IDENTIFICATION OF SOIL AND BIOLOGICAL FACTORS IN CROP ROTATION SYSTEMS WITH SIGNIFICANCE TO WHEAT CROP PERFORMANCE IN THE OVERBERG PRODUCTION AREA OF SOUTH AFRICA

Hans Jurie Human

Thesis presented in partial fulfilment of the requirements for the degree of Master of Agricultural Sciences at the University of Stellenbosch

Study leader: Prof. G.A. Agenbag

March 2008

DECLARATION

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.

Signature:…………….. Date:…………………….

H.J. Human

Abstract

A two year experiment (2004-2005) was conducted at the Tygerhoek Experimental Farm near Riviersonderend in the Western Cape Province of South Africa. The effect of different crop rotation systems on soil properties, disease and insect pests, weed populations, wheat growth, yield and quality in the wheat crop phase, included in these crop rotation systems, was determined. This trial was part of a long term crop rotation experiment started in 2002.

This trial was laid out as a block design with four replications. Crop rotation systems included wheat, barley, canola, lupins and pasture phases which consisted of medics and clovers planted collectively. Soil samples were taken at each replication for N-incubations for determination of mineral N (NO_3^- -N plus NH_4^+ -N) at 0-150 mm soil depth. A basic soil chemical analysis was done at 0-150 mm and 150-300 mm soil depths, respectively. Each sub-plot (replication) consisted of a 3 m^2 block that was divided into a 1.5 m^2 block for harvest and smaller 0.25 m^2 blocks for samples that were taken at different growth stages throughout both seasons. Dry mass and nitrogen (N) content of different plant components, leaf area index, disease symptoms and pest damage were recorded from each sample.

Trends in basic soil chemical properties mostly differed between crop rotation systems during different seasons while similar trends in soil mineral nitrogen occurred. Highest soil mineral N levels occurred after one or two consecutive years of pasture while levels after a lupin phase were disappointingly low in both seasons. These high soil mineral N levels showed similar trends to wheat grain quality and some wheat yields, while the most influencing factors on wheat grain yield were probably soil physical properties. Soil mineral N after canola was high during plant after which levels were much lower than many other crop rotation systems. This occurrence will probably need a re-evaluation of N fertilizing programs if the same trends are found in similar, but longer trials.

Lolium spp. was the most prominent weed that occurred in both seasons at some crop rotation systems seemingly with no direct effect from crop rotation. Highest disease incidence mainly from *Septoria* spp. and *Puccinia* spp. occurred, particularly in wheat/wheat rotations, except for *Puccinia* which showed high ratings of disease symptoms in all crop rotations in the drier 2004 season. Lower ratings occurred in crop rotation systems when wheat was preceded by non-wheat crops. Insect pest damage showed no similar trends indicating no direct effect of crop rotation on these pests and/or effective control from applied pesticides in both seasons.

It was concluded that climate was one of the most influencing factors affecting differences and seem to be the main cause for different trends found between these two seasons in similar crop rotation systems. A similar trial with longer duration than this one is thus needed to obtain conclusive trends. This also indicates the importance of integration of crop rotation and management practices that are most optimal during dry and wet seasons, thus limiting risk.

Uittreksel

‘n Eksperiment is oor ‘n twee jaar periode (2004-2005) uitgevoer op Tygerhoek proefplaas naby die dorp Riviersonderend in die Wes Kaap Provinsie van Suid-Afrika. Die effek van verskillende gewasrotasie stelsels op grond eienskappe, siekte en insek peste, onkruid populasies, groei, opbrengs en kwaliteit van koring in die koring fase, ingesluit in hierdie gewasrotasie stelsels, is bepaal. Hierdie eksperiment was deel van ‘n lang termyn gewasrotasie proef wat reeds in die groeiseisoen van 2002 begin is.

Die eksperiment het bestaan uit ‘n blok ontwerp met vier herhalings. Gewasse wat in hierdie gewasrotasie stelsels ingesluit was, was koring, gars, canola, lupiene en weidingsfases wat bestaan het uit medics en klawers wat saam gevestig was. Grondmonsters is by elke herhaling geneem vir N-inkubasies om gemineraliseerde N (NO_3^- -N plus NH_4^+ -N) by 0-150 mm gronddiepte te bepaal. Ekstra grondmonsters is afsonderlik by 0-150 mm en 150-300 mm gronddiepte geneem vir basiese chemiese grondontledings. Elke herhaling het bestaan uit 3 m^2 wat verdeel was in ‘n 1.5 m^2 perseel om geoes te word en kleiner 0.25 m^2 sub-persele vir verskillende trekkings van koringplante by verskillende groeistadiums. ‘n Opname (telling) van droë massa en N inhoud van die verskillende plantkomponente, blaar oppervlakte indeks en simptome veroorsaak deur siekte en peste vanuit elke trekking is gemaak.

Tendense in basiese grondontledings tussen verskillende gewasrotasie stelsels het verskil tussen seisoene (2004-2005) terwyl soortgelyke tendense in gemineraliseerde N tussen die gewasrotasie stelsels wel voorgekom het. Hoogste grond gemineraliseerde N het in gewasrotasie stelsels voorgekom waar koring voorafgegaan is deur een en/of twee agtereenvolgende jare van weiding (medics en klawers) terwyl grond gemineraliseerde N na ‘n lupien fase teleurstellend laag was gedurende al twee seisoene. Hierdie hoë vlakke van gemineraliseerde N in die grond het soortgelyke tendense as die kwaliteit sowel as koring opbrengste gehad terwyl fisiese grondeienskappe moontlik ook ‘n groot bydrae tot opbrengste gehad het. Grond gemineraliseerde N na canola gedurende plant was hoog waarna vlakke baie

laer was. Hierdie tendens dui op moontlike her-evaluering van N bemestings programme indien dieselfde neigings in soortgelyke, maar langer eksperimente gevind word.

Die hoogste voorkoms van siekte simptome was hoofsaaklik vanaf *Septoria* spp. en *Puccinia* spp., veral by die koring/koring gewasrotasies, behalwe in die geval in 2004 waar *Puccinia* hoë tellings van simptome by al die gewasrotasie stelsels getoon het. Laer tellings het by gewasrotasie stelsels voorgekom waar koring voorafgegaan is deur ‘n ander gewas as koring. Skade weens insek peste het geen soortgelyke tendense tussen verskillende gewasrotasiestelsels aangedui nie. Dit dui aan dat daar geen direkte effek van gewasrotasie op insek populasies is nie en/of effektiewe beheer deur toediening van pestisiede gedurende al twee hierdie seisoene was.

Lolium spp. was die mees prominentste onkruide teenwoordig met geen aanduidende direkte effek van die verskillende gewasrotasiestels in hierdie twee seisoene op hierdie populasies nie. Tendense tussen gewasrotasie stelsels in die verskillende groeiseisoene dui daarop dat klimaat een van die grootste onafhanklike faktore was wat ‘n effek op verskille tussen gewasrotasie stelsels gehad het. ‘n Soortgelyke, maar langer eksperimentele periode is nodig vir moontlike beter bevestiging van afgeleide tendense. Hierdie resultate dui ook op die belangrikheid van integrering van gewasrotasie stelsels in bestuurspraktyke wat mees optimaal gedurende ‘n groeiseisoen met hoë en lae reënval is.

Dedication

I dedicate this writing to my parents who with their good example, inspiration, stature and love made me who I am today

Acknowledgements

I would like to express my grateful thanks to:

Professor G.A. Agenbag for his immense guidance and provision of this privilege

Dr. M. Hardy for his invaluable assistance and advice

M. la Grange, L. Berner and R. Oosthuizen for their technical assistance

List of Abbreviations

BCW	Barley/Canola/wheat
BLW	Barley/Lupin/wheat
BPW	Barley/pasture/wheat
BPPW	Barley/pasture/pasture/wheat
C	Organic Carbon
°C	Degrees Celsius
CPW	Canola/pasture/wheat
CRS	Crop Rotation System
g	Gram
GSL	Glucosinolates
H^+	Hydrogen Cation
Kg	Kilogram
ℓ	Liter
m	Meter
mm	Millimeter
mg	Milligram
N	Nitrogen
PBPW	Pasture/barley/pasture/wheat
PCW	Pasture/canola/wheat
POPW	Pasture/oats/pasture/wheat
POW	Pasture/oats/wheat
PPCW	Pasture/pasture/canola/wheat
PPOW	Pasture/pasture/oats/wheat
PPW	Pasture/pasture/wheat
PPWW	Pasture/pasture/wheat/wheat
PWW	Pasture/wheat/wheat
t	Metric ton
WBCW	Wheat/barley/canola/wheat
WBLW	Wheat/barley/lupin/wheat
WPPW	Wheat/pasture/pasture/wheat

Contents

Chapter 1

Introduction

Wheat is next to maize the second most important grain crop in South Africa (Kirsten & Meyer, 2005). About 33% of all wheat in South Africa are produced in the Western Cape Province with a total of approximately 685 000 t annually (Anon, 2006). Wheat production in South Africa do not meet the total demand for wheat nationally, thus making South Africa a net importer of wheat. With recent development in technology for production of alcohol and biofuels, increased requirement for wheat grain is possible. From this point of view, increased wheat grain production ha^{-1} under sustainable conditions seems beneficial.

Wheat and barley are the main grain crops that are produced mostly under dry-land conditions in the Overberg area, which is situated in the Western Cape Province. The climate is typical Mediterranean with dry, hot summers and cold, wet winters. This is a winter rainfall area although desultory rainfall in summer does occur in some years. Spring wheat is normally planted in early May with the production season ending in November when the crop is harvested.

Crop rotations mostly increase wheat grain yield and quality when compared to monocropping (Brooke, Ellington & Reeves, 1984; Harris *et al.,* 2007). Due to this effect perpetual monocropping is not common practice in this region and wheat is seldom planted for more than three successive seasons. Producers normally implement crop rotations that include other crops rather than wheat and barley only such as lupins, medics, clovers, lucerne, canola and oats. Although increased yield and quality of wheat grain do occur with crop rotation due to problems such as high weed and disease infestations, soil degradation and high input costs associated with monocropping, little is known about the direct influence from individual and multiple factors in different combinations and concurrences on wheat grain yield and quality within certain crop rotation systems in this region. Monitoring of known influencing factors, and identification of possible interactions between factors, may improve the ability to develop optimal crop rotations and other management practices for any particular production circumstance, ensuring increased wheat yield and quality in this region. This dissertation will mainly focus on the effect of crop rotation on soil and biological factors that influence the performance of the wheat crop during two growing seasons (2004-2005) as part of a long term crop rotation trial started in 2002.

References

ANON, 2006. Abstract Agricultural Statistics. Department of Agriculture, Republic of South Africa.

BROOKE, H.D., ELLINGTON, A. & REEVES, T.G., 1984. Effects of lupin-wheat rotations on soil fertility, crop disease and crop yields. *Aust. J. Exp. Agric. Anim. Husb*. 24, 595-600.

HARRIS, H., MASRI, S., PALA, M., RYAN, J. & SINGH, M., 2007. Rainfed wheat-based rotations under Mediterranean conditions: Crop sequences, nitrogen fertilization and stubble grazing in relation to grain and straw quality. *Eur. J. Agron*. 28(2), 112-118.

KIRSTEN, J. & MEYER, F., 2005. Modeling the wheat sector in South Africa. *Agrekon*. 44(2), 225-237.

Chapter 2

Literature review

The main objective in commercial farm management is to increase production with minimum financial input costs without compromising the biological sustainability of the production system in the long term (Fischer, Santiveri & Vidal, 2002). Wheat production is, from a biological point of view, mainly dependent on two aspects, namely the wheat plant itself and the environment surrounding the wheat plant. Breeding of wheat cultivars contributed to the ability of wheat plants to have higher resistance to diseases and pests, to be more drought resistant, and to have the ability to produce higher yields. This breeding is an everlasting task, contributing to reduced input costs and increased yields. In collaboration to this, the manipulation of the environment surrounding the wheat plant is also important. Crop rotation can be used to manipulate this environment because of effects on factors like soil physical, chemical and biological properties and other biotic factors like crop growth. The following review will mainly focus on these above mentioned factors.

2.1 Effect of crop rotation on different soil properties

2.1.1 Soil physical properties

Soil structure

Soil physical condition can be greatly improved probably causing improved crop growth as a result of increased formation of soil aggregates that ensure better root development. Soil aggregates influence the size and combination of the pores present in soil. Macropores predominantly help with aeration and water infiltration while smaller pores help with retention of soil water. It is thus not only pore size in soil that is important, but a certain combination of different sized pores. A management system can result in a high proportion of smaller pores that increase plant available water and nutrient use efficiency (Galantii *et al.*, 2000). Plant roots were identified as the most important agents in the formation of pores in undisturbed soils by Francis & Haynes (1990). Extra cellular metabolites like polysaccharides, lipids and proteins that are formed from microbial degradation of plant residue, function as cementing agents to stabilise soil aggregates (Blair, Lefroy & Whitbread, 2000; Rydberg, Stenberg & Stenberg, 2000). Decomposing roots and shoots will therefore have an effect on aggragate stability (Rasse, Santos, & Smucker, 2000).

Chan & Heenan, (1996) showed that soil used for the production of lupins and canola was more porous and had a lower shear strength compared to that used for barley production in a rotation system trial conducted in Wagga Wagga, N.S.W., Australia. They found that lupins were very effective in aggregate formation and stabilization, while barley was effective in stabilization, but less in aggregate formation. Pasture legumes also seem to greatly increase pore and aggregate formation (Blair *et al.*, 2006). It therefore seems that cereal crops mostly contribute to the stabilization of aggregates, while legumes and canola contribute to formation and improvement of soil aggregates.

Soil compaction

A good soil structure and aggregate size rather than heavily compacted soil is very important for good seed-soil contact, together with good soil water content to achieve sufficient germination and plant growth (Bouaziz & Bruckler, 1989).

When soil aggregates are destroyed, small soil particles move into spaces between aggregates causing soil compaction and crust formation (Francis & Haynes, 1990). It thus seems more meaningful to express compactibility of soil in terms of soil permeability and pore characteristics rather than only bulk density, because it has a more pronounced effect on plant growth (Soane, 1990).

Some of the most prominent causes for soil compaction are soil tillage, agricultural machinery traffic (Chan & Jayawardane, 1994), and trampling of grazing animals (Blair & Crocker, 2000). The compaction as a result of grazing sheep will probably be higher during two years of pasture than one, due to a longer period of soil compaction from trampling hooves (Blair & Crocker, 2000). Thus, the structural deterioration of soil will probably be the highest in the first grazing season after sowing and also during wet conditions. Above mentioned aspects indicate effects from management practices like grazing by sheep, especially during the first season of pasture in a crop rotation system, should be limited during wet conditions.

Soil compaction can be counteracted mainly through deep tillage, to reduce soil compaction, especially when following a pasture phase, (Agenbag, Kotze' & Langenhoven, 1998) and 'biological drilling' (Cresswell & Kirkegaard, 1995) by strong root systems.

Chan & Heenan (1996) found that crop-induced differences to soil structure were short-lived when conventional tillage practices were used. They concluded that reduced-tillage might for this reason help to improve soil structure. Thus, the more the soil is tilled per season, the higher the risk of destroying soil structure resulting in neutralizing the positive effect of crop rotation on crop productivity. Crop rotation and as well as type and frequency of tillage thus have to be applied correctly for increased yield and sustainability in the long term.

Root systems from certain crops have a better ability to penetrate into deeper soil layers than others, thus causing a more significant 'biological drilling' effect, but differences may be affected by growth conditions. More frequent rainfall may for example result in shallow rooting depths for many crops (Hanson, Merrill & Tanaka, 2002), while biological drilling may also be less efficient when the B-horison of the soil is very dense (Cresswell & Kirkegaard, 1995). Hanson *et al*. (2002) showed that shallow rooted plants (cereals) have a better ability to grow more fine roots in drought than deep rooted plants (legumes and canola), which may favour cereal production in shallow, dry soils.

Various crops can be used in crop rotation for the benefit of biological drilling. Blair *et al*. (2000) suggested that the increase of hydraulic conductivity of the soil when lucerne is grown, is due to its strong rooting characteristics that can result in roots of more than 1.1 m in depth (Pietola & Smucker, 1995). Increased yields of wheat after a canola crop may be the result of better root development due to channels created by the canola roots (Angus, Herwaarden & Howe, 1991) that can grow to depths of more than 1.1m (Cresswell & Kirkegaard, 1995; Hanson *et al*., 2002).

Soil moisture and temperature

Crop rotation can have an effect on the soil moisture content and soil temperature because of differences in crop residue. Crops and production systems which result in more residue on the soil surface can reduce soil temperatures during the day and increase soil moisture content, but these differences are more pronounced in dry compared to very wet seasons (Ashton & Fisher, 1986). The effect is also dependant on residue composition (Magid, McDonagh & Thomsen, 2001), resulting in more residue to be present after a cereal crop and thus possible higher moisture and lower soil temperature. Crop residue from certain crops is also more palatable to grazing animals than others. An example of this is lupins and oats that are probably more palatable than wheat causing more crop residue to be left on the soil surface after a wheat crop than after lupins or oats, thus also having an effect on soil moisture and temperature.

2.1.2 Effect of crop rotation on soil chemical properties

Organic carbon content

The organic carbon content of the soil affects availability of nutrients in soil and for this reason also crop yield and quality. Different crops and rotations of crop can have a significant effect on the sequestration of organic carbon in soil (Post & West, 2002). Blair *et al*. (2000) found that inclusion of legume crops in a crop rotation system increased the carbon content and aggregate stability of soil when compared to wheat monoculture or wheat/fallow systems. The method of soil tillage also has a significant effect on organic carbon content of soil (Dos Santos *et al*., 2002). Legume crops produced in minimum tillage systems may for this reason result in higher soil carbon contents and increased soil fertility.

Nitrogen content

Plant available nitrogen content of soil is one of the most important factors affecting yield of grain crops (Berntsen *et al*., 2002). Plant available nitrogen levels in soil can be significantly increased by using crop rotation included with legumes. Cooper *et al*. (2002) found medics contributed on average 131 kg N ha^{-1} per annum to a successive wheat crop in a medic/wheat rotation. Ley farming with medics can thus be an option to restore nitrogen depleted soils. Collins *et al*. (1998) found yield benefits of wheat after lupins were much higher than that after subterranean clover, while grain protein and soil nitrogen were the highest after subterranean clover. Hamblin, Mason & Rowland (1988) showed an increase of 350 kg ha^{-1} in the yield of wheat after lupins compared to that after wheat in the absence of N fertilizer, but Maali (2003) found no large yield benefit in wheat as a result of lupins in a crop rotation system of four years (wheat/canola/wheat/lupin). The probable cause was that lupin were only planted once every four years. Howe, Kirkegaard & Mele (1999) found the highest accumulation of mineral nitrogen in the soil after canola (94 kg ha^{-1}) in an experiment where mineral nitrogen was measured after wheat, oats, canola, peas and lupins. They suggested that this may be due to biocidal compounds released by canola roots which caused a more rapid decomposition of crop residue and organic material in the soil. Angus, Kirkegaard & Ryan (2006) also found that *Brassica* root tissue released mineralized nitrogen at a higher rate than wheat root tissue.

Nitrogen mineralization can also be affected by the C:N (carbon: mineralized nitrogen) ratio in the crop residue and the soil. Angus, Bolger & Peoples (2003) found a higher proportion of fine roots and therefore a C:N ratio of 19:1 in subterranean clover, compared to a C:N ratio of 26:1 in lucerne. For this reason, N-mineralization after clover was higher in the first year following these crops, but lucerne seemed to have a longer lasting effect on mineralization and plant available nitrogen in the soil. Maali (2003) suggest that lupins improve N-supply during the grain filling stage. This stage is one of the most important growth stages of wheat where sufficient N-supply is needed for a good wheat crop. Different preceding crops therefore, not only affect the total amount of nitrogen available to a following crop, but also the availability before and during the growing season (Gunnarsson & Marstorp, 2002).

Other nutrients

Crops differ in both the ability to absorb nutrients as well as the amount of nutrients absorbed from different soil depths. A deeper rooting crop has the ability to sometimes utilize more nutrients due to their deeper rooting systems compared to crops like wheat with shallower root systems (Hanson *et al*., 2002). Deep rooting crops also seem to have the ability to re-locate nutrients to different soil depths. Loss, Ritchie & Robson (1993) reported that lupins can absorb potassium in the subsoil and deposit it on the top of the soil when the crop residue is left on the soil surface after harvest. Residues of pulse crops and canola have higher concentrations of nitrogen and phosphate than residues from cereal, thus returning more nutrients to the soil than cereal crops (Arshad & Soon, 2002). Dormaar *et al*. (1995) also found that canola absorb more phosphate than wheat and that canola residue may for this reason be more valuable than wheat residue in soil containing low levels of phosphate .

pH

Different crops may affect the rate of acidification in soil. Coventry & Slattery (1991) found that a lupin/lupin rotation may have an acidifying effect in the 0-400 mm soil profile after 15 years, compared to the 0-200 mm profile in a wheat monoculture. This was due to higher nitrogen mineralization and the deeper, more aggressive growing root system of the lupins crop. Loss *et al*. (1993) also suggested that a lupin/wheat rotation may not be sustainable, because of soil acidification. This more pronounced acidifying effect with the lupin/lupin rotation was ascribed to the oxidation of organic nitrogen to nitrate and also due to excretion of H^+ by N_2-fixing legumes that absorb more cations than anions. A favorable pH level is not only a necessity for the uptake of nutrients, but also create a favorable environment for micro-organisms that is needed to form humus and aggregates that will improve the soil condition (Rydberg *et al.*, 2000). For this reason, Ferris *et al*. (1989) came to the conclusion that lupin/wheat crop rotations will not be sustainable on the long run if lime is not applied at regular intervals.

2.1.3 Effect of crop rotation on soil biological properties

Macro-organisms

Presence of macro-organisms (mostly earthworms) in combination with plant roots may have a significant effect on soil physical and chemical properties (Cothier *et al*., 1998; Beukes & Thosago, 2004). Other macro-organisms can also effect soil condition. Ponge, Topoliantz &

Viaux (2000) suggested that enchytraeids could have a more positive influence on soil quality due to their higher tunneling activity (biological tilling) and deposition of feacal pellets than earthworms. For this reason enchytraeids can play an important role in the maintenance of soil structure and can have a influence on soil fertility when earthworm populations are low. Better water infiltration in reduced and direct drilled systems compared to plough based systems is probably due to macro-channels that were created by these organisms and decaying roots (Rasmussen & Schonning, 2000).

Macro-organisms can also increase mineralization of N in soil (Baranski, Edwards & Subler, 1997), due to higher populations of nitrifying and denitrifying bacteria in the drilosphere (soil lining of earthworm burrows) (Berry & Parkin,1999), while Binet *et al*. (2001) found a larger and more active microbial population when earthworms were present in soil.

Macro-organisms can also influence plant pathogenic populations. Benger *et al*. (1993) suggested that severity of *Rhizoctonia solani* can be reduced due to activities of *Aporrectodea trapezoides*. They suggested that the cause for this was soil disturbance, increased plant available N, ingesting of hyphea from *Rhizoctonia solani* and accelerated decomposition of plant residue, thus limiting available nutrient supply to *Rhizoctonia solani*. Davoren & Stephens (1997) demonstrated the reduction of influence of *Rhizoctonia solani* on the growth of subterranean clover and perennial ryegrass due to *Aporrectodea trapezoides* and *Aporrectodea rosea*. Arthropoda like springtails can also influence infection by *Gaeumannomyces graminis* var. *tritici* and *Fusarium* spp. Innocenti, Sabatini & Ventura (2004) concluded that ingestion of conidia and hypha by *Protaphorura armata* lacked cytoplasmic content and *Gaeumannomyces graminis* var. *tritici* and *Fusarium culmorum* was ingested by it. Davoren & Stephens (1995) found that *Aporrectodea trapezoids* and *Aporrectodea rosea* reduced the take-all root disease rating on wheat, while *Aporrectodea trapezoids* did not influence the rating of *Rhizoctonia solani*. Davoren *et al*. (1994) also showed that *Aporrectodea rosea* and *Aporrectodea trapezoids* have the potential to reduce the severity of take-all on wheat under field conditions.

Although soil tillage and especially ploughing, can have a large impact on earthworm populations (Ponge *et al*., 2000), earthworms seemed to be more abundant in cereal compared to legume phases in the rotation system due to more wheat plant residue that decompose more slowly thus causing better food supply for macro-organisms under cereals (Beukes *et al.*, 2004). Crop rotation with minimum till practices thus seem to benefit a variety of macro-organisms and thus the mentioned 'biological tilling' effect.

Micro-organisms

The stability and formation of soil aggregates depend to a large extend on the formation of bonding agents which are derived from soil organic material as well as from fungal hyphae, especially micorhizal hyphae (Blair *et al*., 2000).

Micro-organism populations may be affected by crop rotation used. Clayton, Lupwai & Rice (1998) found that the soil microbial diversity under wheat preceded by red clover, field peas and green manure was much bigger than wheat following wheat or fallow. Arshad, Gill & Izaurralde, (1998) found that wheat and barley yield on wheat stubble averaged less than on canola stubble due to increased populations of micro-organisms from crop rotation that caused more favorable conditions for crop growth. Legume-based crop rotation can also have a very positive effect by supporting the diversity of soil microbial communities (Clayton *et al.*, 1998). Dense canopies produced by canola can create a more humid soil environment which will favour high micro-organism populations and a faster breakdown of crop residue (Bambach *et al.,* 2004). Micro-organisms can also be influenced by the biofumigation effect from canola (Angus *et al*., 1998; Abbott *et al.*, 2000). According to Abbott *et al*. (2000) and Howe *et al*. (2000) the biofumigation effect of canola is due to the production of glucosinolates (GSL), which is converted to isothiocyanates upon hydrolysis. Isothiocyanates have been demonstrated to kill pathogenic nematodes and fungi and may contribute to a reduction in crop diseases and nematode damage. The mature shoot tissue of canola contain very little GSL compared to the root tissues, so that the incorporation of the shoot tissue will not increase the biofumigation effect (Howe *et al.*, 2000). There is however still no certainty on which and to what extend all these above mentioned aspects contribute to the higher yield of wheat when preceded by canola (Abbott *et al.*, 2000).

Tillage can increase and change populations of micro-organisms. Rydberg *et al.* (2000) found that stubble cultivation in the upper 120 mm of a silty clay loam soil increased micro-organisms populations and stimulated microbial biomass, while Clayton *et al*. (1998) found that tillage significantly reduced the diversity of bacteria in the soil. They concluded that conservation tillage and crop rotation supported the diversity of microbial communities.

2.2 Effect of crop rotation on weeds, pests and plant disease

2.2.1 Disease

Incidence of foliar and root disease on crops depends on the characteristics of and interaction between the host, pathogen and environment and how these three aspects are manipulated by management practices. Some host crops show a certain level of resistance to a disease and/or pest that can prevent it from extensive damage and/or maintaining high production levels, while some crops can also not be a host for some diseases and pests at all (Bailey *et al*., 2002). Rotation of hosts with non-hosts will allow time for decomposition of infested crop residues and/or a reduction in the viability of some pathogen survival structures, thus eliminating or decreasing a potential source of disease (Clayton *et al*., 2000).

Bernier & Sturz (1989) showed that intercropping of wheat with non-cereal crops resulted in reduce levels of root diseases. McNamara & Wildermuth (1991) did not find a significant difference in disease levels of common root rot (*Bipolaris sorokiniana*) on wheat planted after wheat, barley and oats, but non-cereal crops like rape, lupins, clovers and lucerne reduced the disease incidence. Clayton *et al.* (2000) also found that inclusion of legumes like lupins and medics in a crop rotation system provide the succeeding crops with nitrogen and reduce disease incidence. Oats may also be an effective break crop to reduce take-all in wheat (Huber & McCay-Buis, 1993), while Ballinger *et al.* (1989) found that eyespot leasons caused by *Pseudosercosporella herpotrichoides* on wheat were less following subterranean clover than wheat. Bambach *et al.* (2004) suggested that *Brassica* oilseeds can be an effective break crop for controlling crown rot of wheat.

Crop rotation is however not always efficient to control disease due to the ability of some pathogens to spread inoculum by wind (Platz & Rees, 1980). Host resistance from the same crop but different cultivars, differing in level of resistance to the pathogen, at other nearby localities can thus probably also reduce disease incidence from wind spreading inoculum.

Crop rotation can also have an effect on disease incidence as result of more vigorous plant growth (reduced plant stress conditions), due to the effect of crop rotation on N availability (Freeman *et al*., 2001) and improved root development (Chan & Heenan, 1996; Angus *et al*., 2004). Such more vigorous plant growth increases resistance of crop to plant pathogens.

