeding is delayed and good ryegrass control is normally achieved, there is now resistance against the knockdown herbicide and the pre-emergent herbicide (Trifluralin). The number of ryegrass plants increase rapidly from year four. Figure 5.5.3 illustrates how the annual gross margin reduces due to the high levels of ryegrass. Resistance decreased the average annual gross margin by R 2001 per hectare over the 10-year period.

The wheat monoculture rotation is affected from the very first year of the rotation because Trifluralin is sprayed as a pre-emergent herbicide. The annual gross margin of this rotation is low from the third year onwards as illustrated by Figure 5.5.3. The ryegrass numbers rise sharply and keeps on increasing until the end of the 10-year period.

The wheat and medic rotation once again proved to have the highest level of control out of all the rotations. It achieves the highest average annual gross margin per hectare. The average annual gross margin decreased by only R 25 per hectare after the effects of this multiple resistance of ryegrass over the 10-year period. The late season control by grazing and topping seems effective methods of control. It prohibits plants from setting seed, resulting in less seeds germinating the following year. Most of the seed in the seedbank have germinated by the time these methods of control are implemented and therefore affects more plants. This rotation with the wheat, canola and legume rotation is the only rotations that keep the number of ryegrass plants setting seed at the end of the 10-year period under 3000 plants per square meter. In this rotation, there are just six plants per square meter setting seed at the end of the 10-year period. What makes this number even more significant is that after the first year of this rotation 19 plants per square meter set seed and with this high level of resistance the rotation still decreases the number.

The wheat and legume rotation are only affected in the third year of the rotation, but from then on, the annual gross margin decrease consistently and the ryegrass numbers keeps increasing. Not even the yield benefits after the legume years can keep the annual gross margin at relatively profitable levels, because of the effects of this resistance.

Lastly, the wheat, canola and legume rotation are affected during the third year of the rotation. This severe form of resistance affects the rotation to such an extent that the gross margin of legume and canola years cannot remain positive. However, the canola breaks the weed numbers enough and the legumes gives a substantial yield boost so that, despite this resistance, the annual gross margin of wheat is never less than R 3400 per hectare per year in this 10-year rotation.

5.6 Conclusion

Crop rotation systems have various benefits, whether it is to manage weeds at a cheaper level, to improve the nitrogen levels in the soil or to mitigate price risks. All of these reasons for rotating crops are done primarily to increase profitability and the sustainability of farming.

For the first scenario, there were no forms of resistance against herbicides by ryegrass “default results”. This can be used to compare scenarios where different forms of resistance should occur. The wheat and canola rotation obtained the highest average annual gross margin per hectare. The wheat and medics rotation had the lowest average annual gross margin. The wheat and medic rotation, however obtained the best level of control of ryegrass while the wheat monoculture system had the lowest level of control. The high gross margin of the wheat and canola rotation is achieved during the wheat years of the rotation. This is due to the yield benefits of the canola and the high level of control in the canola phases. The low gross margins of the wheat and medic rotation are due to the low gross production value obtained from the livestock component in the medic years. The good level of control in the wheat and medic rotation is primarily due to the control achieved through grazing and topping in the medic phase of the rotation. The opportunity cost between "excellent levels of control" and "high gross margins" is clear.

For the scenarios where ryegrass developed a 100% resistance against glyphosate and paraquat the effect of ryegrass on profitability is accentuated. In this scenario, the wheat and canola rotation, obtained the highest annual gross margin per hectare while the wheat monoculture system obtained the lowest. The wheat and canola remained the most profitable rotation, due to the level of control combined with the yield benefits in wheat caused by the canola. However, the effect of this resistance only manifested from the fifth year onwards. The wheat monoculture system had the lowest average annual gross margin, as well as the lowest level of control out of all the rotations. This is caused by the impact of the ryegrass burden on the yield. Contributing factors are; very high cost of herbicides together with beneficial yield effects due to wheat monoculture. Another significant finding from this scenario is the level of control obtained in the wheat and medic rotation. This rotation is the only rotation out of the five rotations simulated to reduce the ryegrass numbers despite the presence of herbicide resistance. What makes this significant is that; this is the rotation during which the most glyphosate is sprayed out of all the rotations. The control during the medic phase is enough to reduce the number of ryegrass plants over the 10-year cycle to zero plants per square meter at the end of the cycle.

The last scenario discussed in this study is when resistance occurs against glyphosate, paraquat and Trifluralin. In this scenario, the wheat and medic rotation obtained the highest average annual gross margin. All of the other rotations were unable to carry this burden created by the resistant ryegrass with exception of the wheat, canola and legume rotation which showed resillience to a limited extent.

What is evident from this scenario is the success of the late season control of ryegrass in the medic phase. This type of control is successful due to the large amount of seeds that have germinated by the time the grazing and topping is implemented. Most of the seeds that were in the seed bank are now seedlings and plants and are eliminated. Thus, the amount of seeds that are deposited back into the soil at the end of the season is very low. Another significant finding of this scenario was that in the wheat, canola and legume rotation the number of ryegrass plants increased substantially in the wheat years. Due to the significant yield boosts of the legumes, the annual gross margin was never less than R 3 400 per hectare per year in the wheat years of that rotation.

To conclude, the more the pressure of the ryegrass burden, the more lucrative a rotational crop becomes in terms of long term profitability and sustainability. The level of ryegrass control, yield benefits and fertilizer savings that were found in this study, makes rotating crops a good option for farmers in the Central Swartland area in terms of profitability and sustainability. The chances of having a completely weed-free paddock and keeping it weed-free in a wheat monoculture system is very slim.

6. Chapter 6: Conclusions, summary and recommendations

6.1 Conclusions

Modern day farmers face an array of challenges such as; rapid urbanization, pollution, climate change, exhaustion of natural resources and an uncertain political environment. The population of the world is rapidly increasing and with this comes an increase in demand for food. The extend of this demand for food is to such a degree that it is predicted that in the next 40 years the world will have to produce more maize and wheat than the world has produced over the last 500 years. To meet the demand the focus is shifting to the effective use of arable land. To compensate for this increase in supply, farmers have to increase production on the limited arable land available. Arable land is limited in absolute terms, therefore, the yields of the available land will have to suffice in solving this problem. This intensifies focus on the main factors that influence yields and a primary factor that affects grain yields negatively, is weeds.

