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EFFECTS OF CROP ROTATION AND TILLAGE SYSTEM ON THE CONTROL OF RYEGRASS (*LOLIUM MULTIFLORUM X PERENNE)* IN WHEAT (*TRITICUM AESTIVUM*) IN THE SWARTLAND PRODUCTION AREA OF SOUTH AFRICA’S WESTERN CAPE PROVINCE

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By

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DECLARATION

I, Sinovuyo Mava Nteyi 211225894, hereby declare that the dissertation for Master Technologie: Agriculture to be awarded is my own work and that it has not previously been submitted for assessment or completion of any postgraduate qualification to another University or for another qualification.

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Abstract

A major challenge facing agriculture today is to sustain the productivity of agricultural systems with the reduction of weed invasion. The Swartland region in the Western Cape (South Africa) is intensively cropped, producing wheat (*Triticum aestivum*) as the major crop. As a result of the weedy ryegrass invasion the wheat yield is reduced. In addition, ryegrass has developed resistance to grass herbicides (graminicides).

This situation has increased the need to use alternative practices for controlling the invasion of ryegrass in wheat fields. In this regard, crop rotation and tillage systems were proposed as techniques to suppress the ryegrass invasion. This could thus maintain a sustainable long-term wheat production system with less application of herbicides, decreased input costs and increased total grain yield. Against this background, the effects of crop rotation and tillage were determined on ryegrass seedling emergence in a field and shade netting experiment, while seed dormancy was determined in the laboratory. The objectives were to compare the wheat production of two crop rotations with mono-cropped wheat and assess the impact on the ryegrass population in no-till and minimum tillage systems.

Analyses of variance on data sets of ryegrass seeds from 2009, 2010 and 2011 were used to determine germination and dormancy percentages in laboratory experiments. The performance of laboratory treatments was evaluated on the basis of germination percentage of seeds. In the field and shade netting experiments, analyses of variance for data from 2007, 2011 and 2012 were used to determine crop rotation x tillage system response. Field and shade netting performance were evaluated on the basis of ryegrass population inhibition and stimulation respectively.

Ryegrass seeds from 2009 and 2010 showed higher germination percentages (80% and 73%) than 2011 (42%). Primary dormancy prevented high germination of newly harvested seeds as dormancy release increase with age of the seed.

Results of field and shade netting experiments showed stimulation of the ryegrass weed population in wheat monoculture under minimum tillage. However, when wheat was rotated with leguminous crops under both tillage systems (minimum-till and no-till) ryegrass was significantly inhibited.

It was concluded that the critical period for weed competition is the first six weeks after planting. Results from this study provide a basis for producers of cereals to make good decisions with regards to timing weed control measures. It is essential to use competitive crop sequences which will inhibit weeds. The challenge is getting this practice adopted and implemented by producers as it will promote conservation agriculture within the region. This study promotes long-term sustainable wheat production systems with an efficient weed management programme that is environmentally friendly using less herbicides within the Swartland region.

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LIST OF ABBREVIATIONS

DPI:	Department of Primary Industry
FAO:	Food and Agriculture Organisation of the United Nations
HD:	High dormancy
LD:	Low dormancy
MDT:	Mouldboard plough
NT:	No-till
TT:	Tine-tillage
WCWL:	Wheat-Canola-Wheat-Lupine
WLWC:	Wheat-Lupine-Wheat-Canola
WMcWMc:	Wheat-Medic-Wheat-Medic
WWWW:	Wheat-Wheat-Wheat-Wheat

DEFINITIONS

Canola: an oilseed rape crop that produces pods from which seeds are harvested and yields valuable cooking oil (U.S. Canola Association, n.d).

Crop rotation: a planting sequence of various crops in the same area (Klingman & Ashton, 1975a, c; Thierfelder & Wall, n.d).

Dormancy: an internal condition of the seed that delays or prevents its germination under favourable environmental conditions for germination and its duration (months and years) varies from species to species (Bewley, 1997; Dekker, 1999; Benech-Arnold *et al*., 2000; Seed dormancy, 2001; Physiology of dormancy, n.d).

Seed germination: the process of emergence of growth of an embryonic plant contained within a seed from resting stage, resulting in the formation of the seedling (Assignment, 2012; Farlex, 2012; Dictionary, n.d; Kennell, n.d).

Herbicides: chemicals that are used to kill plants or inhibit their normal growth (URI, n.d).

Herbicide resistance: the acquired ability of weed population to survive a herbicide application that previously was known to control the population (WSSA, 2011).

***Lolium multiflorum x perenne*:** a hybridised annual produced among Italian ryegrass and perennial ryegrass and is commonly found along roadsides and field margins (AGTR, 2008; Queensland Government, 2011; Peeters, n.d).

Lupine: a genus in the legume family characterised by irregular, five-petaled flowers often blue; occasionally white, red or yellow in colour with a central “keel” which fixes atmospheric nitrogen (Putnam *et al*., 1997; Poisonous plants, 2002).

Medic: an annual self-regenerating legume (temperate) that can survive for many years in the soil through reserves of hard seed (Johnson, 2010; Shrestha *et al*., 2010).

Monoculture: the continuous/repeated planting of the same crop in the same field year after year (Thierfelder & Wall, n.d)

Ryegrass: hairless grass with bright green shiny leaves and often has reddish purple colour at its base (Moore *et al*., 2006).

Tillage: the disturbance of the soil profile prior to planting the next crop (Ghersa & Martinez-Ghersa, 2000).

Wheat (*Triticum aestivum*): is a type of grass best known as cereal grain that is grown all over the world for its highly nutritious and useful grain (Smith, 2012).

Weed: a plant that is growing where it is not wanted, it can have strong and healthy growth, and is able to overgrow valued plants by overcrowding, thus depleting soil nutrients and moisture that would otherwise be available to preferred plants (GardenWeb, 2006).

CHAPTER ONE

INTRODUCTION

1.1 General Introduction

This study was conducted with the purpose of finding alternative ways to manage weeds that are environmentally friendly and reduce the use of pre- and post-emergence herbicides. The aim was to determine whether the crop rotation and tillage systems have an influence on the control of ryegrass weed in wheat producing areas. It was initiated after the development of ryegrass (*Lolium multiflorum x perenne*) weed resistance to some of the herbicides and their negative effects on the soil when they were applied over a long period (Ghersa & Martinez-Ghersa*,* 2000; FAO [Food and Agriculture Organisation of the United Nations], 2003; Zand *et al*., 2010; Ferreira & Reinhardt, 2010). 'Herbicide resistant ryegrass is a serious problem in Western Cape grain producing areas, and threatens more than 100 000 ha of productive grain fields' (Ferreira, 2011:2). Therefore, alternative weed control methods that enhance the use of the natural resource base and environment (Reganold *et al*., 2011) need to be developed. The aim of weed management is to keep the weed population at manageable levels that will not cause major decrease in total grain yield (Hartzler, n.d).

Barros *et al*. (2007) reported that satisfactory weed control can be obtained when the herbicides are applied at doses as recommended on the product label. However, relying on total post-emergence weed control programmes creates a high risk of yield loss, mostly when the control is delayed while the pre-emergent sprays reduce the population of weeds that emerge with crop (Hartzler, n.d).

The Swartland region in the Western Cape with its Mediterranean climate is known as a wheat producing area and is intensively cropped for small grain production. Ryegrass is one of the major grass weeds of winter cereal crops in Western Cape small grain producing areas (Barros *et al*., 2007). Ryegrass was cultivated for turf grass and forage in California and both perennial and annual ryegrass grow quicker than other grasses (Growth and lifespan, n.d; How to manage pests, 2011a). However, ryegrass is a severe competitor with crops in cultivated fields in Mediterranean regions and is now also wide-spread weed in South African cropping systems (Goggin *et al*., 2010). Since ryegrass is a weed that has the same growth habit as the cereal crop, it is very difficult to control in established wheat fields (Agenbag & Maree, 1991; Botha, 2001; Bromilow, 2001; Syngenta, 2010; Smith, 2012). Ryegrass is severely competitive in the initial growth stage of wheat seedlings as it emerges within the first few weeks after planting and is a high nitrogen consuming weed which reduces total grain yields (Klingman & Ashton, 1975a, b & c; Botha, 2001; Blackshaw *et al*., 2005), based on the fact that weeds directly compete with grain crops for light, moisture and soil nutrients at early stages of growth (GardenWeb, 2006; Marais, 1985).

Ryegrass is hairless with bright green shiny leaves and often has a reddish purple colour at its base (below the ground) and grows up to 900 mm when mature (Moore *et al*., 2006; Cook *et al*., n.d). Annual and perennial ryegrasses are very similar to each other, but they can be differentiated at the flowering or seedling stage. Annual ryegrass has 3 to 9 flowers in each spikelet with an outer husk with similar length to that of the spikelet, whereas perennial ryegrass has 4 to 14 flowers with the outer husk half the length of the spikelet with excellent seedling vigour adapted to many soil types. Optimum growth generally occurs at pH 5.6 or higher (Blount *et al*., 2000; Cook *et al*., n.d). The high genotypic plasticity and hybridisation for producing *Lolium multiflorum* x *perenne* among these two grass species (Ferreira *et al*., 2011) makes it a decisive production constraint in crop production as it is one of the most serious, costly and economically damaging crop weeds of annual winter cropping systems (DPI [Department of Primary Industry], 2008; Pollnac *et al*., 2008; Cook *et al*., n.d).

Ryegrass has built up multiple resistance to two herbicides modes of action, namely: group A (ACCase inhibitors [Acetyl-CoA carboxylase]) and group B (ALS inhibitors [acetolactate synthase]) which are the post-emergence herbicide groups used to control grass weeds which infest wheat (Michitte *et al*., 2003; Collavo & Sattin, 2011; Kaundun *et al*., 2012). These inhibitors prevent the germination of a seed. However, Bromilow (2001) found that ryegrass resistant types may form crossbreeds which complicate control in wheat fields and so they become problematic weeds. Weed resistance to herbicides presents one of the greatest economic challenges to agriculture (Ferreira & Reinhardt, 2010), as this evolution of weeds with resistance to herbicides poses a major threat to farmers who are highly dependent on herbicides to control weeds. Economically herbicides and herbicide-resistant weeds have improved agricultural inefficiency and yields as chemicals are costly and have negative impacts on the soil by creating resistance in weeds and environmental contamination when applied over long periods without rotating them (Ghersa & Martinez-Ghersa*,* 2000; FAO, 2003; Zand *et al*., 2010; Ferreira & Reinhardt, 2010). It may take up to five seasons of chemical spraying to clear the soil seed bank of weeds with long dormancy compared to annual weeds with short dormancy which can be cleared by an initial deep ploughing (FAO, 2003).

Due to hybridisation of ryegrass and evolution of resistance to some herbicides it is more complex to control. Therefore alternative weed control measures such as crop rotation, tillage and herbicide group rotation were considered practices to be followed. However, these practices require additional planning and management skills, increasing the complexity of farming due to high production costs such as fuel, fertilisers, machinery and herbicides which influence profit (Fischer *et al*., 2002a; Brinkhuis, Personal communication, 2010; Lombard, Personal communication, 2010; Ryklief, personal communication, 2010).

However, field studies alone have not given enough information for planning a long-term weed management programme; therefore a ryegrass seed laboratory germination experiment was conducted to determine dormancy and viability of seeds. Seed dormancy is a mechanism whereby the growth of a seed is temporally suspended; the seed is viable though metabolically inactive and incapable of germination under conditions normally favourable for the species. In addition dormancy duration (few months up to many years) varies from species to species (Physiology of dormancy, n.d; Seed dormancy, 2001). It is normally imposed by environmental and genetic factors. Seeds undergo this process to ensure the survival of the species over a long period under hostile environmental conditions. Weeds normally have long dormancy and survival capacity which result in a bigger challenge to destroy them. The same reports also stated that seed dormancy is not only caused by a single factor, but includes: seed coat, immature seeds and late ripening, temperature and light.

Crop rotation is a sequence of crop production practices; based on the assumptions that it increases yield and suppresses weed growth (Klingman & Ashton, 1975a, c). It is seen as one of the important tools to control weeds. This is achieved through crop diversification to reduce weed growth by introducing strongly competitive crops and the development of a sustainable production system to maintain cash flows (Klingman & Ashton, 1975a & c; Liebman & Staver, 2001; Ghosheh & Al-Hajaj, 2005).

According to numerous researchers and study results (Klingman & Ashton, 1975c; Anon, 2003; Benjamin *et al*., 2010) crops which emerge after weeds normally give lower yields than when crops emerge first. This is based on the severe competitiveness of weeds for light, nutrients and water at the early stages of growth (Ferreira & Reinhardt, 2010). It is assumed that weed seeds buried through mechanical tillage practices prior to planting, take longer to emerge, which gives crops time to grow stronger before weeds emerge again (Ghersa *et al*., 2000; Benjamin *et al*., 2010). However, some tillage practices are assumed to dig up the same amount of seeds that were buried in the soil in previous seasons to the upper soil surface to germinate again (Dekker, 1999). This results in the need to rotate tillage systems over years to break the life span and uniform distribution of new species (Benjamin *et al*., 2010).

Weed seed banks have to be taken into consideration when planning a weed control programme to minimise weed seed distribution in the field (Dekker, 1999; Benjamin *et al*., 2010). Seed banks of weed species are the mechanisms intended to maintain and spread seeds on and in the soil. They differ in weed species composition, population and distribution depending on herbicides, cropping rotation and tillage method used on each specific farm (Lipton, 1995; Dekker, 1999; Ghosheh & Ali-Hajaj, 2005; Carter & Ivany, 2006; Benjamin *et al*., 2010). It is assumed that variation of seed bank composition and size might be influenced by several variables such as tillage system, crop rotation, previous years' seed production and climate (Dekker, 1999; Ghosheh & Al-Hajaj, 2005).

Sattin and Berti (2013) stated that the competitive effect of a given density of weeds emerging with the crop depended strongly on the length of the period they remain in the field. Effective weed control requires detailed knowledge about the weed species, populations, control methods and their effects on total yield. This is because of variations in weed populations and growth habit in different regions. One fixed model cannot be used in all regions, as in the UK, a combination of chemical and tillage methods is generally practiced to control weeds and this showed success in previous years (Benjamin *et al*., 2010).

This makes it crucial to study the dynamics of weeds in different cropping systems for developing environmentally friendly systems promoting the use of integrated weed management strategies (Hiltbrunner *et al*., 2008). One of the strategies is to suppress weed invasion through crop rotation and tillage systems. These increase competition and also improve soil fertility as they leave a certain percentage of crop residues on top of the soil as a result of yield increase (Fischer *et al*., 2002a & b; Kirsten *et al*., 2005; Brady & Weil, 2008; Ferreira & Reinhardt, 2010). Ahmadvand *et al*. (2009) suggested that weed management strategies should be developed and designed in a way that reduces herbicide applications and environmental damage.