Crop residue left in and on the soil surface between seasons can be a major source of primary inoculum of plant pathogens in the next season, especially plant pathogens like *Septoria* (Hughes & Pedersen, 1992). Bockus & Claassen (1992) concluded that a one year break from wheat give effective control of tan spot (*Pyrenophora tritici-repentis*). One year rotation of wheat with lupins can also be efficient to control tan spot (Bhathal & Loughman, 2001). These one year host free periods are in some cases not very efficient in controlling certain wheat diseases. *Tapesia yallundae* can survive on infected straw buried in soil for at least three years (De Boer *et al*., 1993). Inoculum from *Fusarium pseudograminearum* has the ability to survive for at least two years due to it's saprophytic ability that even seem better than that of take-all (Bambach *et al.*, 2004). Lowering of diseases with the ability to survive on crop residue, for longer than only one break crop period (season), can be achieved through faster breakdown of this plant residue (Cook, 2003).

Occasionally weed control is also a necessity in disease control. Control of host weeds in all non-host crops should be done in time before planting a following crop (Cook, 2003). An example of this is inefficient weed control in a crop preceding a present wheat crop after which weed hosts susceptible for pathogens like take-all are infected, causing higher incidence of infection (Bernier & Sturz*,* 1989).

2.2.2 Insect pests

Control or decrease in populations of insect pests with crop rotation seem to be less effective than the control of disease, because the occurrence of insect pests is more sporadic and it's ability to survive on a wide range of hosts (Brewer & Elliott, 2004). Incidence of insect pests may however occur due to the preference of insects for some crops (Bahlmann, Botha & Govender, 2003) and possible alterations of the environment (habitat) (Brewer & Elliot , 2004). This can be differences in temperature, moisture content of the soil and crop residue which may affect the populations of insect pests, but also their predators and parasitoids (Sigsgaard, 2002).

2.2.3 Weeds

Various crops differ in their competitiveness to weeds. This ability can significantly be influenced by soil and climatic conditions. These conditions and the various crops preceding a wheat crop in crop rotation (Thorne, Yenish & Young, 2007) can thus influence the presence and size of different weed populations in the wheat crop. Canola and lupins has low competitiveness during early growth stages (Friesen, Martin & Van Acker, 2001), while competitiveness increase during later growth stages. Crops like oats and barley are known for their vigorous tillering, increasing their ability to compete with weeds, while the wheat crop itself can be significantly competitive to weeds when compared to other crops (Arshad *et al.*, 1998). Other management practices like grazing, ensilaging (Petch & Smith, 1985), tillage (Cullis *et al.*, 1994; Barberi & Casicio, 2001) and application of herbicides in combination with these mentioned effects could also influence these weed populations. Certain management practices can sometimes be more effective than crop rotation (Barberi & Casicio, 2001). Thus, crop rotation in combination with these management practices and the effectiveness of all these mentioned factors will have a direct effect on weed populations in a wheat crop phase. Observation of diversity and size of weed populations in wheat crops with known preceding crops, management practices and other mentioned influences can thus indicate the effectiveness of management practices used. This can assist in understanding and improvement of weed control with more optimal collaboration of crop rotation and other management techniques adapting to these altering influencing conditional factors.

2.3 Effect of crop rotation on crop growth, yield and quality

Crop response (vegetative growth) of wheat plants are influenced by various components of which some are plant populations, climatic conditions (Elhani *et al*., 2007), wheat genetic characteristics (Anderson *et al*., 1991) and already discussed availability of nutrients as well as the effects of diseases and pests. These components individually and in combination at different ratios (interactions) can influence the above mentioned crop response. Vegetative growth of the wheat plant itself can be subdivided into growth components like the root dry mass, amount of tillers, tiller dry mass, leaf area, leaf dry mass, number of ears and ear dry mass. These vegetative growth and yield components of wheat crops can be used to predict wheat grain yield and quality due to occasional and perpetual similarities between vegetative response of wheat plants to wheat grain yield and quality, depending on specific mentioned interactions that occur. Schultz (1995) reported related variations between yield and tiller density or grains per ear. These interacting components influenced by the vegetative growth of wheat plants can be influenced by crop rotation. Examples of this are the benefit of wheat from oilseeds that was evident in terms of the increased shoot density during the stem elongation stage of wheat (Angus *et al*., 1991). Arshad *et al*. (1998) also demonstrated the benefits of crop rotation compared to monoculture of wheat when they reported increased grain and above ground dry matter yield following canola and field pea than wheat following wheat. Accumulation of nitrogen in vegetative parts of the wheat plant can also have a significant effect on wheat yield (Blacklow & Incoll, 1981), while accumulation in some plant components can greatly be influenced by climatic conditions and crop rotation (Galantini *et al*., 2000). A better understanding of the effect of crop rotation on these vegetative components at a specific location can possibly contribute to better application of different crop rotations to ensure higher wheat grain yield and quality.

Crop rotation can have a significant influence on wheat grain yield and quality depending on factors like climate (Hannah & O’Leary, 1995; Castillo *et al*., 2001) during the growth of current and at previous crops and management practised (Petch & Smith, 1985; Silsbury, 1990). Many results proved this positive effect of crop rotation. Doyle, Herridge & Moore (1988) found an increase in grain yield of 57% for wheat following lupins compare to wheat monoculture when no

N fertilizer was applied without application of fertilizer N. Chan & Heenan (1993) found higher wheat grain yield due to changes in soil properties from lupins, while Brooke, Ellington & Reeves (1984) also reported higher wheat yields following lupins compared to wheat monoculture. Castillo *et al.* (1998) indicated higher wheat quality from inclusion of legumes in crop rotation, while (Maali, 2003) found higher N content in wheat plants included in crop rotation with canola and lupins compare to wheat monoculture. Dear *et al.* (2004) reported higher levels of grain protein in wheat following annual legumes instead of grasses. Harris *et al.* (2007) found increased grain and straw quality with inclusion of medics pastures. Probable causes of these influencing preceding crops may be mainly due to reduction in disease, availability of nutrients from plant residues and influence on soil physical condition from different preceding crops (Chan & Heenan, 1993). Although these mentioned differences in quality is found, the probability of significant differences in wheat grain quality as result of different crop rotation systems in the long term can be due to improved soil properties from crop rotation than monocropping (Maali, 2003), while weather conditions seem to remain one of the most influencing factors (Hanell, L-Baeckström & Svensson, 2004).

Objectives of the study

From the above mentioned literature study it is clear that crop rotation may affect a large variety of soil physical, chemical and biological characteristics, as well as the incidence of weeds, diseases and even insect pests. Specific affects and crop responses to changes in these characteristics may however vary according to soil and climatic conditions. Results reported in literature will for this reason not necessarily be applicable to conditions in the wheat growing areas of South Africa. To determine soil and crop responses to different crop rotation systems under local conditions, a study was conducted in the Overberg wheat producing area of the Western Cape Province of South Africa.

The objectives of this study were to evaluate the effect of crop rotation on some soil characteristics as well as disease-, insect- and weed infestations during the wheat cropping phase of various crop rotation systems and to determine the vegetative growth, yield and quality of the wheat crop in response to these effects.

References

ABBOTT, L.K., GAUCI, C.S., OSLER, F.H.R. & VLIET, P.C.J., 2000. Changes in free living soil nematode and microarthropod communities under a conola-wheat-lupin rotation in Western Australia. *Aust. J. Soil. Res*. 38(1), 47-59.

AGENBAG, G.A., KOTZE', T.N. & LANGENHOVEN, W.R., 1998. The influence of soil tillage on the distribution of medic seeds in the soil, regeneration of medics and wheat yields in a medic wheat rotation. *Field Crop. Res.* 55, 175-181.

ANDERSON, W.K., CARLTON, G.P. & WHAN, B.R., 1991. Potential for increasing early vigour and total biomass in spring wheat. 1. Identification of genetic improvements. *Aust. J. Agric. Res*. 42, 347-361.

ANGUS, J.F., BOLGER, T.P. & PEOPLES, M.B., 2003. Comparison of nitrogen mineralization patterns from root residues of *Trifolium subterraneum* and *Medicago stativa*. *Biol. Fert. Soils*. 38(5), 296-300.

ANGUS, J.F., CRESSWELL, H.P., DAVIES, S.L., GREEN, T.W., KIRKEGAARD, J.A., McCALLUM, M.H. & PEOPLES, M.B., 2004. Improved subsoil macroporosity following perennial pastures. *Aust. J. Exp. Agr.* 44, 299-307.

ANGUS, J.F., GARDNER, P.A., PITSON, G.D. & WONG, P.T.W., 1998. A comparison of six methods to control take-all in wheat. *Aust. J. Agr. Res*. 49, 1225-1240.

ANGUS, J.F., HERWAARDEN, A.F. & HOWE, G.N., 1991. Productivity and break crop effects of winter-growing oilseeds. *Aust. J. Exp. Agric*. 31(5), 669-677.

ANGUS, J.F., KIRKEGAARD, J.A. & RYAN, M.H., 2006. *Brassica* crops stimulate soil N accumulation. *Aust. J. Soil Res*. 44, 367-377.

ARSHAD, M.A., GILL, K.S. & IZAURRALDE, R.C., (1998). Wheat production, weed population and soil properties subsequent to 20 years of sod as affected by crop rotation and tillage. *J. Sustain. Agr*. 12(2/3), 131-154.

ARSHAD, M.A. & SOON, Y.K., 2002. Comparison of the decomposition and N and P mineralization of canola, pea and wheat residues. *Biol. Fertil. Soils*. 36, 10-17.

ASHTON, A.R. & FISHER, R.A., 1986. The effect of conventionally cultivation, direct drilling and crop residues on soil temperatures during the early growth of wheat at Murrumbateman, New South Wales. *Aust. J. Soil Res*. 24, 49-60.

BAHLMANN, L., BOTHA, A.M. & GOVENDER, P., 2003. Leaf epicuticular wax ultrastructure and trichome presence on Russian wheat aphid (*Diuraphis noxia*) resistant and susceptible leaves. *Afr. Entomol*. 11(1), 59-64.

BAILEY, K.L., GOSSEN, B.D., KRUPINSKY, J.M., McMULLEN, M.P. & TURKINGTON, T.K., 2002. Managing plant disease risk in diversified cropping systems. *Agron. J.* 94, 198-209.

BALLINGER, D.J., BROOKE, H.D., COVENTRY, D.R. & KOLLMORGEN, J.F., 1989. Increases in wheat yield on limed soil after reduction of take-all by fungicide application and crop rotation. *Aust. J. Exp. Agr.* 29, 85-89.

BAMBACH, R., HOLLAND, J., KIRKEGAARD, J.A., MOORE, K.J., REBETZKE G.J. & SIMPFENDORFER, S., 2004. Effect of previous crops on crown rot and yield of durum and bread wheat in northern NSW. *Aust. J. Agr. Res*.. 55. 321-334.

BARANSKI, C.M., EDWARDS, C.A. & SUBLER, S., 1997. Earthworm additions increased short-term nitrogen availability and leaching in two grain-crop agroecosystems. *Soil Biol. Biochem*. 29 (3/4), 413-421.

BARBERI, P. & CASCIO, B.L., 2001. Long-term tillage and crop rotation effects on weed seedbank size and composition. *Weed Res*. 41, 325-340.

BENGER, A.M., DAVOREN, C.W., DOUBE, B.M., NEATE, S.M., RYDER, M.H. & STEPHENS, P.M., 1993. Reduced severity of *Rhioctonia solani* disease on wheat seedlings associated with the presence of the earthworm *Aporrectodea trapezoides*. *Soil Biol. Biochem*. 25(11), 1477-1484.

BERNIER, C.C. & STURZ, A.V., 1989. Influence of crop rotations on winter wheat growth and yield in relation to the dynamics of pathogenic crown and root rot fungal complexes. *Can. J. Plant. Pathol.* (11), 114-121.

BERNTSEN, J., HANSEN, E.M., OLESEN, J.E., PETERSEN, B.M. & PETERSEN, J., 2002. Crop nitrogen demand and canopy area expansion in winter wheat during vegetative growth. *Eur. J. Agron*. 16, 279-294.

BERRY, E.C. & PARKIN, T.B., 1999. Microbial nitrogen transformations in earthworm burrows. Soil Biology and Biochemistry. 31(13), 1765-1771.

BEUKES, D.J. & THOSAGO, M.P., 2004. The effects of crop rotation on soil properties related to agriculture: An overview. ARC-Institute for Soil, Climate and Water. South Africa.

BINET, F., CLAPPERTON, M.J., CONNER, R.L. & LEE, N.O., 2001. Earthworms indirectly reduce the effects of take-all (*Gaeumannomyces graminis var. tritici*) on soft white spring wheat (*Triticum aestivum* cv. *Fielder*). *Soil Biol. and Biochem*. 33(11), 1531-1538.

BLACKLOW, W.M. & INCOLL, L.D., 1981. Nitrogen stress of winter wheat changed the determinants of yield and distribution of nitrogen and total dry matter during grain filling. *Aust. J. Plant Physiol*. 8, 191-200.

BLAIR, N. & CROCKER, G.J., 2000. Crop rotation effects on soil carbon and physical fertility of two Australian soils. *Aust. J. Soil Res*. 38(1), 71-84.

BLAIR, N., CROCKER, G.J., FAULKNER, R.D. & TILL, A.R., 2006. Long-term management impacts on soil C, N and physical fertility. Part 3. Tamworth crop rotation experiment. *Soil Till. Res*. 91, 48-56.

BLAIR, G.J., LEFROY, D.B. & WHITBREAD, A.M., 2000. Managing legume leys, residues and fertilizers to enhance the sustainability of wheat cropping systems in Australia. 2. Soil physical fertility and carbon. *Soil Till. Res*. 54(1/2), 77-89.

BHATHAL, J.S. & LOUGHMAN, R., 2001. Ability of retained stubble to carry-over leaf diseases of wheat in rotation crops. *Aust. J. Exp. Agr*. 41, 649-653.

BOCKUS, W.W. & CLAASSEN, M.M., 1992. Effects of crop rotation and residue management practices on severity of tan spot of winter wheat. *Plant Dis*. 76, 633-636.

BOUAZIZ, A. & BRUCKLER, L., 1989. Modeling of wheat imbibition and germination as influenced by soil physical properties. *Soil Sci. Soc. Am. J*. 53(1), 219-227.

BREWER, M.J. & ELLIOTT, N.C., 2004. Biological control of cereal aphids in North America and mediating effects of host plant and habitat manipulations. *Annu. Rev. Entomol*. 49, 219-242.

BROOKE, H.D., ELLINGTON, A. & REEVES, T.G., 1984. Effects of lupin-wheat rotations on soil fertility, crop disease and crop yields. *Aust. J. Exp. Agric. Anim. Husb.* 24, 595-600.

CASTILLO, J.E., FUENTES, M., LÓPEZ-BELLIDO, L. & LÓPEZ-GARRIDO, F.J., 1998. Effects of tillage, crop rotation and nitrogen fertilization on wheat-grain quality grown under rainfed Mediterranean conditions. *Field Crop. Res*. 57, 265-276.

CASTILLO, J.E., LÓPEZ-BELLIDO, F.J., LÓPEZ-BELLIDO, L., & LÓPEZ-BELLIDO, R.J., 2001. Effects of long-term tillage, crop rotation and nitrogen fertilization on bread-making quality of hard red spring wheat. Field Crop. Res. 72, 197-210.

CHAN, K.Y. & HEENAN, D.P., 1993. Effects of lupin on soil properties and wheat production. *Aust. J. Agic. Res*. 44, 1971-1984.

CHAN, K.Y. & HEENAN, D.P., 1996. The influence of crop rotation on soil structure and soil physical properties under conventional tillage. *Soil Till. Res.* 37(2/3),113-125.

CHAN, K.Y. & JAYAWARDANE, N.S., 1994. The management of soil physical properties limiting crop production in Australian sodic soils – A review. *Aust. J. Soil Res*. 32, 13-44.

CLAYTON, G.W., LUPWAYI, N.Z. & RICE, W.A., 1998. Soil microbial diversity and community structure under wheat as influenced by tillage and crop rotation. *Soil Biol. Biochem.* 30(13), 1733-1741.

CLAYTON, G.W., TURKINGTON, T.K. & WOODS, D.L., 2000. The impact of soil incorporation of canola residues and stubble application of chemicals on decomposition and inoculum production by *Leptosphaeria maculans*. *Can. J. Plant Pathol*. 22(2), 155-159.

COLLINS, D., HEENAN, D.P. & McGHIE, W.J., 1998. Impact of lupins, grazed or ungrazed subterranean clover, stubble retention, and lime on soil nitrogen supply and wheat nitrogen uptake, grain yields, and grain protein. *Aust. J. Agr. Res*. 49(3), 487-494.

COOK, R.J., 2003. Take-all of wheat. *Physiol. Mol. Plant P*. 62(2), 73-86.

COOPER, J.E., DALAL, R.C., HOLMES, C.J., KING, A.J., LEHANE, K.J, STRONG, W.M. & WESTON, E.J., 2002. Sustaining productivity of a Vertisol at Warra, Queensland, with fertilizers, no-tillage or legumes. 6. Production and nitrogen benefits from annual medic in rotation with wheat. *Aust. J. Exp. Agr*. 42, 961-969.

COTHIER, R., HORN, R., KOOLEN, A.J. & KUTILEK, M., 1998. Properties of compacted fine-textured soils as affected by crop rotation and reduced tillage. *Soil Till. Res*. 47(1/2), 83-89.

COVENTRY, D.R. & SLATTERY, W.J., 1991. Acidification of soil associated with lupins grown in a crop rotation in north-eastern Victoria. *Aust. J. Agr. Res*. 42(3), 391-397.

CRESSWELL, H.P. & KIRKEGAARD, J.A., 1995. Subsoil amelioration by plant roots-the process and the evidence. *Aust. J. Soil Res.* 33(2), 221-239.

CULLIS, B.R., HEENAN, D.P., LILL, W.J. & TAYLOR, A.C., 1994. Long term effects of rotation, tillage and stubble management on wheat production in southern N.S.W. *Aust. J. Agric. Res*. 45, 93-117.

DAVOREN, C.W., DOUBE, B.M., RYDER, M.H. & STEPHENS, P.M., 1994. Ability of the lumbricid earthworms *Aporrectodea rosea* and *Aporrectodea trapezoids* to reduce the severity of take-all under greenhouse and field conditions. *Soil Biol. Biochem*. 26(10), 1291-1297.

DAVOREN, C.W. & STEPHENS. P.M., 1995. Effect of the lumbricid earthworm *Aporrectodea trapezoids* on wheat grain yield in the field, in the presence or absence of *Rhizoctonia solani* and *Gaeumannomyces graminis var. tritici*. *Soil Biol. Biochem*. 28(4/5), 561-567.

DAVOREN, C.W. & STEPHENS. P.M., 1997. Influence of the earthworms *Aporrectodea trapezoides* and *A. rosea* on the disease severity of *Rhizoctonia solani* on subterranean clover and ryegrass. *Soil Biol.Biochem*. 29(3/4) : 511-516.

DEAR, B.S., SANDRAL, G.A., SWAN, A.D. & VIRGONA, J.M., 2004. Yield and grain protein of wheat following phased perennial grass, lucerne, and annual pastures. *Aust. J. Agric. Res*. 55, 775-785.

DE BOER, R.F., KOLLMORGEN, J.F., MACAULEY, B.J. & STEED., G.R., 1993. Effects of rotation, stubble retention and cultivation on take-all and eyespot of wheat in northeastern Victoria, Australia. *Soil Till. Res*. 25, 263-280.

DORMAAR. J.F., McKENZIE, R.H., SCHAALJE, G.B. & STEWART, J.W.B., 1995. Chemical and biochemical changes in the rhizospheres of wheat and canola. *Can. J. Soil. Sci.* 75(4), 439-447.

DOS SANTOS, H.P., FADIGAS, F. de S., FREIXO, A.A., MACHADO, P.L.O. de A. & SILVA, C.A., 2002. Soil organic carbon and fractions of a rhodic ferralsol under the influence of tillage and crop rotation systems in southern Brazil. *Soil Till Res*. 64, 221-230.

DOYLE, A.D., HERRIDGE, D.F. & MOORE, K.J., 1988. The narrow-leafed lupin (*Lupinus angustifolius L*.) as a nitrogen-fixing rotation crop for cereal production. 3. Residuel effects of lupins on subsequent cereal crops. *Aust. J. Agric. Res*. 39, 1029-1039.

ELHANI, S., GARCIA DEL MORAL, L.F., MARTOS, V., RHARRABTI, Y. & ROYO, C., 2007. Contribution of main stem and tillers to durum wheat (*Triticum turgidum L. var. durum*) grain yield and its components grown in Mediterranean environments. *Field Crop. Res.* 103, 25-35.

FERRIS, I.G., HAIGH, B.M. & HOLFORD, I.C.R., 1989. Atrazine persistence and phytotoxicity on wheat as affected by nitrogen and rotation-induced changes in soil properties. *Aust. J. Agric. Res*. 40(6), 1143-1153.

FISCHER, R.A., SANTIVERI, F. & VIDAL, I.R., 2002. Crop rotation, tillage and crop residue management for wheat and maize in the sub-humid tropical highlands. *Field Crop Res*. 79, 107-122.

FRANCIS, G.S. & HAYNES, R.J., 1990. Effect of mixed cropping farming systems on changes in soil properties on the Canterbury plains. *New Zeal. J. Ecol*. 14, 73-82.

FREEMAN, K.W., JOHNSON, G.V., LUKINA, E.V., MULLEN, R.W., RAUN, W.R., THOMASON, W.E., WESTERMAN, R.L. & WYNN, K.J., 2001. Effect of chloride fertilizers and lime on wheat grain yield and take-all disease. *J. Plant Nutr*. 24(4-5), 683-692.

FRIESEN, L.F., MARTIN, S.G. & VAN ACKER, R.C., 2001. Critical period of weed control in spring canola. Weed Sci. 49(3), 326-333.

GALANTII, J.A., IGLESIAS, J.O., LANDRISCINI, M.R., MIGLIERINA, A.M., & ROSELL, R.A., 2000. The effects of crop rotation and fertilisation on wheat productivity in the Pampean semiarid region of Argentina. *Soil Till Res.* 53(2), 129-135.

GUNNARSSON, S. & MARSTORP, H., 2002. Carbohydrate composition of plant materials determines N mineralization. *Nutr. Cycl. Agroecosys*. 62(2), 175-183.

HAMBLIN, J., MASON, M.G. & ROWLAND, I.C., 1988. Effect of lupins and wheat on the yield of subsequent wheat crops grown at several rates of applied nitrogen. *Aust. J. Exp. Agr.* 28, 91-97.

HANELL, U., L-BAECKSTRÖM & SVENSSON, G., 2004. Quality studies on wheat grown in different cropping systems: A holistic perspective. *Soil Plant Sci.* 54, 254-263.

HANNAH, M.C. & O'LEARY, G.J., 1995. Wheat yield response to rainfall in a long-term multi-rotation experiment in the Victorian Wimmera. *Aust. J. Exp. Agric.* 35, 951-960.

HANSON, J.D., MERRILL, S.D. & TANAKA, D.L., 2002. Root length growth of eight crop species in Haplusoll soils. *Soil Sci. Soc. Am. J.* 66(3), 913-923.

HARRIS, H., MASRI, S., PALA, M., RYAN, J. & SINGH, M., 2007. Rainfed wheat-based rotations under Mediterranean conditions: Crop sequences, nitrogen fertilization, and stubble grazing in relation to grain and straw quality. *Eur. J. Agron.* Article in press.

HOWE, G., KIRKEGAARD, J.A., MEAD, A., NEWELL, M., SARWAR, M. & WONG, P.T.W., 2000. Field studies on the biofumigation of take-all by Brassica break crops. *Aust. J. Agric. Res.* 51, 445-456.

HOWE, G.N., KIRKEGAARD, J.A. & MELE, P.M., 1999. Enhanced accumulation of mineral-N following canola. *Aust. J. Exp. Agric.* 39, 587-593.

HUBER, D.M & McCAY-BUIS, T.S., 1993. A multiple component analysis of the take-all disease of cereals. *Plant Dis.* 77(5), 437-447.

HUGHES, G.R. & PEDERSEN, E.A., 1992. The effect of crop rotation on development of the Septoria disease complex on spring wheat in Saskatchewan. *Can. J. Plant. Pathol.* 14(2), 152-158.

INNOCENTI, G., SABATINI, M.A. & VENTURA, M., 2004. Do Colembola effect of the competitive relationships among soil-borne plant pathogenic fungi? *Pedobiologia* 48(5/6), 603-608.

LOSS, S.P., RITCHIE, G.S.P. & ROBSON, A.D., 1993. Effect of lupins and pasture on soil acidification and fertility in Western Australia. *Aust. J. Exp. Agric*. 33(4), 457-464.

MAALI, S.H., 2003. Biomass production, yield and quality response of spring wheat to soil tillage, crop rotation and nitrogen fertilization in the Swartland wheat producing area of South Africa. University of Stellenbosch. South Africa.

MAGID, J., McDONAGH, J.F. & THOMSEN, T.B., 2001. Soil orgainic matter decline and compositional change associated with cereal cropping in southern Tanzania. *Land Degrad. Dev*. 12, 13-26.

McNAMARA, R. B. & WILDERMUTH, G.B., 1991. Effect of cropping history on soil populations of *Bipolaris sorokiniana* and Common root rot of wheat. *Aust. J. Agric. Res.* 42, 779-790.

PETCH, A. & SMITH, R.W., 1985. Effect of lupin management on the yield of subsequent wheat crops in a lupin-wheat rotation. *Aust. J. Exp. Agric*. 25, 603-613.

PIETOLA, L.M. & SMUCKER, A.J.M., 1995. Fine root dynamics of alfalfa after multiple cuttings and during a late invasion by weeds. *Agron. J*. 87(6), 1161-1169.

PLATZ, G.J. & REES, R.G., 1980. The Epidemiology of Yellow Spot of Wheat in Southern Queensland. *Aust. J. Agric. Res.* 31, 259-267.

PONGE J.F., TOPOLIANTZ, S. & VIAUX, P., 2000. Earthworm and enchytraeid activity under different arable farming systems, as exemplified by biogenic structures. *Plant Soil.* 225 (1/2), 39-51.

POST, W.M. & WEST, T.O., 2002. Soil organic carbon sequestration rates by tillage and crop rotation: A global data analysis. *Soil Sci. Soc. Am. J.* 66(6), 1930-1946.

RASMUSSEN, K.J. & SCHJONNING, P., 2000. Soil strength and soil pore characteristics for direct drilled and ploughed soils. *Soil Till. Res*. 57(1/2), 69-82.

RASSE, D.P., SANTOS, D. & SMUCKER, A.J.M., 2000. Alfalfa root and shoot mulching effects on soil hydraulic properties and aggregation. *Soil Sci. Soc. Am. J*. 64(2), 725-731.

RYDBERG, T., STENBERG, B. & STENBERG, M., 2000. Effects of reduced tillage and liming on microbial activity and soil properties in a weakly-structured soil. *Appl Soil Ecol*. 14(2), 135-145.

SCHULTZ, J.E., 1995. Crop production in a rotation trial at Tarlee, South Australia. *Aust. J. Exp. Agric.* 35, 865-876.

SIGSGAARD, L., 2002. A survey of aphids and aphid parasitoids in cereal field in Denmark, and the parasitoids' role in biological control. *J. Appl. Ent*. 126, 101-107.

SILSBURY, J.H., 1990. Grain yield of wheat in rotation with pea, vetch or medic grown with three systems of management. *Aust. J. Exp. Agric*. 30, 645-649.

SOANE, B.D., 1990. The role of organic matter in soil compatibility: a review. *Soil Till Res*. 16(1-2), 179-201.

THORNE, M.E., YENISH, J.P. & YOUNG, F.L., 2007. Cropping systems alter weed seed banks in Pacific Northwest semi-arid wheat region. *Crop Prot.* 26, 1121-1134.

Chapter 3

Site description, experimental design and crop management

The response of wheat of wheat to preceding crops was measured within a crop rotation experiment that was initiated in 2002. Data collected during the 2004 and 2005 seasons where used in this study.

Locality

The study was conducted at the Tygerhoek Experimental Farm (34°08'S; 19°54'E) near the town of Riviersonderend located in the Overberg wheat producing area in the southern Cape region in South Africa. Soils of this area are mostly shallow with a stony A-horizon that is seldom deeper than 30 cm. The top soil (A-horizon) at the experimental site is mostly sandy loam (Table 3.1) and can be classified as a Glenrosa Form (ortic A on lithocutanic B- horizon) (De Villiers *et al*, 1977).