The primary way farmers have learned to control and eliminate weeds is with the spray of herbicides. If weeds developed resistance against these herbicides weeds still pose a threat to the yield and the sustainability of a farm.

Herbicide resistance is the natural ability of some weed biotypes within a given weed population to survive a certain herbicide treatment that would, if used correctly, effectively control that weed population. Herbicide resistance have been recorded in five species of weeds in the Western Cape. One of these species is annual ryegrass which is also the world's most threatening herbicide resistant weed in terms of profitability and sustainability of farming. Annual ryegrass is common in the Swartland and resistance against glyphosate and paraquat have been recorded (Eksteen, 2007).

Herbicide resistance cause various detrimental effects, such as; decrease in potential income due to the weed burden on the yield of the crop, increase in weed control costs, decrease in the value of the land and a reduction in the number of possible crops that can be produced. These problems can be prevented if herbicide resistance is prevented, or in cases where it is already present, managed correctly. There are numerous ways of preventing, or containing resistance, such as; rotation of herbicide groups and mixtures, correct herbicide application (at the rate as prescribed on the label on the recommended weed sizes), tillage practises, rotational cropping and using grazing in a pasture phase of the crop rotation. The key to prevent and manage herbicide resistance is the integration of chemical, mechanical, physical and biological weed control methods. Herbicides play a pivotal role in the control of weeds but it is necessary to keep the herbicides that are currently available "resistance-free". It takes time to develop herbicides with new "modes of action" and eventually, when a new mode of action is developed, ryegrass has the ability to develop resistance against it quickly.

To prevent and manage herbicide resistance profitably and sustainably, makes decision-making increasingly complex. This also presented a major challenge in this research project. In order to solve complex problems, a multi-disciplinary approach was followed. This allowed integration of specialized knowledge in order to solve rather complex problems within the complex system and environment that a farm exists. This study. This necessitated the development of simulation models underpinned by the systems approach.

This study applied a positive approach to modelling to assess the impact or effects of, specific variables on predetermined criteria, for instance the effect of herbicide resistance on sustainability. By this approach alternate options can be explained scientifically, without being prescriptive. This positive approach was then incorporated in simulation modelling. Simulation modelling allows for the accurate prediction of "what" the likely response between two objects will be, within a specific system. Modelling allows for no disruption of the actual physical system. Various possible outcomes of changes to different variables can be evaluated. This is a much faster evaluation of different outcomes and at a much lower cost. The model needs to determine the effects of changes of single components on full camp or "paddock" scale.

This led to the development of the Resistance and Integrated Management model or RIM-model. It is a computerised decision support tool, which provides information and insight to farmers with regards to the management of annual ryegrass in their long-term decision-making strategies. It focuses on the level of control that can be achieved by a particular ryegrass control strategy and assess the implications on profitability of the particular strategy over a 10-year timeframe. This model was developed in Australia for their local conditions. For it to be applicable in South Africa, all of the assumptions had to be validated by experts. This was done through various interviews and discussions. Lack of research in South Africa and particularly the Swartland necessitated a decision by the panel of experts that for the assumptions for which there were no data in South Africa the current Western Australian data could be used. The Swartland have a similar Mediterranean climate as Western

Australia. Other similarities include; dry land wheat farming, climate, soil type as well as being limited to producing crops in the winter to an extent.

A "typical farm" with "typical crop rotations" each with their "typical ryegrass control strategy" had to be developed. For this purpose, a multi-disciplinary group discussion was held. The various "typical crop rotations" with their particular control strategy was then developed. The prices, yields and chemicals needed for this "typical farm" in the Central Swartland was obtained from local agribusinesses in the area. All the assumptions were validated by the experts through ongoing discussions, after the initial multi-group discussion.

The main aim of this research was to determine the effect that herbicide resistance have, in terms of profitability and sustainability, (level of ryegrass control) on a farm in the Central Swartland. Three scenarios were developed; 1.) a "typical scenario" which serves as a default for comparison, 2.) a scenario where glyphosate and paraquat resistance occur and 3.) a scenario where ryegrass is resistant against glyphosate, paraquat and trifluralin. The five most common crop rotations with their particular "typical ryegrass control strategy" were then simulated over ten years according to the different scenarios. It was done to determine the expected effect the level of control of particular strategies and the subsequent impact have on profitability.

Where no resistance occurred, the wheat and canola rotation achieved the highest average annual gross margin. However, it did not have the highest level of ryegrass control. Control in the wheat phases is poor, but the gross margin of a weed-free wheat phase surpasses any other crop used in the simulations. Therefore, the more weed-free wheat in the rotation the more profitable the rotation. There is a trade-off between cost of control and the margin achieved. The canola crop in the wheat and canola rotation control ryegrass sufficiently for the following wheat crop to achieve high gross margins. This is mainly attributed to canola being a broad-leaf crop and allowing agrochemical benefits. The wheat yield is weed-free and canola has a direct yield benefit to the wheat planted in the following year.

The wheat and the medic rotation achieved the highest level of control. The pasture phase proved to be instrumental in controlling ryegrass. The high intensity of grazing and late-season topping is very successful in controlling ryegrass. However, the gross production value of the livestock component in the pasture phase (medics) is low. The wheat monoculture system has the lowest level of control.

When ryegrass develops resistance against the glyphosate and paraquat herbicides, the wheat and canola rotation again achieved the highest gross margin. The resistance factor only has an effect from the fifth year onwards in this rotation. The gross margin spiralled downwards after the resistant factor kicked in. The annual gross margin of the tenth year was R 1 826 per hectare less than before resistance. The wheat and medic rotation had the highest level of ryegrass control. It is the only rotation, out of the five, that decreased the initial amount of ryegrass plants until the end of the 10-year rotation. This is significant because this rotation used glyphosate the most out of all the rotations, but the methods of control are good. The wheat monoculture system had the lowest level of control, and also the lowest gross margin. This is due to the detrimental effects of the resistant ryegrass.