1.2 Problem Statement

Grain producers in the Western Cape are faced with a serious ryegrass herbicide resistance problem. Wheat is likely to be infested with severely competitive annual ryegrass weeds at its initial growth stage (Klingman & Ashton, 1975c). Reports from previous researchers highlighted that late weed growth has no significant effect on crop yield, however early weed growth at initial growth stages of the crop has an effect on yield. This raised the need to develop early weed control measures at weed initial growth stages to reduce weed competitiveness with the crop. This would help farmers to plan an effective weed management programme with an accurate prediction of the time weeds emerge and develop (see 1.3 A-C below).

In addition, a large seed bank of ryegrass seeds in the soil is experienced due to massive ryegrass seed production. There is a knowledge gap of the weed seed bank and the effects of crop rotation and tillage system on seed bank dynamics (dormancy, germination, dispersal and mortality) among grain producers. The estimation of the viable weed seed available in the soil was done by previous researchers ‘’by extraction of soil from the soil seed bank and either directly separating seed from the soil or germinating seed under uniform environmental conditions but the problem remains on what quantities of dormant seeds remain on the soil’’ (Dekker, 1999:157). This study was undertaken to evaluate effectiveness of crop rotation and tillage rotation programmes on the control of ryegrass weed population.

1.3 Hypotheses

This is the division of the main problem into sub-problems; it is divided so that correspondence exists between the sub-problems and research questions.

A) Is crop rotation an effective way of reducing ryegrass weed infestation for producers of field crops?

B) Does the tillage system influence the rate of ryegrass germination, growth ability and population?

C) What effects do these two practices have on weed seed distribution, dormancy and the seed bank size?

1.4 Aims and Objectives

The main aim of this study was to determine whether crop rotation and different tillage systems can reduce use of herbicides in the control of ryegrass in wheat production. To achieve the main aim of this study, objectives below needed to be carried out effectively;

- Compare the effects on wheat production of two crop rotations (wheat/medic, and wheat/canola/lupine) with mono-cropped wheat.
- Compare the impact on ryegrass weeds of no-till and minimum tillage systems.
- Analyse the weed seed bank under shade netting.
- Compare seed bank under shade netting and field weed population.
- Determine dormancy of ryegrass seed sampled over four years in the laboratory.

This study focused on the Swartland region as one of the high grain producing regions in the Western Cape province of South Africa. Only the data from 2007, 2011 and 2012 were used in this study for the field and shade netting experiments. The reason for using data for these three years instead of one year was to compare years and check consistency in terms of results.

1.5 Importance of the study

Wheat is the main crop produced in the Swartland region due to favourable environmental conditions for its growth. Ryegrass herbicide resistance poses a threat to farmers. The information gained in this study will be utilised in developing more efficient weed management programmes that are cost effective and increase profit while at the same time being environmentally friendly. It is therefore expected that after this research the farmers will practice improved weed management techniques producing higher yields and wheat quality.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter explores the literature on crop and tillage rotations in commercial grain production systems and the use of these systems to improve weed management strategies that should result in higher yields. These include studies on rotation system effects on the control of ryegrass in terms of weed seed banks and seed dormancy.

Weed invasion and distribution patterns were found to vary with time and space within agricultural fields and are associated with reduction of crop yields and reduction in economic returns (Ahmadvand *et al*., 2009; Gerhards *et al*., 2011; Bushong *et al*., 2012). Wheat yield and quality are not affected by a single factor but several factors such as environment, climate, tillage, weeds, insects, diseases and rotation systems, all of which differ greatly between extensive and intensive production systems (Klingman & Ashton, 1975, a, b & c; Van Vuuren, personal communication, 2010; March, personal communication, 2010; Ryklief, personal communication, 2010; Agenbag, 2012).

High levels of weed invasion led to numerous cases of soil seed bank research that have been done to elucidate many aspects of plant communities' dynamics such as colonisation, sensitivity to agricultural practices, improving production in cultivated areas and weed biology (Page *et al*., 2006). Gerhards *et al*. (2011) reported on weed management practices designed to reduce negative effects of weeds on crop growth and yield. The increase in ryegrass population densities results in the decrease in total grain yield (Appleby *et al*., 1976; Syngenta, 2010). This is because of the short growth cycle of ryegrass and its competitiveness with cereals for nutrients mostly at an initial stage (Botha, 2001; Anon, 2010). Gill & Arshad (1995); Mohler (2001b); Ghosheh & Al-Hajaj (2005) and Carter & Ivany

(2006) reported that weed density and disease contamination are also influenced by the type of tillage practice and equipment used in that specific area.

2.2 Seed Dormancy

Dormancy is an internal condition or mechanism whereby the growth of a seed is temporarily suspended but viable, though metabolically inactive and incapable of germination under conditions normally favourable for the species; its duration (months or years) varies from species to species (Bewley, 1997; Benech-Arnold *et al*., 2000; Seed dormancy, 2001; Physiology of dormancy, n.d). It is a very complex process as not all the seeds of a particular species exhibiting seed dormancy have the same mechanisms. It is normally caused by environmental and genetic factors (Koornneef *et al*. 2002; Conway, 2008; Ebrahimi & Eslami, 2011). Seeds undergo this process to ensure the survival of the species over a long period under hostile environmental conditions.

In addition, seed dormancy is often divided into two major categories depending on what part of the seed produces dormancy, namely: exogenous dormancy (caused by conditions outside the embryo) and endogenous dormancy (conditions within the embryo). Benech-Arnold *et al*. (2000) reported that there are normally two phases of seed dormancy, namely primary dormancy (refers to the innate dormancy possessed by seeds when they are dispersed from the mother plant) and secondary dormancy (refers to a dormant state that is induced in non-dormant seed by unfavourable conditions). The process of changing from one phase to another is known as the dormancy cycle. However, any category of dormancy pre-disposes seed to respond to various conditions that favour seedling growth and also lengthens its life span (Shanmugavalli *et al*., 2007).

Seed dormancy is normally affected by many environmental factors such as temperature, moisture and light. Benech-Arnold *et al*. (2000) reported that breaking of dormancy of winter annual weed seeds is stimulated by low winter temperatures although the introduction of secondary dormancy is promoted by high temperatures in summer. However, Conway (2008) reported that the age of a seed also affected the percentage of seed germination and dormancy. It is also assumed that the germination percentage increases as the seed ages, due to loss of dormancy over time. The garden counsellor (2007 – 2011) stated that the grass seed germination rate decreased between 10 to 25% in each year of storage. They also reported that winter annual weed seed dormancy prevails at the end of spring and allows germination after the first rain in autumn.

There is an assumption that annual ryegrass has low dormancy as 99% of seeds germinate within three to five years after seed set, due to the environmental factors (warm and dry) during seed development (DPI, 2008; Goggin *et al*. 2010) and which is also influenced by genetic traits. However, the dormancy can be lengthened by application of herbicides that will suppress seed germination. Seed dormancy is not caused by a single factor but includes factors such as:

- Seed coat – prevents water uptake, exchange of gases and development of an embryo and differ from specie to specie (Haughn & Chaudhury, 2005; Moise *et al*., 2005).
- Immature seeds and after-ripening effects – normally happens when the plants shed their seeds before embryos are fully matured. After-ripening occurs when the seed does not germinate even under favourable conditions. For this, storing needs to be prolonged.
- Temperature – some seeds germinate under normal temperatures but some do not if they are stored at room temperatures. This is due to the number of chilling units (number of cold units) required to break the dormancy.
- Light – some seeds need light to germinate, so photo biological processes have to take place.

2.3 Effects of environmental factors on weeds

Wheat is produced in the Mediterranean climatic region with its shallow, stony soils in the south western coastal region of South Africa (Agenbag & Maree, 1991). However, these climatic conditions are also favourable for the growth of ryegrass (Botha, 2001).

Exposing weed seed to harsh environmental conditions (sun, rain, wind) by keeping them on the upper soil surface and in shallow layers of the soil through no-till, is assumed to increase mortality rate and make it easier to eradicate weed seeds by hand or through herbicide application (as seeds are concentrated in the upper layers of the soil) than when they are buried deeply in the soil (Dekker, 1999; Ghersa *et al*., 2000). In addition, temperatures above 11ºC are optimum for germination of buried seeds and 22ºC for surface seeds, however, lack of water and moisture stress during ryegrass seed development result in fewer annual ryegrass seeds and fewer dormant seeds (DPI, 2008).

Erosion, weed resistance and low soil fertility status are affected by production techniques such as: practice of continuous cereal monoculture, soil tillage, fertilisation and equipment used (Dekker, 1999; Fischer *et al*., 2002a & b; FAO, 2003; Meadows, 2003; Agenbag, 2012). Use of implements (disk, plough, etc.) in conventional tillage increases the risk of soil erosion as it loosens up the top soil and exposes it to wind and water erosion (FAO, 2003; Meadows, 2003) and could also occur in the Swartland region, while minimum tillage and no-till systems improve structural stability of soil aggregates.

2.4 Effects of crop rotation on weeds

Crop rotation is a series of different crops in the same field following a defined order, while monoculture is the continuous planting of the same crop year after year (Thierfelder & Wall, n.d). Several researchers (Dekker, 1999; Fischer *et al*., 2002a; FAO, 2003; Garden organic, n.d) reported that crop rotation showed positive influences in breaking down of pathogens and disease cycles, but it can also have a negative influence on weeds, insects and disease build-up if it is rotated with the host crops with the same tillage systems.

In other parts of the world crop rotation has been seen to be the successful strategy in weed and disease control in winter wheat which also improves soil fertility and supports economic production (Bohan *et al*., 2011; Agenbag, 2012; Bushong *et al*., 2012). It has shown positive results in breaking the pathogen and disease cycles as well as reducing the weed population when crops of unrelated families are rotated (Dekker, 1999; Fischer *et al*., 2002a; Thierfelder & Wall, n.d.). Moyer *et al*. (1994) reported that growing of alternative crops permits a rotation among herbicides with different mode of action for the control of any one weed species and also restricts development of weed resistance. However, the practice of crop rotation has decreased ever since the introduction of modern agriculture with tillage and agro-chemicals as pest and weed control tools (Bohan *et al*., 2011). Crop rotation helps to increase productivity through improving yields and a subsequent reduction in agricultural chemical dependency on pest and weed control by disturbing their resistance (Fischer *et al*., 2002a & b; FAO, 2003; Kirsten *et al*., 2005), mostly when rotated with leguminous crops.

Monoculture with a no-till system is more susceptible to weeds, high weed seed banks and diseases, as they seem to occur with higher incidence than when wheat is rotated in conventional tillage with leguminous crops (Agenbag & Maree, 1989; Lamprecht *et al*., 1999; Fischer *et al*., 2002b; FAO, 2003; Kirkegaard *et al*., 2004; Agenbag, personal communication, 2009; Bohan *et al*., 2011; Bushong *et al*., 2012). This was supported by the results of Ferreira & Reinhardt (2010) that showed reduction in ryegrass weed plant numbers per square metre when wheat was planted on medic and barley plant residues. This is because of the allelopathic effects, diversification patterns of disturbance, shading, and spreading growth ability of medic (Lamprecht *et al*., 2004; Ferreira & Reinhardt, 2010; Bushong *et al*., 2012).

In Brazil and Uruguay, oats and sunflower are used respectively as alternative winter crops to suppress weed growth, as seeds from annual crops can persist from one season to the next under monoculture cropping sequences (Moyer *et al*., 1994). Fischer *et al*. (2002a) reported that the effects of rotation on wheat and maize in Mexico showed lengthening of the growing cycle of maize in the following season while some weeds did not emerge in the medic pasture in winter. The medic pasture is likely to have a positive effect on soil nitrogen reserves after harvesting and prior to planting wheat in the next season (Fischer *et al*., 2002a).

Kruidhof *et al*. (2008) reported that white lupine residues severely reduced establishment of weeds because they contain quinolizidine alkaloids which were leached from the shoot and were still present and active in the soil with an inhibitory effect. These researchers also discovered that oilseed rape (canola) had a strong competitive ability during autumn and could be the best choice for weed management (Moyer *et al*., 1994). In addition, primary findings from the research conducted by Bushong *et al*. (2012) comparing continuous wheat versus a canola and wheat rotation showed economic differences in controlling annual grasses. Canola-wheat rotations showed greater yields and returns than continuous wheat. However, these results were obtained when using herbicides; it is still unknown what will happen when no herbicides are used in these rotations.

Continuous spring wheat in conservation tillage systems has failed in the past due to the build-up of annual grass weeds (Moyer *et al*., 1994). In addition, the results from field assessment of crop residues for allelopathic effects in a study conducted by Ferreira & Reinhardt (2010) showed that medic and lupine suppressed ryegrass weed, although their percentage of suppression depended on the nature (fine residues like those of medic are more effective as opposed to coarse residues of lupine) and amount (less residues lead to less weed control) of crop residues left in soil. According to FAO (2003) seeds planted with inadequate equipment at the wrong depth because of poorly prepared seed beds may result in poor seedling establishment and produce poor yields. It is assumed that better results can be obtained when crop rotation is incorporated with effective tillage systems.

2.5 Effects of tillage systems on weeds

Disturbance (tillage) of soil prior to planting the next crop helps to stimulate early root growth of weed seedlings, promoting crop competitive ability (Ghersa & Martinez-Ghersa*,* 2000; Mohler, 2001a) and also reduces weed numbers during the initial growth stage of crop seedlings (Klingman & Ashton, 1975a; Oriade & Forcella, 1999; FAO, 2003; Ghosheh & Al-Hajaj*,* 2005). Benech-Arnold *et al*. (2000) and Benjamin *et al*. (2010) reported that different seed bed preparation practices might cause changes in the degree of dormancy, seedling emergence and growth and these interact with favourable conditions such as weather variables, to break dormancy.

Moyer *et al*. (1994) defined conservation tillage as a tillage system that maintains at least 30% crop residues on the soil surface after planting. Soil tillage is a widely used method for seedbed preparation and it can be used as a weed management tool to retain the accepted amount of crop residues on the soil surface which may influence conditions for weed emergence, weed seed production and buries some weed seeds in agronomic cropping systems (Moyer *et al*., 1994; Torresen & Skuterud, 2002; Tuesca & Puricelli, 2007; Johnson *et al*., 2009; Cook *et al*., n.d). However, Cipriotti *et al*. (2011) reported soil tillage as a factor facilitating colonisation of invasive weed species.