Table 3.1 General description of soil chemical and physical properties at the experimental site

Soil depth		**0 - 15 cm**	**15 - 30 cm**
Particle size distribution	Clay (< 0.002 mm)	19.00%	-
	Silt (0.002-0.02 mm)	22.90%	-
	Sand (0.02-2.0 mm)	58.10%	-
	Stone (>2 mm)	55.80%	-
Chemical analysis	pH (KCl)	5.6	5.0
	%C	1.58%	1.28%
	%N	0.01%	-

Climate

The Overberg area is characterized as a winter rainfall area with Mediterranean type climate although rain also occurs during the summer months. The mean annual rainfall over a 60 year period at Tygerhoek is 430.8 mm of which 297.8 mm on average occurs during the months April to October and 133.0 mm during the months November to March. The monthly rainfall during the period of 2003- 2005 as well as the 60 year mean is summarized in Figure 3.1. Rainfall recorded during 2003 are included as soil moisture and crop production conditions experienced in 2003 are likely to have had an influence on wheat production in the subsequent year (2004).

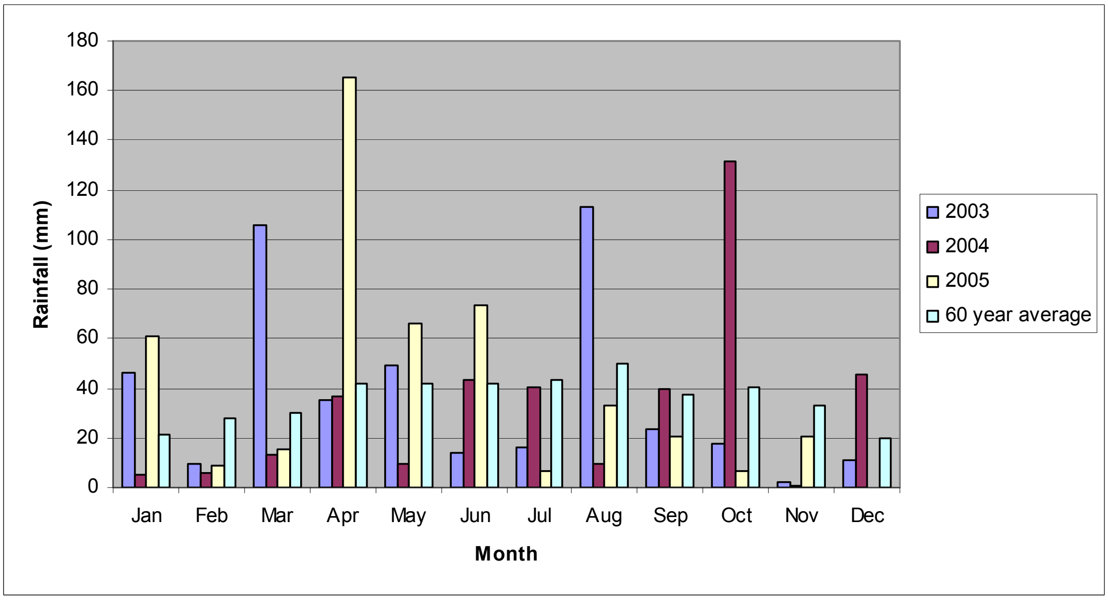


Figure 3.1 Monthly rainfall during 2003-2005 compared with average monthly rainfall during a 60 year period at Tygerhoek

Although the long term mean monthly rainfall data show a clear winter rainfall pattern (Fig 3.1), the monthly rainfall recorded during the period 2003-2005 varied widely within months and years, indicating the extreme variability in rainfall in the Overberg region. Both very wet (March 2003; April 2005; August 2003; October 2004) and very dry (May 2004; June 2003; July 2003 & 2005; August 2004; October 2005) spells for example, did occur during the experimental period.

Rainfall from November 2003 to April 2004 was 74.4 mm compared to 297.1 mm for the same period in 2004 to 2005. While total rainfall during the wheat growing season (May to October) was 275 mm mm in 2004 and 228 mm in 2005, 132 mm of rain was recorded in October 2004 alone. Thus although rainfall during the 2004 growing season was higher than the same period in 2005, rainfall from May to September in 2004 was much lower than the same period in 2005. The relatively dry 2004 growing season was therefore preceded by a dry November to April in 2003/2004, compared to a moist November to April in 2004/2005 followed by an average growing season rainfall in 2005. It can thus be concluded that the rainfall during 2004 (May to September) was below, and rainfall during 2005 was similar to, the long-term (60 year) mean rainfall for the growing season

The average daily temperature per month over a 60 year period during the period May to September does not differ by more than 5°C (Appendix 1), with an average of 13.4°C for the months of May to October. In contrast to this, the average daily temperature recorded during November to April over a 60 year period is 20.5°C.

Experimental layout

The large-scale crop rotation trail within which the current study was undertaken covers an area of 27 ha with two replications. Each replication comprises a number of plots (each 25 m x 100 m in size) that were randomly allocated to a crop rotation treatment. Replication was based on soil differences across the experimental site. The chemical composition of soils across the experimental site was corrected to a depth of 150 mm as indicated from detailed soil sampling and accepted soil norms for cropping systems practiced in the Overberg area (ARC-SGI, 2007). Based on the soil amelioration prior to the start of the main experiment, it was assumed that all macro- and micro-elements would exceed minimum requirement levels for optimum plant growth. The soil of the whole experimental area was ripped twice to a depth of 200-300 mm after application of lime and gypsum in January/February 2002 to allow for some mixing of the lime into the soil profile and to break any compaction layers.

Crops were first established in their allocated 25 x 100m plots of the large scale trail during April-May 2002. Several of these 25 x 100 m plots were selected for use in the current study that was conducted during 2004 and 2005 growing seasons. To ensure similar soil types amongst crop sequences in the current study, it was decided to use treatment plots that were located in the close proximity to one another in a single replication of the large scale trail. Plots representing a wide range of crop sequences were selected. Plots used and a schematic layout for the 2004 and 2005 seasons are presented in Table 3.2 and Fig 3.2 respectively. Replication for the present study was provided by four randomly located 1m x 3 m sub-plots per 25 m x 100 m treatment plot (Appendix 3).

The crops used in the crop sequences shown in Table 3.2 were canola (cv. ATR Hyden), lupin (cv. Tanjil), oats (cv. SSH 421), wheat (cv. SST 57) and pasture which consisted of a mixture of medic (cv. Santiago, Caliph and Parabinga) and clover (cv. Balansae, Nungarin and Gosse). As the large scale trial had started in 2002, wheat in the present study that was planted in 2004 was preceded by two years of crop production and wheat in 2005 by 3 years of crop production. The plot used in 2004 for the PPW rotation was again used in 2005 for the PPWW rotation, but for all other crop rotation systems, different plots were used in 2004 and 2005 respectively.

Table 3.2 Crop Rotation Systems (CRS) and plots included in the trial in 2004 and 2005

2004		2005	
CRS	**Plot nr.**	**CRS**	**Plot nr.**
PW **W**	4.2	PPW **W**	5.3
BC **W**	3.4	WBC **W**	3.2
PC **W**	4.4	PPC **W**	5.2
BL **W**	3.5	WBL **W**	3.3
PO **W**	4.3	PPO **W**	5.4
BP **W**	8.5	PBP **W**	2.7
CP **W**	8.6	POP **W**	2.8
PP **W**	5.1	BPP **W**	10.4
PP **W**	5.3	WPP **W**	10.1

W – Wheat; **B** – Barley; **O** – Oats;
C – Canola; **L** – Lupin; **P** – Pasture
W in bold represents wheat planted in 2004 and 2005

Crop and pasture management practices for each 25 x 100 m treatment plot in the large scale experiment was the same as those applied by no-till conservation farmers using the best available practice technology. Sheep grazed the pastures at a stocking rate of 4.5 merino eves during the late autumn, winter and spring (May to November) and grazed on crop and pasture residues (within the same rotation treatment) during summer and early autumn. Because different crop residues had different palatability sheep removed more residues from some 25 x 100 m plots than from others, resulting in differing soil cover provided by residues. Since oats was cut for silage rather than harvested for grain, oats plots had far lower crop residues post harvest compare to the other crops.

Appropriate herbicides were applied to all plots for the control of summer and winter weeds before and after wheat was planted in both 2004 and 2005. A detailed description of the applied herbicides in each season is presented in Chapter 5.

Wheat was planted during the second week of May in both 2004 and 2005 under no-till conditions with a customized planter with spring loaded tines fitted with knife-point openers followed by press wheels spaced 250 mm apart. Seed was placed at 20 mm depth, with fertilizer placed beneath it, behind the knife-point openers. In 2004, wheat seed had a 1000 kernel weight of 37.3 g and was planted at a rate of 80kg ha^{-1}, while in 2005, 70 kg ha^{-1} with a 1000 kernel weight of 32.8 g was planted. A fertilizer mixture containing 20 kg N, 15 kg P and 10 kg S per hectare was placed below planted wheat seeds in both 2004 and 2005.

In 2004, 142 kg LAN (40 kg N ha^{-1}) was broadcasted as a topdressing 48 days after planting onto wheat following wheat and oats, 178 kg LAN (50 kg N ha^{-1}) onto wheat following canola while wheat following pasture and lupin was broadcasted with 100 kg LAN (28 kg N ha^{-1}) at 48 days after planting. In 2005, 100 kg LAN (28 kg N ha^{-1}) was broadcasted at 44 days after planting as an early topdressing to all plots.

Various chemicals for the control of diseases and pests were applied by a tractor driven sprayer or by plane in 2004 and 2005. A detailed discussion of fungicides and pesticides used post planting is presented in Chapter 5.

The canola, lupins and wheat crops that preceded wheat planted in 2004 and 2005 were harvested. Pastures were grazed and oats was cut for silage in the year preceding wheat production.

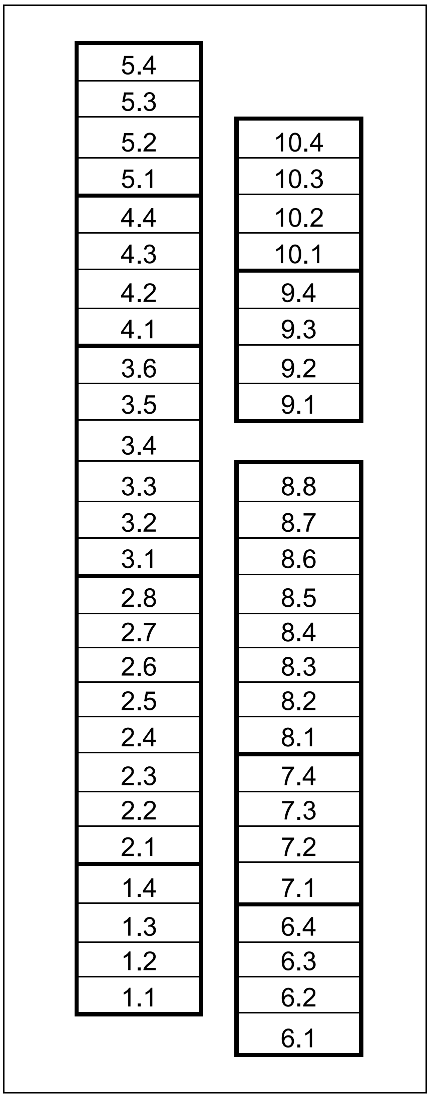


Figure 3.2 Schematic layout of the replication of the crop rotation trail from which plots were selected for use in the current study in 2004 and 2005. Selected crop rotation systems (CRS) and their plot numbers are presented in Table 3.2

Data collection and analyses

A summary of the various kinds of data collected in this study is presented in Table 3.4. Details of the data collection and of analytical procedures used are presented in the following chapters. Data analysis was based on a complete randomized design with nine main plots (treatments) and four replications within each main plot. The analysis computes sample error and allows for comparison of treatment 'means' using the Fisher's LSD test (P=0.05) (StatSoft, Inc., 2004)

Table 3.4 Data collected and analyzed during 2004 and 2005 of Tygerhoek experimental farm

Soil data
Basic chemical analysis
N-present (NO_3^- -N + NH_4^+ -N) before and after incubation

Disease data
Visual description of pathogens present on roots, stems and leaves

Plant data
Mass of roots, tillers, leaves and ears (if present)
Amount of tillers present
Leaf area index
N present in stems, leaves and ears

Yield and quality
Ton ha^{-1}
Ears m^{-2}
Spikelets per ear
Kernels per spikelet
Thousand kernel mass
Falling number
Mixing characteristics (Mixograph)
Grain protein
% Flour

References

ARC-SGI, 2007. Production of small grains in the winter rainfall region. The research and technology manager, ARC-Small Grain Institute, Private Bag X29, Bethlehem, 9700.

DE VILLIERS, J.M., LAMBRECHTS, J.J.N., LE ROUX, J., LOXTON, R.F., MACVICAR, C.N., MERRY-WEATHER, F.R., VAN ROOYEN, T.H., VERSTER, E. & VON M. HARMSE, H.J., 1977. Soil Classification: A binomial system for South Africa. Dept. Agric. Techn. Services, Pretoria.

STATSOFT, INC, 2004. STATISTICA (data analysis software system), version 7. www.statsoft.com.

Chapter 4

Effect of crop rotation on soil mineral nitrogen levels and basic soil chemical properties

Introduction

Diversification of crops used in a crop rotation system alters the pattern and degree of nutrient removal in soils (Campbell, Grant & Peterson, 2002) and in addition to this, in the case of legumes, the degree of nitrogen fixation (Armstrong *et al*., 1997). For this reason, crop rotation may have an effect on soil fertility and the growth and yield of succeeding crops. The aim of this study was to determine the effect of different preceding crops on soil chemical properties, including mineralizable and N concentration, during the wheat producing phase in different crop rotation systems.

Materials and methods

Details of the experimental locality, climate, treatments, layout, agronomical practices used and statistical analyses are presented in Chapter 3.

Soil samples were collected for each treatment plot during the last week of April 2004 and the last week of April 2005 (0-150 mm and 150-300 mm) in each of the four replicate sub-plots from each plot (Chapter 3) in order to determine the soil chemical properties. Chemical analyses of soil samples were done by the Department of Agriculture Western Cape at Elsenburg using standard methods (The Non-Affiliated Soil Analysis Work Committee, 1990). To determine the effect of crop rotation on N-mineralization potential and residual soil N at the time of planting, top soil (0-150 mm) samples were taken from each sub plot at the end of April in 2004 and 2005. Samples from the four replications of each crop rotation system were mixed together and sieved through a 1 mm sieve. Each of these 100 g sub-samples was incubated at 75% soil water capacity in a sealed plastic bottle. Total mineral N (NO_3^- -N plus NH_4^+ -N) present before incubation from separate bottles were determined (day 0 of incubation period) and again after 3, 7, 14, 28 and 42 days of incubation. Incubations of samples collected in 2004 season were done at 10, 15, 20 and 25 °C. Incubation of soil samples in 2005 was only done at 20°C due to similar trends found between different temperatures in 2004. Analyses for NO_3^- -N and NH_4^+ -N were done using the indophenol-blue (Keeney, Miller & Pace, 1982) and salicylic acid (Cataldo, Schrader & Young, 1975) methods respectively.

Results and discussion

pH

Soil pH differed (P=0.05) between a number of crop rotation systems at both the 0-150 and 150-300 mm soil depths in 2004 and at the 150-300 mm soil depth in 2005 (Table 4.1). In 2004 the lowest pH was found in the crop rotation system where wheat followed a canola crop in the 0-150 mm (PCW: 5.20) and 150-300 mm (PCW: 4.95) soil profile. This may be due to the acidifying effect of a N-flush caused by biofumigation from canola roots (Howe, Kirkegaard & Mele, 1999) when grown after a nitrogen fixing legume pasture (Williams, 1980; Haynes, 1983; Bolan, Hedley & White, 1991; Burle, Focchi & Mielniczuk, 1997). Although the highest soil pH values for both the 0-150 mm and 150-300 mm profiles in 2004 were found in crop rotation systems where wheat followed a pasture crop, these values were in most cases not significantly different (P=0.05) from values found where wheat for example followed canola in a cash cropping system (BCW: 5.53). The pH of the PCW rotation was the only crop rotation system. No significant differences in soil pH values for different crop rotation systems were found in the 0-150 mm soil profile in 2005, while in contrast to 2004, the highest value in the 150-300 mm soil profile was found where wheat followed a canola crop (PPCW: 5.93) and the lowest where wheat followed a legume pasture (BPPW: 5.23), while no significant differences (P=0.05) in this soil depth occurred between the remainder of crop rotation systems.

In general it is therefore clear that pH values for both years did not show any specific trend and most values were within the range of pH (KCl) = 5.0 to 7.0. Asher, Edwards & Islam (1980) found maximum or near-maximum growth for wheat at a pH (KCl) of 5.5 to 6.5. It thus seems probable that pH did not have any significant effect on growth and yield of wheat in the different crop rotation systems. Differences in pH found between crop rotation systems are therefore most probably due to sampling errors or differences in soil texture which may effect the leaching of calcium and would anyway not have an effect on the growth and yield of the wheat crop. Differences in pH, not measured after application of lime in 2002, are another probable cause for these differences. Large annual differences found with the same crop rotation systems was most probably due to the fact that different plots were used for the same crop rotation system in different years (Chapter 3). The effect of preceding crops on soil pH is likely to show only after several years of treatment (Coventry & Slattery, 1991).

Table 4.1 Soil chemical properties in 2004 and 2005 at 0 - 150 and 15 - 300 mm soil depths at different crop rotation systems (CRS)

pH (KCl)					
2004			**2005**		
CRS	**0-150mm**	**150-300mm**	**CRS**	**0-150mm**	**150-300mm**
PW **W**	5.55^{ABC}	5.08^{BC}	PPW **W**	5.68^{A}	5.60^{AB}
BC **W**	5.53^{ABC}	5.25^{ABC}	WBC **W**	6.00^{A}	5.50^{AB}
PC **W**	5.20^{C}	4.95^{C}	PPC **W**	5.93^{A}	5.93^{A}
BL **W**	5.48^{ABC}	5.03^{BC}	WBL **W**	5.88^{A}	5.48^{AB}
PO **W**	5.25^{BC}	5.10^{ABC}	PPO **W**	5.80^{A}	5.70^{AB}
BP **W**	5.40^{ABC}	5.20^{ABC}	PBP **W**	5.68^{A}	5.35^{AB}
CP **W**	5.80^{A}	5.33^{AB}	POP **W**	5.80^{A}	5.43^{AB}
PP **W**	5.43^{ABC}	5.05^{BC}	BPP **W**	5.43^{A}	5.23^{B}
PP **W**	5.63^{AB}	5.40^{A}	WPP **W**	5.45^{A}	5.35^{AB}
Mean	5.47	5.15	**Mean**	5.74	5.51
%C					
2004			**2005**		
CRS	**0-150mm**	**150-300mm**	**CRS**	**0-150mm**	**150-300mm**
PW **W**	1.43^{BC}	1.34^{A}	PPW **W**	1.68^{ABCD}	1.43^{AB}
BC **W**	1.33^{C}	1.15^{A}	WBC **W**	1.73^{ABC}	1.28^{BC}
PC **W**	1.39^{BC}	1.06^{A}	PPC **W**	1.76^{AB}	1.54^{A}
BL **W**	1.52^{ABC}	1.22^{A}	WBL **W**	1.59^{BCD}	1.27^{BC}
PO **W**	1.42^{BC}	1.10^{A}	PPO **W**	1.61^{BCD}	1.41^{AB}
BP **W**	1.48^{ABC}	1.08^{A}	PBP **W**	1.39^{D}	1.23^{C}
CP **W**	1.66^{AB}	1.30^{A}	POP **W**	1.44^{CD}	1.21^{C}
PP **W**	1.55^{ABC}	1.24^{A}	BPP **W**	1.78^{AB}	1.32^{BC}
PP **W**	1.73^{A}	1.27^{A}	WPP **W**	1.94^{A}	1.42^{AB}
Mean	1.50	1.20	**Mean**	1.66	1.35
Soil Resistance (Ohms)					
2004			**2005**		
CRS	**0-150mm**	**150-300mm**	**CRS**	**0-150mm**	**150-300mm**
PW **W**	602.5^{AB}	895.0^{AB}	PPW **W**	435.0^{B}	655.0^{ABC}
BC **W**	535.0^{B}	1025.0^{AB}	WBC **W**	432.5^{B}	587.5^{BCD}
PC **W**	600.0^{AB}	1130.0^{A}	PPC **W**	425.0^{B}	482.5^{D}
BL **W**	592.5^{AB}	967.5^{AB}	WBL **W**	435.0^{B}	580.0^{BCD}
PO **W**	852.5^{A}	1050.0^{AB}	PPO **W**	542.5^{AB}	565.0^{CD}
BP **W**	782.5^{AB}	1102.5^{AB}	PBP **W**	567.5^{A}	727.5^{A}
CP **W**	747.5^{AB}	1025.0^{AB}	POP **W**	520.0^{AB}	687.5^{AB}
PP **W**	550.0^{AB}	875.0^{AB}	BPP **W**	225.0^{C}	355.0^{E}
PP **W**	575.0^{AB}	842.5^{B}	WPP **W**	435.0^{B}	670.0^{ABC}
Mean	648.6	990.3	**Mean**	446.4	590.0

Table 4.1 Continued

P (mg kg^{-1}) (Citric acid)					
2004			**2005**		
CRS	**0-150mm**	**150-300mm**	**CRS**	**0-150mm**	**150-300mm**
PW **W**	47.75^{A}	30.00^{A}	PPW **W**	30.25^{B}	17.50^{B}
BC **W**	38.50^{A}	24.25^{A}	WBC **W**	54.50^{AB}	30.75^{AB}
PC **W**	44.75^{A}	22.75^{A}	PPC **W**	55.00^{AB}	41.00^{AB}
BL **W**	39.75^{A}	20.00^{A}	WBL **W**	50.75^{AB}	31.25^{AB}
PO **W**	52.50^{A}	28.00^{A}	PPO **W**	56.50^{AB}	45.75^{A}
BP **W**	39.50^{A}	16.75^{A}	PBP **W**	60.75^{A}	36.25^{AB}
CP **W**	47.25^{A}	20.00^{A}	POP **W**	51.50^{AB}	36.00^{AB}
PP **W**	51.00^{A}	26.25^{A}	BPP **W**	45.00^{AB}	25.25^{AB}
PP **W**	36.25^{A}	17.75^{A}	WPP **W**	47.25^{AB}	25.50^{AB}
Mean	44.14	22.86	**Mean**	50.17	32.14
Ca (cmol(+) kg^{-1})					
2004			**2005**		
CRS	**0-150mm**	**150-300mm**	**CRS**	**0-150mm**	**150-300mm**
PW **W**	5.51^{B}	4.21^{BC}	PPW **W**	5.19^{AB}	4.24^{B}
BC **W**	5.76^{B}	3.95^{C}	WBC **W**	6.18^{AB}	4.29^{B}
PC **W**	4.97^{B}	3.85^{C}	PPC **W**	6.57^{A}	5.56^{A}
BL **W**	6.44^{B}	4.25^{BC}	WBL **W**	5.86^{AB}	4.04^{B}
PO **W**	4.83^{B}	3.92^{C}	PPO **W**	5.08^{AB}	4.58^{AB}
BP **W**	5.23^{B}	4.30^{BC}	PBP **W**	5.12^{AB}	4.02^{B}
CP **W**	7.13^{AB}	4.94^{AB}	POP **W**	5.10^{AB}	4.10^{B}
PP **W**	5.49^{B}	4.27^{BC}	BPP **W**	4.75^{B}	3.69^{B}
PP **W**	9.19^{A}	5.31^{A}	WPP **W**	4.80^{B}	3.74^{B}
Mean	6.06	4.33	**Mean**	5.41	4.25
K (mg kg^{-1})					
2004			**2005**		
CRS	**0-150mm**	**150-300mm**	**CRS**	**0-150mm**	**150-300mm**
PW **W**	326.50^{AB}	206.75^{AB}	PPW **W**	250.25^{AB}	188.50^{B}
BC **W**	292.75^{B}	169.75^{B}	WBC **W**	219.27^{B}	205.50^{AB}
PC **W**	286.00^{B}	176.00^{B}	PPC **W**	381.50^{A}	349.50^{A}
BL **W**	250.00^{B}	140.25^{B}	WBL **W**	336.75^{AB}	229.25^{AB}
PO **W**	242.75^{B}	180.00^{AB}	PPO **W**	329.25^{AB}	271.25^{AB}
BP **W**	298.75^{B}	163.50^{B}	PBP **W**	373.00^{AB}	271.25^{AB}
CP **W**	257.50^{B}	140.25^{B}	POP **W**	245.25^{AB}	188.25^{B}
PP **W**	410.50^{A}	258.75^{A}	BPP **W**	324.75^{AB}	210.75^{AB}
PP **W**	275.25^{B}	197.75^{AB}	WPP **W**	213.00^{B}	150.50^{B}
Mean	293.33	181.44	**Mean**	297.00	229.42

W – Wheat; **B** – Barley; **O** – Oats; **C** – Canola; **L** – Lupin; **P** – Pasture

Means followed by the same letter in a column are not significantly different

Percentage carbon (%C)

Percentage carbon (%C) in the 0-150 mm soil layeres differed (P=0.05) between crop rotation systems in both 2004 and 2005 (Table 4.1). Soil organic carbon content did not differ in the 150-300 mm layers in 2004, but sign differences were recorded in this layer in 2005.

Higher values and differences between crop rotation systems were in both years found in the 0-150 mm soil profile when compared to the 150-300 mm profile. This is not surprising as the no-tillage methods used to establish the different crops did not result in any mixing of crop residue deep into the soil profile.

Highest soil organic carbon values in the 0-150 mm profile were found where wheat was planted after two years of legume pasture in 2004 (PPW: 1.73) and 2005 (WPPW: 1.94). In 2004 the lowest %C in the 0-150 mm profile was found where wheat followed canola in a cash cropping system (BCW: 1.33), but in 2005 the lowest %C was found where wheat followed one year of legume pastures (PBPW: 1.39).

In general these results confirmed earlier studies (Dalal *et al.*, 1996; Reeves, 1997; Crocker, Holford & Schweitzer, 1998; Fowler *et al.*, 2002) that showed that soil carbon content benefit from long periods of ley farming (legume pasture), but trends found in this study were not strong, because the different crop rotation systems only started in 2002 (Chapter 3). Although %C in the 0-150 mm soil profile varied between approximately 1.3 % and 1.7 to 1.9 % in 2004 and 2005 respectively, values for the same crop rotation systems varied largely between years. These large annual variations may be either due to different breakdown rates of different crop residues from one year to the next and/or already mentioned different climatic conditions and/or different plots used for the same crop rotation system in different years.

Rainfall during the 2003 growing season (May to September) was 215.6 mm compared to 143.3 mm for the same period in 2004, while rainfall from October 2003 to April 2004 and the same period from 2004 to 2005 was 91.7 and 428.9 mm respectively. Excretions of root exudates contribute to the %C present in soil (Van de Geijn, Van Veen & Merckx, 1989; Plantureux *et al.*, 2000). When annual crops die, their roots start to decay also contributing to the pool of soil carbon while soil moisture stimulates the decay of plant residues (Leffelaar, Van Dam & Van Shöll, 1997). It is thus probable that similar root mass at different crop rotation systems was produced during the higher rainfall in the growing season in 2003 compared to 2004, while the lower rainfall from October 2003 to April 2004 compared to the same period from 2004 to 2005 contributed to a slower decay of the roots in the soil. These possible differences in growth and decay could have resulted in the different trends in %C found between crop rotation systems between 2004 and 2005.

Soil Resistance (ohm cm^{-1})

Wheat can be classified as a crop with moderate resistance against salinity with a value of approximately 400 - 800 mS m^{-1} (1315 - 658 ohm cm^{-1}) (Buys, 1986). It therefore is possible that soil resistance levels within these array of values of >600 mS m^{-1} (<878 ohm cm^{-1}) (Bresler, Carter & McNeal, 1982) or >700 mS m^{-1} (<752 ohm cm^{-1}) (Buys, 1986) may have a negative effect on wheat growth and yield.

Mean values for the 0-150 mm profile ranged between 645.6 ohm cm^{-1} in 2004 and 446.4 ohm cm^{-1} in 2005, while that of the 150-300 mm ranged between 990.3 ohm cm^{-1} in 2004 and 590.0 ohm cm^{-1} in 2005 (Table 4.1).