The third scenario demonstrated the effect of extremely herbicide resistant ryegrass. A known resistance (glyphosate and paraquat) and an unknown resistance (trifluralin) were simulated. Resistance against trifluralin have been reported in Western Australia, making it possible that resistance against this herbicide may occur in South Africa and particularly in the Swartland. All of the rotations proved susceptible except the wheat and medic rotation. The level of control in the wheat and medic rotation is of such a high standard that it still lowers the amount of ryegrass plants that set seed during the assessment period.

With low ryegrass plant numbers and high yields wheat remain the most profitable crop for the Central Swartland. However, as the amount of ryegrass increases, other ways of control needs consideration, which is one of the primary reasons crop rotation systems was adopted in the Swartland. With low ryegrass prevalence the wheat and canola rotation is attractive with high gross margins. When the ryegrass burden increases the medic pasture phase have to be considered. To conclude the primary research question have been answered through these simulations. It demonstrates the cost of herbicide resistant ryegrass to the typical farmer of the Central Swartland. These results and findings emphasizes the fact that farmers have to be proactive rather than reactive in terms of weed management and profitability.

6.2 Summary

The first chapter defines herbicide resistance and then turns the focus to the various species of weeds that have been recorded. It shows resistance against herbicides in a global context and then in a South African context. Of these resistant weeds, ryegrass has long been the world's most severe example of herbicide resistance. Lolium spp. or annual ryegrass is also a common weed in the wheat industry of the Western Cape, particularly the Swartland. Annual ryegrass has developed resistance against glyphosate and paraquat in the Swartland area of the Western Cape. Herbicide resistance leads to: a decrease in potential income and the value of the land, increase in weed control costs and a reduction in the number of possible crops that can be produced. In this study, the focus is on the decrease in the potential income and the increase in weed control costs that herbicide resistance cause. The final research question was: What are the financial implications of herbicide resistance of ryegrass on a "typical farm" in the Central Swartland?

Chapter 2 consists of a literature review that starts with a brief discussion of the weed, annual ryegrass itself, its biological composition, germination patterns and damage to crops. Cases of resistance against paraquat and glyphosate have been recorded in the Swartland. An overview of the South African, Western Cape and the Swartland's wheat industries reached the conclusion that the Swartland is the biggest wheat producing area in the Western Cape. The Western Cape being the biggest wheat producing province in South Africa shows how big a role player the Swartland is in the South African national context. The Swartland is responsible for more than 60% of the total wheat production and area planted in the Western Cape from 2006-2016. A comparison between major wheat producing areas of South Africa and Australia are made to form an idea of relative importance. Australia do a lot of research on the costs of herbicide resistance. The extent of it demonstrates how herbicide resistance can endanger the South African wheat industry.

Chapter 3 discussed the importance of understanding that a farm is a complex system consisting of different interrelated components. Simulation modelling offers the benefits to study a real-life situation without disturbing the physical system. This is crucial in terms of farming it allows for timely evaluation of various possible outcomes in a cost-and time efficient manner. It is important that the various assumptions and components of this model is well understood by the user.

Chapter 4 focused on the RIM-model, which is a simulation model developed in Australia. RIM allows the user to simulate different combinations of weed control treatments on different levels of ryegrass infestations. It observes predicted impacts on ryegrass populations, crop yields and economic outcomes. The various assumptions used in the model were validated by experts in specific fields. The data and values of a "typical farm" with its "typical crop rotations" and "typical ryegrass control strategies" were formulated. Data and values were obtained from agribusinesses in the Central Swartland. A multi-disciplinary group discussion was held to validate these values and to verify that they were representative of a "typical wheat farm" in the Central Swartland. After the multi-disciplinary discussion follow-up interviews were conducted to ensure the data is as accurate as possible.

Chapter 5 contain the results and findings of this study. Three scenarios were used to determine the financial implications of herbicide resistance of ryegrass on a 'typical farm' in the Central Swartland. The level of control a particular rotation and control strategy can achieve under resistant ryegrass circumstances was also assessed. The first scenario, which served as the basis for comparison, was the 'typical farm' with the five most 'typical crop rotations' each with their particular 'ryegrass control strategy'. The second scenario contained ryegrass that developed resistance against glyphosate and paraquat. The third scenario entailed ryegrass that developed resistance against glyphosate, paraquat and trifluralin. It was evident from the strategies how important crop rotation is in controlling ryegrass, especially resistant ryegrass. The wheat monoculture strategy completely lost all profitability and sustainability when resistance occurred, while the wheat and medic rotation proved resilient in terms of ryegrass and resistant ryegrass. It was evident how much herbicide resistance lowers the gross margin of a certain rotation.

6.3 Recommendations

The focus aspect of this study was to demonstrate the effect herbicide resistance has on a typical Central Swartland wheat farm. The use of the updated RIM-model seemed credit-worthy of performing this task, as discussed and confirmed by the panel of experts questioned in this study. As soon as more research with regards to controlling ryegrass numbers becomes available in the Swartland the model should be updated. The model remains site specific to the homogenous area of the Swartland, particularly the Central Swartland. It would be valuable if the model could be customized so that it can be used in other wheat producing areas. For instance, a pasture such as Lucerne could be included in the model due to the popularity of Lucerne used to control ryegrass in the Southern Cape area. A negative aspect of the model is, is that it has fixed assumptions, formulations and calculations and in order to include another crop or pasture, the required data with regard to the crop, controlling ryegrass would be needed.

The RIM-model must be rolled out to farmers in the Swartland area to raise awareness of the threats of herbicide resistant ryegrass. It is useful as a tool, to simulate different methods of control and their effects on ryegrass numbers.

More empirical research should be made available with regard to recorded cases of herbicide resistance. There is a general feeling that ryegrass has developed resistance against the various “fops and dims” herbicide groups, but no recorded cases have been found. However, this is important information for farmers to know, so that they can stop spraying these herbicides if ryegrass has developed resistance against it in order to make the necessary adjustments and save money. It is also important that farmers are aware of using, not only herbicides as means of controlling weeds, but use various different integrated methods. This is especially important due to the amount of time it takes to develop herbicides with new modes of action. Therefore, it is important to keep the herbicides that are working effectively, resistance free.