Type of tillage practice used contributes to spatial weed distribution and weed shifts through differential seed movement and position of weed seeds in the soil profile as it digs up buried seeds prior to planting (Pollnac *et al*., 2008; Johnson *et al*., 2009). This variety in burial depth affects germination and emergence of seed as the germination rate decreases with an increase in depth (Benech-Arnold *et al*., 2000; Carter & Ivany, 2006; DPI, 2008). The weed seeds in conventionally managed fields are often distributed in patches and generally moved more than two metres from their source while under reduced tillage they are concentrated at or near the soil surface (Torresen & Skuterud, 2002; Pollnac *et al*., 2008). These authors also reported that weed seeds could be dispersed over longer distances when mature plants were caught in farm machinery, such as combines, spraying equipment and seed drills.

In America many farmers have changed from mouldboard ploughs and disc implements to cultivators, sweep ploughs and rod weeders that do not turn the soil or bury the plant residue (Moyer *et al*., 1994). In addition a reduced tillage practice leaves the soil surface covered with crop residues, this practice was also attempted by Brazilian and Norwegian producers in order to reduce cost and soil erosion (Torresen & Skuterud., 2002). However, high weed densities in no-till were seen to be associated with continuous crop production systems (Moyer *et al*., 1994). Benjamin *et al*. (2010) reported that combinations of different tillage systems in a long term programme have been researched and designed to be compatible with economically and environmentally sustainable production. By using these systems in the long term, it should be possible to maintain weed infestations at manageable levels (Ghersa & Martinez-Ghersa, 2000; Ghosheh & Al-Hajaj, 2005; Benjamin *et al*., 2010).

Previous research done by Agenbag & Maree (1991) compared conventional mouldboard plough (MDT), tine-tillage (TT) and no-till (NT) to evaluate the effects of tillage systems on crop yield. They reported an increase in grain yield in all the treatments for the first four years. Even though MDT plots produced significantly higher yields than both tillage systems in the first year, NT out-yielded both other treatments in the fourth year. Numerous researchers (Liebman & Staver, 2001; Barros *et al*., 2007; DPI, 2008) reported restraint of weed germination and delayed emergence in reduced or no-till practice but higher weed seed survival when compared with other tillage systems. This is because ryegrass seeds are small and shallow germinators and water loss through evaporation in no-till is less than in conventional tillage as the soil is covered by plant residue. This promotes rapid evaporation in conventional tillage which reduces water availability for early growth (Botha, 2001; Ghosheh & Al-Hajaj, 2005).

In contrast, according to FAO (2003) and Botha (2001) no-till leads to a high potential of weed germination and earlier crop seedling emergence as seedlings establish and tiller more strongly than in conventional tillage systems. The reduced yield in the no-till treatment was associated with increased weeds, slow early crop growth and more stubble during planting (FAO, 2003; Torresen *et al*., 2003). Seed can totally lose its viability when buried for two years under the soil at depths of 10-15cm (DPI, 2008).

Cook *et al*. (n.d.) reported that seed survival was reduced when the soil was undisturbed as deep cultivation of soil prolongs seed life. In contrast, Moyer *et al*. (1994) and Torresen and Skuterud (2002) reported that conservation tillage caused an increase in densities of annual and perennial weeds that did not normally occur in conventionally cultivated fields. In Brazil and Argentina there was a decline in annual weeds in no-till systems (Torresen & Skuterud, 2002). This was similar to the literature that stated that annual weeds usually have lower densities in conservation tillage systems than in conventional tillage systems (Moyer *et al*., 1994). However, the same author also reported that in a long-term detailed analysis of weed populations in cropping systems, annual weed populations were not influenced by tillage systems.

Continuous single cropping systems increased weed management problems in conservation agriculture (Moyer *et al*., 1994). The weed seeds that were left in the upper soil surface in reduced tillage are likely to germinate and emerge at the time of sowing and increase competition with the crop (Torresen & Skuterud, 2002). ‘The peak germination (80% of seeds) located at the depth of 20 mm occurs at the break of the season after the first two instances of rainfall that exceed 20 mm in the soil’ (Cook *et al*., n.d: 3). The majority of shallowly buried seeds normally germinate in autumn and mid-winter, although undisturbed conditions are favourable for seedling survival.

Johnson *et al*. (2009) reported that tillage had a greater effect on weed density than crop rotation. It was reported that reduced tillage affected species richness and increased the seed bank density in the upper soil layers (Hiltbrunner *et al*., 2008). However, Kruidhof *et al*. (2008) and Moyer *et al*. (1994) reported that reliance on mechanical cultivation is undesirable, as it damages soil structure, increases risk of frost damage to crops and also increases soil erosion. In addition hand weeding can be used, but this practice requires sufficient labour and is costly. Therefore alternative system-oriented approaches to weed management need to be developed, such as management approaches which ensure an early competitive advantage to the crop.

2.6 Weed seed bank

Torresen & Skuterud (2002) reported that history of weeds and weed control are reflected in the weed seed bank. The seed bank is composed of a variety of weed species' seeds which comprise two groups of seeds, the active and dormant seed banks that were produced over several years, the numbers of which change with time (Dekker, 1999). This researcher also found that diversity of the weed population led to adaptation and flexibility of the seed bank to withstand any environmental changes to ensure its survival and dispersal. Seed bank size is determined by the number of weed seeds colonised in that specific area at the time samples were taken and is also influenced by the seed dispersal rate through agricultural practices (tillage, cropping system, harvest) and natural environmental factors such as wind and water (Ghersa & Martinez-Ghersa, 2000).

The report by Torresen *et al*. (1999) stated that reduced tillage that involved crop rotation effectively suppresses weeds. However, there is still lack of information about the effectiveness of these control measures and their role on ryegrass weed invasion in the cropped fields. In the results of previous researchers (Dekker, 1999; Ghersa *et al*., 2000; Thorne *et al*, 2007; Benjamin *et al*., 2010) it was indicated that crop rotation and tillage altered the weed seed bank, weed population and composition. The variation in seed bank size was reported to be influenced by type of tillage system practised (Dekker, 1999; Torreson *et al*., 2003; Ghosheh & Al-Hajaj*,* 2005). Findings of the latter showed that conventional tillage had a negative effect on controlling of weeds as it resulted in a higher density of deeply buried weed seeds in the soil. No-till under low levels of weed seeds had shown positive results in controlling and reducing weeds and limiting chemical application (Dekker, 1999; FAO, 2003). Conversely, the results of a study conducted by Carter and Ivany (2006) found the opposite effect of tillage system on weed control.

2.7 Weed herbicide resistance

The development of non-selective herbicides made no-till cropping systems feasible, as they control a wide spectrum of weeds (Moyer *et al*., 1994). The reliance on and repeated use of herbicides in conservation tillage production practices was the only widely used method for combating weeds (Moyer *et al*., 1994; Torresen *et al*., 1999). This is also currently the case in Western Cape cereal cropping. This method however led to new weed problems in the form of shifts in the dominance of species in weed communities, and increase in the evolution of herbicide-resistant weeds. This occurs mostly when the same mode-of-action herbicide group, particularly the high-risk Groups A and B, are used (Eksteen *et al*., 2000; Hiltbrunner *et al.*, 2008; Johnson *et al*., 2009; Ferreira & Reinhardt, 2010; Collavo & Sattin, 2011; Cook *et al*., n.d). These affect ryegrass weed seed banks in a positive and negative way, as they delay germination but increase the level of dormancy and also have a negative effect on crop yield (DPI, 2008; Gerhards *et al*., 2011). These latter authors also reported that herbicide applications had greater negative effects on crop yields when applied on low seed densities than on higher densities. In Brazil herbicide applications and costs were reduced with about 50% when cover crops such as corn or soya beans were used in conservation tillage systems seeded directly into the cover crop residue without herbicides being applied (Moyer *et al*., 1994).

When a plant is able to survive and reproduce in spite of exposure to normally lethal doses of herbicides, the plant has inherited herbicide resistance (Johnson *et al*., 2009). These herbicide resistant individuals can produce a large number of viable seeds that can be a serious and significant weed problem. In addition it was reported by numerous researchers that weed herbicide resistance is also found in orchards, vineyards, olives and wheat fields of the Western Cape and Europe (Eksteen *et al*., 2000; Ferreira & Reinhardt, 2010; Collavo & Sattin, 2011). The same phenomenon was observed in Australia by Cook *et al*. (n.d); they stated that there were at least 40 populations of annual ryegrass and other species resistant to glyphosate (Group M) on the Liverpool Plains of northern New South Wales (Australia). Marshall and Moss (2008) also reported evolution of weed resistance due to repeated use of glyphosate for fallow control in the UK. Johnson *et al*. (2009) stated that any escaped weed from imposed control strategies will grow and reproduce. This imposes a requirement for a change in the management of that weed to prevent a further increase in its population demographics.

2.8 Effects of weeds on crop yield

Moechnig *et al*. (n.d) reported that yield loss varied among locations and years even at the same weed density. According to Marais (1985), Mabasa (2009) and Sattin and Berti (2013) the presence of uncontrolled weeds led to a serious reduction of average crop yield. In addition, allowing weeds to compete for a longer period increases yield reduction (Marais, 1985; Hartzler, 2004). Yield reduction is also affected by climate as it has an impact on time of weeding, for example in high rainfall season, weeding can be delayed but without seriously affecting yield at early crop vegetative stage. Nevertheless in a dry season, delaying weeding for the same period could reduce crop yield (Marais, 1985; Mabasa, 2009). Ryegrass is a serious constraint in agricultural production systems as it competes for available resources essential for plant growth, resulting in crop yield reduction (Botha, 2001; Moore *et al*., 2006; DPI, 2008; Ferreira & Reinhardt, 2010; Gerhards *et al*., 2011; Cook *et al*., n.d).

Appleby *et al*. (1976) and Syngenta (2010) reported that the increase in ryegrass density resulted in a decrease in total grain yield. In addition, yield decrease with an increase in weed density was also reported by Torresen *et al*. (1999), Pollnac *et al*. (2008) and Cipriotti *et al*. (2011) where forage yield and quality in the grassland were reduced by invasive weeds. Ahmadvand *et al*. (2009) found that the tuber yield of potato declined with increasing weed population and weed presence duration. The reason for these increased densities was because more weeds survived to the next growing season and produced more seeds (Torresen *et al*., 1999; Peterson & Higley, 2000). In a similar weed study with maize, Marais (1985) reported that the greatest reduction in grain yields in the presence of weeds occurred from day 40 to 50 after planting. Estimation of maize yield loss due to weeds was 98 kg of grain per day. During a 10 day period, under drought stress, yield reduction was 2% per day on weedy plots although where there was no apparent competition for water, yields were reduced by 1% per day during this time. Therefore, in weedy plots under dry conditions, there could be a 20% of total yield reduction in the course of the critical 10 day period and 10% yield reduction in wetter conditions during the same period.

If an area was invaded with 200 weed plants per square meter, it could result in a reduction of up to 50% in yield and could produce 45000 seeds per square metre under favourable conditions (Gramshaw, 1972; Cook *et al*., n.d.) This makes the weed coverage denser and can increase its competitive ability with crops. However, competitive ability and damage are associated with the time the weeds emerge and the period of controlling them. The decrease in crop yield occurs mostly when ryegrass weed seeds germinate before or with crops rather than when they germinate after the crop, as they compete strongly for nutrients at early growth stages (Cook *et al*., n.d). The area that is highly infested by ryegrass may be more susceptible to host some of the pathogens such as bacteria *Rathayibacter toxicus* and *Clavibacter* spp that cause annual ryegrass toxicity, Ergot fungus (*Claviceps purpurea*) which contaminates grains and

Rhizoctonia fungus (*Gaeumannomyces graminis* var. *tritici*) which causes 'take all' and wilting of the crops (DPI, 2008; Cook *et al*., n.d).

Whenever seedlings survive the control measures and are allowed to grow until they produce seeds, they pose a threat of multiplication in the following season (Torresen *et al*., 1999), as 99% of a viable ryegrass seed bank germinates within three to five years after seed set (Cook *et al*., n.d). Therefore, the presence of weeds can serve as a visual indicator of potential yield loss as they compete directly with the crop (Pollnac *et al*., 2008; Bohan *et al*., 2011). As was reported by Mabasa (2009), timing of weed control is crucial; therefore it is important to develop weed management tools in the early stages of invasion during the critical period of weed competition. The critical period of weed competition is the period of time during crop growing season in which the crop must be free of weeds to prevent crop yield loss due to weed competition (Hartzler, 2004; Ahmadvand *et al*., 2009).

CHAPTER THREE

Germination and seed longevity of ryegrass (*Lolium multiflorum* x *perenne*)

3.1 Materials and Methods

A laboratory study of *Lolium multiflorum x perenne* seed was undertaken in the winter of 2012 to determine the effects of seed age on germination percentage and dormancy. Gramshaw (1972) and Bewley (1997) reported that seed is considered to be germinated when the radicle has emerged from the lemma and palea and terminates with the elongation of the embryonic axis (Figure 3.1). The seeds were collected towards the end of the previous seasons when they were mature but before they were dispersed from the parent plant, *i.e*. in October of the years 2008, 2009, 2010 and 2011 at Langgewens research farm (33º17' S, 18º42' E). This locality is described as a typical Mediterranean-type due to its rainfall distribution pattern, with a long-term average of 397 mm per annum, of which about 80% occurs during the autumn/winter/spring months of April to September (Agenbag, 2012). The temperatures of 22/14°C that were used when incubating seeds, correlate with temperatures of the soil surface during mid-autumn in the Swartland region. However, data for 2008 seeds are not presented in the results as seeds were collected at an immature growth stage resulting in zero seed germination.

Figure 3.1 Geminated seeds after seven days of incubation

The incubation experiments were repeated three times. The first experiment was conducted in May, the second one in July and the last experiment in August using 100 seeds of ryegrass in each one.

The harvested seeds were threshed by hand and cleaned to remove chaff and empty seeds, and then stored in sealed paper bags at room temperature. The layout was according to a randomised block design with ten replicates, equalling 100 seeds per sample for each year (years 2009, 2010 & 2011). Ten seeds of ryegrass weed from each sample (2009, 2010 & 2011) were placed on two layers of filter paper in 95 mm diameter Petri-dishes and moistened with five millilitre distilled water. Petri-dishes were sealed with Parafilm® and placed in an incubator set at 12h/12h day/night cycle and a temperature range of 22°C during the day and 14°C at night.

Germination was determined after seven and fourteen days of incubation respectively, by counting the number of seeds germinated. The purpose of collecting data at these times was to determine whether the seed had low dormancy (LD) or high dormancy (HD), as it was assumed in a previous study by Goggin *et al.* (2010) that ryegrass has lower dormancy due to the harsh conditions during seed development and maturity. It is assumed that the LD seed will germinate within a week and the HD seed after two to six weeks. All germinated seeds were counted and removed from the Petri-dish at seven days and those that failed to germinate after seven days were returned to the incubator for a further seven days. After fourteen days, germinated and non-germinated seeds were recorded to determine percentage germination and dormancy (Ferreira, 2011).