Although significant, differences (P=0.05) were not large with only two homogenous groups at both depths in 2004, but larger differences did occur in 2005. The only measurement that was seemingly significantly lower than the rest was from the crop rotation system where wheat was preceded by two years of pasture at the 0-150 mm (BPPW: 225.0 ohm cm^{-1}) and 150-300 mm soil depth (BPPW: 355.0 ohm cm^{-1}) in 2005. These values might have a significantly larger negative effect on wheat growth and yield compared to the remainder of crop rotation systems.

Thus, although levels of salinity were relatively high and probably had an effect on growth of wheat crop at most of the crop rotation systems used, differences between crop rotation systems showed no clear trends for different soil profiles or years. It can thus be concluded that crop rotation systems in this study probably did not have an effect on electrical conduction of soils.

Phosphorus (Citric acid)

In spite of differential P applications aimed at minimizing differences in soil P across the whole site before the study started (Chapter 3), P content in the 0-150 mm soil profile ranged between 36.25 and 52.50 mg kg^{-1} in 2004 and between 30.25 and 60.75 mg kg^{-1} in 2005 (Table 4.1). P contents in the 150-300 mm soil profile were generally lower and varied between 16.75 and 30.0 mg kg^{-1} in 2004 and between 17.5 and 45.75 mg kg^{-1} in 2005.

Depending on the stone fraction in soil, a threshold of >50 mg kg^{-1} (citric acid method) (Anon, 1995) is sufficient for a wheat crop, thus indicating below optimal P levels in most of the crop rotation systems in the 0–150 mm soil profile. No significant differences due to crop rotation systems were found in both the 0-150 and 150-300 mm soil profile during 2004. In 2005 highest P contents were found where wheat was planted after one year of pasture (PBPW: 60.75 mg kg^{-1}) in the 0-150 mm and after oats (PPOW: 45.75 mg kg^{-1}) in the 150-300 mm soil depth. Lowest P contents in 2005 were found where wheat followed on wheat stubble at the 0-150 mm (PPWW: 30.25 mg kg^{-1}) and 150-300 mm (PPWW: 17.50 mg kg^{-1}) depths.

Although P content in the soil profile may influence root growth (Ae & Otani, 1996; Claassen, Schmid & Steingrobe, 2001; Fitter *et al.*, 2001; Fitter *et al.*, 2002). Such differences were not likely in 2004. No significant difference (P=0.05) in P level in the 150-300 mm profile was found between the different crop rotation systems.

Legume plants contain greater P concentrations than cereal (Howes, Ozanne & Petch, 1976; French & Schultz, 1978) which implies greater uptake of P from soil. The data presented did not indicate any clear trends between crop rotation systems to indicate increased P uptake or higher P contents in the 0-150 mm soil profile due to more P returned by plant debris from legumes. It must however be remembered that all legume pastures and crop residue were grazed and crop rotations were only practiced since the 2002 season (Chapter 3).

As already mentioned legume crops require more P compared to grass species. Results of this study are also inconclusive in this regard because P contents found as a result of crop rotation that include legumes (medic and clover pastures and lupins) are not consistently lower than crop rotation systems that include only oilseeds and cereals (wheat, barley, canola, oats). As was reported by Dormaar *et al.* (1995) no indication of significant differences ($P=0.05$) in soil P content of soil due to the production of canola crops (with a higher ability for P uptake compared to wheat) was found.

Calcium (cmol(+) kg^{-1})

In spite of differential liming before the experiment started in 2002, significant differences in calcium content were found in the 0-150 mm and 150-300 mm soil profiles in both years (Table 4.1). As also found with the other soil chemical properties, values for the same crop rotation systems varied considerably between years and no clear trend could be found between the different crop sequences.

Potassium (mg kg^{-1})

Potassium contents in the 0-150 mm soil layer varied between 242.75 mg kg^{-1} and 410.10 mg kg^{-1} in 2004 and 213.00 mg kg^{-1} and 381.50 mg kg^{-1} in 2005 (Table 4.1). Although K contents in the 150-300 mm soil profile were generally lower, all values were well above the threshold values of 50-70 mg kg^{-1} (Anon, 1995), above which, no response to K-fertilizer applications to wheat are expected. Although significant, differences due to the crop rotation systems, did not show any clear trends. The conclusion must be drawn that the experimental period during which the different crop rotations were used, were too short for any clear trends with regard to different crops to develop.

Mineral-N (NO_3^--N plus NH_4^+-N)

During 2004 soil samples, collected before planting from different crop rotation systems, were incubated at temperatures of 10, 15, 20 and 25°C. Results (Figure 4.1) showed higher mineral-N contents (mg N per kg soil) as a result of higher incubation temperatures. The monthly 60 year average temperature from May (14.8°C) to June (12.2°C) at Tygerhoek Exprerimental Farm however differs with only 2.6 °C (Appendix 1). Thus, soil temperatures at different planting times should not cause sign variation in the amount of N mineralized during a 42 day period after planting over years. In addition to this, trends found for increasing temperatures did not differ due to crop rotation used (data not shown). The discussion of the results will therefore only focus on the mineral-N (NO_3^--N plus NH_4^+-N) in the soil at sampling time (0 days) and the N mineralized during a 42 day incubation period at 20°C.

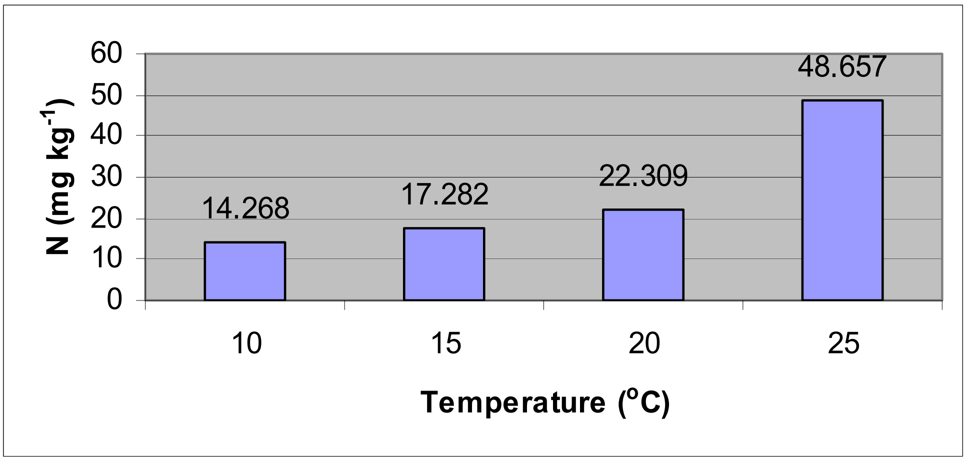


Figure 4.1 Effect of temperature on average N mineralized (NO_3^--N plus NH_4^+-N) in soil from different crop rotation systems during a 42 day period in 2004

Both the residual N in the soil at sampling (day 0) and the N mineralized during a 42 day incubation period showed significant differences in different crop rotation systems in 2004 and 2005 (Table 4.2).

As no soil tillage was done prior to planting and the soil samples were taken in April (about 15 days before planting of wheat) total mineral-N at day 0 represented the nitrogen carried over from the previous season (residual N) as well as N mineralized during the preceding summer. The highest total mineral-N (Day 42) in both 2004 and 2005 was measured in a crop rotation system where wheat followed two years of legume pasture (PPW: 2004; WPPW: 2005). High residual mineral-N contents were also found where wheat followed canola in a crop rotation system that also included legume pastures (PCW: 2004; PPCW: 2005). These results were somewhat unexpected, because canola has a higher N requirement than wheat (Anon, 2001). Where wheat followed a canola crop in the absence of legume pastures (BCW: 2004; WBCW: 2005) residual mineral N-contents were significant lower. In crop rotation system where wheat followed either oats or another wheat crop, intermediate N contents were found.

Table 4.2 Mineral N (NO_3^- -N plus NH_4^+ -N) (mg kg^{-1}) in soil from different crop rotation systems (CRS) after incubation at 20 °C as measured at the beginning (Day 0) and the end (Day 42) of the incubation period

2004				**2005**			
CRS	**mg kg^{-1}**			**CRS**	**mg kg^{-1}**		
	Day 0	**Day 42**	**Day 42 - Day 0**		**Day 0**	**Day 42**	**Day 42 - Day 0**
PW **W**	41.83^{D}	82.53^{E}	40.70^{CD}	PPW **W**	87.67^{B}	No data	No data
BC **W**	42.68^{D}	79.62^{E}	36.94^{D}	WBC **W**	45.52^{E}	59.60^{GF}	14.08^{DE}
PC **W**	77.13^{B}	98.83^{D}	21.70^{E}	PPC **W**	89.04^{B}	96.96^{CB}	7.92^{E}
BL **W**	36.56^{E}	85.47^{E}	48.91^{B}	WBL **W**	31.73^{G}	47.09^{G}	15.36^{DE}
PO **W**	68.03^{C}	104.58^{D}	36.56^{D}	PPO **W**	59.35^{D}	78.31^{DE}	18.96^{CDE}
BP **W**	69.19^{C}	114.02^{C}	44.83^{BC}	PBP **W**	38.41^{F}	69.36^{EF}	30.94^{ABC}
CP **W**	65.57^{C}	125.43^{B}	59.86^{A}	POP **W**	46.53^{E}	87.34^{CD}	40.80^{A}
PP **W**	107.10^{A}	140.21^{A}	33.11^{D}	BPP **W**	68.77^{C}	103.73^{B}	34.96^{AB}
PP **W**	75.56^{B}	127.82^{B}	52.25^{AB}	WPP **W**	103.46^{A}	128.25^{A}	24.79^{BCD}
Mean	64.85	106.50	41.65	**Mean**	63.39	83.83	23.48

W – Wheat; **B** – Barley; **O** – Oats; **C** – Canola; **L** – Lupin; **P** – Pasture

Means followed by the same letter in a column are not significantly different

Surprisingly, low total mineral N contents at day 0 were found where wheat followed a lupin crop. This may be either due to a much lower N-fixing potential of lupins (Chalk, 1998; Hartley & Van Kessel, 2000) or later release of N-fixed by the lupin crop (Agenbag & Maali, 2003). Total N mineralized until the 42 day incubation period (Day 42) where wheat was planted after lupins (WBLW) was about 38.38 mg kg^{-1} less in 2005 than in 2004 that may be the result of the lower rainfall experienced during the growing season of lupins (May to September) in 2004 (Chapter 3). Heenan (1995) also reported lower yields and protein from wheat following lupins when rainfall was very low compared to other seasons, while Dalal *et al.* (1996) also reported higher fixation of N by legume pastures compared to grain legume. This is probably not only because of N that was not removed by harvesting the grain, but also due to less N losses due to gaseous emissions by legume plants that were grazed frequently and thereby not allowed to flower (during which gaseous emissions are usually higher) and produce seeds during the pasture phase (Johnson & Raun, 1999).

Total mineral-N mineralized during a 42 day period (day 42-day 0) (Table 4.2) of incubation gives an indication of N availability during the very critical 30 - 60 days after planting which is during the tillering period of the wheat crop (Anon, 1985). Although still significant, differences in N mineralization in soils between crop rotation systems for the first 42 days of incubation were smaller compared to that found at planting (day 0). Except for generally low mineral-N contents of soil incubated during the first 42 days where wheat followed canola (PCW: 2004; PPCW, WBCW: 2005), trends with regard to the other crop rotation systems were not clear. The low values obtained where wheat was planted after canola were again unexpected after the high residual N values found. Although more data in this regard are needed, these results suggest that N recommendations of wheat following canola should be re-evaluated to ensure that sufficient N is available during this 42 day period, especially in N depleted soils. The highest total N mineralized during the 42 day period in both years was however found where wheat followed a legume pasture (CPW, PPW: 2004; POPW: 2005), illustrating the high contribution of N from legume pasture to the following grain crop as also found by Fillery, McNeill & Zhu (1998) and Cooper *et al.* (2002).

Total available mineral N (N at day 0 plus N-mineralized, thus day 42) again illustrated the ability of legume pasture crops to supply nitrogen to follow-up crops, because the highest values in both years were normally obtained where wheat was planted after pastures (PPW, CPW , BPW: 2004; WPPW, BPPW: 2005). Higher mineral N values were normally obtained in the crop rotation systems where wheat was preceded by two consecutive years of pasture (PPW: 2004; BPPW, WPPW: 2005) compared to crop rotation systems where wheat was preceded by a non-legume crop between the pasture and wheat crops (POW, PCW, PWW: 2004; PPOW, PPCW, PPWW: 2005). This suggests a rapid depletion of soil N from annual legume pastures when the pasture is followed by a non-legume crop (Baldock & Peoples, 2001). Lowest values were again obtained where wheat was planted after lupins, canola or wheat in the absence of legume pastures (BCW, PWW, BLW: 2004; WBLW, WBCW: 2005). In contrast to Loss, Ritchie & Robson (1993) these results indicate that the potential of a lupin crop to supply mineral N to crops planted in the following season is not different from the non-legume crops used in this study.

Average amount of N mineralized during the 42 day incubation period was also higher in 2004 than in 2005 (except at PPW: 2004; WPPW: 2005) indicating higher mineralization potential caused by the dryer summer of 2003/2004 compared to 2004/2005 summer as also shown by Giambiagi, Pirolo & Rimolo (1992).

Conclusions

It is well documented that elements like P, Ca and K deeper in the soil profile can be made more accessible to shallow rooted cereal crops by deeper rooted crops like lupins and canola (Loss *et al.*, 1993). No indications of such trends have been found in this study. This study did show that legume pastures may have a positive effect on the soil chemical condition, as the highest values with regard to pH, %C, P, Ca, and K were found in the soil samples taken from rotation systems that included one or two years of legume pasture.

In general the data obtained with the basic soil chemical analyses were not very conclusive indicating that the experimental period was too short or that the crop rotations did not have a large effect on most of the soil chemical properties. A high degree of variability or various elements among plots at the start of the trial as well as a high variability and stone fraction might also contribute to the lack of clear trends.

Mineral-N content of the soil at planting (residual N) and N mineralized during a 42 day incubation period however clearly showed the positive effect of legume pastures on mineral N availability to the following wheat crop and thereby confirmed earlier reports (Crocker *et al.*, 1998). The contribution made by a legume grain like lupins with regard to the N requirements of the following wheat crop is however less than that of legume pastures.

Although the residual N at planting after a canola crop was unexpectedly high, N-mineralization after planting was low. These aspects will however need a more detailed study.

References

ANON, 1985. Department of Agronomy and Pastures. Illustration of successive growth stages of spring wheat. Faculty of Agricultural Science, University of Stellenbosch, South Africa.

ANON, 1995. Dokumentasie van Bemestingaanbevelingsprogram (ESOLAD). Elsenburg Landbou. Privaatsak X1, Elsenburg, 7606.

ANON, 2001. Canolaverbouing in die Wes- en Suid-Kaap. Hoofdirektoraat Landbou: Wes-Kaap, Privaatsak X1, Elsenburg, 7606.

AE, N. & OTANI, T., 1996. Sensitivity of phosphorus uptake to changes in root length and soil volume. *Agron. J.* 88, 371-375.

AGENBAG, G.A. & MAALI, S.H., 2003. Effect of soil tillage, crop rotation and nitrogen application rates on soil mineral-N levels in the Swartland wheat producing area of South Africa. *S. Afr. J. Plant Soil*. 20(3), 119-126.

ARMSTRONG, E.L., HEENAN, D.P., PATE, J.S. & UNKOVICH, M.J., 1997. Nitrogen benefits of lupins, field pea, and chickpea to wheat production in south-eastern Australia. *Aust. J. Agric. Res.* 48(1), 39-47.

ASHER, C.J., EDWARDS, D.G. & ISLAM, A.K.M.S., 1980. pH Optima for crop growth: Results of a flowering solution culture experiment with six species. *Plant Soil* 54, 339-357.

BALDOCK, J.A. & PEOPLES, M.B., 2001. Nitrogen dynamics of pastures: nitrogen fixation inputs, the impact of legumes on soil nitrogen fertility, and the contributions of fixed nitrogen to Australian farming systems. Aust. J. Exp. Agric. 41, 327-346.

BOLAN, N.S., HEDLEY, M.J. & WHITE, R.E., 1991. Processes of soil acidification during nitrogen cycling with emphasis on legume based pastures. *Plant Soil* 134, 53-63.

BRESLER, E., CARTER, D.L. & McNEAL, B.L., 1982. Saline and Sodic Soils. Advanced series and Agricultural Sciences. Springer-Verlag, Berlin Heidelberg, New York.

BURLE, M.L., FOCCHI, S. & MIELNICZUK, J., 1997. Effect of cropping systems on soil chemical characteristics, with emphasis on soil acidification. *Plant Soil* 190, 309-316.

BUYS, A.J. 1986. Bemestingshandleiding. Second edition. Die Missstofvereniging van Suid-Afrika. P.O. Box 1821, Pretoria 0001, South Africa.

CAMPBELL, C.A., GRANT, C.A. & PETERSON, G., 2002. Nutrient considerations for diversified cropping systems in the Northern Great Plains. Agron. J. 94, 186-198.

CATALDO, D.A., HAROON, H., SCHRADER, L.E. & YOUNG, V.L., 1975. Rapid colorometric determination of nitrate in plant tissue by nitration of salicylic acid. *Commun. in Soil Science and plant analysis*. 6(1), 71-80.

CHALK, P.M., 1998. Dynamics of biologically fixed N in legume-cereal rotations: a review. *Aust. J. Agric. Res.* 49(3), 303-316.

CLAASSEN, N., SCHMID, H. & STEINGROBE, B., 2001. Root production and root mortality of winter barley and its implication with regard to phosphate acquisition. *Plant Soil* 237, 239-248.

COOPER, J.E., DALAL, R.C., HOLMES, C.J., KING, A.J., LEHANE, K.J., STRONG, W.M. & WESTON, E.J., 2002. Sustaining productivity of a Vertisol at Warra, Queensland, with fertilizers, no-tillage or legumes. 6. Production and nitrogen benefits from annual medic in rotation with wheat. *Aust. J. Exp. Agric*. 42, 961-969.

COVENTRY, D.R. & SLATTERY, W.J., 1991. Acidification of soil associated with lupins grown in a crop rotation in north-eastern Victoria. *Aust. J. Agric. Res*. 42(3), 391-397.

CROCKER, G.J., HOLFORD, I.C.R. & SCHWEITZER, B.E., 1998. Comparative effects of subterranean clover, medic, lucerne, and chickpea in wheat rotations, on nitrogen, organic carbon, and moisture in two contrasting soils. *Aust. J. Soil. Res*. 36, 57-72.

DALAL, R.C., HOSSAIN, S.A., STRONG, W.M., WARING, S.A. & WESTON, E.J., 1996. Comparison of legume-based cropping systems at Warra, Queensland. 1. Soil nitrogen and organic carbon accretion and potentially mineralizable nitrogen. *Aust. J. Soil. Res*. 34, 273-287.

DORMAAR. J.F., McKENZIE, R.H., SCHAALJE, G.B. & STEWART, J.W.B., 1995. Chemical and biochemical changes in the rhizospheres of wheat and canola. *Can. J. Soil. Sci.* 75(4), 439-447.

FILLERY, I.R.P., McNEILL, A.M. & ZHU, C., 1998. A new approach to quantifying the N benefit from pasture legumes to succeeding wheat. *Aust. J. Agric. Res*. 49(3), 427-436.

FITTER, A.H., LEYSER, H.M.O., LINKOHR, B.I. & WILLIAMSON, L.C., 2002. Nitrate and phosphate availability and distribution have different effects on root system and architecture of Arabidopsis. *The Plant Journal*. 29, 751-760.

FITTER, A.H., LEYSER, H.M.O., RIBRIOUX, S.P.C.P. & WILLIAMSON, L.C., 2001. Phosphate availability regulates root system architecture in Arabidopsis. *Plant Physiol.* 126, 875-882.

FOWLER, S.M., LAMPKIN, N.H., LEIFERT, C., LEITCH, M., LITTERICK, A.M., ROBINSON, D., ROBSON, M.C. & WATSON, C.A., 2002. The agronomic and economic potential of break crops for ley/arable rotations in temperate organic agriculture. *Adv. Agron*. 77, 369-427.

FRENCH, R.J. & SCHULTZ, J.E., 1978. The mineral content of cereals, grain legumes and oilseed crops in South Australia. *Aust. J. Exp. Agric. and Animal Husbandry*. 18, 579-585.

GIAMBIAGI, N., PIROLO, T. & RIMOLO, M., 1992. Influence of drought on the production of mineral nitrogen in a typical argiudol of the Pampas. *Soil. Biol. Biochem*. 25, 101-108.

HARTLEY, C. & VAN KESSEL, C., 2000. Agricultural management of grain legumes: has it led to an increase in nitrogen fixation? *Field Crop. Res*. 65, 165-181.

HAYNES, R.J., 1983. Soil acidification induced by leguminous crops. *Grass Forage Sci.* 38, 1-11.

HEENAN, D.P., 1995. Effects of broad-leaf crops and their sowing time on subsequent wheat production. Field Crop. Res. 43, 19-29.

HOWE, G.N., KIRKEGAARD, J.A. & MELE, P.M., 1999. Enhanced accumulation of mineral-N following canola. *Aust. J. Exp. Agric*. 39, 587- 593.

HOWES, K.M.W., OZANNE, P.G. & PETCH, A., 1976. The comparative phosphate requirements of four annual pastures and two crops. *Aust. J. Agric. Res*. 27, 479-488.

JOHNSON, G.V. & RAUN, W.R. 1999. Improving nitrogen use efficiency for cereal production. Agron. J. 91(3) 357-363.

LEFFELAAR, P.A., VAN DAM, A.M. & VAN SCHÖLL, L., 1997. Mineralization of nitrogen from an incorporated catch crop at low temperatures: experiment and simulation. *Plant Soil* 188, 211-219.

LOSS, S.P., RITCHIE, G.S.P. & ROBSON, A.D., 1993. Effect of lupins and pasture on soil acidification and fertility in Western Australia. *Aust. J. Exp. Agric.* 33(4), 457-464.

KEENEY, D.R., MILLER, R.H. & PACE, A.L., 1982. Chemical and microbiological properties. In: methods of soil analyses. *Agronomy, no 9, part 2, Second edition.*

PLANTUREUX, S., RENAUD, V.G., TRAORE',O., TREMBLAY, V.B. & TUBEILEH, A., 2000. Effect of root mucilage and modeled root exudates on soil structure. *Eur. J. Soil. Sci*. 51, 575-581.

REEVES, D.W., 1997. The role of soil organic matter in maintaining soil quality in continuous cropping systems. *Soil & Tillage Res.* 43, 131-167.

THE NON-AFFILIATED SOIL ANALYSIS WORK COMMITTEE, 1990. Handbook of standard soil testing for advisory purposes. Soil Science society of South Africa.

VAN DE GEIJN, S.C., VAN VEEN, J.A. & MERCKX, R., 1989. Plant- and soil related controls of the flow of carbon from roots through the soil microbial biomass. *Plant Soil* 115, 179-188.

WILLIAMS, C.H., 1980. Soil acidification under clover pasture. *Australian Journal of Experimental Agriculture and Animal Husbandry*. 20, 561-567.

Chapter 5

The effect of crop rotation on plant density, crop residue, diseases, pests and weeds in wheat

Introduction

Increased resistance to chemicals used for the chemical control of pests and diseases in wheat (Christopher *et al*., 1990; Llewellyn & Powles, 2001) are one of many factors that has resulted in producers applying crop rotation to improve pest and disease management practices in cropping systems (Dyck & Liebman, 1993; Bailey *et al*., 2002). Crop rotation has been shown to be more sustainable than conventional monoculture, especially when combined with conservation farming methods (Benger *et al*, 1993; Clayton, Lupwayi & Rice, 1998; Finlay, Johansson & Paul, 2004) with advantages and disadvantages compared to conventional methods. One disadvantage is that more crop residues are left in and on the soil surface, thus increasing the ability of some plant pathogens to survive between seasons (Cook & Haglund, 1991; Cook, Paulitz & Smiley, 2002). Crop residues on the soil surface may increase soil moisture available to crops (Chan & Heenan, 1996). Possible changes in plant disease, insect pests and weeds present on and in the wheat crop, crop residue on the soil surface and different plant densities in response to different crop rotation systems, are reported.

Materials and Methods

Details of the experimental locality, climate, layout and statistical analyses are presented in Chapter 3. The nine crop rotation systems used in 2004 and 2005 respectively are presented in Table 3.2 and consist of a 100 m × 25 m plot from which four sub-plots (replications) were selected. Each of these replications consisted of a 3 m^2 area which was divided into two 1.5 m^2 blocks, reserved for crop yield measurements at the end of the season, while the other sub-block was divided into six smaller blocks of 0.25 m^2 each for collection of wheat samples at different growth stages of the wheat crop.

The percentage (%) of soil covered by preceding crop residue in each replication was estimated using a point technique. A square frame consisting of six rows each consisting of six pins welded to one side of the frame providing a grid of 36 points was used. The distance between the rows and pins within rows was 100 mm. The sampling frame was placed at two positions in opposite corners of the blocks representing each replication, thus giving a total of 72 points at each replication. A 'strike' was recorded when the tip of a pin made contact with any plant residue rather than the bare soil. Crop residue cover (%) was then determined by dividing the total strikes per replication by the total amount of points (72 points).

It is probable that some wheat plants can still die during the seedling stage, due to factors like disease (Wiese, 1977; Scott, 1990) and drought stress (Blum, 1996; Asido *et al*., 2002; Kumar & Tomar, 2004). Seedling counts were therefore made about 25 days after planting to exclude some of these probable dying seedlings. This was done by counting the number of wheat plants in each of the six sub-blocks to determine the average amount of plants present m^{-2} at each replication per crop rotation. The 1000 kernel mass (g), row width of the planter (250 mm) and seeding rate was used to collaborate the number of wheat seeds planted m^{-2} (Chapter 3). The percentage seedling survival (%SS), was calculated for both 2004 and 2005.

The weeds that were present in the different plots before planting were controlled chemically. All chemical applications before planting of wheat in both 2004 and 2005 are presented in Table 5.1. The different chemicals and mixtures of chemicals were applied by tractor mounted sprayer (Chapter 3) to the different crop rotation systems depending on species of weeds present on each plot. The different chemicals (trade names) and dosage rates are presented in Table 5.1, while active ingredients of these chemicals are presented in Appendix 2.

Table 5.1 Trade names and dosage of chemicals applied at different crop rotation systems at different days before wheat was planted in 2004 and 2005

2004		
PWW / PCW / POW		
Days before plant	**Chemical**	**Dosage ha^{-1}**
5	Roundup® CT MCPA®	1.2 ℓ 0.5 ℓ
BCW / BLW / BPW / CPW / PPW		
Days before plant	**Chemical**	**Dosage ha^{-1}**
5	Roundup® CT	1.2 ℓ
2005		
PPWW / PPCW / PPOW		
Days before plant	**Chemical**	**Dosage ha^{-1}**
114	Roundup® 360 2.4 D amien®	1.5 ℓ 0.5 ℓ
8	Roundup® 500 MCPA®	1 kg 0.5 ℓ
WBLW / PBPW / POPW		
Days before plant	**Chemical**	**Dosage ha^{-1}**
115	Roundup® 360 2.4-D amien®	2.5 ℓ 1 ℓ
22	Gramoxone®	1.25 ℓ
BPPW / WPPW		
Days before plant	**Chemical**	**Dosage ha^{-1}**
49	Roundup® 360 MCPA®	1.5 ℓ 0.75 ℓ
8	Speed up® Roundup® 500	1.6 ℓ 1 kg
WBCW		
Days before plant	**Chemical**	**Dosage ha^{-1}**
94	Roundup® 360	3.5 ℓ
22	Gramoxone®	1.25 ℓ

W – Wheat; **B** – Barley; **O** – Oats; **C** – Canola
L – Lupin; **P** – Pasture

A visual scoring system was used to evaluate weed populations. Ratings were done at 43, 112 and 139 days after planting and 44, 77 and 121 days after planting in 2004 and 2005 respectively. This visual evaluation (scoring) was done to determine the weed populations present within the wheat crop. This scoring consisted of 0 (no weeds present), 1 (>25% of plot area was infested with weeds), 2 (25-50% of plot area was infested) and 3 (>50% of plot area was infested) for each individual weed species present in each of the 3 m^2 replications per crop rotation treatment.

Herbicides, fungicides and pesticides applied after wheat was planted to all crop rotation systems are presented in Table 5.2. All these applications were also done by tractor mounted sprayer, except at the end of 2004, when some spraying was done by airplane. Some of the fungicides were only applied to the crop rotations where wheat was followed by wheat as indicated in Table 5.2.