In Australia, it was found that to improve and optimize ryegrass control, the focus need to shift towards the control of the ryegrass seedbank. Various methods of eliminating the seed, such as catching and crushing during harvesting can be employed. Methods of controlling and eliminating the seed of ryegrass are yet to be employed in South Africa. Therefore, research concerning the economic feasibility of seed catching techniques and methods in South Africa needs to be done as it would be of value to the wheat industry.

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8. Annexures

Annexure A: Budgets for different crops of typical farms in the Central Swartland.

INKOMSTE EN KOSTEBERAMINGS VAN

KORING

MIDDEL SWARTLAND (MALMESBURY/MOORREESBURG/PORTERVILLE)

2016
KORING

Item	Maand	Eenheid	Prys per eenheid	Hoeveel-heid	Toedeel%	Waarde Rand Per Ha
BRUTO INKOMSTE						
Produk Inkomste		ton	R 4,000.00	2.750		**R 11,000.00**
Graan Inkomste	DES	ton	R 4,000.00	2.750		**R 11,000.00**
Bemarkingskoste/Aftrekkings		ton	R 828.00	2.750		**R 2,277.00**
Vervoerdifferensiaal	DES	ton	R 550.00	2.750		R 1,512.50
Graad diskonto - B2	DES	ton	R 180.00	2.750		R 495.00
Heffing Statutêr	DES	ton	R 35.00	2.750		R 96.25
Heffing GraanSA (vrywillig)	DES	ton	R 3.00	2.750		R 8.25
Silo-deurvoer	DES	ton	R 40.00	2.750		R 110.00
Bemarking/Verskansing	DES	ton	R 20.00	2.750		R 55.00
BRUTO INKOMSTE BY PLAASHEK		**ton**	**R 3,172.00**	**2.750**		**R 8,723.00**
ALLOKEERBARE KOSTE						
Saad		kg	71.4% gesertifiseerde	105.000		**R 733.50**
Gekoop / Gesertifiseerd	APR	kg	R 7.90	75.000		R 592.50
Eie (behandel, Flite)	APR	kg	R 4.70	30.000		R 141.00
Kalk en Gips						**R 128.00**
Dolomitiese Kalk (23Ca+11Mg)	MAR	kg	R -	-		R -
Kalsitiese Kalk (30Ca)	MAR	ton	R 320.00	2.000	20%	R 128.00
Bemesting			90N + 14P + 8K + 16S			**R 2,277.15**
Stikstof - N met plant (KAN)	MEI	kg	R 18.00	25.000		R 450.00
Stikstof - N kopbemesting (Ureum)	JUN	kg	R 13.75	65.000		R 893.75
Fosfaat - P met plant (MAP)	MEI	kg	R 35.00	14.000		R 490.00
Kalium - K	MEI	kg	R 15.00	8.000		R 120.00
Swael - S met plant en kopbemes	MEI	kg	R 9.90	16.000		R 158.40
Spoorelemente	MEI	ha	R 165.00	1.000		R 165.00
Onkruidbeheer - Voor Plant (doodspuit)						**R 94.05**
Net voor Plant Doodspuit						
Round-up Turbo 450 SL : glyphosate	MEI	liter	R 62.70	1.500		R 94.05
Onkruidbeheer - Met plant (voor-opkoms)						**R 462.00**
Sakura 85 WG : Pyroxasulfone	MEI	liter	R 3,696.00	0.125		R 462.00
Onkruidbeheer - Na Opkoms						**R 323.61**
Resolve : bromoxynil/pyrasulfotole	JUN	liter	R 291.50	0.750		R 218.63
Glean 75 DF : chlorsulfuron	JUN	kg	R 2,123.00	0.008		R 16.98
Brush-Off 600WG : metsulfuron-methyl	JUN	kg	R 2,200.00	0.004		R 8.80
Axial 45 EC : Pinoxadien	JUN	liter	R 495.00	0.800	20%	R 79.20
Plaag- / Insekbeheer						**R 88.88**
Chlorpyrifos 480 EC	JUN	liter	R 88.00	0.400		R 35.20
Lamda 50 EC	JUL	liter	R 101.20	0.150		R 15.18
Methomex 900 SP (bolwurm)	SEP	kg	R 192.50	0.200		R 38.50
Swam- / Siektebeheer						**R 261.25**
Prosper Trio : spiroxamine + tebuconazole + triadime	JUL	liter	R 291.50	0.500		R 145.75
Orius / Riza 200 EW	AUG	liter	R 154.00	0.750		R 115.50
Materiaalkoste						**R -**
Baaltou/-net	DES	baal				R -

INKOMSTE EN KOSTEBERAMINGS VAN

CANOLA TT (TRIASIEN TOLERANT)

MIDDEL SWARTLAND (MALMESBURY/MOORREESBURG/PORTERVILLE)