The results are discussed in relation to the germination and emergence behaviour of seeds in the field.

3.2 Data Analyses

The interaction of years and experiments on germination was examined using Analysis of Variance (ANOVA). The germination percentage represents percentage of the maximum germination possible in all treatments.

3.3 Results

The germination percentage of seeds collected over three years (2009, 2010 & 2011) differed significantly after seven days of incubation (Table 3.1). However, after fourteen days of incubation germination percentage of 2011 seeds differed significantly from those of 2009 and 2010. Germination and dormancy were influenced by age, as more mature seeds had high germination percentages compared to those newly harvested ones which showed more dormancy. The failure to prevent ryegrass from forming seeds in a particular season increased the seed bank size, and lead to high infestations in the following seasons.

Table 3.1 Effect of seed age on percentage germination of viable seeds after 14 days of incubation

Years	Germination rate after 7 days (%)	Germination rate after 14 days (%)
2009	76[a]	80[a]
2010	69[b]	73[a]
2011	40[c]	42[b]
LSD ≤0.05	7	7

* Means with the same letter are not significantly different at the 0.05 probability level

The results showed that cumulative germination percentage of 2011 seeds differed significantly from both 2009 and 2010 seeds in all experiments (Table 3.2). It also shows significant differences between 2009 seeds in experiment 1 and experiment 2 with a high germination percentage of ryegrass seeds during the first seven days of incubation. After fourteen days of incubation experiment 1 and experiment 2 differed significantly.

Table 3.2 Percentage germination after 14 days of incubation for three experiments

	Experiment 1		Experiment 2		Experiment 3	
Years	Germination after 7 days (%)	Germination after 14 days (%)	Germination after 7 days (%)	Germination after 14 days (%)	Germination after 7 days (%)	Germination after 14 days (%)
2009	86[a]	87[a]	71[bc]	75b[c]	72[bc]	77[abc]
2010	77[ab]	81[ab]	66[bc]	72b[c]	64[c]	66[c]
2011	42[d]	43[d]	40[d]	44[d]	39[d]	39[d]
LSD ≤0.05	12	12	12	12	12	12

* Means with the same letter are not significantly different at the 0.05 probability level

3.4 Discussion

The germination percentages after seven and fourteen days of germination were significantly affected by time (Table 3.1; Figure 3.2). As Benech-Arnold *et al*. (2000) reported that dormancy and dormancy release of both summer and winter annuals fluctuate seasonally. In this study it was found that the maximum germination percentages differed between years and experiments. Failing to control ryegrass seedlings and allowing it to produce seeds would be problematic over the next three years as seeds would still be viable and able to germinate.

The high germination percentage for 2009 and 2010 occurred after fourteen days of seed incubation (Table 3.2; Figure 3.3). It varied between years with significantly lower germination occurring for seeds collected in 2011. The delay in weed control at earlier stages of growth, increased competition and resulted in reduced grain yields and a highly weed populated area.

Figure 3.2 Effect of seed age on percentage germination of viable seeds after 7 and 14 days of incubation

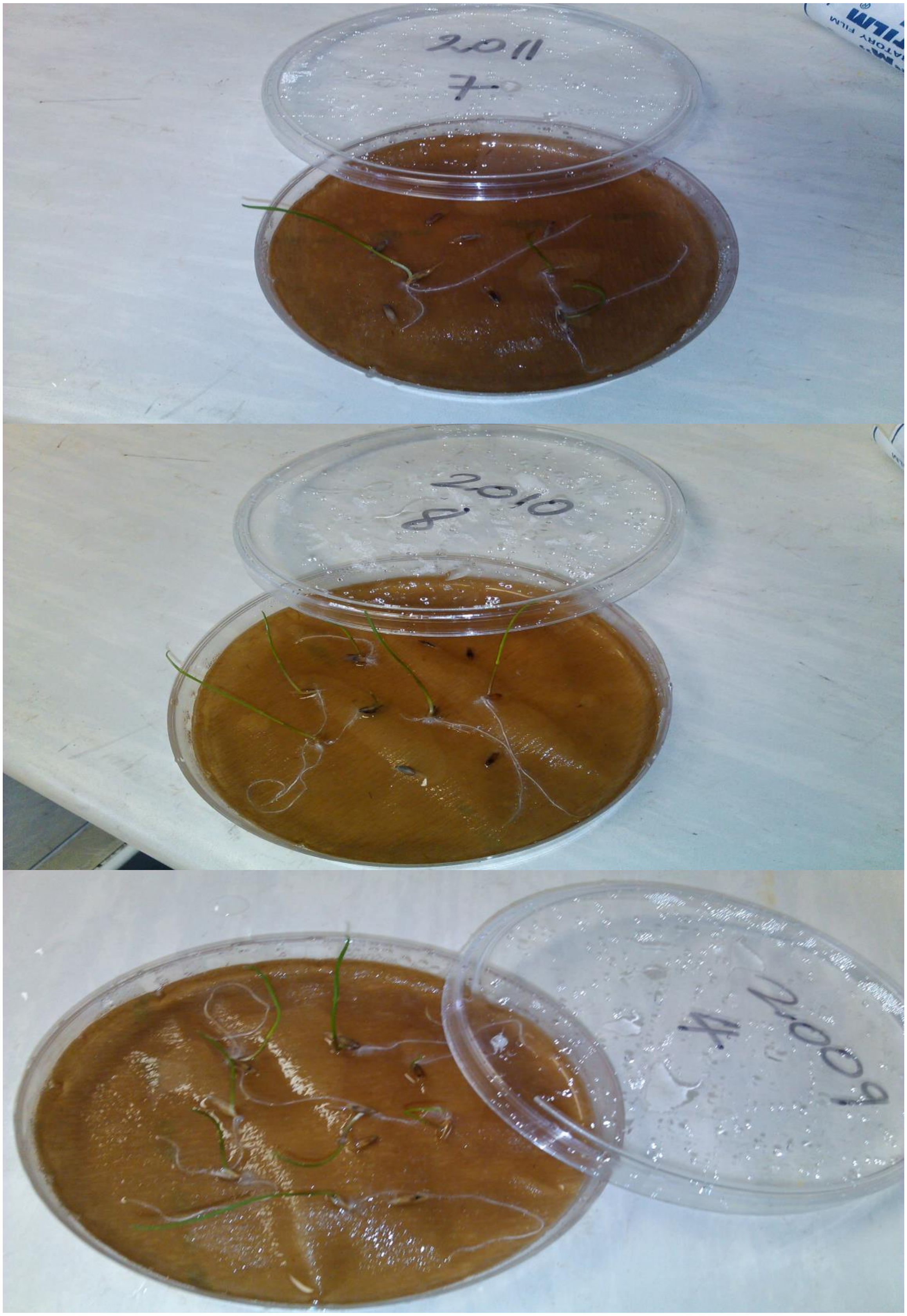

Figure 3.3 Germinated ryegrass seeds after 14 days of incubation

Germination of ryegrass increased with incubation time. The germination percentages at seven and fourteen days respectively, were significantly affected by the seed age in this study. Similar results were reported by Gramshaw (1972) and Conway (2008) who stated that the percentage of seed dormancy was affected by the age. The major increase in germination with age is due to loss of dormancy with time. The low germination percentage of seeds collected in 2011 confirms the findings of Gramshaw (1972) who stated that seeds harvested and stored for 18 weeks germinated faster than the freshly harvested seeds. These results showed characteristics of the dormancy pattern found in seeds of many winter annual grass species which after-ripen rapidly in dry storage (Gramshaw, 1972).

The cumulative germination of above 50% for seeds collected in 2009 and 2010 indicates that the seeds had already after-ripened and had been stored enough to break primary dormancy to reach peak germination of above 50%. Results also showed that under unlimited moisture, a high percentage of germination may occur, similar to field experiment results of 2011 (Chapter 5). Delayed planting of winter crops may thus allow ryegrass to germinate and emerge early in the season. The cumulative germination percentage below 50% for 2011 indicated that newly matured ryegrass seeds have a dormancy cycle of more than six months before they get to the peak germination state of above 50%. These results correspond with those of Benech-Arnold *et al*. (2000) where the high dormancy level of seeds was on the recently dispersed seeds and confirmed that germination of annual seeds did not occur in any season except in their growing season. The release of primary dormancy in older seeds increased germination percentage of seeds collected in 2009 and 2010.

After fourteen days of incubation, 43% of seeds collected in 2011 geminated in experiment 1, followed by 44% and 39% in experiment 2 and experiment 3, respectively (Table 3.2; Figure 3.4). For all three experiments there were no significant differences between seed germination percentages for seeds from 2011, as they had a low cumulative germination percentage. This corresponds with results obtained by Conway (2008) who reported that the dormancy period for newly formed seed was the first 8-9 weeks. However, data for seeds collected in 2010 differed significantly between experiment 1 and 3 with low germination observed in experiment 3. Similar results were obtained for 2009 seeds, as experiment 1 differed significantly from experiment 2. This shows that the germination of ryegrass was influenced not only by the age of the seeds, but also by the season. This corresponds with the finding that mature primary dormant seeds can enter into a state of secondary dormancy in response to unfavourable conditions, but remain viable for a long period (Bewley, 1997).

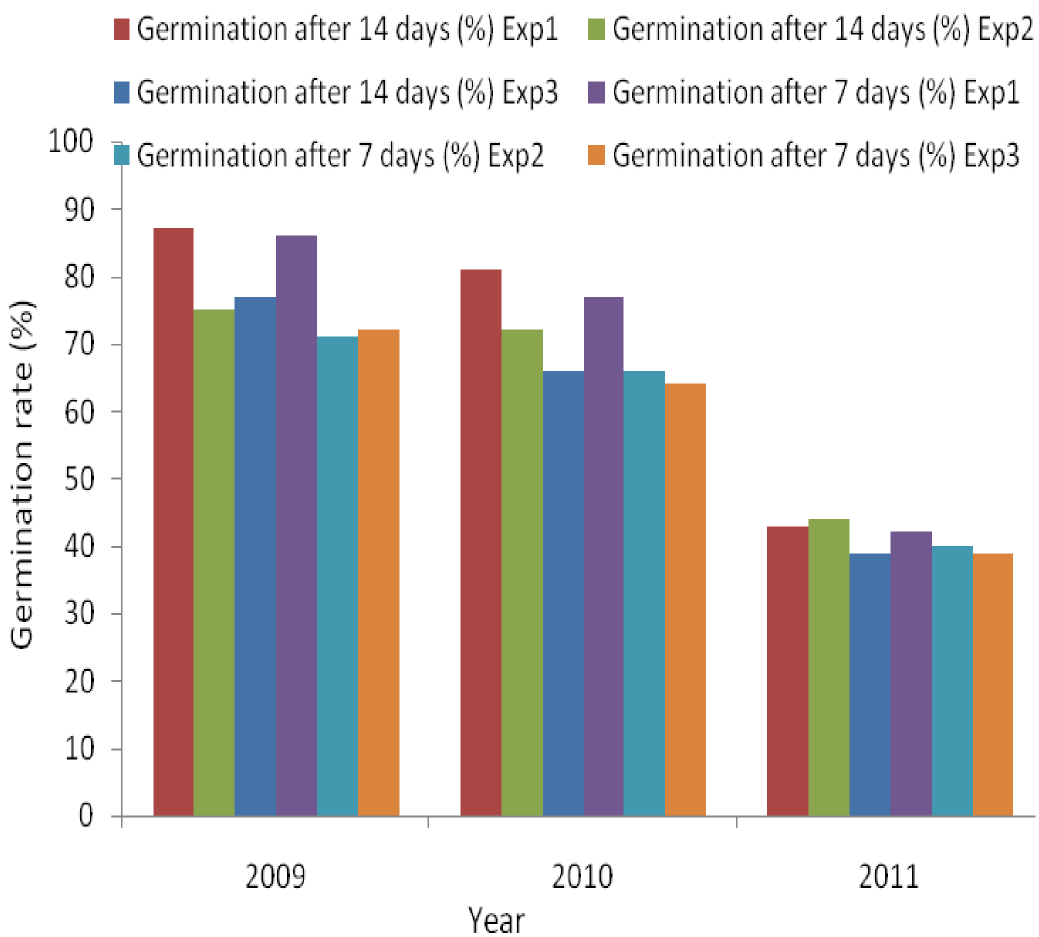

Figure 3.4 Germination percentages of ryegrass seeds after 14 days of incubation in three experiments

All seeds were collected in different years and therefore these large differences suggest that the years tested differed with regard to either the length of their period of primary dormancy or age of the seed. The number of seeds germinated was strongly related to the proportion of the seed bank that has been released from dormancy, and viable seeds (Benech-Arnold *et al*., 2000). Cumulative ryegrass seed germination of below 50% after 14 days of incubation as was found for the 2011 seeds in this study, indicated that seed after-ripening and dormancy release were not yet met at the time of the experiment.

These findings are in agreement with results by Cook *et al*. (n.d), who reported that peak germination (80% of seeds) occurs at the window period after the first two incidents of rainfall that exceed 20 mm in the field. Also, Borger *et al*. (2011) reported that seeds of *Chloris truncate* (windmill grass) had up to 80% germination following dormancy (after-ripening) release. Due to the rapid germination rate of ryegrass it may germinate earlier in the season prior to planting. It will therefore germinate earlier than the planted wheat, which may give a competitive advantage to the weeds. Ryegrass may reduce the potential yield of wheat by utilising moisture and nutrients that would otherwise be available to the crop. Pre-planting practices such as soil tillage on its own will therefore not be very efficient to control ryegrass weed. The best control of this species would likely be obtained with long-term crop and tillage rotation systems, as was reported by Fischer *et al*. (2002a & b) and Ferreira and Reinhardt (2010).

3.5 Recommendations and Conclusion

It would be advisable to consider the time of planting as well as the accurate time of weed control for this species. This can only be achieved by determining the life cycle, times of emergence and growth in the agricultural system, seed production and seed dormancy of ryegrass. Prevention and early control of any weed from producing seeds is an important practice that needs to be followed in order to control or reduce the soil seed bank. Germination percentage of a seed depends on dormancy release which requires different types of treatment to break and prepare a seed to germinate in the forthcoming season (Shanmugavalli *et al*., 2007). This means each type of weed will require different treatments or control measures in the field. The complete loss of viability of annual ryegrass seeds can be achieved when they are buried at 10-15 cm in the soil for two years (DPI, 2008). However, it can also be achieved by exposing seeds to harsh environmental conditions (wind, sunlight, rain, frost), although they will take longer to lose viability totally than when they are buried deep in the soil.