Table 5.2 Trade names and dosage of chemicals applied on wheat crop at all crop rotation systems at different days before wheat was planted in 2004 and 2005

2004		
Days after plant	**Chemical**	**Dosage ha^{-1}**
58	Cossack® Ballista® Folimat®	0.3 kg 0.5 ℓ 0.08 ℓ
	Capitan®	0.4 ℓ
65	Punch C® *	0.4 ℓ
76	Capitan®	0.4 ℓ
134	Rogor® ***	0.75 ℓ
155	Sipermethrin® *** Chlorpyrifos® ***	0.15 ℓ 0.5 ℓ
2005		
Days after plant	**Chemical**	**Dosage ha^{-1}**
48	Hussar® Ballista® Buctril® DS	200 g 0.5 ℓ 0.35 ℓ
54	Capitan® ** Metasystox®	0.4 ℓ 0.5 ℓ
96	Opus® Metasystox®	0.8 ℓ 0.5 ℓ

W – Wheat; **B** – Barley; **O** – Oats; **C** – Canola; **L** – Lupin; **P** – Pasture

*	Only applied at the PWW crop rotation system
**	Only applied at the PPWW crop rotation system
***	Application was done by plane

Wheat plants from different sub-blocks (0.25 m^2) were sampled at different growth stages (days after plant) in 2004 and 2005 to determine insect (Table 5.6) and disease symptoms. From these samples, 20 plants were randomly selected from each sub-block sample. Plants were removed from blocks by spade to a depth of 100 mm. All soil was then washed from the roots of each plant after which the roots were cut from the plants. A scoring system was used to evaluate foliar and stem diseases. A scoring of symptoms of insect damage, soil-borne as well as foliage diseases were made on these samples (Bailey, Domitruk & Lafond, 1998), but pathogens or insects were not identified by pathogenic/laboratory tests.

Discoloration of basal stems was regarded as a positive symptom for soil-borne diseases (Wiese, 1977; Scott, 1990; Grains Research and Development Corporation, 1992). Scoring consisted of 0 - 3 (0 = no symptoms; 1 = 1 to 4 plants showed symptoms; 2 = 5 to 10 plants showed symptoms and 3 = 11 to 20 plants showed symptoms). Similar scoring system was used by Bailey *et al*., (2001).

The scoring of foliar disease symptoms on leaves and stems as well as insect damage were also done using a scoring scale of 0 to 3. Scoring was done separately for the top part (flag leaf and the second leaf just below the flag leaf) and bottom part (remaining living leaves) of the wheat plants similar to techniques used by Couture (1980) and Ball *et al*. (1993). Scoring consisted of 0 = no visual symtoms; 1 = >0-25% of plant area showed symptoms; 2 => 25-50% of plant area showed symptoms and 3 = >50% of plant area showed symptoms. Although identification and severity of infection by pathogens and damage by pests was based only on a visual basis, it still gave a valuable estimation of their presence in and on the wheat plants for the individual crop rotation systems.

Results and discussion

Percentage crop residue cover (%CR)

The percentage crop residue covering the soil surface (%CR) after planting of wheat in both 2004 and 2005 are presented in Table 5.3. Significant differences (P=0.05) due to crop rotations were found in both years with the highest %CR where wheat was planted after wheat in 2004 (PWW: 61%) and 2005 (PPWW: 69%). The lowest %CR was found at crop rotations where wheat was preceded by oats in 2004 (POW: 33%) and one year of pasture (POPW: 35%) in 2005. High values where wheat was planted after wheat (PWW; PPWW) may be due to the large quantities of residue produced by wheat crops, but may also indicate that the grazing animals probably preferred plant residue from other crops used in the different crop rotations, or a slower decomposition of plant residue from wheat compared to other crops. Low %CR values where wheat was planted after oats in both 2004 (POW) and 2005 (PPOW) are most probably due to the fact that oats was cut for silage and most of the biomass therefore removed.

Table 5.3 Percentage crop residue cover (%CR) on the soil surface at different crop rotation systems (CRS) after wheat was planted in 2004 and 2005

% Crop residue cover			
2004		**2005**	
CRS	**%**	**CRS**	**%**
PW **W**	61^{A}	PPW **W**	69^{A}
BC **W**	49^{ABC}	WBC **W**	54^{B}
PC **W**	51^{ABC}	PPC **W**	44^{BC}
BL **W**	38^{BC}	WBL **W**	51^{B}
PO **W**	33^{C}	PPO **W**	53^{B}
BP **W**	43^{BC}	PBP **W**	44^{BC}
CP **W**	40^{BC}	POP **W**	35^{C}
PP **W**	52^{AB}	BPP **W**	41^{BC}
PP **W**	48^{ABC}	WPP **W**	55^{AB}
Mean	46	**Mean**	50

W – Wheat; **B** – Barley; **O** – Oats; **C** – Canola;
L – Lupin; **P** – Pasture

Means followed by the same letter in a column are not significantly different

Percentage seedling emergence and survival (%SS)

Percentage seedling emergence and survival (%SS) varied between 40 and 64% in 2004 and between 68 and 83% in 2005 (Table 5.4), a clear indication of the more favorable conditions which prevailed at planting during 2005.

The highest %SS in 2004 was found where wheat was planted after another cereal (PWW: 62%; POW: 64%). These values were, with the exception of the CPW rotation, significantly higher than values found for all rotations where wheat was planted after a pasture crop (PPW: 48%, 40%; BPW: 48%) or lupins (BLW: 44%). The higher value found where wheat was planted on wheat residue (PWW) coincided with the high crop residue cover (%CR) and therefore a possible enhanced retention of available soil moisture (Chan *et al*., 1996) during the dry conditions which prevailed at planting in this year (2004). This is however not true for the crop rotation system where wheat was preceded by oats (POW) which had the lowest percentage crop residue cover (33%) (Table 5.3), but the highest %SS (64%). The low %SS for crop rotations where wheat was planted after pastures or lupins could have been caused by heavy ryegrass infestations (PPW: Table 5.5), but other factors such as more compacted soil due to grazing (Blair & Crocker, 2000) probably also had a negative effect.

In 2005, %SS was, as already mentioned, generally higher than in 2004 and differences between crop rotations seemed to be less, with significant differences between crop rotation systems which included pasture (POPW: 83%; PBPW, BPPW: 68%) (Table 5.4). In all these rotations wheat was planted after a pasture crop, indicating that crop rotation did not effect %SS in this year.

Table 5.4 Percentage seedling survival (%SS) and density of wheat plants for the different crop rotation systems (CRS) in 2004 and 2005

Surviving seedlings				Plant density			
2004		2005		2004		2005	
CRS	**%SS**	**CRS**	**%SS**	**CRS**	**Plants m^{-2}**	**CRS**	**Plants m^{-2}**
PW **W**	62^{A}	PPW **W**	75^{AB}	PW **W**	133^{A}	PPW **W**	161^{AB}
BC **W**	55^{ABC}	WBC **W**	69^{AB}	BC **W**	117^{ABC}	WBC **W**	148^{AB}
PC **W**	59^{AB}	PPC **W**	75^{AB}	PC **W**	126^{AB}	PPC **W**	161^{AB}
BL **W**	44^{CD}	WBL **W**	74^{AB}	BL **W**	94^{CD}	WBL **W**	157^{AB}
PO **W**	64^{A}	PPO **W**	73^{AB}	PO **W**	136^{A}	PPO **W**	157^{AB}
BP **W**	48^{BCD}	PBP **W**	68^{B}	BP **W**	103^{BCD}	PBP **W**	145^{B}
CP **W**	59^{AB}	POP **W**	83^{A}	CP **W**	126^{AB}	POP **W**	178^{A}
PP **W**	48^{BCD}	BPP **W**	68^{B}	PP **W**	102^{BCD}	BPP **W**	146^{B}
PP **W**	40^{D}	WPP **W**	72^{AB}	PP **W**	86^{D}	WPP **W**	154^{AB}
Mean	53		73	**Mean**	114		156

W – Wheat; **B** – Barley; **O** – Oats; **C** – Canola; **L** – Lupin; **P** – Pasture

Means followed by the same letter in a column are not significantly different

Plant population (plants m^{-2})

A plant population of 150 - 170 plants m^{-2}, especially with the row widths used in this study (250 mm), is considered to be sufficient for high yielding wheat crops in most areas of the Overberg wheat production area (ARC-SGI, 2005). All crop rotation systems studied in 2004 (Table 5.4) had plant populations of less than 140 plants m^{-2}. As could be expected from the %SS, the highest populations were found where wheat was planted after oats (POW: 136 plants m^{-2}) or wheat (PWW: 133 plants m^{-2}) and the lowest where wheat was planted after pasture crops (PPW: 86 plants m^{-2}; PPW: 102 plants m^{-2}; BPW: 103 plants m^{-2}) or lupins (BLW: 94 plants m^{-2}). Values of less or about 100 plants m^{-2}, might have a large effect on yield in dry seasons such as 2004 when wheat plants tend to have less tillers (Reeves, 1975; Domitruk *et al.*, 2000).

In 2005 populations were generally higher compared to 2004 and varied between 178 plants m^{-2} (POPW) and 145 plants m^{-2} (PBPW). Seedling populations for all crop rotation systems in 2005 were therefore close to the optimum range of 150-170 plants m^{-2} and should not have had any limiting effect on yield.

Weed population

Weed infestations were determined at 43, 112 and 139 days after planting in 2004 and at 44, 77 and 121 days after planting in 2005 (Table 5.5). Post emergence herbicides (Cossack® : 2004; Hussar® : 2005) were applied at 58 and 48 days after planting in the respective years and would therefore had no effect on the initial weed populations counted, while counts at later stages would give an indication of the efficiency of the herbicide applications. Although all different weed species present in wheat crops of 2004 and 2005 were identified, only populations of ryegrass (*Lolium* spp.) were probably high enough to influence wheat growth. Only ryegrass infected treatments (Table 5.5) will be discussed.

During 2004, the highest ryegrass populations at 43 days after planting were found in the crop rotation systems where wheat was preceded by lupins (BLW: 3.00) or by two years of pasture (PPW: 3.00) (Table 5.5). Scorings of 3.0 for all of these systems indicated that 50 - 100% of the land area was infested. Where wheat was planted after one year of pasture (BPW), a score of 2.75 indicated an infestation of 25 - 50%. All other crop rotations showed infestations of less than 25% (scoring of less than 2) with the lowest scoring of only 0.25 where wheat was planted after canola (PCW). In 2005 the highest infestations at 44 days after plant, with scores of 3.00 and 2.75 respectively, were recorded where wheat was planted after wheat (PPWW) and one year of pasture (POPW). Where wheat was planted after two years of pasture a score of 2.25 was recorded. All other crop rotations showed scores of less than 2.0.

Scorings done after the post-emergence herbicides applications (58 and 48 days after planting) in 2004 and 2005 respectively. Although the weed infestations in most crop rotations declined after application, scores at 112 and 139 days after planting in 2004 and 77 and 121 days after planting in 2005, showed severe infestations in one of the two plots where wheat was planted after two years of pasture (PPW) in 2004 and after wheat (PPWW) in 2005. These results may indicate possible resistance to the herbicides used. High initial infestations recorded for these plots, however, indicated that herbicide applications to preceding crops were probably not efficient.

Table 5.5 Visual scoring (0=0 infestation; 1=>0-25%; 2=>25-50%; 3=>50%) of ryegrass populations (*Lolium* spp*)* present in wheat crop at different crop rotation systems (CRS) during 2004 and 2005 seasons at various days after wheat was planted

CRS	**2004**			**Mean**	**CRS**	**2005**			**Mean**
	Days after plant					**Days after plant**			
	43	**112**	**139**			**44**	**77**	**121**	
PW **W**	1.25^{CD}	0.25^{C}	0.75^{BCD}	0.75	PPW **W**	3.00^{A}	3.00^{A}	2.75^{A}	2.92
BC **W**	1.25^{CD}	0.25^{C}	0.00^{D}	0.50	WBC **W**	1.00^{D}	0.00^{F}	0.00^{C}	0.33
PC **W**	0.25^{D}	0.00^{C}	0.00^{D}	0.08	PPC **W**	1.25^{D}	0.75^{CDE}	0.25^{C}	0.75
BL **W**	3.00^{A}	1.00^{B}	1.00^{BC}	1.67	WBL **W**	1.00^{D}	0.25^{EF}	0.00^{C}	0.42
PO **W**	1.75^{BC}	0.00^{C}	0.25^{CD}	0.67	PPO **W**	1.75^{C}	1.50^{B}	1.25^{B}	1.50
BP **W**	2.75^{AB}	0.50^{BC}	1.25^{AB}	1.50	PBP **W**	1.00^{D}	0.00^{F}	0.00^{C}	0.33
CP **W**	1.50^{C}	0.50^{BC}	0.75^{BCD}	0.92	POP **W**	2.75^{A}	1.25^{BC}	0.00^{C}	1.33
PP **W**	3.00^{A}	0.25^{C}	0.50^{BCD}	1.25	BPP **W**	1.00^{D}	0.50^{DEF}	0.00^{C}	0.50
PP **W**	3.00^{A}	2.75^{A}	2.00^{A}	2.58	WPP **W**	2.25^{B}	1.00^{BCD}	1.00^{B}	1.42
Mean	1.97	0.61	0.72	1.10	**Mean**	1.67	0.92	0.58	1.06

W – Wheat; **B** – Barley; **O** – Oats; **C** – Canola; **L** – Lupin; **P** – Pasture

Means followed by the same letter in a column are not significantly different

Insect pests

Scoring of damage on wheat plants from insect pests did not indicate conclusive trends between any of the crop rotations at most of the sampling dates. For this reason, only results obtained at 98 and 99 days after wheat was planted, in 2004 and 2005 respectively, are presented (Table 5.6). Visual symptoms caused by the Russian wheat aphid and bollworm were almost negligible and occurred at random between the different crop rotation systems with no clear trend (Data not presented). Symptoms scored and presented in Table 5.6 are therefore only damage on leaves most likely caused by the grain slug (*Lema erythrodera*) and sand mites (*Halotydeus destructor*) (ARC-SGI, 2005). From the results it is clear that most damage occurred on the lower part of the plants, but the severity of damage seemed too minimal for any significant effect on grain yield. These results therefore did not provide any evidence to show that insect damage in wheat crops are affected by the crop rotation system under consideration.

Table 5.6 Effect of crop rotation on insect pest damage (0=0 damage; 1=>0-25%; 2=>25-50%; 3=>50%) on wheat at 98 and 99 days after wheat was planted during 2004 and 2005 respectively

2004			**2005**		
CRS	**98 days after planting**		**CRS**	**99 days after planting**	
	Bottom	**Top**		**Bottom**	**Top**
PW **W**	1.25	0.00	PPW **W**	0.00	0.00
BC **W**	1.00	0.25	WBC **W**	1.00	0.00
PC **W**	1.25	0.00	PPC **W**	0.00	0.00
BL **W**	1.00	1.00	WBL **W**	0.25	0.00
PO **W**	1.50	0.50	PPO **W**	0.00	0.00
BP **W**	1.00	0.25	PBP **W**	1.00	0.25
CP **W**	1.00	0.75	POP **W**	0.00	0.50
PP **W**	1.00	0.50	BPP **W**	0.75	0.75
PP **W**	1.00	0.00	WPP **W**	0.50	1.75
Mean	1.11	0.36	**Mean**	0.39	0.36

W – Wheat; **B** – Barley; **O** – Oats; **C** – Canola; **L** – Lupins; **P** – Pasture

Means followed by the same letter in a column are not significantly different

Foliar and stem diseases

Scoring of disease symptoms present on stems and leaves of wheat plants sampled in different crop rotations during 2004 and 2005 are presented in Tables 5.7 and 5.8 respectively. The following diseases were visually indentified: *Puccinia recondita* (Brown rust), *Septoria tritici* (Septoria tritici blotch), *Drechslera campanulata* (Ring spot), which is the anamorph of *Pyrenophora semeniperda* (Campbell & Medd, 2005) and *Pyrenophora tritici-repentis* (Tan spot) (Wiese, 1977; Scott, 1990; Grains Research and Development Corporation, 1992).

At 58 days after planting in 2004 higher scores of *Septoria* were recorded on plants where wheat was planted after wheat (PWW) with a score of 3.00 at the lower and 2.25 at the top parts of the plants.

The herbicide, Capitan, was applied at 58 and 76 days after planting in 2004 and 2005 respectively to all crop rotations, while an extra application (Punch C) was applied at 65 days after planting to the crop rotation system with two consecutive years of wheat (PWW) in 2004 only, because of high disease infestations observed (Table 5.2). All these applications should have had an effect on the scoring of disease symptoms at 98 and 99 days after planting for 2004 and 2005 respectively (Table 5.7 and 5.8).

At 98 days after planting in 2004, all the leaves on the bottom part of the wheat plants were already dead, probably due to water stress and to a lesser extend due to insect pests and disease infestations (Table 5.7). Scoring was therefore only done on the top part of the wheat plants. Some plots did not have green leaves left even on the top parts of the plants and for this reason the number of replications with no green leaves left is indicated in Table 5.7. At this stage (98 days after planting) the highest score for *Septoria* (1.5) was still recorded where wheat was planted after wheat (PWW).

Very few symptoms of *Puccinia, Pyrenophora* or *Drechslera* were observed in any of the wheat samples from different crop rotations at 58 days after planting, but a high incidence of *Puccinia* symptoms were recorded in the top parts of plants at 98 days after planting (Table 5.7). No significant differences in further disease symptoms of wheat plants between crop rotation systems were found. At that stage high scores for *Drechslera* were also recorded where wheat was planted after wheat (PWW: 3.00) and canola (BCW: 3.00).

Table 5.7 Effect of crop rotation systems (CRS) on foliar and stem disease incidence damage (0=0 damage; 1=>0-25%; 2=>25-50%; 3=>50%) on wheat plants at different days after wheat was planted in 2004

58 days after plant (2004)								
CRS	**Bottom**				**Top**			
	Puccinia	***Septoria***	***Pyrenophora***	***Drechslera***	***Puccinia***	***Septoria***	***Pyrenophora***	***Drechslera***
PW **W**	0.00	3.00	0.25	1.00	0.00	2.25	0.00	1.00
BC **W**	1.00	1.00	0.00	0.50	1.00	0.50	0.00	0.50
PC **W**	1.00	1.00	0.00	1.00	1.00	1.00	0.00	1.00
BL **W**	1.00	1.00	0.75	0.75	1.00	1.00	0.00	0.75
PO **W**	1.00	1.00	0.25	0.75	1.00	1.00	0.00	0.75
BP **W**	1.00	0.50	0.00	0.00	0.25	0.75	0.00	0.00
CP **W**	1.00	0.75	0.25	0.00	1.00	1.00	0.00	0.00
PP **W**	1.00	1.00	0.00	0.25	0.50	0.50	0.00	0.50
PP **W**	0.75	0.75	0.00	0.75	0.75	0.25	0.00	0.00
Mean	0.86	1.11	0.17	0.56	0.72	0.92	0.00	0.50

98 days after plant (2004)				
CRS	**Top**			
	Puccinia	***Septoria***	***Pyrenophora***	***Drechslera***
PW**W**	2.50	1.50	0.00	3.00
BC **W**	3.00 ***	0.00 ***	0.00***	3.00 ***
PC **W**	3.00 *	0.60*	0.00*	0.00*
BL **W**	3.00 ***	1.00 ***	0.00***	1.00 ***
PO **W**	3.00	0.00	0.00	0.50
BP **W**	3.00	0.75	0.00	0.75
CP **W**	3.00	0.00	0.00	0.00
PP **W**	3.00	1.00	0.00	0.5
PP **W**	3.00 ***	1.00 ***	0.00 ***	0 .00***
Mean	2.94	0.65	0.00	0.97

W – Wheat; **B** – Barley; **O** – Oats; **C** – Canola; **L** – Lupin; **P** – Pasture

*	All leaves dead in one of the four replicates
**	All leaves dead in two of the four replicates
***	All leaves dead in three of the four replicates

Means followed by the same letter in a column are not significantly different

During 2005 Capitan was applied at 54 days after planting and Opus at 96 days after planting to all wheat crops (Table 5.2). Scoring at 36 and even at 58 days after planting (Table 5.8) should for this reason not be affected by herbicide applications.

In general very little foliar disease symptoms were recorded during 2005. At 36 days after planting a highest score of 1.0 was recorded for *Septoria* where wheat was planted after wheat (PWW) and *Drechslera* where wheat was preceded by two successive years of pastures (PPW).

At 58 days after plant all scores were, with the exception of a score of 2.0 for *Drechslera* where wheat was planted after wheat (PPWW), still ≤1.0. During the sampling at 99 days after planting, scores of ≤1.25 for the bottom parts and ≤1.0 for the top parts were recorded for all diseases. Highest scores were obtained with *Puccinia* and *Septoria*, but no clear trend with regard to crop rotation used could be identified.

Table 5.8 Effect of crop rotation systems (CRS) on foliar and stem disease incidence (0=0 damage; 1=>0-25%; 2=>25-50%; 3=>50%) on wheat plants at different days after wheat was planted in 2005

36 days after plant (2005)				
CRS	**Bottom**			
	Puccinia	***Septoria***	***Pyrenophora***	***Drechslera***
PPW **W**	0.00	1.00	0.00	0.00
WBC **W**	0.00	0.00	0.00	0.00
PPC **W**	0.00	0.00	0.00	0.25
WBL **W**	0.00	0.00	0.00	0.00
PPO **W**	0.00	0.00	0.00	0.00
PBP **W**	0.00	0.50	0.25	0.25
POP **W**	0.00	0.00	0.00	0.25
BPP **W**	0.00	0.00	0.00	0.00
WPP **W**	0.00	0.00	0.00	1.00
Mean	0.00	0.17	0.03	0.19

58 days after plant (2005)				
CRS	**Bottom**			
	Puccinia	***Septoria***	***Pyrenophora***	***Drechslera***
PPW **W**	0.00	1.00	0.00	2.00
WBC **W**	0.25	0.00	0.00	0.50
PPC **W**	0.00	0.25	0.00	0.75
WBL **W**	0.00	0.50	0.00	1.00
PPO **W**	0.00	1.00	0.00	0.50
PBP **W**	0.00	1.00	0.50	0.00
POP **W**	1.00	0.75	0.00	0.00
BPP **W**	0.00	0.00	0.00	0.50
WPP **W**	0.50	0.50	0.00	0.50
Mean	0.19	0.56	0.06	0.64

99 days after plant (2005)								
CRS	**Bottom**				**Top**			
	Puccinia	***Septoria***	***Pyrenophora***	***Drechslera***	***Puccinia***	***Septoria***	***Pyrenophora***	***Drechslera***
PPW **W**	0.50	1.00	0.00	0.25	0.00	1.00	0.00	1.00
WBC **W**	1.25	0.50	0.00	0.50	1.00	0.75	0.00	0.50
PPC **W**	1.00	1.00	0.00	0.00	0.00	1.00	0.00	0.25
WBL **W**	1.00	0.00	0.00	0.25	0.75	0.75	0.00	0.50
PPO **W**	1.00	0.75	0.00	0.00	0.00	1.00	0.00	0.25
PBP **W**	1.00	0.50	0.25	0.50	1.00	0.50	0.00	0.25
POP **W**	1.00	0.00	0.00	0.00	1.00	1.00	0.00	0.00
BPP **W**	0.50	1.25	0.00	0.00	0.25	0.75	0.00	0.00
WPP **W**	1.25	0.00	0.00	0.00	0.75	0.50	0.00	0.50
Mean	0.94	0.56	0.03	0.17	0.53	0.81	0.00	0.36

W – Wheat; **B** – Barley; **O** – Oats; **C** – Canola; **L** – Lupin; **P** – Pasture

Means followed by the same letter in a column are not significantly different

These results showed that *Septoria* was the most prominent disease in wheat during the 2004 and 2005 seasons of the crop rotation trial at Tygerhoek. Being a very good saprophyte and probably having a higher ability to survive on remaining plant debris between seasons (Wiese, 1977; Scott, 1990; Grains Research and Development Corporation), crop rotation systems that include two successive years of wheat tend to show higher scores for *Septoria*, as also found by Bailey *et al*. (1999) and Hunter *et al*. (2004). Trends for other diseases as a result of the crop rotation used were not clear. From the results it is also clear that disease symptoms were more severe during the year with lower rainfall (2004).

Soil borne diseases

Results obtained from scoring of symptoms in wheat due to soil borne diseases are presented in Table 5.9. In 2004, the highest score at 98 days after planting was recorded where wheat was planted after oats (POW: 1.00), but in contrast to most other crop rotations, symptoms of soil borne diseases did not increase in this rotation with samples at 112 and 139 days after planting. Highest scores at 139 days after planting in 2004 were recorded where wheat was planted after wheat (PWW: 2.00), two years of pasture (PPW: 2.00, 1.25) or canola (PCW: 1.75). Scores of not more than 2.0, however indicated that for all crop rotations, less than 50% of the plants examined showed symptoms.

In 2005 no symptoms were observed in any of the crop rotations for samples collected at 36 and 58 days after planting (Table 5.9), while very low scores of less than 1.0 occurred at 99 days after planting. Highest scores were however again obtained where wheat was planted after oats (PPOW: 0.75).

Higher scores recorded for soil borne infection of wheat at 139 days after planting where wheat was planted after wheat in 2004 confirmed the carry over effect of pathogens from one season to the next on residue from the same crop left on the soil surface (Cook *et al*., 2002). However the relatively high levels of infection shown for wheat after pasture or canola are difficult to explain.

As rainfall between seasons probably also had an effect on survival of inoculum of soil borne diseases between seasons, the far lower rainfall from October 2003 to April 2004 compared to the same period for 2004 to 2005 (Chapter 3) probably resulted in lower rates of decomposition of residue before the wheat was planted in 2004, thus explaining the higher scorings in 2004 compared to 2005. From these results there was however no clear indication of a probable direct effect from biofumigation from canola (Angus *et al*.,1994; Desmarchelier, Kirkegaard & Wong, 1996; Kirkegaard & Sarwar, 1998; Howe *et al*., 2000) as very few diseases were found in any crop sequence in 2005 and scores of 1.0 (BCW) and 1.75 (PCW) at 138 days after planting were recorded where wheat was planted after canola in 2004.

Table 5.9 Effect of crop rotation systems (CRS) on incidence (0=0 damage; 1=>0-25%; 2=>25-50%; 3=>50%)of soil borne disease on wheat at different days after wheat was planted in 2004 and 2005

2004				**2005**			
CRS	**Days after planting**			**CRS**	**Days after planting**		
	98	**112**	**139**		**36**	**58**	**99**
PW **W**	0.25	0.75	2.00	PPW **W**	0.00	0.00	0.00
BC **W**	0.00	0.00	1.00	WBC **W**	0.00	0.00	0.25
PC **W**	0.25	0.25	1.75	PPC **W**	0.00	0.00	0.00
BL **W**	0.00	0.00	1.00	WBL **W**	0.00	0.00	0.50
PO **W**	1.00	0.75	1.00	PPO **W**	0.00	0.00	0.75
BP **W**	0.25	0.25	1.00	PBP **W**	0.00	0.00	0.50
CP **W**	0.00	0.00	0.00	POP **W**	0.00	0.00	0.00
PP **W**	0.00	0.25	2.00	BPP **W**	0.00	0.00	0.00
PP **W**	0.00	0.25	1.25	WPP **W**	0.00	0.00	0.00
Mean	0.19	0.28	1.22	**Mean**	0.00	0.00	0.22

W – Wheat; **B** – Barley; **O** – Oats; **C** – Canola; **L** – Lupin; **P** – Pasture

Conclusions

Crop rotations that included two successive seasons of wheat production resulted in a higher percentage crop residue cover after planting of the wheat crop than rotation systems where wheat is preceded by legume pasture (medics and clover), canola or lupins.

This higher crop residue cover tends to have a positive effect on percentage seedling emergence and survival (plants m^{-2}) during years with low early season rainfall. These trends were, however not as perspicuous, because percentage seedling emergence and survival could also have been affected by other factors such as ryegrass infestations and soil compaction due to grazing animals. Results also showed larger differences due to crop rotation used in seasons with below average rainfall (2004) compared to seasons with near average rainfall (2005).

Results on the effect of different crop rotations on weeds, insect pests and diseases of the wheat crop were very inconclusive and showed no clear trend. This could be due to the fact that the different crop rotations (crop sequences) had only been implemented since 2002 and it is likely that the effects of crop rotation together with appropriate weed, disease and pest management inputs on these parameter (variables) would only be expressed after several years of implementation of the crop rotation treatments.