2016
CANOLA TT

Item	Maand	Eenheid		Prys per eenheid	Hoeveel-heid	Toedeel%		Waarde Rand Per Ha
BRUTO INKOMSTE								
Produk Inkomste		ton	R	6,000.00	1.300		R	7,800.00
Graan Inkomste	DES	ton	R	6,000.00	1.300		R	7,800.00
Bemarkingskoste/Aftrekkings		ton	R	4.00	1.300		R	5.20
Heffing Statutêr	DES	ton	R	-	1.300		R	-
Heffing GraanSA (vrywillig)	DES	ton	R	4.00	1.300		R	5.20
Bemarking/Verskansing	DES	ton	R	-	1.300		R	-
BRUTO INKOMSTE BY PLAASHEK		ton	R	5,996.00	1.300		R	7,794.80
ALLOKEERBARE KOSTE								
Saad		kg		100% gesertifiseerde	4.000		R	940.00
Gekoop / Gesertifiseerd	APR	kg	R	235.00	4.000		R	940.00
Eie (behandel, Galmano Plus)	APR	kg	R	17.50	-		R	-
Kalk en Gips							R	128.00
Dolomitiese Kalk (23Ca+11Mg)	MAR	kg	R	-	-		R	-
Kalsitiese Kalk (30Ca)	MAR	ton	R	320.00	2.000	20%	R	128.00
Bemesting				80N + 14P + 8K + 20S			R	2,158.00
Stikstof - N met plant (KAN)	APR	kg	R	18.00	20.000		R	360.00
Stikstof - N kopbemesting (Ureum)	JUN	kg	R	13.75	60.000		R	825.00
Fosfaat - P met plant (MAP)	APR	kg	R	35.00	14.000		R	490.00
Kalium - K	APR	kg	R	15.00	8.000		R	120.00
Swael - S met plant en kopbemes	APR	kg	R	9.90	20.000		R	198.00
Spoorelemente	APR	ha	R	165.00	1.000		R	165.00
Onkruidbeheer - Voor Plant (doodspuit)							R	94.05
Net voor Plant Doodspuit								
Round-up Turbo 450 SL : glyphosate	APR	liter	R	62.70	1.500		R	94.05
Onkruidbeheer - Met plant (voor-opkoms)							R	199.65
Trifluralin 480 EC	APR	liter	R	71.50	1.500		R	107.25
Simazine 500 SC	APR	kg	R	46.20	2.000		R	92.40
Onkruidbeheer - Na Opkoms							R	264.00
Poquer 120 EC / clethodim	JUN	kg	R	330.00	0.800		R	264.00
Plaag- / Insekbeheer							R	114.18
Sluggit Slakpille / metaldehyde	APR	kg	R	23.10	8.000	25%	R	46.20
Alpha-Thrin 100SC / Indoksakarb	JUN	liter	R	143.00	0.100		R	14.30
Lamda 50 EC / lambda-cyhalothrin	JUN	liter	R	101.20	0.150		R	15.18
Methomex 900 SP (bolwurm)	SEP	kg	R	192.50	0.200		R	38.50
Swam- / Siektebeheer							R	178.75
Prosaro 250 EC	AUG	liter	R	550.00	0.650	50%	R	178.75
Materiaalkoste							R	-
Baaltou/-net	DES	baal					R	-
Losarbeid							R	15.00
Klippe ry / Ander / Ander	JAAR	ha	R	15.00	1.000		R	15.00
Oesversekering							R	-

INKOMSTE EN KOSTEBERAMINGS VAN

MEDIC VESTIG

MIDDEL SWARTLAND (MALMESBURY/MOORREESBURG/PORTERVILLE)

2016

MEDIC VESTIG

Item	Maand	Eenheid	Prys per eenheid		Hoeveel-heid	Toedeel%	Waarde Rand Per Ha	
BRUTO INKOMSTE								
Produk Inkomste		ton	R	-	-		R	-
Ruvoer Inkomste	DES	ton	R	-	-		R	-
Bemarkingskoste/Aftrekkings		ton	R	-	-		R	-
Heffing Statutêr	DES	ton	R	-	-		R	-
Heffing GraanSA (vrywillig)	DES	ton	R	-	-		R	-
Bemarking/Verskansing	DES	ton	R	-	-		R	-
BRUTO INKOMSTE BY PLAASHEK		ton	R	-	-		R	-
ALLOKEERBARE KOSTE								
Saad		kg	100% gesertifiseerde		15.000		R	1,275.00
Gekoop / Gesertifiseerd	APR	kg	R	85.00	15.000		R	1,275.00
Eie	APR	kg	R	35.00	-		R	-
Kalk en Gips							R	128.00
Dolomitiese Kalk (23Ca+11Mg)	MAR	kg	R	-	-		R	-
Kalsitiese Kalk (30Ca)	MAR	ton	R	320.00	2.000	20%	R	128.00
Bemesting			5N + 10P + 0K + 0S				R	440.00
Stikstof - N met plant (KAN)	APR	kg	R	18.00	5.000		R	90.00
Stikstof - N kopbemesting (Ureum)	JUN	kg	R	13.75	-		R	-
Fosfaat - P met plant (MAP)	APR	kg	R	35.00	10.000		R	350.00
Kalium - K	APR	kg	R	15.00	-		R	-
Swael - S met plant en kopbemes	APR	kg	R	9.90	-		R	-
Spoorelemente	APR	ha	R	-	-		R	-
Onkruidbeheer - Voor Plant (doodspuit)							R	94.05
Net voor Plant Doodspuit								
Round-up Turbo 450 SL : glyphosate	APR	liter	R	62.70	1.500		R	94.05
Onkruidbeheer - Met plant (voor-opkoms)							R	107.25
Trifluralin 480 EC	APR	liter	R	71.50	1.500		R	107.25
Onkruidbeheer - Na Opkoms							R	264.00
Poquer 120 EC / clethodim	JUN	kg	R	330.00	0.800		R	264.00
Plaag- / Insekbeheer							R	32.50
Dimetoaat 400 EC	JUN	liter	R	65.00	0.500		R	32.50
Swam- / Siektebeheer							R	-
							R	-
Materiaalkoste							R	-
Baaltou/-net	DES	baal					R	-
Losarbeid							R	15.00
Klippe ry / Ander / Ander	JAAR	ha	R	15.00	1.000		R	15.00
Oesversekering							R	-
Brand op Oeste en Transito	DES	%	R	-	-		R	-
SASRIA (oproer en stakings)	DES	%	R	-	-		R	-
Kontrakdienste							R	5.50

INKOMSTE EN KOSTEBERAMINGS VAN

MEDIC BESTUUR

MIDDEL SWARTLAND (MALMESBURY/MOORREESBURG/PORTERVILLE)