It may be concluded that ryegrass seeds collected in 2009 had the highest cumulative germination percentage compared to seeds from 2010 and 2011. In all experiments, cumulative germination percentage after fourteen days of incubation of *Lolium multiflorum x perenne* for 2009, 2010 and 2011 showed figures of 75-87%, 66-81% and 39-44%, respectively. This means that older seeds had a high possibility of germinating at the early stages of crop growth. This was similar to the results from the field and shade netting experiments where the highest incidence of ryegrass population counts was recorded in the first six weeks after planting. They also indicated that dormancy (after-ripening) requirements inhibited germination for most of the newly harvested ryegrass seeds (2011) as maximum germination of only 40% was achieved.

The percentage ryegrass seed germination is affected by the age of the seed. It increases as the seed ages due to loss of dormancy over time. It can be concluded that after initial dormancy, ryegrass has a high germination percentage rate as was observed for seeds after two years of storage. Although seeds collected in 2009 and 2010 showed the highest germination percentage after a 14 day incubation period, differences were not significant with all germination percentages above 75%. It is likely that 2011 ryegrass seed dormancy and germination were influenced by a primary dormancy phase. An early emerging ryegrass seedling has the potential to be controlled by early post-emergence herbicides that are usually applied to wheat from mid-May in the Western Cape.

Knowledge with regard to ryegrass germination and dormancy period obtained in this study can certainly help to improve weed control in the field crops of Western Cape, by facilitating models that explore the influence of factors such as tillage and crop rotation on germination and emergence. There was a variation in germination rate of ryegrass seed from all years, although the current study did not confirm if the remaining seeds were dormant or not viable. There is still much to be learnt about the key processes involved in germination and dormancy, such as timing of ryegrass emergence in relation to crop emergence as this depends on the dynamics of dormancy release.

CHAPTER FOUR

Effects of crop rotation and tillage on weedy ryegrass (*Lolium multiflorum* x *perenne*) seed banks in the field

4.1 Materials and Methods

The shade netting and field data were gathered from a long-term tillage/crop rotation trial in the 2011 and 2012 growing seasons in the Swartland region at Langgewens research farm (33.276822'S, 18.703171'E) near Malmesbury, Western Cape, on a shallow (250-300 mm) sandy loam soil with a gravel and stone (shale) content of 44.6% in the A horizon. This locality is described as a typical Mediterranean-type due to its rainfall distribution pattern, with a long-term average of 397 mm per annum, of which about 80% occurs during the autumn/winter/spring months of April to September (Agenbag, 2012). Wheat is one of the main crops produced in this region and rotational crops include canola, lupine, medic and oats. The following cropping sequences were selected for this experiment: Monoculture wheat (WWWW), Wheat-Medic-Wheat-Medic (WMcWMc) and Wheat-Canola-Wheat-Lupine (WCWL).

The effects of crop rotation and tillage systems on the incidence and severity of ryegrass infestation in the cropped area were determined after a four year crop rotation and repeated after the first year of the following cycle. Collection of field experiment data on ryegrass was conducted only in 2011 and 2012, while data for shade netting was first collected in 2007, followed by data gathering in both 2011 and 2012. All the tillage trial plots maintained the cropping sequence they were allocated in 2002. In 2007, shade netting experiments were established to evaluate the effectiveness of crop rotation and tillage systems on the weed population and seed bank. The ryegrass weed population counts under shade netting were done at the beginning of the experiment in 2007. The weed population of 2007 was used as a baseline for each treatment and compared to the inhibition or stimulation of ryegrass by 2011 and 2012. By counting the weed seedling numbers for each treatment after four years (2011) and again after one year (2012), population changes could be determined. This was repeated after a four year crop rotation cycle (2011) and again after a short-term rotation (2012). The experiments were conducted in a randomised block design with four replicates.

4.1.1 Experiment 1 (shade netting)

The shade netting weed seed bank study was conducted from the data collected after a crop rotation cycle of four years (2007-2010), during the fifth year (2011) and repeated in the sixth year (2012). Soil samples for the weed seed bank study were collected in March 2007 in the field from all plots before they were sub-divided into these tillage and crop rotation treatments prior to crop planting. In all years of sampling, a 40 mm diameter soil core was used up to a depth of 50 mm in the field to take ten soil samples per plot. This zone is believed to contain the previous year’s weed seeds, which would likely germinate in the growing season (Page *et al*., 2006).

The ten soil core samples of each treatment collected were bulked together in a plastic seedling tray of 300 mm length x 270 mm width x 100 mm height (Figure 4.1). Soil samples were spread evenly in seedling trays after being thoroughly mixed. They were then placed under shade netting as a semi-controlled environment which was irrigated to create favourable conditions which would stimulate germination. Overhead micro sprinkler irrigation was used for irrigation of ten minutes each day to simulate field conditions (Page *et al*., 2006). After plant emergence, seedlings were allowed to develop for five weeks to be more easily identifiable, then counted and removed (Ghosheh & Al-Hajaj, 2005; Page *et al*., 2006) (Figure 4.2). Only ryegrass seed bank data from WWWW, WCWL and WMcWMc rotations were used in the analyses presented in this study.

Figure 4.1 Seedling trays with soil samples collected in the field for seed bank study under shade netting

Figure 4.2 Emerged ryegrass seedlings at four weeks

4.1.2 Experiment 2 (field)

Field data were gathered from April to August in both years 2011 and 2012. Two tillage systems, defined as no tillage (no-till) and minimum tillage (min-till) were used in this study. In both systems, a no-till planter was used at planting. Different cropping sequences were performed under no-till and min-till over time namely WWWW, WMcWMc and WCWL (Table 4.1). Data were only collected in the wheat plots in this study, but all phases of crop rotation and tillage systems were presented in each year.

Each main plot was subdivided into two sub-plots allocated to two tillage treatments, namely:

- No-till (soil left undisturbed until planting and then planted with a no-till planter),
- Minimum-till (soil scarified in March/April and then planted with a no-till planter).

Table 4.1 Schematic representation of field experiment at Langgewens

REP 1		REP 2		REP 3		REP 4	
WMcWMc Min-till	WMcWMc No-till	WWWW Min-till	WWWW No-till	WLWC No-till	WLWC Min-till	WCWL Min-till	WCWL No-till
WWWW No-till	WWWW Min-till	WCWL No-till	WCWL Min-till	WCWL Min-till	WCWL No-till	WLWC No-till	WLWC Min-till
WLWC Min-till	WLWC No-till	WMcWMc No-till	WMcWMc Min-till	WMcWMc Min-till	WMcWMc No-till	WWWW Min-till	WWWW No-till
WCWL No-till	WCWL Min-till	WLWC Min-till	WLWC No-till	WWWW No-till	WWWW Min-till	WMcWMc Min-till	WMcWMc No-till

*All crop sequences start with the first letter in the sequence in 2007

The decision to use these two tillage systems was influenced by the fact that they are more representative of conservation agricultural production practices that need to be promoted to grain producers within the region. It was also aimed at the improvement of organic matter status of the soil and also to prevent soil erosion as this region is exposed to various erosion factors (wind and water). The total number of sub-plots was 32, with eight sub-plots in each block of a replicate. Ryegrass weed seedling densities were counted at three weeks, six weeks, nine weeks and twelve weeks after planting, using one steel grid quadrant frame of 0.25 square metre placed in the centre of each sub-plot. Samples were measured by counting the number of emerged ryegrass seedlings emerging at each interval. All emerged seedlings at the time of sampling were counted and removed (Figure 4.3).

Figure 4.3 Quadrant used to count emerged ryegrass seedling at three weeks after planting

4.2 Data Analyses

Data were analysed between the time intervals in order to determine differences between times in terms of the ryegrass population. Data combined for years and treatments for both field and shade netting experiments were also analysed.

Analysis of variance (ANOVA) was performed to determine significant differences in weed population and to test effects of tillage and crop rotation treatments and possible interactions. Treatment means were compared using least significant difference (LSD) test at a probability level of 5% (P = 0.05). Crop rotations in each tillage system were analysed using the *t*-test (P = 0.05).

4.3 Results

Results of Experiment 1 are given first, where the ryegrass seedbank was assessed using seed trays under shade netting (4.3.1). This is followed by the results of the field experiment (Experiment 2, numbered 4.3.2).

4.3.1 Ryegrass seed bank assessment under shade netting

The ryegrass population was significantly increased by wheat monoculture compared to the other three crop rotations (Table 4.2). It also showed a rapid increase over years thus opposite results were obtained from other rotation systems which showed a decrease in ryegrass populations. In 2011, a high inhibition percentage in ryegrass populations was observed for wheat planted in rotation after canola, lupine and medic compared to wheat monoculture. However, Table 4.2 shows that in 2012 there was a decrease of ryegrass inhibition percentage among these rotation systems. The three rotational systems all inhibited weed germination.

While the wheat monoculture system (WWWW) stimulated ryegrass weed growth by over 50% in 2011, and more than doubled the ryegrass weed populations in 2012 (compared with the 2007 weed levels), all of the crop rotation systems inhibited over three quarters of the weed growth, as can be seen by the negative percentages for both years shown in Table 4.2. The lowest ryegrass population inhibition was observed in 2012 compared to 2011, this is represented graphically in the discussion of results in chapter 5 (see Figure 5.3; actual counts on Appendix A).

Table 4.2 Average percentage inhibition (-) or stimulation (+) in the number of ryegrass seedlings recorded in seedling trays for different cropping systems at Langgewens for both 2011 and 2012 compared to 2007 data

2007		2011	2012
Cropping system	**Plants m^{-2}**	**Total Count %**	**Total Count %**
WLWC	15502[a]	-97[a]	-80[a]
WCWL	14935[a]	-97[a]	-90[a]
WMcWMc	7074[b]	-88[a]	-78[a]
WWWW	1423[b]	52[b]	116[b]
LSD ≤0.05	6116	62	152

* Means with the same letters are not significantly different at the 0.05 probability level

Wheat monoculture under minimum-till differed significantly from other rotations in 2011 (Table 4.3), but was similar to the results obtained in 2012 for crop rotation in both tillage systems. Wheat monoculture under min-till stimulated ryegrass seedling populations in both years compared with no-till, while crop rotation (WLWC) and tillage systems (no-till) highly inhibited ryegrass populations with 99% in 2011. However, in 2012 a high inhibition of ryegrass populations of 92% was obtained under WCWL-no-till rotation (Table 4.3).

The stimulation and inhibition percentages varied between years and agricultural practices applied here showed that each crop rotation associated with a certain tillage system influenced the ryegrass population differently from one another. Wheat monoculture in both tillage systems was the most ryegrass-population-stimulating practice in both years. A severe invasion of ryegrass on a wheat farm increases competition and can have a dramatic effect on crop growth and reduce farm productivity.

Table 4.3 Average percentage inhibition (-) or stimulation (+) in the number of ryegrass seedlings recorded in seedling trays for different cropping and tillage systems at Langgewens for both 2011 and 2012 compared to 2007 data

2007		2011		2012	
Cropping system	**Plants m^{-2}**	**No-till Total Count %**	**Minimum-till Total Count %**	**No-till Total Count %**	**Minimum-till Total Count %**
WLWC	15502[a]	-99[a]	-94[a]	-81[a]	-80[a]
WCWL	14935[b]	-97[a]	-97[a]	-92[a]	-87[a]
WMcWMc	7074[c]	-94[a]	-83[ab]	-80[a]	-75[a]
Control WWWW	1423[d]	0[b]	103[c]	0[a]	232[b]
LSD ≤0.05		84	84	223	223

* Means with the same letters are not significantly different at the 0.05 probability level

Wheat monoculture under minimum-till significantly differed from the other three rotation systems (Table 4.4). While cumulative results of crop rotation (WCWL) under no-till inhibited ryegrass weed populations by over -95%, and -92% under minimum till, respectively compared to monoculture (WWWW). Wheat monoculture stimulated ryegrass weed populations by over 100% under minimum till. Table 4.4 shows that the three rotational systems all inhibited weed germination in both no-till and minimum tillage systems; this is represented graphically in the discussion of the results in Chapter 5 (see Figure 5.8).

Table 4.4 Average percentage inhibition (-) or stimulation (+) in the number of ryegrass seedlings recorded in seedling trays for different cropping and tillage systems at Langgewens for both 2011 and 2012 seasons combined

Cropping system	Tillage system	Total count %
WLWC	Minimum-till	-87[a]
WCWL		-92[a]
WMcWMc		-79[a]
WWWW		167[b]
WLWC	No-till	-90[a]
WCWL		-95[a]
WMcWMc		-87[a]
Control (WWWW)		0[a]
LSD ≤0.05		146

* Means with the same letters are not significantly different at the 0.05 probability level

4.3.2 Ryegrass seed bank assessment in the field

During 2011 the highest ryegrass population was observed for wheat monoculture at six weeks after planting (Table 4.5; Figure 4.4). However, this changed significantly in 2012 as the highest population was observed at three weeks after planting (Figure 4.5). In contrast, both 2011 and 2012 wheat monoculture stimulated ryegrass populations compared to the other three rotation systems, which suppressed ryegrass populations. The ryegrass seedlings were removed after every count so that the re-growth could be measured again after three weeks (see actual counts in Appendix B & C). The findings showed that ryegrass populations changed and differed with time within the season. This makes it very important to know the exact period when ryegrass shows high germination and competition with crops, and time control measures to prevent reduced crop yields.

Table 4.5 Average percentage inhibition (-) or stimulation (+) in the number of ryegrass seedlings recorded in different cropping systems at Langgewens for both 2011 and 2012

Cropping system	Year	Percentage ryegrass seedling inhibition or stimulation			
		3 wks	6 wks	9 wks	12 wks
WLWC	2011	-59[a]	-63[a]	-67[a]	-71[a]
WCWL		-80[a]	-81[a]	-80[a]	-80[a]
WMcWMc		-67[a]	-68[a]	-68[a]	-67[a]
WWWW		30[b]	36[b]	33[b]	29[b]
LSD ≤0.05		39	31	25	25
WLWC	2012	-49[a]	-59[a]	-61[a]	-62[a]
WCWL		31[ab]	-53[a]	-59[a]	-63[a]
WMcWMc		-21[a]	-90[a]	-90[a]	-92[a]
WWWW		174[b]	5[b]	-8[b]	-5[b]
LSD ≤0.05		152	39	33	33

* Means with the same letters are not significantly different at the 0.05 probability level

Figure 4.4 Ryegrass seedlings in the wheat monoculture cropping system in 2011 at six weeks after planting

Figure 4.5 Ryegrass seedlings in the wheat monoculture cropping system in 2012 at six weeks after planting

Data from the 2011 field experiment showed no significant effect from the no-till treatment on ryegrass populations at all time intervals. However, there were significant differences between no-till and minimum tillage system at nine and twelve weeks after planting, respectively (Table 4.6); this is represented graphically in the discussion of the results in Chapter 5 (see Figure 5.4). No-till at nine weeks and minimum-till at twelve weeks, significantly differed from each other. No-till inhibited over 50% of the ryegrass population compared to minimum till which inhibited it less than 35% in the 2011 season. Different results were obtained in 2012 where minimum-till had a high population of ryegrass (112%) and stimulated ryegrass seedlings at three weeks after planting. This differed significantly from no-till treatments which inhibited ryegrass (-44.08%) as it showed low populations for the same period. However, at 12 weeks after planting minimum-till showed better inhibition compared to no-till as it was populated with fewer ryegrass seedlings which increased the treatment's inhibition percentage to -67% (see Figure 5.4). Findings showed that minimum tillage stimulates early germination of ryegrass compared to no-till. This may be caused by improved soil seed contact in minimum tillage. Delayed weed control in minimum tillage must be avoided to minimise a decrease in crop yield.