References

ARC-SGI, 2005. Guidelines for the production of small grains in the winter rainfall region. The Director, ARC Small Grain, Private Bag X29, 9700.

ANGUS, J.F., DESMARCHELIER, J.M., GARDNER, P.A. & KIRKEGAARD, P.A., 1994. Biofumigation: isothiocyanates released from Brassica roots inhibit growth of the take-all fungus. *Plant Soil*. 162(1), 107-112.

ASIDO, S., BONFIL, J., COHEN, S., DOLGIN, B., HEBBE, Y., KLEIN, D., MUFRADI, I., 2002. Establishment of wheat seedlings after early sowing and germination in an arid Mediterranean environment. *Agron J*. 94, 585-593.

BAILEY, K.L., DERKSEN, D.A., GOSSEN, B.D., LAFOND, G.P. & WATSON, P.R., 2001. Effect of tillage and crop rotation on root and foliar diseases of wheat and pea in Saskatchewan from 1991 to 1998: univariate and multivariate analyses. *Can. J. Plant Sci*. 81(4), 789-803.

BAILEY, K.L., DOMITRUK, D. & LAFOND, G.P., 1998. Effects of row spacing, seeding rate and seed-placed phosphorus on root diseases of spring wheat and barley under zero tillage. *Can. J. Plant Sci.* 78 (1), 145-150.

BAILEY, K.L., DUCZEK, L.J., LAFOND, G.P., Reed, S.L. & SUTHERLAND, K.A., 1999. Survival of leaf spot pathogens on crop residues of wheat and barley in Saskatchewan. *Can. J. Plant Soil*. 21, 165-173.

BAILEY, K.L., GOSSEN, B.D., KRUPINSKY, J.M., McMULLEN, M.P. & TURKINGTON, T.K., 2002. Managing plant disease risk in diversified cropping systems. *Agron. J*. 94, 198-209.

BALL, D.A., CHASTAIN, T.G., SMILEY, R.W., UDDIN, W., WYSOCKI, D.J. & ZWER, P.K., 1993. Influence of crop management practices on physiologic leaf spot of winter wheat. *Plant Dis*. 77, 803-810.

BENGER, A.M., DAVOREN, C.W., DOUBE, B.M., NEATE, S.M., RYDER, M.H. & STEPHENS, P.M., 1993. Reduced severity of *Rhioctonia solani* disease on wheat seedlings associated with the presence of the earthworm *Aporrectodea trapezoides*. *Soil Biol. Biochem*. 25(11), 1477-1484.

BLAIR, N. & CROCKER, G.J., 2000. Crop rotation effects on soil carbon and physical fertility of two Australian soils. *Aust. J. Soil Res*. 38(1), 71-84.

BLUM, A., 1996. Crop responses to drought and the interpretation of adaptation. *Plant Growth Regul.* 20, 135-148.

CAMPBELL, M.A. & MEDD, R.W., 2005. Grass seed infection following inundation with *Pyrenophora semeniperda*. *Biocontrol Sci. Techn*. 15(1), 21-36.

CHAN, K.Y. & HEENAN, D.P., 1996. Effect of tillage and stubble management on soil water storage, crop growth and yield in a wheat-lupin rotation in southern NSW. *Aust. J. Agr. Res.* 47, 479-488.

CHRISTOPHER, J.T., HOLTUM, J.A.M., LILJEGREN, D.R. & POWLES, S.B., 1991. Cross-Resistance to herbicides in annual ryegrass (*Lolium rigidum*). *Plant Physiol*. 95, 1036-1043.

CLAYTON, G.W., LUPWAYI, N.Z. & RICE, W.A., 1998. Soil microbial diversity and community structure under wheat as influenced by tillage and crop rotation. *Soil Biol. Biochem*. 30(13), 1733-1741.

COOK, R.J. & HAGLUND, W.A., 1991. Wheat yield depression associated with conservation tillage caused by root pathogens in the soil not phytotoxins from the straw. *Soil Biol. Biochem*. 23(12), 1125-132.

COOK, R.J., PAULITZ, T.C. & SMILEY, R.W., 2002. Insights into the prevalence and management of soilborne cereal pathogens under direct seeding in the Pacific Northwest, U.S.A. *Can. J. Plant Pathol.* 24, 416-428.

COUTURE, L., 1980. Assessment of severity of foliage disease of cereals in cooperative evaluation tests. *Can. Plant. Dis. Surv*. 60(1), 8-10.

DESMARCHELIER, J.M., KIRKEGAARD, J.A. & WONG, P.T.W., 1996. In vitro suppression of fungal root pathogens of ceraals by Brassica tissues. *Plant Pathol*. 45(3), 593-603.

DOMITRUK, D.R., DUGGAN, B.L. & FOWLER, D.B., 2000. Yield component variation in winter wheat grown under drought stress. *Can. J. Plant Sci*. 80(4), 739-745.

DYCK, E. & LIEBMAN, M., 1993. Crop rotation and intercropping strategies for weed management. *Ecol. Appl.* 3(1), 92-122.

FINLAY, R.D., JOHANSSON, J.F. & PAUL, L.R., 2004. Microbial interactions in the mycorrhizosphere and their significance for sustainable agriculture. *Microbial Ecol.* 48, 1-13.

GRAINS RESEARCH AND DEVELOPMENT, 1992. Cereal leaf and stem diseases. National Farmers Federation House, PO Box E6, Queen Victoria Terrace ACT, 2600.

HOWE, G., KIRKEGAARD, J.A., MEAD, A., NEWELL, M., SARWAR, M. & WONG, P.T.W., 2000. Field studies on the biofumigation of take-all by Brassica break crops. *Aust. J. Agric. Res*. 51, 445-456.

HUNTER, T., LOVELL, D.J., NICKOLS, A.R., PARKER, S.R. & WELHAM, S.J., 2004. Position of inoculum in the canopy affects the risk of *Septoria tritici* blotch epidemics in winter wheat. *Plant Pathol.* 53, 11-21.

KIRKEGAARD, J.A. & SARWAR, M., 1998. Biofumigation potential of brassicas. *Plant Soil*. 201, 71-89.

KUMAR, G.T. & TOMAR, S.M.S., 2004. Seedling survivability as a selection criterion for drought tolerance in wheat. *Plant Breeding*. 123, 392-394.

LLEWELLYN, R.S. & POWLES, S.B., 2001. High levels of herbicide resistance in rigid ryegrass (*Lolium rigidum*) in the wheat belt of Western Australia. *Weed Technol*. 15, 242-248.

REEVES, T.G., 1975. Effect of annual ryegrass (*Lolium rigidum* Gaud.) on yield of wheat. *Weed Res.* 16, 57-63.

SCOTT, D.B., 1990. Wheat diseases in South Africa. Grain Crops Research Institute. Department of Agricultural Development. Private Bag X144, Pretoria, South Africa.

WIESE, M.V., 1977. Compendium of wheat diseases. The American Phytopathological Society. 3340 Pilot Knob Road, St. Paul, Minnesota.

Chapter 6

The effect of crop rotation on the vegetative components, ear development and N-content of spring wheat

Introduction

Yield and quality of wheat may be affected by different crop rotations (Lopez-Ballido *et al*., 1998; Berzsenyi, Gyorffy, Lap, 2000) and these responses often correlate with differences in growth (Chan & Heenan, 1996; Castillo *et al*, 2000; Galantini *et al*., 2000) and N-content (Maali, 2003) present in different plant components at different growth stages of the wheat plant. In this chapter the effect of different crop rotation systems on the response in the vegetative components, ear development and N-content of spring wheat over two growing seasons (years) will be discussed.

Materials and Methods

More details of the locality, climate, experimental layout, general production techniques and statistical analyses are presented in Chapter 3. The different vegetative components and N-content were determined from twenty wheat plants per replication that were sampled during the booting stage (58 days after planting), anthesis (98 days after planting) and grain filling stage (139 days after planting) in 2004 and during the tillering stage (39 days after planting), booting stage (58 days after planting), and anthesis (99 days after planting) during 2005. To determine root growth, plants with roots attached where removed from each replication (sub-block) (Chapter 3) by spade to about 100 mm soil depth. The soil was then washed from roots to get rid of the soil, cut from the plants, dried, weighed and multiplied with the number of plants m^{-2} (Table 5.4) to determined root dry mass m^{-2}.

Twenty plants were randomly selected from a 0.25 m^{-2} sub-plot in each replication. For each sample the total number of tillers and ears were counted and divided by the number of plants per sample. The number of tillers/ears per plant was multiplied by the number of plants m^{-2} (Table 5.4) to calculate the number of tillers m^{-2} and ears m^{-2}.

Leaves and ears were separated from the stems after which the area of the green leaves was measured using a Li-Cor leaf area meter. From this the leaf area-index (LAI) was calculated by multiplying the leaf area per plant with the number of plants m^{-2}. The stems, ears (where applicable) and green and dead leaves were dried for 48 hours at 80 ºC and weighed. From this, stem-, leaf- and ear dry mass m^{-2} were calculated.

After this, the dried plant material was milled to determine the %N in leaves, stems and ears using a Technikon Infra Alyser 400. Due to insufficient material, the %N of some of especially the samples taken at the early growth stages, was not measured. The measured %N was then used to calculate the N mass in the stems, leaves and ears m^{-2}.

Results and Discussion

Root dry mass

Root dry mass of wheat plants (g m^{-2}) at 58 and 36 days after planting in 2004 and 2005 respectively showed significant differences due to the crop rotation system (Table 6.1). In 2004 the highest root mass was produced by wheat plants grown after canola (PCW: 28.6 g m^{-2}; BCW: 24.8 g m^{-2}) and oats (POW: 27.3 g m^{-2}) and the lowest where wheat was grown after pastures (PPW: 7.3 g m^{-2} and BPW: 9.3 g m^{-2}) or on wheat stubble (PWW: 10.6 g m^{-2}).

Table 6.1 Root dry mass of wheat plants as affected by different crop rotation systems (CRS) at 58 and 36 days after planting in 2004 and 2005 respectively

Root dry mass/Ground area (g m $^{-2}$)			
2004		2005	
CRS	**58 days**	**CRS**	**36 days**
PW **W**	10.6^{C}	PPW **W**	4.1^{AB}
BC **W**	24.8^{AB}	WBC **W**	3.0^{B}
PC **W**	28.6^{A}	PPC **W**	2.9^{B}
BL **W**	13.0^{BC}	WBL **W**	3.9^{B}
PO **W**	27.3^{A}	PPO **W**	5.8^{A}
BP **W**	9.3^{C}	PBP **W**	4.3^{AB}
CP **W**	13.5^{BC}	POP **W**	4.7^{AB}
PP **W**	7.3^{C}	BPP **W**	3.8^{B}
PP **W**	12.6^{BC}	WPP **W**	4.0^{AB}
Mean	16.3	**Mean**	4.1

W – Wheat; **B** – Barley; **O** – Oats; **C** – Canola; **L** – Lupin;

P – Pasture

Means followed by the same letter in a column are not significantly different

In 2005 root development was measured on a very early stage (36 days after plant) and although significant values due to the crop rotation system were still shown, values were much smaller. The highest root dry mass was however again produced by wheat plants grown after oats (PPOW: 5.8 g m^{-2}), but in contrast to 2004 the lowest mass was produced where wheat followed canola (PPCW: 2.9 g m $^{-2}$: WBCW: 3.0 g m^{-2}). Low root dry mass values were again shown where wheat followed two years of pasture (BPPW: 3.8 g.m^{-2}), but also after lupins (WBLW: 3.9 g m^{-2}). The higher root dry mass found in both years where wheat followed an oat crop or in 2004 where wheat was grown after canola supported earlier studies which showed that oats may either act as a break crop and therefore does not host soil borne wheat pathogens (ARC-SGI, 2007), while canola may have a biofumigation (allelopathic) effect on non-desirable soil organisms (Kirkegaard & Sarwar, 1998; Smith, Kirkegaard & Howe, 2004). It is also possible that soil physical properties are improved by the strong tap-root systems of preceding canola crops (Angus, Herwaarden & Howe, 1991). The poor root development found with wheat after a pasture phase may be due to soil compaction as a result of grazing which occurred in winter, while the soil was wet (Bendotti *et al*, 1993). The poor root development found with wheat after canola or lupins during 2005 is however difficult to explain, but may be due to the early sampling date with root growth not yet fully developed.

Stem number and stem dry mass

During 2004, mean stem number increased from 292 stems m^{-2} at 58 days after planting to 335 stems m^{-2} 98 days after planting after which it decreased to 315 stems m^{-2} at 139 days after planting (Table 6.2). With a mean plant population of 114 plants m^{-2} (Table 5.4), these values indicated a mean of 2.6 to 2.8 stems per plant during 2004. During 2005, mean stem number increased from 478 stems m^{-2} at 36 days after planting to 614 stems m^{-2} at 58 days after planting, but decreased thereafter to 526 stems m^{-2} (Table 6.2). With a mean plant population of 156 plants m^{-2}, these values indicated means of 3.1 to 3.9 stems per plant. Rainfall during 2005 (Figure 3.1) therefore not only favored germination and seedling establishment (Chapter 5), but also tillering.

Stem numbers m^{-2} and stem dry mass (g m^{-2}) were affected by crop rotation systems at all sampling dates (days after planting) during both 2004 and 2005 (Table 6.2), but ranking orders of the different crop rotation systems varied between samplings. Individual samplings on small sub-plots therefore did not necessarily give an accurate value of the different crop rotation systems due to variable conditions. For this reason it may be better to focus on mean values only.

During 2004, the lowest number of stems was produced by wheat planted either after two years of pasture (PPW: 239) or lupins (BLW: 248). These rotations also had the lowest number of plants m^{-2} (Table 5.4). The highest mean number of stems was produced in 2004 by wheat planted after one year of pasture (CPW: 381), canola (PCW: 371) or oats (POW: 360). These crop rotation systems also had high plant populations (Table 5.4), which indicated that conditions at planting and during the early growth stages were very important and the determining factors for high plant population/stem numbers during 2004.

During 2005, the highest mean number of stems m^{-2} was again produced by wheat planted after one year of pastures (POPW: 655) which also had the highest plant population (Table 5.4). High mean number of stems was also found where wheat was planted after two years of pasture (WPPW: 583) and as in 2004, after oats (PPOW: 582), while low mean number of stems was found where wheat followed canola (WBCW: 468; PPCW: 472) or wheat (PPWW: 488).

As these high and low mean numbers of stems were found with plant populations that were very similar, tillering in these plots must be the result of differences in growth conditions such as nitrogen supply and not differences during germination and seedling growth. The rotation where wheat was planted after canola during 2004 (PCW) for example showed high residual N contents at planting (Table 4.2), while wheat after pasture possibly benefited from high N-mineralization as shown by the incubation studies (Table 4.2). The poor tillering where wheat was planted after two succeeding years of pasture in 2004 (PPW) and after wheat in 2005, may be due to severe competition from *Lolium* spp. (Table 5.5).

Mean stem dry mass during 2004 and 2005 showed very similar responses compared to mean stem numbers (Table 6.2) (Appendix 4). Differences in stem mass were for this reason the result of the already discussed differences in stem numbers and thus conditions that affected plant populations and tillering, and not due to differences in the mass of individual stems.

Table 6.2 Stems m^{-2} and stem dry mass (g m^{-2}) of wheat plants at different growth stages (days after planting) as affected by different crop rotation systems during 2004 and 2005

Stem number (Tillers m $^{-2}$)									
2004					**2005**				
CRS	**Days after planting**			**Mean**	**CRS**	**Days after planting**			**Mean**
	58	98	139			36	58	99	
PW **W**	307^{ABC}	314^{AB}	366^{ABC}	329	PPW **W**	438^{AB}	535^{B}	491^{AB}	488
BC **W**	283^{ABC}	309^{AB}	245^{BCD}	279	WBC **W**	386^{B}	567^{AB}	452^{AB}	468
PC **W**	389^{A}	331^{AB}	393^{AB}	371	PPC **W**	347^{B}	552^{AB}	518^{AB}	472
BL **W**	248^{BC}	277^{B}	221^{CD}	248	WBL **W**	499^{AB}	656^{AB}	407^{B}	521
PO **W**	359^{AB}	361^{AB}	360^{ABC}	360	PPO **W**	612^{A}	539^{B}	596^{AB}	582
BP **W**	217^{C}	416^{AB}	277^{ABCD}	303	PBP **W**	463^{AB}	661^{AB}	496^{AB}	540
CP **W**	298^{ABC}	443^{A}	402^{A}	381	POP **W**	623^{A}	673^{AB}	668^{A}	655
PP **W**	304^{ABC}	273^{B}	372^{ABC}	316	BPP **W**	445^{AB}	599^{AB}	588^{AB}	544
PP **W**	219^{C}	294^{AB}	203^{D}	239	WPP **W**	489^{AB}	740^{A}	520^{AB}	583
Mean	292	335	315	314	**Mean**	478	614	526	539

Stem dry mass (g m^{-2})									
2004					**2005**				
CRS	**Days after planting**			**Mean**	**CRS**	**Days after planting**			**Mean**
	58	98	139			36	58	99	
PW **W**	22.3^{B}	212.4^{AB}	351.6^{AB}	195.4	PPW **W**	7.9^{BC}	38.0^{C}	410.8^{A}	152.2
BC **W**	28.5^{AB}	301.8^{A}	306.4^{B}	212.2	WBC **W**	9.6^{ABC}	60.3^{AB}	412.2^{A}	160.7
PC **W**	53.8^{A}	218.7^{AB}	501.8^{A}	258.1	PPC **W**	7.0^{C}	43.8^{BC}	464.8^{A}	171.9
BL **W**	21.1^{B}	189.1^{AB}	256.3^{B}	155.5	WBL **W**	11.5^{AB}	63.4^{A}	414.9^{A}	163.3
PO **W**	30.4^{AB}	235.5^{AB}	294.3^{B}	186.7	PPO **W**	11.9^{AB}	43.4^{BC}	581.9^{A}	212.4
BP **W**	8.1^{B}	188.0^{AB}	347.3^{AB}	181.1	PBP **W**	9.9^{ABC}	67.2^{A}	461.6^{A}	179.6
CP **W**	23.7^{B}	229.8^{AB}	409.0^{AB}	220.8	POP **W**	12.5^{A}	53.1^{ABC}	571.6^{A}	212.5
PP **W**	17.5^{B}	176.6^{B}	325.6^{AB}	173.2	BPP **W**	9.2^{ABC}	53.3^{ABC}	468.9^{A}	177.1
PP **W**	9.3^{B}	132.1^{B}	225.6^{B}	122.3	WPP **W**	8.7^{ABC}	60.3^{AB}	421.5^{A}	163.5
Mean	23.9	209.3	335.3	189.5	**Mean**	9.8	53.6	467.6	177

W – Wheat; **B** – Barley; **O** – Oats; **C** – Canola; **L** – Lupin; **P** – Pasture

Means followed by the same letter in a column are not significantly different

Leaf dry mass

In 2004, leaf dry mass (g m^{-2}) was much lower than in 2005, during corresponding growth stages (58 and 98/99 days after planting) (Table 6.3), due to the already discussed lower rainfall, subsequent lower plant populations and less tillers per plant in 2004 than 2005.

Leaf dry mass (g m^{-2}) showed similar variation between sampling dates, due to the small sampling area and variation within plots of the same crop rotation, as found for stem numbers. For this reason only mean values for the three different sampling dates during 2004 and 2005 respectively will be discussed although significant differences due to the crop rotation system used were found for all sampling dates.

Trends for mean leaf dry mass were very similar to that found with mean stem numbers, indicating the same factors influencing both tillering and leaf growth. The highest leaf dry mass in 2004 were therefore produced where wheat was planted after one year of pasture (CPW: 78.9 g m^{-2}), canola (PCW: 76.3 g m^{-2}) or oats (POW: 63.9 g m^{-2}) and the lowest after two years of pasture (PPW: 46.4 g m^{-2}) or lupins (BLW: 51.5 g m^{-2}) (Table 6.3). During 2005 the highest leaf dry mass was again produced by wheat planted after oats (PPOW: 108.3 g m^{-2}) or one year of pasture (POPW: 101.9 g m^{-2}) and the lowest where wheat was planted after wheat (PPWW: 59.2 g m^{-2}) or canola (WBCW: 81.2 g m^{-2} : PPCW: 86.7 g m^{-2}).

Low leaf dry mass may also be the result of competition from weeds such as ryegrass (*Lolium* spp) as high populations of ryegrass were found where wheat was planted after two years of pasture (PPW) in 2004 and after wheat (PPWW) in 2005 (Table 4.5).

Table 6.3 Leaf dry mass of wheat plants (g m^{-2}) at different growth stages (days after planting) in response to different crop rotation systems (CRS) during 2004 and 2005

Leaf dry mass (g m^{-2})									
2004					**2005**				
CRS	**Days after planting**			**Mean**	**CRS**	**Days after planting**			**Mean**
	58	98	139			36	58	99	
PW **W**	29.8^{B}	97.8^{A}	80.0^{ABCD}	69.2	PPW **W**	15.0^{C}	60.9^{C}	162.5^{AB}	59.2
BC **W**	35.0A^{B}	90.7^{A}	51.9^{E}	47.5	WBC **W**	16.0^{BC}	84.7^{ABC}	143.0^{B}	81.2
PC **W**	62.5^{A}	85.5^{A}	81.0^{ABC}	76.3	PPC **W**	13.0^{C}	66.5^{BC}	180.5^{AB}	86.7
BL **W**	28.1^{B}	69.6^{A}	56.9^{DE}	51.5	WBL **W**	19.6^{ABC}	91.2^{AB}	152.4^{AB}	87.7
PO **W**	36.2^{AB}	88.7^{A}	66.8^{BCDE}	63.9	PPO **W**	23.3^{AB}	65.6^{BC}	235.9^{A}	108.3
BP **W**	12.2^{B}	77.8^{A}	81.7^{ABC}	57.2	PBP **W**	18.0^{ABC}	97.0^{A}	180.2^{AB}	98.4
CP **W**	31.8^{B}	111.8^{A}	93.2^{A}	78.9	POP **W**	24.7^{A}	82.1^{ABC}	199.0^{AB}	101.9
PP **W**	21.0^{B}	70.3^{A}	83.1^{AB}	58.1	BPP **W**	16.2^{BC}	81.0^{ABC}	178.6^{AB}	91.9
PP **W**	13.4^{B}	68.0^{A}	57.8^{CDE}	46.4	WPP **W**	16.3^{BC}	92.2^{AB}	164.7^{AB}	91.1
Mean	26.1	84.5	72.5	61.0	**Mean**	18.0	80.1	177.4	89.6

W – Wheat; **B** – Barley; **O** – Oats; **C** – Canola; **L** – Lupin; **P** – Pasture

Means followed by the same letter in a column are not significantly different

Leaf area index (LAI)

Leaf area index (LAI) calculated from the area of green leaves per plant and the number of plants m^{-2}, is an indication of the photosynthetic potential of the crop. High LAI values which are maintained over a long period therefore indicate a high yield potential, but increasing LAI values also may cause increases in overshadowing and thus a reduced photosynthetic rate (Puckridge & Ratkowsky, 1971; Bugbee & Salisbury, 1988). Very low LAI values were found in 2004 while higher values occurred in 2005 at flowering stage (98/99 days after planting) (Table 6.4). Unfortunately these values during 2004 were not maintained for a long period (leaf area duration was thus short) and ranking orders for different crop rotation systems again varied between sampling dates. Yield potentials were for this reason probably much higher (especially during 2005) than indicated by measurements done at the flowering stage and mean values for different sampling dates (excluding 139 days after planting in 2004 because almost all of the leaves were already dead at this stage) were again most probably a more reliable indication of the potentials for different crop rotations.

Highest mean LAI during 2004 was obtained where wheat was planted after canola (PCW: 1.03) and after one year of pasture (CPW: 0.95; BPW: 0.84) and the lowest where wheat was planted after two years of pasture (PPW: 0.57, 0.50) or lupins (BLW: 0.50), which correspond to ranking orders found for crop components such as root development (Table 6.1), tillering (Table 6.2) and leaf dry mass (Table 6.3).

During 2005, mean LAI values varied between 1.00 and 1.29 which indicated yield potentials of about 0.9 to 1.2 tons ha^{-1} (Richards & Townley-Smith, 1987). Highest mean values were obtained from wheat planted after oats (PPOW: 1.29) or one year of pasture (PBPW: 1.22) and the lowest mean values were obtained from wheat after canola (PPCW: 1.00; WBCW: 1.06) or wheat (PPWW: 1.03) which again also correspond with their performance with regard to other crop components tested.

Table 6.4 Leaf area index (LAI) of wheat (g m^{-2}) at different growth stages (days after planting) in response to different crop rotation systems during 2004 and 2005

Leaf area index (LAI)									
2004					**2005**				
CRS	**Days after planting**				**CRS**	**Days after planting**			
	58	98	139	**Mean**		36	58	99	**Mean**
PW **W**	0.53^{B}	1.13^{ABC}	0.01**	0.83	PPW **W**	0.15^{D}	1.04^{C}	1.89^{AB}	1.03
BC **W**	0.66^{B}	0.57^{CD}	0.14**	0.62	WBC **W**	0.24^{BCD}	1.48^{ABC}	1.46^{B}	1.06
PC **W**	1.21^{A}	0.85^{ABCD}	0.01**	1.03	PPC **W**	0.17^{CD}	1.11^{BC}	1.73^{AB}	1.00
BL **W**	0.50^{B}	0.49^{D}	0.02**	0.50	WBL **W**	0.29^{ABC}	1.63^{ABC}	1.52^{AB}	1.15
PO **W**	0.71^{AB}	0.79^{BCD}	0.02**	0.75	PPO **W**	0.33^{AB}	1.17^{BC}	2.37^{A}	1.29
BP **W**	0.26^{B}	1.42^{A}	0.03**	0.84	PBP **W**	0.28^{BCD}	1.91^{A}	1.46^{B}	1.22
CP **W**	0.64^{B}	1.25^{AB}	0.01**	0.95	POP **W**	0.42^{A}	1.69^{AB}	1.14^{B}	1.08
PP **W**	0.41^{B}	0.73^{BCD}	0.04**	0.57	BPP **W**	0.20^{CD}	1.49^{ABC}	1.57^{AB}	1.09
PP **W**	0.26^{B}	0.74^{BCD}	0.04**	0.50	WPP **W**	0.25^{BCD}	1.92^{A}	1.21^{B}	1.13
Mean	0.58	0.89	0.04	0.73	**Mean**	0.26	1.49	1.59	1.12

W – Wheat; **B** – Barley; **O** – Oats; **C** – Canola; **L** – Lupin; **P** – Pasture

** Data was not analyzed statistically due to no green leaves left at some replications

Means followed by the same letter in a column are not significantly different

Ear dry mass and number of ears

Responses with regard to both the number of ears m^{-2} and dry mass of ears (g m^{-2}) for different crop rotation systems in 2004 and 2005 were similar to that at harvest (Chapter 7) (Table 7.1) and will be discussed in Chapter 7.

Total dry mass of wheat plants

Total dry mass of wheat plants at the different sampling dates was calculated as the sum of stem dry mass, leaf dry mass and ear dry mass in g m^{-2}. As a result, trends for total dry mass were very similar to that of individual plant components (Table 6.5).

During 2004, total dry mass at flowering (98 days after planting) varied between 212.9 g m^{-2} where wheat was planted after two years of pasture (PPW) and 455.7 g m^{-2} where wheat was planted after canola (BCW).

Lowest total dry mass at flowering (99 days after planting) in 2005 was obtained where wheat was planted after canola (WBCW: 595.2 g m^{-2}), lupins (WBLW: 614.8 g m^{-2}) or wheat (PPWW: 617.0 g m^{-2}) and the highest where wheat was planted after oats (PPOW: 891.1 g m^{-2}) or one year of pasture (POPW: 865.5 g m^{-2}). As these crop rotations also on average (mean values for three sampling dates) produced respectively the lowest and highest total dry mass, it is clear that not only did vegetative growth and development of wheat plants differed between the 2004 and 2005 growing season due to rainfall, but the vegetative growth and development of wheat in response to crop rotation also differed.

In general best vegetative growth and development of wheat during the drier 2004 season were obtained where wheat was planted after either one year of pasture (CPW: 444.3 g m^{-2}) or canola (PCW: 462.3 g m^{-2}) in a crop rotation where wheat was rotated with one year of canola and legume pastures (medics and clovers) and the poorest vegetative growth where wheat was planted after two years of these legume pastures. Differences may to a large extent be attributed to differences in plant populations (germination and seedling survival), N availability and weed (*Lolium* spp.) infestations (Chapter 5).