2016

MEDIC BESTUUR

Item	Maand	Eenheid	Prys per eenheid		Hoeveel-heid	Toedeel%	Waarde Rand Per Ha	
BRUTO INKOMSTE								
Produk Inkomste		ton	R	-	-		R	-
Ruvoer Inkomste	DES	ton	R	-	-		R	-
Bemarkingskoste/Aftrekkings		ton	R	-	-		R	-
Heffing Statutêr	DES	ton	R	-	-		R	-
Heffing GraanSA (vrywillig)	DES	ton	R	-	-		R	-
Bemarking/Verskansing	DES	ton	R	-	-		R	-
BRUTO INKOMSTE BY PLAASHEK		ton	R	-	-		R	-
ALLOKEERBARE KOSTE								
Saad		kg			-		R	-
Gekoop / Gesertifiseerd	APR	kg	R	85.00	-		R	-
Eie	APR	kg	R	35.00	-		R	-
Kalk en Gips							R	128.00
Dolomitiese Kalk (23Ca+11Mg)	MAR	kg	R	-	-		R	-
Kalsitiese Kalk (30Ca)	MAR	ton	R	320.00	2.000	20%	R	128.00
Bemesting			0N + 0P + 0K + 0S				R	-
Stikstof - N met plant (KAN)	APR	kg	R	18.00	-		R	-
Stikstof - N kopbemesting (Ureum)	JUN	kg	R	13.75	-		R	-
Fosfaat - P met plant (MAP)	APR	kg	R	35.00	-		R	-
Kalium - K	APR	kg	R	15.00	-		R	-
Swael - S met plant en kopbemes	APR	kg	R	9.90	-		R	-
Spoorelemente	APR	ha	R	-	-		R	-
Onkruidbeheer - Voor Plant (doodspuit)							R	-
Net voor Plant Doodspuit								
							R	-
Onkruidbeheer - Met plant (voor-opkoms)							R	-
							R	-
Onkruidbeheer - Na Opkoms							R	311.03
Poquer 120 EC / clethodim	JUN	kg	R	330.00	0.800		R	264.00
Round-up Turbo 450 SL : glyphosate (Pasturetop)	SEP	liter	R	62.70	0.750		R	47.03
Plaag- / Insekbeheer							R	32.50
Dimetoaat 400 EC	JUN	liter	R	65.00	0.500		R	32.50
Swam- / Siektebeheer							R	-
							R	-
Materiaalkoste							R	-
Baaltou/-net	DES	baal					R	-
Losarbeid							R	15.00
Klippe ry / Ander / Ander	JAAR	ha	R	15.00	1.000		R	15.00
Oesversekering							R	-
Brand op Oeste en Transito	DES	%	R	-	-		R	-
SASRIA (oproer en stakings)	DES	%	R	-	-		R	-

Annexure B: The typical paddock of a typical farm of the Central Swartland.

Main parameters

	Wheat	Barley	Canola	Legume	
Weed-free yields	2,8	2,7	1,3	1,1	t/ha
Grain prices	3172	2982	5996	3100	R/t
Yield benefit from dry seeding	5 %	2 %	10 %	5 %	
Yield loss if delayed seeding	10 %	5 %	20 %	10 %	

	Hay	Silage	Bales	
Production costs	1250	1750	190	R/ha
Fodder prices	2000	850	850	R/t
Operation cost of sprayer	120,0			R/ha
Average area cropped	1 000			ha

Sheep

Animal Gross Margin	291	R/DSE
Mature ryegrass last spring:	2	plant/m^2

Low | Medium | High

Control options

		Cost (R/ha) Wheat & Barley	Cost (R/ha) Canola & Legumes	Cost (R/ha) Pastures	% of ryegrass controlled Wheat & Barley	% of ryegrass controlled Canola & Legumes	% of ryegrass controlled Pastures
Enter herbicide names, cost and % ryegrass controlled:							
Knock-down herbicides	Round-up Turbo 450 @ 1.5L	105	105	105	95%	95%	95%
	Ciplaquat @ 2L	110	110	110	95%	95%	95%
Double-knock	Glyphosate/Paraquat	215	215	215	100%	100%	100%
Pre-emergence herbicides	Trifluralin 480 EC+Sustain	180	242	180	80%	80%	80%
	Wrestler (Boxer) @ 3L	450		450	85%		
	Sakura 850 WG @ 125g	450		450	95%		
	Simazol SC @ 2L		90			85%	
	KERB 500 WP @1.9L		937	937		70%	50%
Post-emergence herbicides	Axial 45 EC @1L	360			60%		
	Monitor 75 WG @ 40g	350			70%		
	Aramo 50 @ 1L		300			70%	
	Simanex 500 SC		120			85%	
	Vega 240 EC @ 500ml		300	300		50%	50%
Enter additional control options:							
Spring options	Define 1st spring option	10	10	10	70%	70%	70%
	Define 2nd spring option	10	10	10	70%	70%	70%
Harvest options	Define 1st harvest option	10	10	10	70%	70%	70%
	Define 2nd harvest option	10	10	10	70%	70%	70%

More prices... | More options...

Save Profile

Paddock name:	Middle
Your name:	Swartland

SAVE	LOAD	Swartland, Middle
SAVE	LOAD	Swartland, Suidelike
SAVE	LOAD	Swartland, Sandveld
SAVE	LOAD	Swartland, Rooi Karoo
CLEAR	LOAD	Swartland, Default

More Prices...

Your current paddock is:
Swartland, Middle

BACK

RIM Ryegrass

Establishment costs

		Cereals	Canola	Legume	Volunt	Medics	Cadiz
					1st year of pasture		
Seed (standard rate)	R/ha	734	940	400	n.a.	1275	1050
incl. dressing / cleaning / inoculum / etc.							
Fertilisers - standard, average practice	R/ha	2277	2158	309	0	440	160
- following a legume	R/ha	1850	1850				
Additional costs (incl. application costs)	R/ha	1111	1029	1200	0	765	100
Insecticides, Fungicides, Insurance, Gypsum and lime, Contract work and Planting cost.							
Cost reduction if green manure is planned	R/ha	0	0	50			
(none if only opportunistic)							
Input compensation for residue removal	R/ha	500					
(from haying or from exporting baled residues)							

Other costs

Contractor costs:		
• Mouldboard plough	R/ha	275
• Mowing pasture	R/ha	445
• Swathing	R/ha	160
Environmental cost of soil disturbance	R/ha	0,0