Table 4.6 Average percentage inhibition (-) or stimulation (+) in the number of ryegrass seedlings recorded in different tillage systems at Langgewens for both 2011 and 2012 seasons combined

Tillage system	Year	Percentage ryegrass seedling inhibition or stimulation			
		3 wks	**6 wks**	**9 wks**	**12 wks**
No-till	2011	-57[a]	-60[a]	-60[a]	-60[a]
Min-till		-32[a]	-28[a]	-31[b]	-34[b]
LSD ≤0.05		36	32	27	36
No-till	2012	-44[a]	-57[a]	-43[a]	-44[b]
Min-till		112[b]	-42[a]	-67[a]	-67[a]
LSD ≤0.05		126	34	28	29

* Means with the same letters are not significantly different at the 0.05 probability level

When rotating wheat with canola, lupine or medic in both tillage systems the population of ryegrass differed significantly from wheat monoculture under min-till in 2011 (Table 4.7). It had higher stimulation values of ryegrass populations in all growth stages. Similar trends were observed in 2012 (Table 4.8).

Table 4.7 Average percentage inhibition (-) or stimulation (+) in the number of ryegrass seedlings recorded in different cropping and tillage systems at Langgewens for 2011

Cropping system	No-till				Minimum-till			
	Percentage ryegrass seedling inhibition or stimulation							
	3 wks	6 wks	9 wks	12 wks	3 wks	6 wks	9 wks	12 wks
WLWC	-49^{ab}	-58^{ab}	-65^{a}	-73^{a}	-69^{ab}	-68^{a}	-69^{a}	-70^{a}
WCWL	-91^{a}	-93^{a}	-92^{a}	-91a	-68^{ab}	-68^{a}	-68^{a}	-69^{a}
WMcWMc	-86^{a}	-88^{a}	-82^{a}	-76^{a}	-49^{ab}	-49^{ab}	-54^{ab}	-58^{b}
Control (WWWW)	0^{bc}	0^{b}	0^{b}	0^{b}	59^{c}	72^{c}	66^{c}	58^{b}
LSD ≤0.05	72	64	54	50	72	64	54	50

* Means with the same letters are not significantly different at the 0.05 probability level

Table 4.8 Average percentage inhibition (-) or stimulation (+) in the number of ryegrass seedlings recorded in different cropping and tillage systems at Langgewens for 2012

Cropping system	No-till				Minimum-till			
	Percentage ryegrass seedling inhibition or stimulation							
	3 wks	6 wks	9 wks	12 wks	3 wks	6 wks	9 wks	12 wks
WLWC	-49^{a}	-36^{abc}	-40^{ab}	-43^{ab}	-49^{a}	-82^{a}	-82^{a}	-82^{a}
WCWL	-44^{a}	-42^{abc}	-42^{ab}	-45^{ab}	106^{ab}	-64^{ab}	-76^{a}	-81^{a}
WMcWMc	-84^{a}	-91^{a}	-89^{a}	-90^{a}	42^{a}	-90^{a}	-92^{a}	-93^{a}
Control (WWWW)	0^{a}	0^{bc}	0.^{b}	0^{b}	347^{b}	9^{c}	-16^{b}	-10^{b}
LSD ≤0.05	252	68	56	59	252	68	56	59

* Means with the same letters are not significantly different at the 0.05 probability level

The highest incidence of ryegrass occurred in wheat monoculture plots as was also observed for all time intervals (Table 4.9). In contrast, plots planted to wheat after lupine, canola and medic showed a reduction in ryegrass populations. Crop rotation showed ryegrass inhibition effects compared to monoculture which stimulated ryegrass populations. Practicing monoculture in the field increases the weed seed bank size and would lead to a highly weed infested field with reduced productivity.

Table 4.9 Average percentage inhibition (-) or stimulation (+) in the number of ryegrass seedlings recorded in different cropping systems at Langgewens for both 2011 and 2012 seasons combined

Cropping	Percentage ryegrass seedling inhibition or stimulation			
system	3 wks	6 wks	9 wks	12 wks
WLWC	-54[a]	-61[a]	-64[a]	-67[a]
WCWL	-24[a]	-67[a]	-70[a]	-72[a]
WMcWMc	-44[a]	-79[a]	-79[a]	-79[a]
WWWW	102[b]	20[b]	13[b]	12[b]
LSD ≤0.05	79	21	17	19

* Means with the same letters are not significantly different at the 0.05 probability level

When wheat-medic rotation was practiced under minimum-till and no-till it did not significantly differ from wh

eat-lupine and wheat-canola rotations. However, wheat monoculture under minimum-till was significantly different from the other three rotation systems in both years (Table 4.10). Findings showed that tillage system incorporated with crop rotation had a positive effect by inhibiting ryegrass populations. In contrast, monoculture under minimum till stimulated ryegrass populations. Therefore, planting the same crop continuously, even under different tillage systems is a constraint in grain production systems as it could stimulate weed populations.

Table 4.10 Average percentage inhibition (-) or stimulation (+) in the number of ryegrass seedlings recorded in different cropping and tillage systems at Langgewens for both 2011 and 2012 seasons combined

Cropping system	No-till				Minimum-till			
	Percentage ryegrass seedling inhibition or stimulation							
	3 wks	6 wks	9 wks	12 wks	3 wks	6 wks	9 wks	12 wks
WLWC	-49^{a}	-47^{a}	-53^{a}	-58^{a}	-59^{a}	-75^{a}	-76^{a}	-76^{a}
WCWL	-68^{a}	-67^{a}	-67^{a}	-68^{a}	19^{a}	-66^{a}	-72^{a}	-75^{a}
WMcWMc	-85^{a}	-89^{a}	-85^{a}	-83^{a}	-3^{a}	-69^{a}	-73^{a}	-75^{a}
(Control) WWWW	0^{a}	0^{b}	0^{b}	0^{b}	203^{b}	41^{b}	25^{b}	24^{b}
LSD ≤0.05	118	46	37	40	118	46	37	40

* Means with the same letters are not significantly different at the 0.05 probability level

CHAPTER FIVE

DISCUSSION

5.1 Effect of crop rotation on the ryegrass population

Generally, the wheat monoculture treatment was significantly different from crop rotations as it showed an increase in ryegrass seedling population. The three rotation systems showed good inhibition of ryegrass numbers (Table 4.5 & 4.9; Figure 5.1 & 5.2). Similar results were obtained from shade netting experiments (Table 4.2; Figure 5.3). Results showed that medic suppressed ryegrass the most of all crops at all time intervals (Table 4.9; Figure 5.2). This decrease in numbers of emerged seedlings and thus increased percentage inhibition was observed after six weeks and remained in place throughout the season as it appeared that there were few seeds that showed the ability to emerge late in the season. High numbers in ryegrass populations were observed early in the season, but decreased as the season progressed. Also, the long-term rotation (four years) showed better results compared to one year from wheat monoculture.

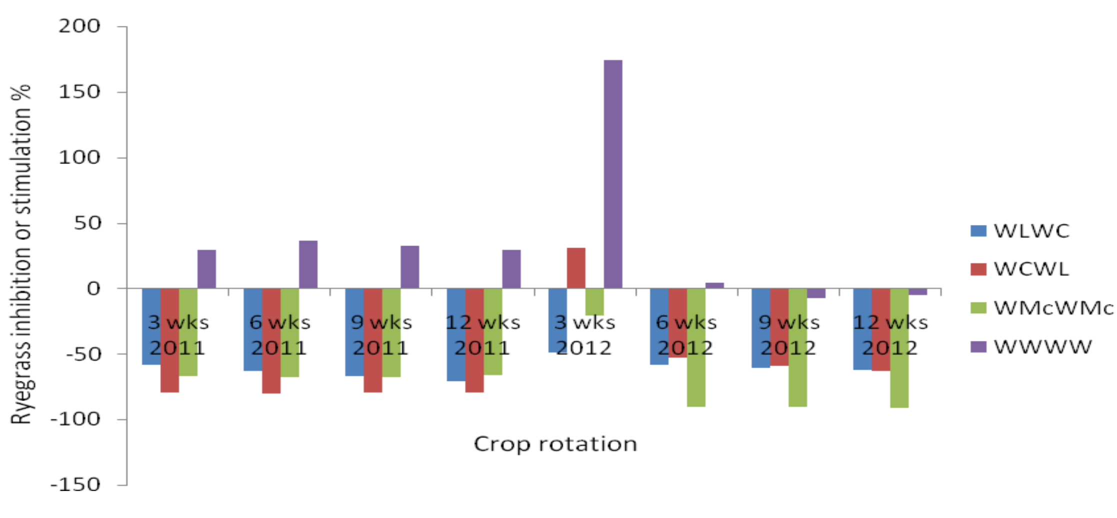

Figure 5.1 Average percentage inhibition (-) or stimulation (+) in the number of ryegrass seedlings recorded in different cropping systems at Langgewens for both 2011 and 2012

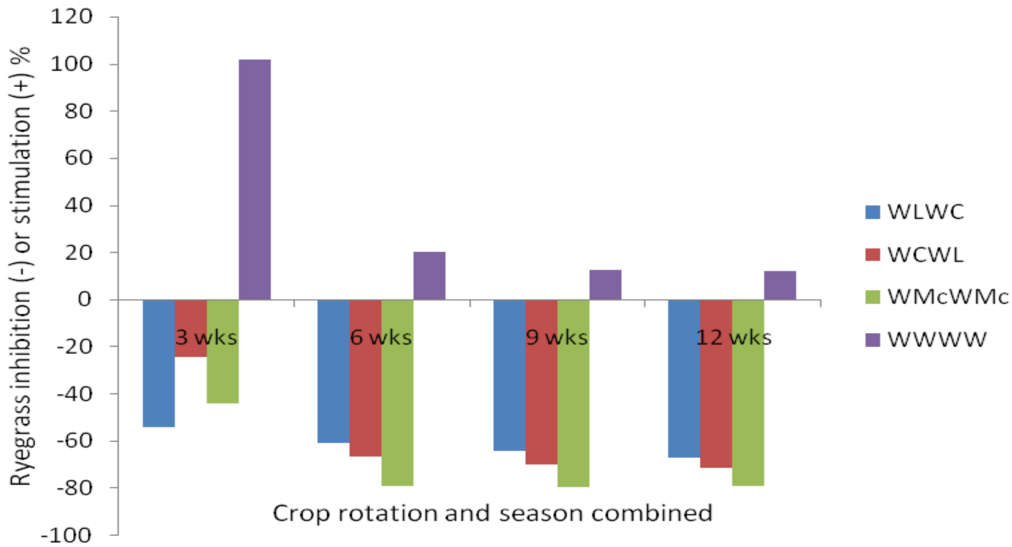

Figure 5.2 Average percentage inhibition (-) or stimulation (+) in the number of ryegrass seedlings recorded in different cropping systems at Langgewens for both 2011 and 2012 combined

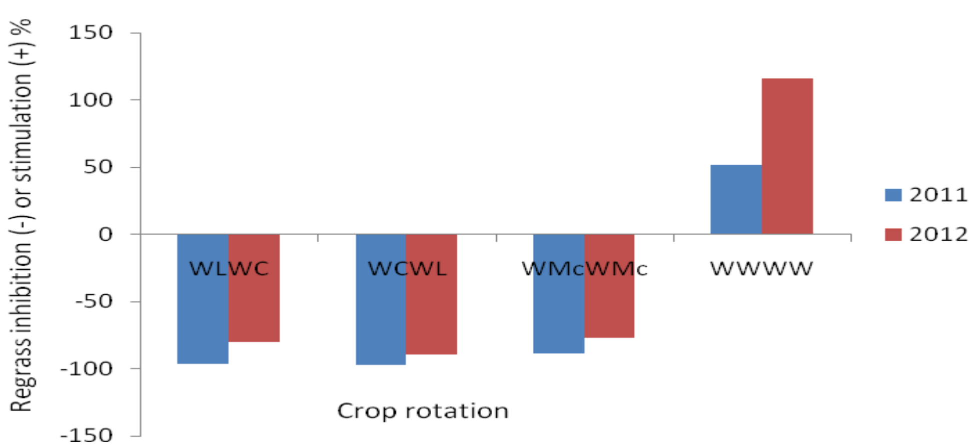

Figure 5.3 Average percentage inhibition (-) or stimulation (+) in the number of ryegrass seedlings recorded in seedling trays for different cropping systems at Langgewens for 2011 and 2012

The significant differences between years as a main effect are probably associated with climate as it differs year by year and also with the rotation cycle. Early rain in a season supports early germination and emergence of ryegrass (Table 5.1). This was supported by the results observed in the first three weeks after planting in year 2012 compared to 2011, as the other three crop rotation systems resulted in inhibition below -50% compared to wheat monoculture that stimulated ryegrass population by 174% (Table 4.5; Figure 5.1). This was because of prolific emergence of ryegrass seedlings early, even prior to planting as climate conditions were favourable for stimulating germination. However, there was a long dry period of two weeks (in late April) that occurred prior to planting in 2011 season, which resulted in late planting towards the end of May (Table 5.1). The rainfall cut-off (after the first weed count) probably forced the remaining ryegrass seeds to go into secondary dormancy and most of them germinated later in the season. This assisted the crop to compete effectively at the initial growth stages and to develop faster. Crop rotation compared to monoculture suppressed ryegrass, as the inhibition percentage under rotation increased after planting as measured at weeks six and nine weeks respectively, while the wheat monoculture treatments showed stimulation in ryegrass populations.