During the higher rainfall season (2005), yield potentials created by vegetative growth and development were generally higher and best results were obtained where wheat was planted after one year of pasture (POPW: 345.9 g m^{-2}) or oats (PPOW: 345.1 g m^{-2}) in rotations where wheat was rotated with oats and legume pastures. During this year, growth and development of wheat planted after either canola (WBCW: 255.3 g m^{-2} ; PPCW: 277.8 g m^{-2}) or wheat crops (PPWW: 246.3 g m^{-2}) were less than after the already mentioned pasture/oats systems, although differences in plant population also contributed to the differences in this year. Other factors such as ryegrass infestations where wheat was planted after wheat (Table 5.4) probably also played an important role.

Table 6.5 Total dry mass (roots excluded) of wheat plants (g m^{-2}) at different growth stages (days after planting) in response to different crop rotation systems during 2004 and 2005

Total dry plant mass (g m^{-2})									
2004					**2005**				
CRS	**Days after planting**			**Mean**	**CRS**	**Days after planting**			**Mean**
	58	**98**	**139**			**36**	**58**	**99**	
PW **W**	52.0^{B}	346.2^{AB}	783.9^{AB}	394.0	PPW **W**	22.9^{C}	98.9^{C}	617.0^{A}	246.3
BC **W**	63.6^{AB}	455.7^{A}	686.0^{ABC}	401.8	WBC **W**	25.7^{ABC}	144.9^{ABC}	595.2^{A}	255.3
PC **W**	116.2^{A}	334.7^{AB}	936.1^{A}	462.3	PPC **W**	20.0^{C}	110.3^{BC}	703.1^{A}	277.8
BL **W**	49.1^{B}	293.9^{AB}	521.1^{BC}	288.0	WBL **W**	31.1^{ABC}	154.7^{AB}	614.8^{A}	266.9
PO **W**	66.6^{AB}	365.3^{AB}	666.5^{ABC}	366.1	PPO **W**	35.2^{AB}	109.0^{BC}	891.1^{A}	345.1
BP **W**	20.3^{B}	280.9^{AB}	685.8^{ABC}	329.0	PBP **W**	27.9^{ABC}	164.2^{A}	703.7^{A}	298.6
CP **W**	55.5^{B}	368.6^{AB}	908.9^{A}	444.3	POP **W**	37.2^{A}	135.2^{ABC}	865.5^{A}	345.9
PP **W**	38.5^{B}	276.1^{AB}	679.3^{ABC}	331.3	BPP **W**	25.4^{BC}	134.3^{ABC}	738.6^{A}	299.4
PP **W**	22.7^{B}	212.9^{B}	432.8^{C}	222.8	WPP **W**	25.0^{BC}	152.5^{AB}	654.9^{A}	277.5
Mean	53.8	326	700	360.0	**Mean**	27.8	133.8	709.3	290.3

W – Wheat; **B** – Barley; **O** – Oats; **C** – Canola; **L** – Lupin; **P** – Pasture

Means followed by the same letter in a column are not significantly different

N production (g m^{-2}) of leaves, stems and ears of wheat

The total N content (g m^{-2}) of wheat plants sampled at 139 days after planting in 2004 and at 99 days after planting in 2005 showed significant differences due to the crop rotation used (Table 6.6). In 2004 the N content varied between 5.1 g m^{-2} where wheat was planted after two years of pasture (PPW) and 6.4 g m^{2} where wheat followed lupins (BLW) to 11.0 g m^{-2} and 12.0 g m^{-2} where wheat was planted after canola (PCW) and one year of pasture (CPW) respectively.

In 2005, lowest N content was obtained from wheat planted after lupins (WBLW: 10.5) and canola (WBCW: 10.7). The highest N contents were once again obtained where wheat was planted after oats (PPOW: 15.6) and after one year of pastures (POPW: 13.9). N content in wheat plants during 2005 were therefore even at 99 days after planting substantially higher compared to that at maturity (139 days after planting) in 2004. This incidence is most probably due to lower rainfall in 2004 causing reduced growth and thus lower N uptake (Deidda, Giunta & Motzo, 1995). Although N content of green leaves for the 139 days after planting sampling during 2004 were not included, because the material of some samples were not enough to be analyzed, it would not make much of a difference because the dry mass of these samples were very small. The higher N contents (g m^{-2}) for 2005, show similar trends than the higher biomass production during the higher rainfall season and for this reason it was no surprise to find that crop rotations that produced the highest biomass in the respective years, also resulted in the highest N contents.

Table 6.6 N content (g m^{-2}) of wheat (roots excluded) in response to different crop rotation systems during 2004 and 2005

Plant N-weight/Ground area (g m^{-2})			
2004		**2005**	
CRS	**Days after planting**	**CRS**	**Days after planting**
	139		**99**
PW **W**	8.4^{AB}	PPW **W**	11.6^{AB}
BC **W**	7.9^{AB}	WBC **W**	10.7^{B}
PC **W**	11.0^{A}	PPC **W**	12.1^{AB}
BL **W**	6.4^{B}	WBL **W**	10.5^{B}
PO **W**	8.9^{AB}	PPO **W**	15.6^{A}
BP **W**	9.1^{AB}	PBP **W**	12.5^{AB}
CP **W**	12.0^{A}	POP **W**	13.9^{AB}
PP **W**	8.6^{AB}	BPP **W**	13.9^{AB}
PP **W**	5.1^{B}	WPP **W**	11.5^{AB}
Mean	8.6	**Mean**	12.5

W – Wheat; **B** – Barley; **O** – Oats; **C** – Canola; **L** – Lupin; **P** – Pasture

Means followed by the same letter in a column are not significantly different

Conclusions

Response in growth of wheat plants differ between years probably due to differences in growth conditions (rainfall and/or soil) or because the crop rotations were used for only a few years and conditions like soil fertility, weeds and diseases have not yet stabilized.

During 2004 the highest vegetative growth were recorded with wheat after one year of pasture or canola in systems where wheat was rotated with canola and legume pastures and to a lesser extend where wheat was planted after oats in a pasture/oats/wheat rotation. Worst results where obtained with wheat after two years of pasture. Vegetative growth and development response to crop rotation had similar trends with differences found in plant populations and root growth.

During 2005 best results were obtained with wheat after either one year of pasture or oats in pasture/oats/wheat rotations and the worst vegetative growth where wheat was planted after either wheat or canola. Although plant establishment (plant populations) and root development again contributed to differences found, other factors such as severe weed infestations (*Lolium* spp.) may play a role.

References

AGENBAG, G.A. & MAALI, S.H., 2003. Effect of soil tillage, crop rotation and nitrogen application rates on N content of spring wheat (*Triticum aestivum*) in the Swartland wheat producing area of South Africa. *S. Afr. J. Plant Soil* 21(4), 255-260.

ARC-SGI, 2007. Production of small grains in the winter rainfall region. The research and technology manager, ARC-Small Grain Institute, Private Bag X29, Bethlehem, 9700.

ANGUS, J.F., HERWAARDEN, A.F. & HOWE, G.N., 1991. Productivity and break crop effects of winter-growing oilseeds. *Aust. J. Exp. Agric*. 31(5), 669-677.

BENDOTTI, S., EASTHAM, J., HOWELL, M.R. & PROFFITT, A.P.B., 1993. The effect of sheep trampling and grazing on soil physical properties and pasture growth of a red-brown earth. *Aust. J. Agr. Res*. 44(2), 317-331.

BERZSENYI, Z., GYORFFY, B. & LAP, D., 2000. Effect of crop rotation and fertilization on maize and wheat yields and yield stability in a long-term experiment. *Europ. J. Agronomy* 13, 225-244.

BUGBEE, B.G. & SALISBURY, F.B., 1988. Exploring the limits of crop productivity. *Plant Physiol*. 88, 869-878.

CASTILLO, J.E., LOPEZ-BELLIDO, L., LOPEZ-BELLIDO, F.J. & LOPEZ-BELLIDO R.J., 2000. Effects of tillage, crop rotation and nitrogen fertilization on wheat under rainfed Mediterranean conditions. *Agron. J*. 92(6), 1054-1063.

CHAN, K.Y. & HEENAN, D.P., 1996. Effect of tillage and stubble management on soil water storage, crop growth and yield in a wheat-lupin rotation in southern NSW. *Aust. J. Agr. Res.* 47, 479-488.

DEIDDA, M., GIUNTA, F. & MOTZO, R., 1995. Effects of drought on leaf area development, biomass production and nitrogen uptake of durum wheat grown in a Mediterranean environment. *Aust. J. Agric. Res.* 46, 99-111.

GALANTINI, J.A., IGLESIAS, J.O., LANDRISCINI, M.R., MIGLIERINA, A.M. & ROSELL, R.A., 2000. The effects of crop rotation and fertilization on wheat productivity in the Pampean semiarid region of Argentina 2. Nutrient balance, yield and grain quality. *Soil Till. Res.* 53, 137-144.

KIRKEGAARD, J.A. & SARWAR, M., 1998. Biofumigation potential of *brassicas*. 1. Variation in glucosinolate profiles of diverse field-grown *Brassicas*. *Plant Soil*, 201, 71-89.

LOPEZ-BELLIDO, L., FUENTES, M., CASTILLO, J.E. & LOPEZ-BELLIDO, F.J., 1998. Effect of tillage, crop rotation and nitrogen fertilization on wheat grain quality grown under rainfed Mediterranean conditions. *Field Crop Res.* 57, 265-276.

PUCKRIDGE, D.W. & RATKOWSKY, D.A., 1971. Photosynthesis of wheat under field conditions. *Aust. J. Agric. Res.* 22, 11-20.

RICHARDS, R.A. & TOWNLEY-SMITH, T.F., 1987. Variation in leaf area development and its effect on water use, yield and harvest index of droughted wheat. *Aust. J. Agric. Res.* 38, 983-982.

SMITH, B.J., KIRKEGAARD, J.A. & HOWE, G.N., 2004. Impacts of *Brassica* break crops on soil biology and yield of following crops. *Aust. J. Agr. Res.* 55, 1-11.

Chapter 7

The effect of crop rotation on yield and quality of spring wheat

Introduction

Grain yield and quality of wheat are affected by different preceding crops (Chan & Heenan, 1996; Baldock *et al*., 2004). These yield and quality responses are however often related to climatic (seasonal) conditions during the wheat and different preceding crop phases (Angus *et al*., 1994) in a crop rotation system. Thus, the objective of this study was to determine the effect of different crop rotation systems on yield and quality of spring wheat grown in the Ruens wheat producing area of South Africa over two consecutive growing seasons.

Materials and Methods

More details of the locality, climate, experimental layout, general production techniques and statistical analyses are presented in Chapter 3.

Grain yield was calculated using yield components measured on a 1.5 m^2 area from each replication (sub-plot) (Chapter 3) that was harvested by hand. A combine harvester was used on the remainder of each 0.25 ha plots that was however not used in this study. The yield components measured were thousand kernel mass (g), ears m^{-2}, spikelets per ear and kernels per spikelet (Table 7.1). All ears for each replication (sub-plot) (1.5 m^{-2}) were collected and counted. Fifty ears from each sub-plot were selected randomly and the number of spikelets per ear was counted. There-after all ears were thrashed to determine the grain yield (g m^{-2} converted to t ha^{-1}). The thousand kernel mass (TKM) of each sub-plot was determined by using a Numigral seedcounter to count 1000 seeds for each collected sub-plot which was subsequently weighed. To determine the number of kernels m^{-2} and kernels per spikelet, the following equations were used:

i) Number of kernels m^{-2} = Grain yield (g m^{-2}) ÷ TKM (g) × 1000

ii) Kernels per spikelet = Number of kernels m^{-2} ÷ (Number of ears m^{-2} × Number of spikelets per ear)

Quality parameters measured were grain protein (%), falling number (sec), dough development time (min) and flour yield (%) (Table 7.2). The Hagberg falling number was determined using a Falling Number 1400 apparatus (AACC, 1983). Grain protein was measured using near infra-red spectroscopy (Technikon Infra Alizer 400). Dough development time was determined by using the mixograph method. Flour yield was determined from 100 g samples by using a Brabender Quadrumat Senior mill.

Results and Discussion

Yield

Yield and yield components for different crop rotation systems in 2004 and 2005 are presented in Table 7.1. Although calculated yields (from 1.5 m^{-2}) were slightly different from that obtained by combine harvesting, trends for different rotation systems were similar. Further discussions of yield will therefore focus only on the calculated yield.

Grain yield obtained in 2004 (mean: 2.057 t ha^{-1}) was generally lower compared to 2005 (mean: 3.758 t ha^{-1}) and significant yield differences (P=0.05) occurred between different crop rotation systems in 2004, but not in 2005 (Table 7.1).

In 2004, the highest yield was produced with cash crop rotations where wheat was preceded by canola (BCW: 2.405 t ha^{-1}); lupins (BLW: 2.250 t ha^{-1}) and one year of pasture (CPW: 2.250 t ha^{-1}), followed by one of the two crop rotation systems where wheat was preceded by one year of pasture (BPW: 2.193 t ha^{-1}). These yields were significant higher than yields produced by crop rotations where wheat was preceded by two consecutive years of pasture (PPW: 1.778 t ha^{-1}; 1.836 t ha^{-1}).

Although no significant differences (P=0.05) in yield of wheat due to the different crop rotation systems used, were found in 2005, the highest yields were produced by crop rotations where wheat was planted after one year of pasture (POPW: 4.018 t ha^{-1}), canola (PPCW: 4.017 t ha^{-1}) or oats (PPOW: 4.012 t ha^{-1}). Lower yields were again produced by crop rotations where

Table 7.1 Effect of different crop rotation systems (CRS) on yield and yield components of wheat grain crops in 2004 and 2005 at Tygerhoek

Wheat yield Calculated (t ha^{-1})				**Wheat yield Combine harvested (t ha^{-1})**			
2004		**2005**		**2004**		**2005**	
CRS	**t ha^{-1}**	**CRS**	**t ha^{-1}**	**CRS**	**t ha^{-1}**	**CRS**	**t ha^{-1}**
PW **W**	1.967^{BCD}	PPW **W**	3.432^{A}	PW **W**	2.115	PPW **W**	3.564
BC **W**	2.405^{A}	WBC **W**	3.800^{A}	BC **W**	2.216	WBC **W**	3.581
PC **W**	1.970^{BCD}	PPC **W**	4.017^{A}	PC **W**	2.064	PPC **W**	3.657
BL **W**	2.250^{AB}	WBL **W**	3.658^{A}	BL **W**	2.333	WBL **W**	3.375
PO **W**	1.868^{BCD}	PPO **W**	4.012^{A}	PO **W**	2.056	PPO **W**	3.615
BP **W**	2.193^{ABC}	PBP **W**	3.991^{A}	BP **W**	2.360	PBP **W**	3.539
CP **W**	2.250^{AB}	POP **W**	4.018^{A}	CP **W**	2.546	POP **W**	3.471
PP **W**	1.778^{D}	BPP **W**	3.513^{A}	PP **W**	1.955	BPP **W**	2.985
PP **W**	1.836^{CD}	WPP **W**	3.382^{A}	PP **W**	2.131	WPP **W**	3.129
Mean	2.057	**Mean**	3.758	**Mean**	2.197	**Mean**	3.435
Ears m^{-2}				**Thousand kernel mass (g)**			
2004		**2005**		**2004**		**2005**	
CRS	**Ears**	**CRS**	**Ears**	**CRS**	**g**	**CRS**	**g**
PW **W**	221^{A}	PPW **W**	265^{AB}	PW **W**	26.6^{BC}	PPW **W**	32.7^{C}
BC **W**	217^{AB}	WBC **W**	267^{AB}	BC **W**	29.3^{BC}	WBC **W**	36.7^{A}
PC **W**	222^{A}	PPC **W**	286^{AB}	PC **W**	26.0^{C}	PPC **W**	34.0^{BC}
BL **W**	217^{AB}	WBL **W**	256^{AB}	BL **W**	27.6^{BC}	WBL **W**	36.4^{AB}
PO **W**	220^{A}	PPO **W**	297^{A}	PO **W**	26.1^{C}	PPO **W**	35.7^{AB}
BP **W**	214^{AB}	PBP **W**	268^{AB}	BP **W**	30.0^{AB}	PBP **W**	37.9^{A}
CP **W**	224^{A}	POP **W**	283^{AB}	CP **W**	28.8^{BC}	POP **W**	37.7^{A}
PP **W**	187^{AB}	BPP **W**	250^{B}	PP **W**	30.1^{AB}	BPP **W**	34.1^{BC}
PP **W**	174^{B}	WPP **W**	261^{AB}	PP **W**	32.9^{A}	WPP **W**	33.9^{BC}
Mean	211	**Mean**	270	**Mean**	28.6	**Mean**	35.5
Spikelets per ear				**Kernels per spikelet**			
2004		**2005**		**2004**		**2005**	
CRS	**Spikelet**	**CRS**	**Spikelet**	**CRS**	**Kernels**	**CRS**	**Kernels**
PW **W**	16.7^{AB}	PPW **W**	16.6^{ABC}	PW **W**	2.0^{B}	PPW **W**	2.4^{A}
BC **W**	15.2^{C}	WBC **W**	17.1^{AB}	BC **W**	2.5^{A}	WBC **W**	2.3^{A}
PC **W**	15.4^{C}	PPC **W**	16.8^{ABC}	PC **W**	2.2^{AB}	PPC **W**	2.5^{A}
BL **W**	15.6^{BC}	WBL **W**	17.4^{A}	BL **W**	2.4^{A}	WBL **W**	2.3^{A}
PO **W**	15.5^{BC}	PPO **W**	16.5^{ABC}	PO **W**	2.1^{B}	PPO **W**	2.3^{A}
BP **W**	17.0^{A}	PBP **W**	16.2^{BC}	BP **W**	2.0^{B}	PBP **W**	2.5^{A}
CP **W**	15.8^{ABC}	POP **W**	16.0^{C}	CP **W**	2.2^{AB}	POP **W**	2.4^{A}
PP **W**	16.1^{ABC}	BPP **W**	16.7^{ABC}	PP **W**	2.0^{B}	BPP **W**	2.5^{A}
PP **W**	15.1^{C}	WPP **W**	16.6^{ABC}	PP **W**	2.1^{B}	WPP **W**	2.3^{A}
Mean	15.8	**Mean**	16.7	**Mean**	2.2	**Mean**	2.4

W – Wheat; **B** – Barley; **O** – Oats; **C** – Canola; **L** – Lupin; **P** – Pasture

Means followed by the same letter in a column are not significantly different

wheat followed two consecutive years of pasture (BPPW: 3.513; WPPW: 3.382 t ha^{-1}), but also where wheat was planted in wheat stubble (PPWW: 3.432 t ha^{-1}). Low yields obtained with the crop rotation system including two consecutive years of wheat (PPWW) may be the result of higher weed (Table 5.4) and *Septoria* (Table 5.8) infestations. Low yields obtained in both years with wheat after two successive years of pasture, may be the result of heavy infestations with *Lolium spp.* in 2004 (Table 5.4) and compacted soil conditions which result in low plant populations (Table 5.4) and poor root development (Table 6.1) in both years. Although plant development were somewhat more vigorous in 2005, probable soil compaction caused by the grazing of animals during winter months when the soil is wet (Bendotti *et al*., 1993), is likely to have resulted in generally poor plant development in spite of high soil mineral nitrogen contents (Table 5.5). The more relatively high vegetative growth during 2005, which eventually resulted in non-significant yield differences, were most probably due to the higher rainfall and thus higher soil moisture contents which reduces the negative effect of soil compaction.

Although it is not that easy to give reasons for the crop rotations that resulted in the highest wheat yields, high yields obtained where wheat was planted after one year of pasture (CPW: 2004; POPW: 2005) or after oats in 2005 (PPOW) show similar trends than the high plant populations (good establishment), excellent rooting (root mass) and generally vigorous plant growth measured in these rotations (Appendix 5). Reasons for high yields obtained where wheat was planted after canola (BCW: 2004; PPCW: 2005) and especially lupins in 2004 (BLW), which showed high *Lolium* infestations and generally poor crop growth, are however not that clear.

Ears m^{-2}

On average, higher number of ears m^{-2} was produced in 2005 (270 ears m^{-2}) compared to 2004 (211 ears m^{-2}), due to more plants m^{-2} (Table 5.4) and more vigorous plant growth (Tables 6.2; 6.3) during the higher rainfall year. Ears m^{-2} of the wheat crop was significantly affected by the crop sequence used in both 2004 and 2005 (Table 7.1). Lowest number of ears m^{-2} was produced where wheat followed after two consecutive years of pasture in 2004 (PPW: 174 ears m^{-2}) and 2005 (BPPW: 250 ears m^{-2}). This again showed similar trends than the low number of plants m^{-2} recorded for these crop rotations (Appendix 6). Because these rotations also produced low grain yields these results indicated that ears m^{-2} made a major contribution to differences in grain yield.

The highest number of ears m^{-2} was recorded in crop rotations where wheat was preceded by one year of pasture in 2004 (CPW: 224 ears m^{-2}) or oats in 2005 (PPOW: 297 ears m^{-2}). These rotations showed vigorous plant growth, as measured by tiller numbers, leaf area, plant weights (Tables 6.2-6.4), root mass (Table 6.1), high numbers of plants m^{-2} (Table 5.4) and eventually high grain yields (Table 7.1). In contrast to high rainfall years such as 2005, where number of ears m^{-2} showed similar trends than grain yield, ear numbers did not always show clear trends than yield in dry years due to the well known (Evans, Fischer & Wardlaw, 1975) compensation ability of wheat for different yield factors. In 2004 for example, high numbers of ears m^{-2} were produced where wheat was planted after canola (PCW: 222 ears m^{-2}) and on wheat stubble (PWW: 221 ears m^{-2}), but these rotation systems did not produce high grain yields.

Thousand kernel mass

On average thousand kernel mass was higher in 2005 compared to 2004 (Table 7.1), probably due to greater availability of soil moisture during the grain filling phase of the wheat crop in 2005. Thousand kernel mass (TKM) of the wheat crop differed significantly as a result of the crop rotation systems practiced in both 2004 and 2005, but different trends were found in different years (Appendix 6).

In 2004, the highest thousand kernel mass was recorded for the two crop rotation systems where wheat was preceded by two succeeding years of pasture (PPW: 30.1g; 32.9 g). These rotations produced the lowest number of ears m^{-2} and lowest grain yields. The lowest thousand kernel mass was produced where wheat was planted after a canola crop (PCW: 26.0 g), oats (POW: 26.1 g) or on wheat stubble (PWW: 26.6 g). These rotations resulted in high numbers of ears m^{-2}. In general similar trends between TKM and ears m^{-2} therefore did not exist during 2004.

In 2005 the highest thousand kernel mass was produced in the crop rotation systems where wheat was preceded by one year of pasture (PBPW: 37.9; POPW: 37.7 g) or canola (WBCW: 36.7 g) and the lowest thousand kernel mass where wheat was planted on wheat stubble (PPWW: 32.7 g). In contrast to 2004, TKM did not show a strong relation with ears m^{-2} and some crop rotations which produced high TKM values (PBPW; POPW) and also produced high numbers of ears m^{-2}, indicating less competition between different growth components within the same plant during the higher rainfall year of 2005.

Spikelets per ear

Spikelets per ear in the different crop rotation systems in 2004 and 2005 are presented in Table 7.1.

The number of spikelets per ear that was produced where wheat was preceded by one year of pasture (BPW: 17.0) in 2004, was significantly higher than the number of spikelets produced where wheat was preceded by canola (BCW: 15.2; PCW: 15.4) or two years of pasture (PPW: 15.1). The low numbers of spikelets per ear where wheat was preceded by canola was probably due to low availability of mineral N (Pouzet, 1995) following the canola as indicated by low soil mineral N levels (Table 4.2), during the period when wheat was planted till 60 days after planting when spikelet initiation occurred. The low numbers of spikelets per ear where wheat was preceded by two consecutive years of pasture (PPW), on the other hand, was most probably caused by low soil N availability due to competition from weeds (Table 5.4) and less available soil moisture.

The highest number in 2005 was recorded where wheat was preceded by lupins (WBLW: 17.4) and the lowest where wheat was preceded by one year of pasture (POPW: 16.0). Thus, differences in spikelets per ear seemed to be smaller in 2005 compared to 2004, most probably due to the higher rainfall and thus high soil moisture availability in 2005.

Kernels per spikelet

Kernels per spikelet for different crop rotation systems in 2004 and 2005 are summarized in Table 7.1. In 2004 the number of kernels per spikelet varied between 2.0 (BPW: 2.0; PPW: 2.0; PWW: 2.1) and 2.5 (BCW), while high values of 2.4 kernels per spikelet were also produced where wheat was planted after lupins (BLW). In 2005 values varied between 2.3 and 2.5 kernels per spikelet and no significant differences (P=0.05) due to crop rotation used were found in this higher rainfall year.

Grain protein (%)

On average, percentage grain protein of the wheat crop was higher in the low rainfall and low yielding year of 2004 (13.8%) compare to the high rainfall and high yielding year of 2005 (12.2%) and thereby illustrating the well known (Castillo, *et al.,*1998; Savin & Stone, 1999) negative trend between wheat yield and percentage grain protein (Table 7.2) (Appendix 6).

In 2004 the highest percentage grain protein was produced where wheat was preceded by two years of pasture (PPW: 14.4%; 14.7%). Low grain yields were recorded in these rotations. High protein contents were also produced where wheat followed after canola (PCW: 14.6%), but this system produced an average grain yield. Where wheat was planted after canola, but without a preceding pasture crop (BCW), the lowest protein percentage (12.2%) was recorded, but this wheat crop produced the highest yield. Where wheat was preceded by lupins (BLW), a similar trend namely low protein but a high yield was obtained. All protein values were however above 12% and should therefore be regarded as high in spite of the negative trend with grain yield, which indicated that nitrogen availability was not a real problem.

In 2005, highest percentage grain protein was again recorded in the crop rotation where wheat was preceded by two consecutive years of pasture (BPPW: 12.7%) and the lowest in the crop rotation system where wheat was preceded by one year of pasture (POPW: 11.9%) or planted in wheat stubble (PPWW: 11.9%). These crop rotations respectively produced the highest and second lowest grain yields (Table 7.1). Where wheat was planted after canola in a rotation which also included two consecutive years of pasture (PPCW), high protein contents as well as high yields were also recorded. It is therefore clear that crop rotations, where wheat followed after two consecutive years of legume pastures, again resulted in high grain protein contents but generally low yields. This negative relation between grain yield and protein content however did not exist for all crop rotations in 2005 because no differences in grain yield was recorded.