Machinery

Harvester:		
• Maintenance costs	R/ha /year	135
• Fuel consumption	l/ha	12,0
• Diesel price	R/l	12,0
Purchase cost of:		
• Narrow windrow chute	R	500
• Chaff cart	R	70 000
• Harrington seed destructor (HSD)	R	160 000
• Bale direct system (BDS)	R	140 000
Machinery repayments:		
• Loan duration	years	6
• Interest rate		11%

More Options…

Your current paddock is:
Swartland, Middle

BACK

RIM Ryegrass

Crops

		Wheat	Barley	Canola	Legume
Seeding rate - Standard	kg/ha	100	70	3	60
- High	kg/ha	125	100	5	80
Harvest index		0,40	0,40	0,40	0,30
% of fodder yield relative to the above harvest index					80%

Pre-emergents loss of efficiency when dry seeding	10%

Yield benefits

- for **canola**, following a legume	25%
- for **cereals**, following a legume	30%
following a green manured legume	25%
- for **all crops**, after mouldboarding (permanent benefit)	5%

Yield penalties

	Wheat	Barley	Canola	Legume
- for not swathing	2%	3%	10%	0%
- for crop-topping	5%	5%	5%	5%

- on **crops**, from pre- and post-emergents phytotoxic effects	2%

- on **Canola** if break between canola crops is only 1 year	10%
- on **Legumes** if break between legumes is only 1 year	5%

Pastures - 3rd consecutive year of medics

Grazing intensity:	Stocking rates DSE/ha	Rye-grass control	Hay production t/ha
• when standard	4,5	80%	
• when high in spring	6,5	95%	
• when hay is planned	4,0	100%	1,0
• when hay only is planned (no grazing)			2,0

Ryegrass control

Plants (in crop/pasture):

No-till (knife-point)	40%
Full cut (direct drill)	80%
Topping - Cereals	75%
- Canola/Legumes	75%
- Pastures	90%
Swathing	40%
Swathing + spray	90%

Plants (crop/pasture sacrifice):

Green / brown manuring, mowing	100%

Seeds (harvest weed seed control):

Catch & chaff tramlining	85%
Catch & HSD or BDS	85%
Catch & burn: chaff cart dumps	85%
Catch & burn: narrow windrows	85%
Whole-paddock burning (residues)	60%

Annexure C: Different effects of different levels of ryegrass on the gross margin of a typical farm in the Central Swartland.

Central Swartland	Starting Ryegrass Density (plants per m^2)								
	2			20			100		
W+W+W+C (37% of area used for 2016)	Typical	Glyphosate and paraquat resistance	Glyphosate, paraquat and trifluralin resistance	Typical	Glyphosate and paraquat resistance	Glyphosate, paraquat and trifluralin resistance	Typical	Glyphosate and paraquat resistance	Glyphosate, paraquat and trifluralin resistance
Average gross margin over 10 years (per hectare):	R2 969	R2 498	R968	R1 929	R1 374	R968	R1 273	R732	-R244
Loss due to resistance	R -	R 471	R 2 001	R -	R555	R961	R -	R541	R1 517
Percentage gross margin loss due to resistance		16%	67%		29%	50%		42%	119%
Wheat yield loss because of ryegrass:	3%	9%	28%	15%	22%	37%	23%	31%	43%
Canola yield loss because of ryegrass:	12%	16%	25%	25%	27%	31%	28%	30%	32%

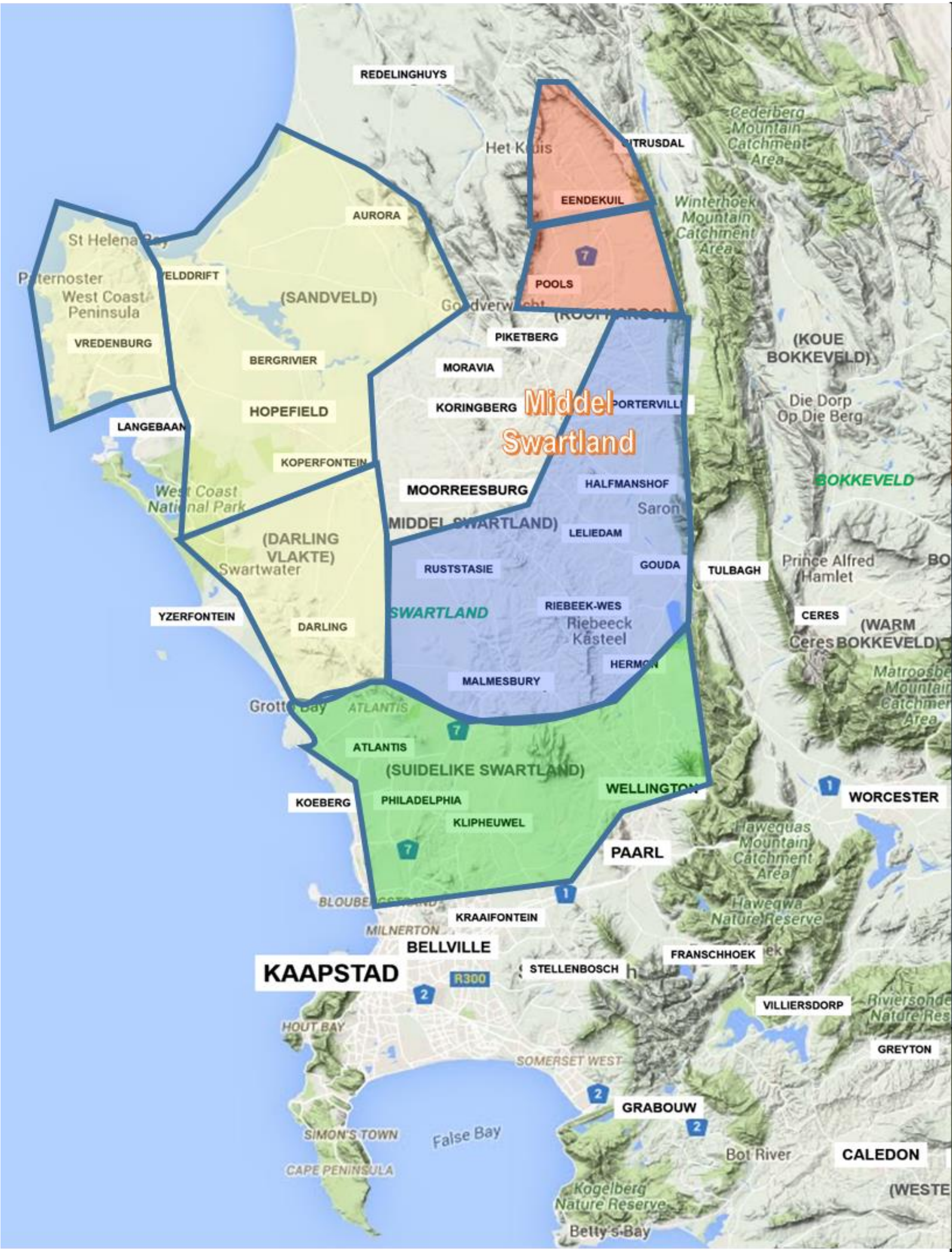
Central Swartland	Starting Ryegrass Density (plants per m^2)								
	2			20			100		
W+W+W+W (12.40% of area)	Typical	Glyphosate and paraquat resistance	Glyphosate, paraquat and trifluralin resistance	Typical	Glyphosate and paraquat resistance	Glyphosate, paraquat and trifluralin resistance	Typical	Glyphosate and paraquat resistance	Glyphosate, paraquat and trifluralin resistance
Average gross margin over 10 years (per hectare):	R2 488	R1 699	R329	R1 278	R608	-R434	R650	R54	-R735
Loss due to resistance		R 789	R 2 159	R -	R 670	R 1 712	R -	R 595	R 1 384
Percentage gross margin loss due to resistance		32%	87%		52%	134%		92%	213%
Wheat yield loss because of ryegrass:	9%	18%	34%	23%	30%	42%	30%	37%	46%