Table 5.1 Summary of monthly average rainfall for 2011 and 2012 seasons at Langgewens research farm, Swartland region

	2011			2012		
Months	**Average Rainfall (mm)**	**Average Minimum Temperature (ºC)**	**Average Maximum Temperature (ºC)**	**Average Rainfall (mm)**	**Average Minimum Temperature (ºC)**	**Average Maximum Temperature (ºC)**
April	34	14	26	51	13	25
May	95	11	21	32	9	20
June	102	9	18	63	8	17
July	30	9	19	46	7	16
August	46	8	18	88	6	16
September	21	8	21	59	8	19
October	16	11	24	17	11	23
November	22	11	25	8	13	27
Total	366			364		

Rainfall distribution was good at the 2012 season was high at the beginning of the season, with no long dry periods as in 2011 (Table 5.1). This favoured conditions for both crop and ryegrass growth in the first three weeks after planting. Nevertheless, under these conditions the results of 2012 differed compared to those of 2011, but wheat monoculture still had a low weed inhibition percentage compared to the three rotation systems, namely WLWC, WCWL and WMcWMc. In 2012 the wheat monoculture at three weeks after planting did not differ significantly from wheat-canola rotation but differed from the other two rotations compared to the same period in 2011 (Table 4.5; Figure 5.1). Similarly, wheat-canola did not differ significantly from both the wheat-lupine and wheat-medic rotations.

As the season progressed results were similar to those of 2011, where wheat monoculture stimulated the ryegrass population compared to other crop rotation systems. The results from both years combined showed similar results (Table 4.9; Figure 5.2), and correspond to literature (Agenbag & Maree, 1989; Lamprecht *et al*., 1999; Fischer *et al*., 2002b; FAO, 2003, Kirkegaard *et al*. 2004). Bohan *et al*. (2011) and Bushong *et al*. (2012) reported that in other parts of the world crop rotation is a successful tool in weed control in winter wheat and also supported economic production.

Rotation of wheat with crops from other plant families has improved suppression ability over ryegrass as presented in these results (Table 4.5 & 4.2; Figure 5.1 & 5.3). This confirmed the results of Dekker (1999), Fischer *et al*. (2002a), and Thierfelder and Wall (n.d), who reported that where crops of unrelated families were rotated, results were positive in reducing pathogens, diseases and weed populations. Planting wheat after medic resulted in an average of more than -70% inhibition of ryegrass (Table 4.9; Figure 5.2). This showed that medic suppressed ryegrass during its rotation phase as fewer ryegrass plants grew and managed to produce seed to germinate in the following season, as was also shown by Ferreira & Reinhardt (2010), who reported that there was a reduction in ryegrass weed plant numbers per m^2 when wheat was planted in medic and barley residues.

In the wheat after lupine rotation for both years combined, the average inhibition percentage of ryegrass was -60%, which is -10% below wheat-medic rotation, but still far better than wheat monoculture which stimulated the ryegrass population (Table 4.9; Figure 5.2). The inhibition of ryegrass by lupine in this study confirms the results of Kruidhof *et al*. (2008), where the white lupine residues severely reduced establishment of weeds as it has an inhibitory effect caused by quinolized alkaloids that were leached from the shoots and were still present and active in soil.

Rotating wheat with canola in field experiment also showed suppression of ryegrass as it averaged over -58% suppression (Table 4.9; Figure 5.2), similar to the results by Kruidhof *et al*. (2008) and Bushong *et al*. (2012) who all reported that oilseed rape (canola) had a strong competitive ability in controlling annual grass weeds, competing economically and also showing greater yield and net returns than wheat monoculture. However, shade netting results from 2011 and 2012 showed different results as wheat-canola (93%), wheat-lupine (88%) and wheat medic rotations (83%) inhibited ryegrass population (Table 4.2; Figure 5.3).

5.2 Effect of tillage systems on ryegrass populations

Higher numbers of ryegrass seedlings emerged under minimum tillage than in the no-till system in both 2011 and 2012 at three weeks after planting (Table 4.6; Figure 5.4), confirming results by DPI (2008) who stated that buried annual ryegrass seeds germinated faster than those on the soil surface with the optimum position for germination being 2 cm deep. Slight soil disturbance with a tine or chisel in minimum tillage improves soil seed contact and induces early weed seed germination. The improved depth of seeds in the soil profile and soil seed contact stimulated germination when conditions were favourable. However, seed germination of annual ryegrass is reduced when tine depth is increased to more than 2 cm into the soil (Benech-Arnold *et al*., 2000; DPI, 2008). Leaving the seeds on the soil surface also suppressed ryegrass germination. This was also confirmed by Benech-Arnold *et al*. (2000) who reported that exposure of seeds to light may inhibit germination.

Although the numbers of seedlings in min-till and no-till treatments differed from each other, tillage systems did not differ significantly in the 2011 season in the first six weeks after planting (3 & 6 weeks). However, in the next six weeks (9 &

12 weeks) results showed significant differences between the time intervals among the same tillage system (minimum-till) while, on the other hand, time intervals had no effect on no-till results (Table 4.6; Figure 5.4). This resulted in a no-till system that significantly differed from the high inhibition observed in minimum-till over twelve weeks. No-till showed better suppression than minimum-till in 2011 at all time intervals (Table 4.6; Figure 5.4), similar to findings reported by Dekker (1999) and Ghersa *et al*. (2000) who reported that exposing seed to harsh environmental conditions (sun, rain, wind etc) by keeping them on the upper surface increased mortality and reduced germination compared with when they were buried.

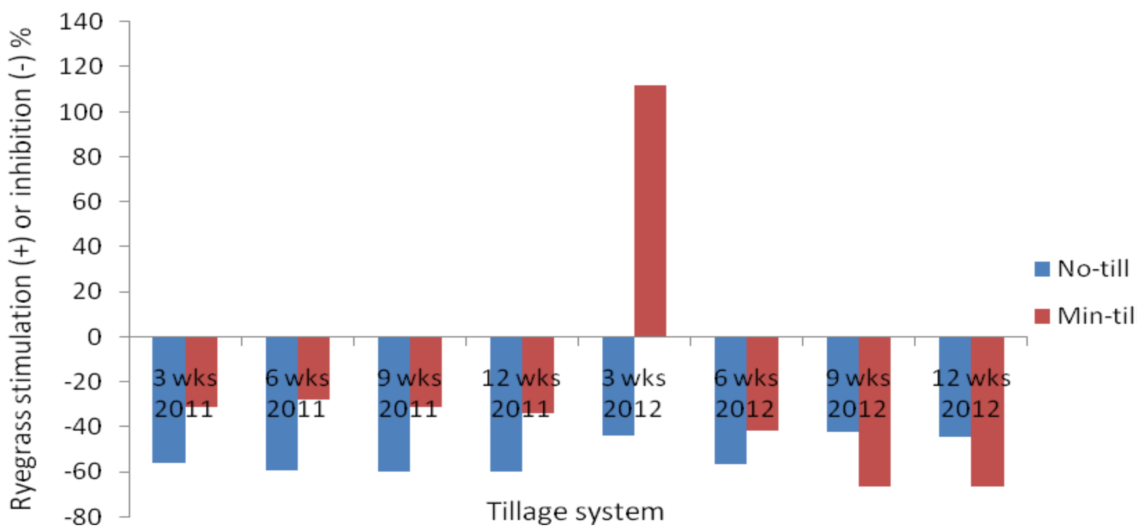

Figure 5.4 Average percentage inhibition (-) or stimulation (+) in the number of ryegrass seedlings recorded in different tillage systems at Langgewens for both 2011 and 2012

Conversely, in 2012 the inhibition percentage for minimum-till was very inconsistent and it significantly differed from no-till in the first three weeks as it stimulated ryegrass numbers by 112% compared to no-till which inhibited it by -44% (Table 4.6; Figure 5.4). This is probably because of the rainfall pattern (Table 5.1). In weeks six and nine of the 2012 season, there were no significant differences between tillage systems in their effects on the ryegrass population. There was a drastic change at week twelve where both years showed similar results with significant difference between the tillage systems. However, in 2011 no-till exhibited a high inhibition of -60% compared to minimum-till that had -34%, which is in agreement with DPI (2008). In the 2012 season, minimum-till inhibited ryegrass emergence more efficiently with a percentage of -67% compared to no-till with -44%. Although these results differed to findings of DPI (2008) they were similar to those of numerous other researchers (Klingman & Ashton, 1975a; Oriade & Forcella, 1999; Botha 2001; FAO, 2003; Ghosheh & Al-Hajaj, 2005) who reported that soil disturbance prior to planting reduced weeds at the initial growth stage of the crop.

These differences in results between the years were associated with variation in climate. Field results differed significantly in the first three weeks (Table 4.6; Figure 5.4). No-till had a higher inhibition percentage (-50%) than minimum-till (40%) that stimulated ryegrass populations in the first three weeks after planting, as was also reported by DPI (2008) and Hiltbrunner *et al*. (2008). Low inhibition of minimum-till as well as high inhibition of no-till on ryegrass seed banks can be directly related to seed age and dormancy. Annual ryegrass seed germination percentage is affected by age of the seeds and also by environmental conditions (Conway, 2008; The garden counsellor, 2007-2011). As in this study, planting commenced after the first autumn rains and the results showed high ryegrass populations in the first three weeks after planting (Table 4.6; Figure 5.4). These results are in agreement with the results of DPI (2008) and Cook *et al*. (n.d), who also reported that the peak germination period of annual ryegrass (80%) occurred at the break of season after the first two instances of rainfall that exceeded 20 mm in the field.

5.3 Effects of crop rotation and tillage on ryegrass population

All crop rotations under no-till differed significantly from the wheat monoculture control. However there were no significant differences between time intervals of three weeks throughout seasons in 2011 and 2012 (Table 4.7 & 4.8; Figure 5.5 & 5.6). Similar results were observed under shade netting (Table 4.3 & 4.4; Figure

5.7 & 5.8). Different results were obtained under minimum-till with different crop rotations. At three, six and nine weeks after planting in the 2011 season, wheat monoculture under minimum-till differed significantly from the other three crop rotations as it stimulated ryegrass populations as compared to the control (Table 4.7; Figure 5.5). During the same period, under minimum-till wheat-medic, wheat-lupine and wheat-canola rotations had high suppressive percentages, but did not differ significantly from each other.

Contrasting results were obtained in 2012 where wheat monoculture and wheat-canola rotations under minimum-till did not differ significantly at three weeks after planting. However, wheat monoculture differed significantly from wheat-medic and wheat-lupine rotations, while wheat-canola was not significantly different from these two rotations (Table 4.8; Figure 5.6). At three weeks after planting during the 2012 season, wheat monoculture (347%), wheat-canola (42%) and wheat-medic rotations (106%) stimulated ryegrass populations, while the wheat-lupine rotation(-49%) showed a positive inhibition effect by reducing the population of ryegrass seedlings. These differences probably are associated with climate variation between the years.

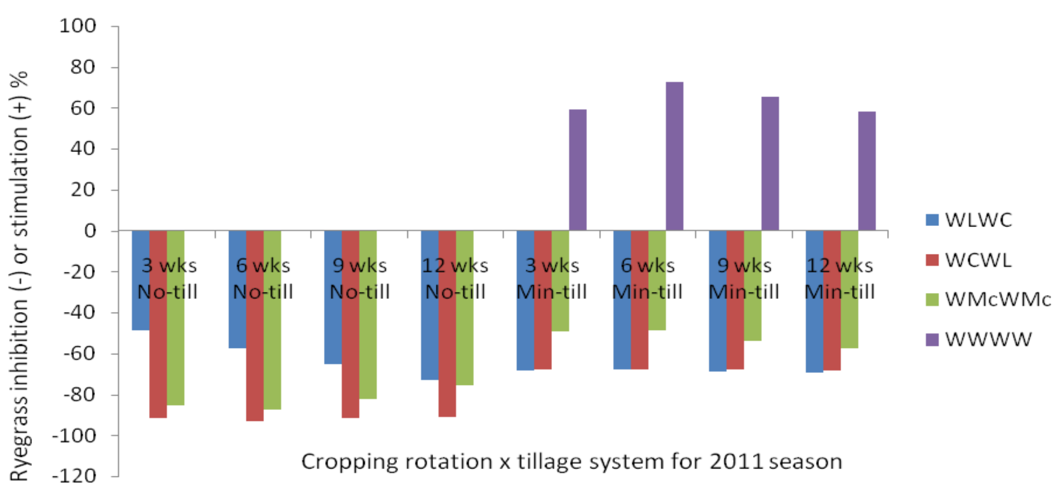

Figure 5.5 Average percentage inhibition (-) or stimulation (+) in the number of ryegrass seedlings recorded in different cropping and tillage systems at Langgewens for 2011

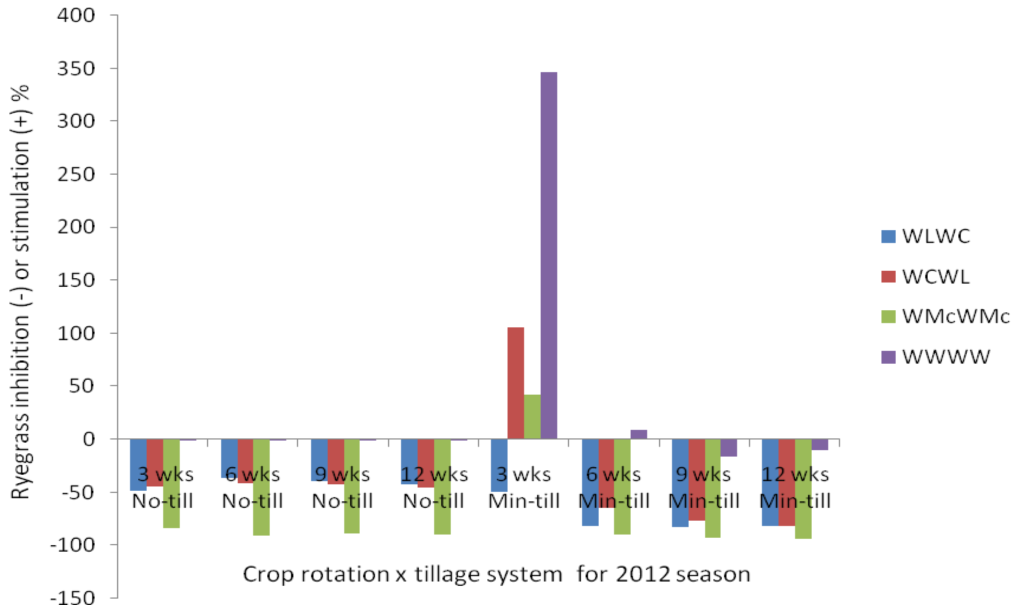

Figure 5.6 Average percentage inhibition (-) or stimulation (+) in the number of ryegrass seedlings recorded in different cropping and tillage systems at Langgewens for 2012

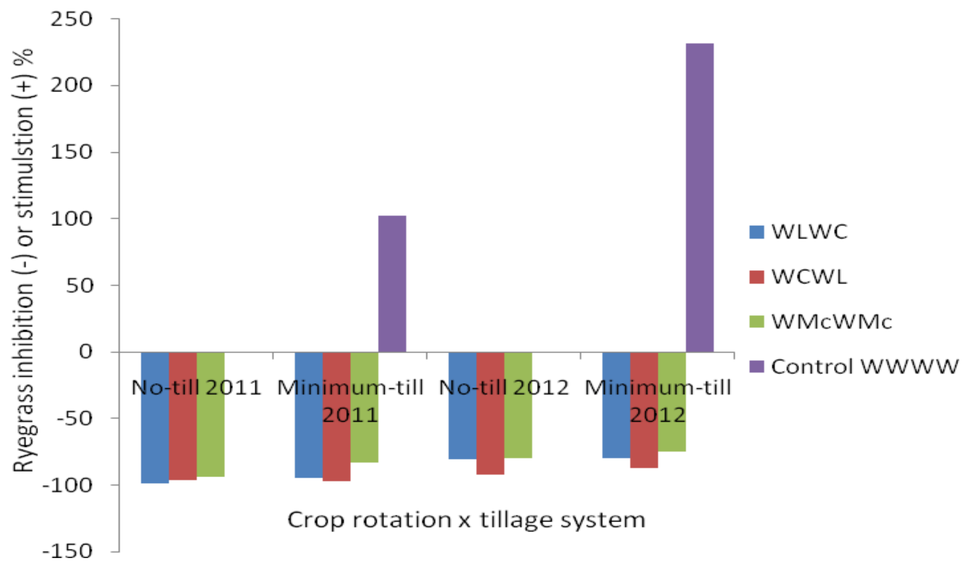

Figure 5.7 Average percentage inhibition (-) or stimulation (+) in the number of ryegrass seedlings recorded in seedling trays for different cropping and tillage systems at Langgewens for 2011 and 2012

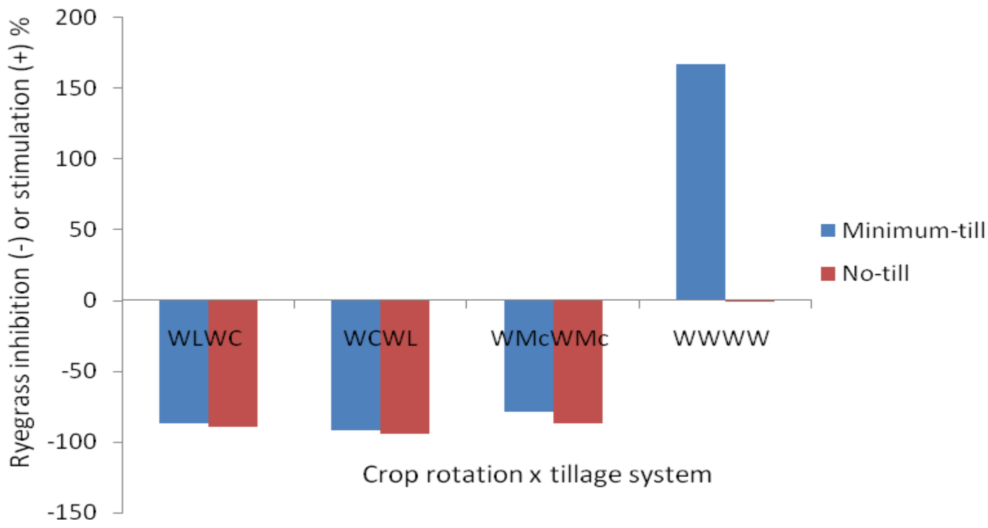

Figure 5.8 Average percentage inhibition (-) or stimulation (+) in the number of ryegrass seedlings recorded in seedling trays for different cropping and tillage systems at Langgewens for both 2011 and 2012 combined

In week six of 2012 the wheat-medic rotation out-performed all three rotations by suppressing ryegrass seedlings per square metre to -92%. At the same time, wheat monoculture (9%) differed significantly from wheat-medic (-92%), wheat-lupine (-82%) and wheat-canola (-64%) systems, showing positive results of weed inhibition through crop rotation (Table 4.8; Figure 5.6). Because of favourable conditions at the beginning of the 2012 season, high germination percentage of ryegrass seeds was observed for the first three weeks after planting, similar to results obtained by Benech-Arnold *et al*. (2000).

All three crop rotations under minimum-till significantly differed from wheat monoculture at both weeks nine and twelve after planting in the 2012 season. Ryegrass populations were sharply reduced by wheat-medic rotations which inhibited ryegrass (by -89% & -93%), wheat-lupine (-82% & -82%), and wheat-canola rotation (-76% & -81%). These were better than wheat monoculture (-16% and -10%). In both years combined, wheat monoculture under minimum-till differed significantly from the other three crop rotations in both tillage systems compared to the control, as it showed a high stimulation of ryegrass seedling populations, especially in the first three weeks (Table 4.10). Results showed that the inhibitory effect of these agricultural practices on the ryegrass population increased over time. Wheat-medic rotation under no-till out-performed all other rotations followed by wheat-lupine and wheat-canola under minimum-till. Shade netting results showed a different sequence compared to the field experiments, as the highest inhibition of ryegrass densities was achieved under no-till by all rotations (with a wheat-canola rotation the highest), followed by wheat-lupine and wheat-medic rotations. Wheat monoculture remained the highest ryegrass stimulating practice.

5.4 Recommendations

The findings of this study have several implications for weed management in agricultural fields, as also suggested by Pollnac *et al*. (2008). First, if the germination percentage of ryegrass is reduced it could increase wheat yield since weed competition will be less. Herbicide costs can be reduced by using crop rotation to suppress weeds as this practice decreases establishment of new ryegrass populations and its expansion. Planting highly competitive cover crops could help in suppressing weed growth and also decrease the weed seed bank. In addition, this practice will help the following crops to be more competitive with the remaining weed population.

Practising minimum tillage with leguminous crops (lupine and medic) in rotation could reduce the establishment of new ryegrass populations as it is suppressed and following crops' competitiveness increase. From these results farmers could be advised to rotate wheat with medic, especially those farmers who practise mixed farming (with small stock) as this crop reduces the invasion of ryegrass into the crop fields and also provides good pastures for sheep. These leguminous crops also have positive benefits on soil fertility as they are nitrogen fixing crops. This means they require minimum fertilisation which will result in a reduction in input cost (fertiliser) during the planting phase, while at the same time they release nitrogen to the soil that will be available to the following crop.

When looking at their benefits from an economic point of view they seem to be a good choice of crops to be rotated with wheat. Leguminous crops have three important benefits namely:

1. weed suppression
2. reducing herbicide use
3. nitrogen fixation and thus reduction in fertiliser use.

5.5 Conclusion

The results of the field experiments were similar to those obtained under shade netting. They both showed that the critical period for weed competition is the first six weeks after planting. These findings will assist farmers to determine the crucial time of weed management on their farms. It also showed that there was no significant difference between minimum-till and no-till in the ability of the type of tillage to suppress ryegrass populations. However, their effect on reducing weed populations does depend on the type of crop rotation. Incorporating the right tillage system with the right crop rotation could obtain the best results.

The results showed that the inhibition percentage of ryegrass increased with time for all cropping sequences. This is because germination and emergence of ryegrass seeds also decrease with time due to unfavourable conditions during the season, so that these practices will help to promote unfavourable conditions for germination of seeds as a result of a reduced seed bank. Results from this study provide a basis for producers of cereals to make good decisions with respect to timely weed control measures. It is important to keep the weed density as low as possible in the long term. It is essential to use competitive crop sequences that control particular weeds and to allow for the application of appropriate selective herbicides to control specific weeds.

Ryegrass has a similar life cycle to that of wheat and therefore it is able to survive and increase in continuous wheat cropping sequences. Higher levels of residues in the no-till compared to minimum-till delayed emergence in the first three weeks after planting (Table 4.6).

In conclusion the no-till wheat-medic rotation, reduced weed seeds to a large extent compared to all other rotation systems while wheat monoculture enhanced ryegrass germination. Knowledge of both genetic and morphological diversity of ryegrass and biological production practices could support in the research approach on the development of integrated control methods.

In future, it would be necessary to take into consideration the possibly of groundwater contamination with herbicides and impacts on consumers' health by promoting conservation and organic farming. This will help to reduce excessive use and reliance on herbicides to control weeds. Herbicides inputs can be reduced by practising good weed management strategies such as tillage, appropriate cropping sequences, planting of cover crops and appropriate timing of weed control period.

These are the possible studies that can be done in future:

1. Effect of ryegrass on growth, yield and quality of wheat;
2. Effect of climate on ryegrass growth dynamics and seed bank size.

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Personal References

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Van Vuuren, H		Emerging farmer	Factors affecting wheat yield	20 August 2010	Personal communication	

Appendix A

Actual count of ryegrass populations under shade netting for both 2011 and 2012 at Langgewens research farm

Crop Rotation	Tillage	/m² 2007	/m² Count 1 2011	/m² Count 2 2011	/m² Total population 2011	/m² Count 1 2012	/m² Count 2 2012	/m² Total population 2012
WWWW	Min-till	716	756	199	955.2	2746	597	3343
WWWW	No-till	716	159	80	239	318	40	358
WLWC	No-till	22089	1	1	2	2746	557	3303
WLWC	Min-till	22089	597	279	876	2826	796	3622
WCWL	Min-till	13890	40	40	80	2269	398	2667
WCWL	No-till	13890	80	40	119	1035	358	1393
WMcWMc	No-till	3821	40	40	80	677	119	796
WMcWMc	Min-till	3821	199	119	318	995	398	1393
WWWW	Min-till	2746	358	80	438	5293	1393	6686
WWWW	No-till	2746	478	80	557	2428	597	3025
WLWC	No-till	9353	1	1	2	4020	637	4657
WLWC	Min-till	9353	119	1	120	3662	876	4537
WCWL	Min-till	14726	159	40	199	1194	119	1313
WCWL	No-till	14726	199	119	318	438	119	557
WMcWMc	No-till	5293	119	80	199	1154	478	1632
WMcWMc	Min-till	5293	199	80	277	876	119	995
WWWW	No-till	597	756	1	757	8915	1751	10666
WWWW	Min-till	597	1632	239	1871	2667	279	2945
WLWC	No-till	18786	716	517	1234	1751	637	2388
WLWC	Min-till	18786	279	239	517	2786	438	3224
WCWL	Min-till	18029	358	119	478	2189	716	2905
WCWL	No-till	18029	40	1	40	3940	995	4935
WMcWMc	Min-till	14845	318	318	637	517	40	557
WMcWMc	No-till	14845	40	40	80	1313	239	1552
WWWW	No-till	16312	1194	318	1512	5094	557	5652
WWWW	Min-till	1632	836	438	1274	7005	1234	8239
WLWC	Min-till	11781	119	119	239	915	199	1114
WLWC	No-till	11781	1	1	2	438	119	557
WCWL	No-till	13094	40	1	41	2070	279	2348
WCWL	Min-till	13094	1	1	2	1950	398	2348
WMcWMc	No-till	4338	1	1	2	955	279	1234
WMcWMc	Min-till	4338	398	119	517	1592	159	1751

Appendix B

Actual count of ryegrass populations in the field experiment for 2011 at Langgewens research farm

Crop rotation	Tillage	Count 1 /m²	Count 2 /m²	Count 3 /m²	Count 4 /m²	Total population /Season /m²
WWWW	Min-till	1032	260	184	180	1656
WWWW	No-till	504	76	96	32	708
WLWC	No-till	60	68	0	0	128
WLWC	Min-till	200	40	24	20	284
WCWL	Min-till	164	96	76	56	392
WCWL	No-till	20	8	32	4	64
WMcWMc	No-till	120	0	108	224	452
WMcWMc	Min-till	468	68	28	20	584
WWWW	Min-till	1080	588	264	164	2096
WWWW	No-till	600	208	184	244	1236
WLWC	No-till	48	16	40	4	108
WLWC	Min-till	464	172	140	148	924
WCWL	Min-till	420	96	84	96	696
WCWL	No-till	112	4	20	40	176
WMcWMc	No-till	104	44	88	24	260
WMcWMc	Min-till	648	252	72	60	1032
WWWW	Min-till	920	416	540	800	2676
WWWW	No-till	1520	720	560	488	3288
WLWC	No-till	1640	152	108	124	2024
WLWC	Min-till	16	8	8	8	40
WCWL	Min-till	180	16	28	8	232
WCWL	No-till	32	0	4	8	44
WMcWMc	No-till	16	0	40	28	84
WMcWMc	Min-till	12	16	88	12	128
WWWW	Min-till	2108	1824	920	524	5376
WWWW	No-till	1828	1816	1200	860	5704
WLWC	No-till	152	84	40	16	292
WLWC	Min-till	128	64	92	28	312
WCWL	Min-till	172	36	200	116	524
WCWL	No-till	132	100	36	44	312
WMcWMc	No-till	328	20	36	12	396
WMcWMc	Min-till	24	8	0	12	44

Appendix C

Actual count of ryegrass populations in the field experiment for 2012 at Langgewens research farm

Crop rotation	Tillage	Count 1 /m²	Count 2 /m²	Count 3 /m²	Count 4 /m²	Total population /Season /m²
WWWW	Min-till	504	448	748	1000	2700
WWWW	No-till	80	280	536	440	1336
WLWC	No-till	0	360	256	160	776
WLWC	Min-till	88	136	272	264	760
WCWL	Min-till	160	80	128	76	444
WCWL	No-till	0	500	640	444	1584
WMcWMc	No-till	40	60	84	40	224
WMcWMc	Min-till	32	20	48	60	160
WWWW	Min-till	204	400	412	736	1752
WWWW	No-till	160	880	640	584	2264
WLWC	No-till	320	1080	1080	864	3344
WLWC	Min-till	80	0	32	52	164
WCWL	Min-till	292	124	44	4	464
WCWL	No-till	20	220	400	344	984
WMcWMc	No-till	0	40	160	0	200
WMcWMc	Min-till	44	0	32	20	96
WWWW	No-till	120	720	1360	696	2896
WWWW	Min-till	160	292	320	256	1028
WLWC	No-till	0	60	120	44	224
WLWC	Min-till	0	12	40	20	72
WCWL	Min-till	120	84	140	56	400
WCWL	No-till	80	320	340	176	916
WMcWMc	Min-till	36	0	0	0	36
WMcWMc	No-till	0	8	40	36	84
WWWW	No-till	28	800	440	492	1760
WWWW	Min-till	252	244	168	112	776
WLWC	Min-till	12	4	64	20	100
WLWC	No-till	0	120	100	60	280
WCWL	No-till	40	160	200	68	468
WCWL	Min-till	96	4	32	4	136
WMcWMc	No-till	4	40	96	56	196
WMcWMc	Min-till	132	12	24	4	172

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Sinovuyo Mava Nteyi sadly passed away on 24/01/2014, and was awarded the degree post-humously.