Central Swartland	Starting Ryegrass Density (plants per m^2)								
	2			20			100		
W+W+W+LP (6% of area)	Typical	Glyphosate and paraquat resistance	Glyphosate, paraquat and trifluralin resistance	Typical	Glyphosate and paraquat resistance	Glyphosate, paraquat and trifluralin resistance	Typical	Glyphosate and paraquat resistance	Glyphosate, paraquat and trifluralin resistance
Average gross margin over 10 years (per hectare):	R2 436	R1 897	R821	R1 563	R1 061	R152	R1 036	R545	-R287
Loss due to resistance		R 539	R 1 615	R -	R 502	R 1 411	R -	R 490	R 1 323
Percentage gross margin loss due to resistance		22%	66%		32%	90%		47%	128%
Wheat yield loss because of ryegrass:	13%	20%	33%	23%	30%	41%	30%	36%	47%
Legume yield loss because of ryegrass:	42%	44%	50%	52%	53%	55%	54%	54%	55%

Central Swartland									
	Starting Ryegrass Density (plants per m^2)								
	2			20			100		
W+C+W+LP (2.5% of area)	Typical	Glyphosate and paraquat resistance	Glyphosate, paraquat and trifluralin resistance	Typical	Glyphosate and paraquat resistance	Glyphosate, paraquat and trifluralin resistance	Typical	Glyphosate and paraquat resistance	Glyphosate, paraquat and trifluralin resistance
Average gross margin over 10 years (per hectare):	R2 822	R2 367	R1 719	R2 135	R1 664	R1 072	R1 701	R1 238	R683
Loss due to resistance		R 455	R 1 103	R -	R 470	R 1 063	R -	R 463	R 1 019
Percentage gross margin loss due to resistance		16%	39%		22%	50%		27%	60%
Wheat yield loss because of ryegrass:	1%	5%	13%	7%	13%	21%	13%	19%	28%
Canola yield loss because of ryegrass:	11%	18%	25%	23%	27%	32%	27%	30%	34%
Legume yield loss because of ryegrass:	15%	30%	42%	29%	43%	48%	33%	46%	49%

Central Swartland									
	Starting Ryegrass Density (plants per m^2)								
	2			20			100		
W+M+W+M (18% of area)	Typical	Glyphosate and paraquat resistance	Glyphosate, paraquat and trifluralin resistance	Typical	Glyphosate and paraquat resistance	Glyphosate, paraquat and trifluralin resistance	Typical	Glyphosate and paraquat resistance	Glyphosate, paraquat and trifluralin resistance
Average gross margin over 10 years (per hectare):	R2 252	R2 252	R2 227	R2 081	R2 081	R1 868	R1 722	R1 722	R1 384
Loss due to resistance		R -	R 25	R -	R -	R 213	R -	R -	R 338
Percentage gross margin loss due to resistance		0%	1%	0%	0%	10%	0%	0%	20%
Wheat yield loss because of ryegrass:	0%	0%	0%	2%	3%	7%	9%	9%	16%

Annexure D: Map of the Central Swartland.



HOOF GEBIED	SUB-GEBIED	DORP-GEBIED
SANDVELD	SANDVELD WES	VREDENBURG
	SANDVELD NOORD	VELDDRIFT
		BERGRIVIER
		AURORA
		HOPEFIELD
		KOPERFONTEIN
	DARLING VLAKTE / SANDVELD SUID	DARLING
ROOI KAROO EN EENDEKUIL	NOORD VAN ROOI KAROO	EENDEKUIL
	ROOI KAROO	POOLS
MIDDEL SWARTLAND	MIDDEL SWARTLAND NOORD (MOORREESBURG)	PIKETBERG
		MORAVIA
		KORINGBERG
		MOORREESBURG
	MIDDEL SWARTLAND SUID (MALMESBURY/PORTERVILLE)	PORTERVILLE
		HALFMANSHOF
		LELIEDAM
		GOUDA
		RIEBEEK-WES
		HERMON
		RUSTSTASIE
		MALMESBURY
SUIDELIKE SWARTLAND	SUIDELIKE SWARTLAND (KLIPHEUWEL/WELLINGTON) (HOË REËNVAL GEBIED)	KOEBERG
		PHILIDELPHIA
		KLIPHEUWEL
		WELLINGTON
		ATLANTIS