Table 7.2 Effect of crop rotation systems (CRS) on bread making quality of wheat produced 2004 and 2005 at Tygerhoek

Grain protein (%)				**Falling number (sec)**			
2004		**2005**		**2004**		**2005**	
CRS	**%**	**CRS**	**%**	**CRS**	**sec**	**CRS**	**sec**
PW **W**	13.7^{ABC}	PPW **W**	11.9^{C}	PW **W**	349^{ABC}	PPW **W**	365^{AB}
BC **W**	12.2^{D}	WBC **W**	12.0^{BC}	BC **W**	301^{D}	WBC **W**	332^{C}
PC **W**	14.6^{A}	PPC **W**	12.6^{AB}	PC **W**	354^{ABC}	PPC **W**	368^{A}
BL **W**	12.7^{CD}	WBL **W**	12.1^{ABC}	BL **W**	323^{CD}	WBL **W**	354^{ABC}
PO **W**	14.2^{AB}	PPO **W**	12.0^{BC}	PO **W**	369^{A}	PPO **W**	363^{AB}
BP **W**	13.5^{BC}	PBP **W**	12.6^{AB}	BP **W**	359^{AB}	PBP **W**	345^{ABC}
CP **W**	14.1^{AB}	POP **W**	11.9^{C}	CP **W**	373^{A}	POP **W**	335^{BC}
PP **W**	14.7^{A}	BPP **W**	12.7^{A}	PP **W**	348^{ABC}	BPP **W**	340^{ABC}
PP **W**	14.4^{AB}	WPP **W**	12.3^{ABC}	PP **W**	335^{BC}	WPP **W**	345^{ABC}
Mean	13.8	**Mean**	12.2	**Mean**	346	**Mean**	350
Mixograph dough development (min)				**Flour yield (%)**			
2004		**2005**		**2004**		**2005**	
CRS	**min**	**CRS**	**min**	**CRS**	**%**	**CRS**	**%**
PW **W**	3.18^{B}	PPW **W**	3.25^{A}	PW **W**	72.3^{AB}	PPW **W**	73.0^{AB}
BC **W**	3.15^{B}	WBC **W**	2.83^{AB}	BC **W**	71.8^{B}	WBC **W**	74.2^{AB}
PC **W**	2.93^{BC}	PPC **W**	2.68^{B}	PC **W**	73.7^{AB}	PPC **W**	74.3^{AB}
BL **W**	3.18^{B}	WBL **W**	2.93^{AB}	BL **W**	71.9^{B}	WBL **W**	73.5^{AB}
PO **W**	2.63^{C}	PPO **W**	2.95^{AB}	PO **W**	72.7^{AB}	PPO **W**	72.9^{AB}
BP **W**	3.33^{AB}	PBP **W**	2.75^{AB}	BP **W**	73.8^{AB}	PBP **W**	74.1^{AB}
CP **W**	3.28^{AB}	POP **W**	2.73^{AB}	CP **W**	74.5^{A}	POP **W**	74.9^{A}
PP **W**	3.00^{BC}	BPP **W**	2.98^{AB}	PP **W**	72.9^{AB}	BPP **W**	73.6^{AB}
PP **W**	3.60^{A}	WPP **W**	2.88^{AB}	PP **W**	72.7^{AB}	WPP **W**	71.9^{B}
Mean	3.1	**Mean**	2.9	**Mean**	72.9	**Mean**	73.6

W – Wheat; **B** – Barley; **O** – Oats; **C** – Canola; **L** – Lupin; **P** – Pasture

Means followed by the same letter in a column are not significantly different

Falling number (sec)

A falling number of 250 sec and higher is required for flour to be used for bread baking purposes (ARC-SGI, 2007). In 2004 falling numbers varied between 301 sec (lowest) where wheat was planted after canola (BCW) and 373 sec (highest) where wheat was planted after one year of legume pastures (CPW) (Table 7.2). In 2005 falling numbers varied between 332 sec (lowest) where wheat was again planted after canola (WBCW) and 368 sec (highest) where wheat was also planted after canola (PPCW), but in a rotation which included legume pastures. It is therefore clear that although different crop rotation systems resulted in significant differences (P=0.05) in falling numbers of the wheat grain in both years, values are above the norm set for good bread making quality. Differences between crop rotations are therefore irrelevant and because it did not show any trends similar to that for grain yield or grain protein content, should be ignored.

Mixograph dough development time (MDDT) (min)

Mixograph dough development time (MDDT) is an indication of both protein quantity and quality and times of <2.2 min and >3.3 minutes are considered as not acceptable for good bread making purposes, while a time of 2.6 minutes is considered to be optimal (ARC-SGI, 2007). In this study MDDT of the wheat produced in 2004 varied between 2.63 min (lowest) where wheat was planted after oats (POW) and 3.6 min (highest) where wheat was preceded by two succeeding years of legume pastures (PPW) with a mean value for all the crop rotations of 3.1 min (Table 7.2). In 2005 the lowest MDDT (2.68 min) was measured with wheat planted after canola (PPCW) and the highest (3.25 min) with wheat planted in wheat stubble (PPWW) with a mean of 2.9 min for all rotations. Dough development times for most of the wheat produced in different crop rotations were therefore within the limits for good bread making in spite of significant differences due to crop rotation in both years. Because MDDT values did not have trends similar to that for grain protein contents and the same wheat cultivar was grown in all rotations, differences in MDDT are difficult to explain. The larger differences in dough development time between crop rotation systems in 2004 compare to 2005, were however similar to larger differences in grain protein contents during 2004, which might indicated differences in water stress during the grain filling stages. Such differences in water stress might also have an effect on glutenine : gliadine protein ratios (Savin & Stone, 1999) and therefore also protein quality.

Flour yield (%)

Percentage flour yield is an important milling parameter, because it represents the quantity of flour that can be extracted from the grain of wheat. Mean flour yields did not differ much between

2004 (72.9%) and 2005 (73.6%) (Table 7.2). These values as well as individual values for all crop rotations tested were, in spite of significant differences due to crop rotation, within the 70 to 76 % range generally found for hard wheat cultivars (Bergman *et al.*, 1998).

The highest flour yield in 2004 (74.5%) was recorded for wheat grown after canola (CPW), while a flour yield of 74.9% was measured for wheat after pasture and oats (POPW) in 2005. The lowest flour yields were recorded where wheat was grown in cash cropping systems in 2004 (BCW: 71.8 %; BLW: 71.9 %), but in 2005 lowest flour yields were measured where wheat was preceded by two succeeding years of pasture (WPPW: 71.9 %). In general high flour yields were associated with plump kernels (high thousand kernel mass), but in this study flour yield did not show clear responses with either thousand kernel mass or yield in 2004. Although the rotation that resulted in die highest flour yield in 2005 (POPW), also gave the highest yield and a high thousand kernel mass, correlations were again not very convincing and therefore not shown.

Conclusions

Climatic conditions caused larger and more variable differences in yield due to crop rotation systems in 2004 compared to 2005. Although similar trends due to crop rotation used were shown for yield and yield components as found for other parameters measured, such as plants m^{-2}, weed infestations, tillering and mineral-N contend of the soil, other factors (not measured in this study) such as soil compaction from trampling sheep might also have caused significant differences in plant growth and yield.

Trends indicated that wheat preceded by one year of pasture seemed to result in higher yields during seasons with below (2004) and near average (2005) rainfall compared to wheat preceded by two succeeding years of pasture. Cash cropping systems (where wheat is preceded by barley, canola and lupins) and crop rotation systems with wheat preceded by one year of pasture seemed to have the highest yield during a season with below average rainfall. Differences in yield between crop rotation systems were found to be much less during a season with higher rainfall (2005).

Results from both years indicated that legume pastures, as used in this study in various combinations within different crop rotation systems, always seemed to have a positive effect on the wheat grain protein of the following wheat crop compare to other crops used.

References

AACC, 1983. Falling number determination. In approved methods, 8th edn. American Association of Cereal Chemists Inc., St. Paul, MN, USA.

ANGUS, J.F., GARDNER, P.A., KIRKEGAARD, J.A. & KOETZ, E., 1994. Effect of Brassica break crop on the growth and yield of wheat. *Aust. J. Agric. Res*. 45, 529-545.

ARC-SGI, 2007. Guidelines for the production of small grains in the winter rainfall region. University of Stellenbosch. SABBI. SAB Maltings (Pty) Ltd.

BALDOCK, J.A., BELLOTTI, W.D., COX, J.W. & SADRAS, V.O., 2004. Crop rotation effect on wheat grain yield as mediated by changes in the degree of water and nitrogen co-limitation. *Aus. J. Agric. Res*. 55, 599-607.

BENDOTTI, S., EASTHAM, J., HOWELL, M.R. & PROFFITT, A.P.B., 1993. The effect of sheep trampling and grazin on soil physical properties and pasture growth ofot a red-brown earth. *Aus. J. Agric. Res.* 44(2), 317-331.

BERGMAN, C.J., CAMPBELL, K.G., FINNEY, P.L., GUALBERTO, D.G. & SORRELS, M.E., 1998. Genotype and environment effects on wheat quality traits in a population derived from a soft by hard cross. *Cereal Chem .* 75(5), 729-737.

CASTILLO, J.E., FUENTES, M., LOPEZ-BELLIDO, F.J. & LOPEZ-BELLIDO, L., 1998. Effect of tillage, crop rotation and nitrogen fertilization on wheat grain quality grown under rainfed Mediterranean conditions. *Field Crop Res.* 57, 265-276.

CHAN, K.Y. & HEENAN, D.P., 1996. Effect of tillage and stubble management on soil water storage, crop growth and yield in a wheat-lupin rotation in southern NSW. *Aust. J. Agric. Res*. 47, 479-488.

EVANS, L.T., FISCHER, R.A. & WARDLAW, I.F., 1975. Wheat. In: L.T. Evans (ed.). Crop Physiology. Cambridge University Press, London UK.

POUZET, A., 1995. Agronomy. In: D. Kimber & D.I. McGregor (eds.). Brassica oilseeds: Production and utilization. CAB International, Oxon, UK.

SAVIN, R. & STONE, P.J., 1999. Grain quality and its physiological determinants. In: E.H. Satorre and G.A.Slafer (eds.). wheat: ecology and physiology of yield determination. Food Product Press, New York, USA.

Chapter 8

Summary

Crop rotation has a significant effect on wheat crops produced in the Overberg area of the Western Cape. This is why crop rotation is a well integrated practice of crop management used by wheat producers in this area. Although positive effects of crop rotation on wheat yield and quality are often observed, the direct significance and combination of specific crops and the integrated effect from different aspects responsible for this, on the following wheat crop, is not always known. Identification of these aspects and their significance can thus contribute to the better understanding of these integrated effects and thus crop rotation. This understanding thus increase the ability for combining the most optimal crop rotation system for each unique wheat producing situation in this area.

Climate had a significant effect on wheat production in this study. The study continued for two seasons of which the first (2004) had a much lower rainfall season than the average for this area while the second year (2005) had a near average rainfall season. Wheat response to different crop rotation systems was larger in the dry year, but the response to the same crop rotation in the different seasons also seemed to differ in some cases. Due to this variability of rainfall it will be best to use crop rotations that result in optimal wheat crop response in dry as well as wet years.

Number of ears m^{-2} and kernels per spikelet in the dry year, but only number of ears m^{-2} during the wet year seemed to be the only yield components that showed similar trends to grain yield, in response to crop rotations used, while % grain protein was the only quality component that showed clear trends in response to different crop rotation systems used. Crop rotations that included one year of legume pasture and/or canola seem to have a positive effect on wheat growth, yield and quality in both dry and wetter years, while the effect of lupins and oats in wet and dry years seemed to be more variable. Two consecutive years of pasture (medics and clover) seem to result in unacceptable low yields compared to other crop rotation systems tested, although high wheat grain quality was found in crop rotation systems where wheat was planted after pastures. When wheat was planted directly into wheat stubble, yield and quality were not as good as when planted after one year of pastures or canola.

No clear trends were identified to relate to crop rotation used to soil chemical properties. More detailed soil analyses for a longer period than the two years of this study is probably needed. N incubation studies indicated more mineralized N present when legume pasture was included in crop rotation, while soil N mineralized after lupins was surprisingly low. Intermediate soil N mineralization was found when wheat followed a cereal crop. High levels of mineralized N were present after canola at planting of wheat, while N mineralization after planting was low. This finding needs further study.

Soil mineralized N seemed to be the most important aspect influencing wheat yield and quality during a wetter year, while plant populations and vegetative growth of the wheat plants were the most indicative components of wheat yield in a dry year. This was probably influenced by the availability of soil water rather than the amount of N mineralized in the soil. High soil N mineral levels in soils with two consecutive years of legume pasture, at which lowest yields occurred, give an indication of other factors, not measured in this study, which also had a significant influence. Due to this conclusion it seems essential to include soil penetrometer and soil field water capacity measurements during further similar studies.

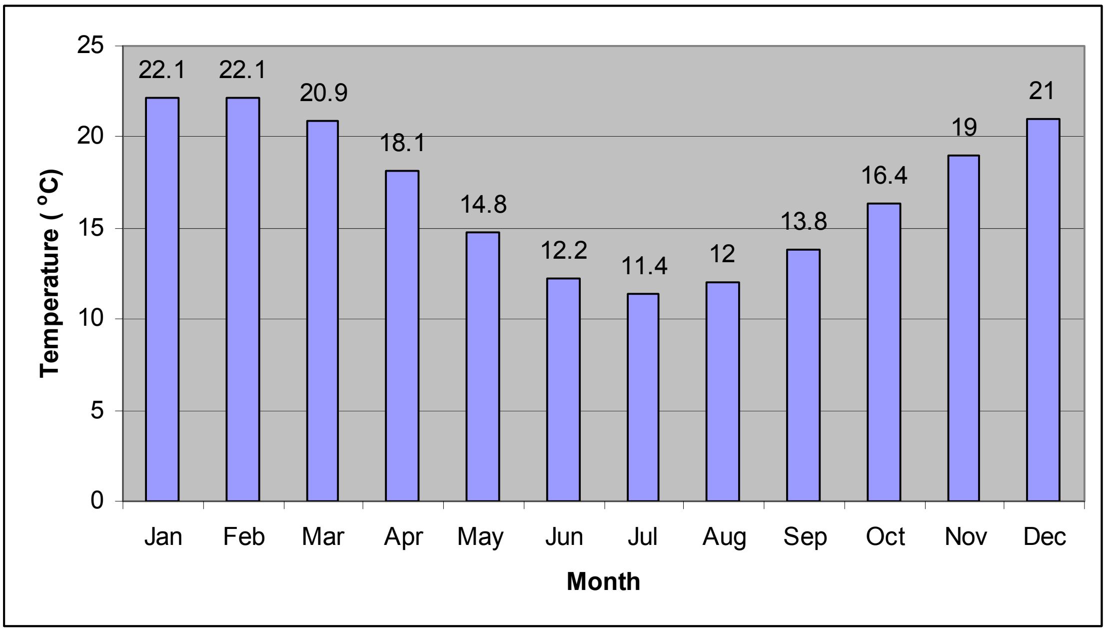
Other factors influencing wheat grain yield and quality such as weed and disease infestations also occurred. Weed populations (primarily *Lolium* spp.) seemed to influence wheat yield and quality that occurred randomly at different crop rotation systems in both years and indicate the importance of effective weed control by integrating crop rotation and herbicide usage into a management strategy. A significantly higher percentage of soil was covered with crop residue when wheat was planted directly into wheat stubble instead of after canola, oats, lupin and legume pasture. This higher percentage of residue cover seemed to cause increased seedling survival and higher incidence of infection from *Septoria*. Less significant trends of foliar and stem disease at the other crop ration systems were recorded. The only other disease symptoms worth mentioned were *Puccinia* that occurred about 90 days after wheat was planted in both years, but no significant difference were found due to crop rotation systems. Symptoms from soil borne disease did occur, but did not seem to have any significant effect on yield and quality of wheat. Symptoms from insect pests were very low and also did not seem to have any significant effect on wheat yield and quality, thus indicating very effective control of insect pest populations due to application of pesticides during these two growing seasons.

Higher disease incidence and low seedling survival occurred during the dry year while lower disease incidence and higher seedling survival occurred during the wetter year. These trends were similar to vegetative growth and grain yield for these crop rotation systems. From this it is clear that different combinations of similar factors can influence wheat performance due to differing climate, indicating the importance for a longer trial than this study. More detailed scoring and identification techniques during a longer trial than the present study are also needed for more conclusive trends in crop residue cover, disease and pest incidence in wheat crops in different crop rotations.

From the above it is clear that although this study provides some very valuable results that contribute to a better understanding on the integrated effects of crop rotation on crop production, this very important field of study need some more research.

Appendix

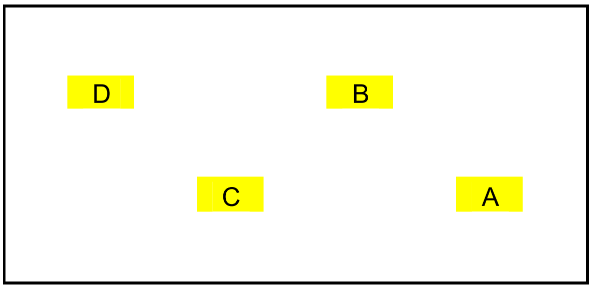
Appendix 1 – Average daily temperature each month during a 60 year period at Tygerhoek



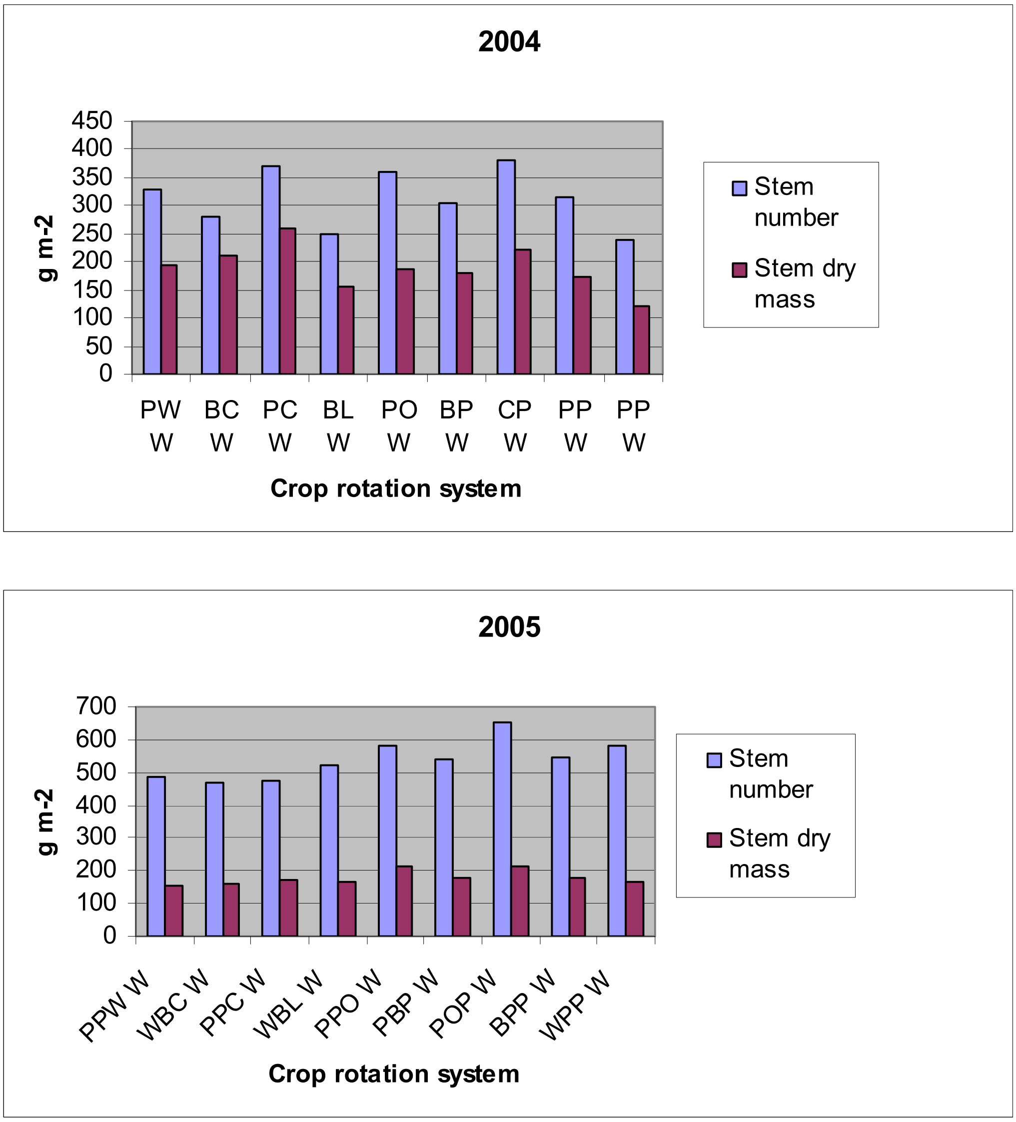
Appendix 2 - Trade names, active ingredients and concentrations of chemicals applied before and after planting of wheat in 2004 and 2005

Trade name	Active ingrediant/s	Concentration
Roundup CT	glyphosate - isopropylammonium	240 g / ℓ
MCPA	Potassium salt	400 g / ℓ
2.4 D amien	Dimethyl amine salt	480 g / ℓ
Gramoxone	Paraquat dicloride	200 g / ℓ
Speed up	(Wetting agent)	
Cossack	Iodosulfuron - methylsodium / mesosulfuron-methyl + safener	30 / 30 g / kg
Ballista	Methylated vegetable oil / emulsifier	700 / 300 g / ℓ
Folimat	Omethoate	400 g / ℓ
Punch C	Carbendazim / flusilazole	125 / 250 g / ℓ
Capitan	Flusilazol	250 g / ℓ
Rogor	Dimethoate	400 g / ℓ
Sipermethrin	Cypermethrin	200 g / ℓ
Chlorpyrophos	Chlorpyrifos	480 g / ℓ
Hussar	Iodosulfuron	50 g / kg
Metasystox	Oxydemeton - methyl	100 g / ℓ
Opus	Epoxiconazole	125 g / ℓ

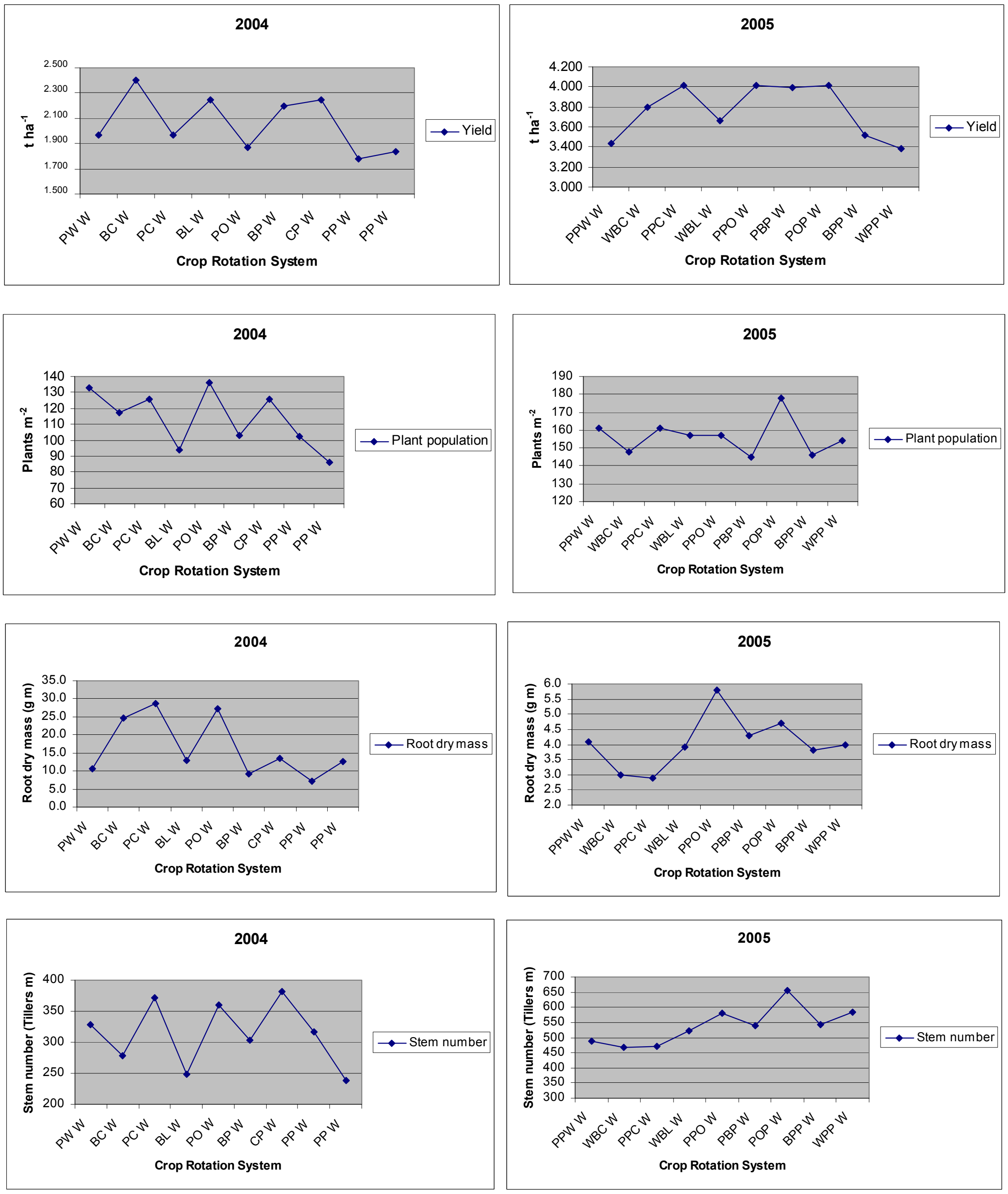
Appendix 3 - The layout of the sub-plots (replications A, B, C and D) within each plot



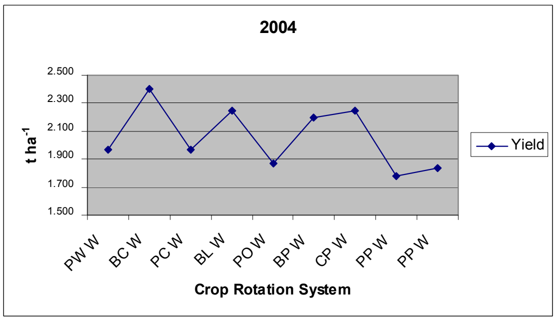
Appendix 4 – Stem numbers (Tillers m^{-2}) and stem dry mass (g m^{-2}) as affected by crop rotation systems in 2004 and 2005

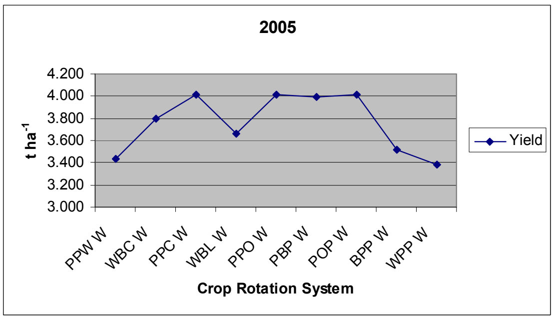


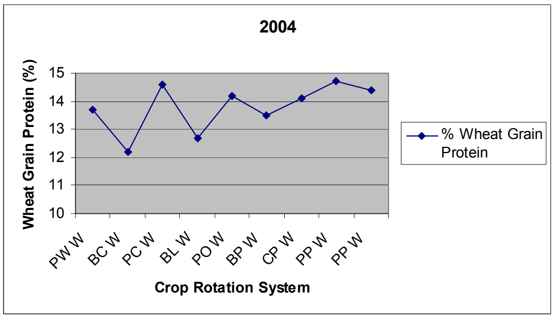
Appendix 5 - The effect of crop rotation on wheat plant populations, root growth, tillering and wheat grain yield during two growing seasons in 2004 and 2005 respectively

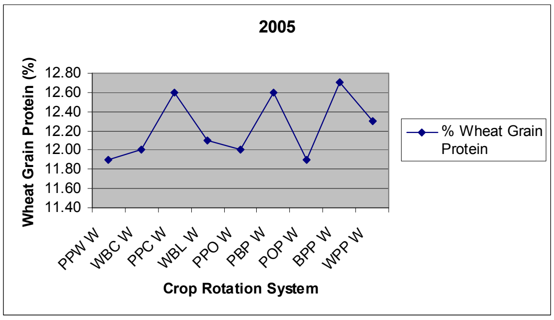


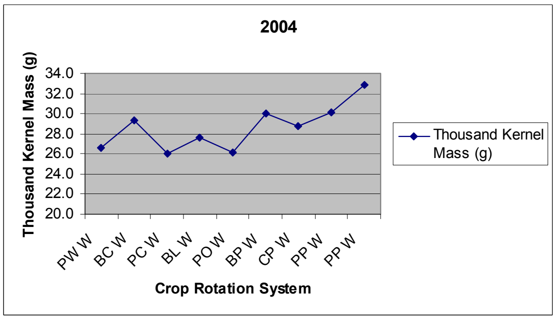
Appendix 6 – The effect of crop rotation on wheat plant populations and wheat grain yield and quality components during two growing seasons in 2004 and 2005 respectively

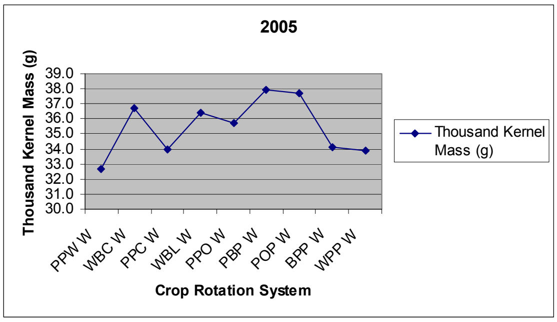


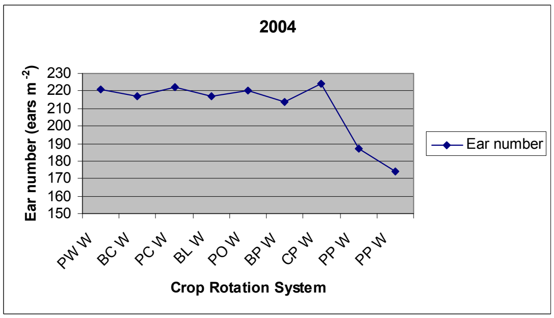


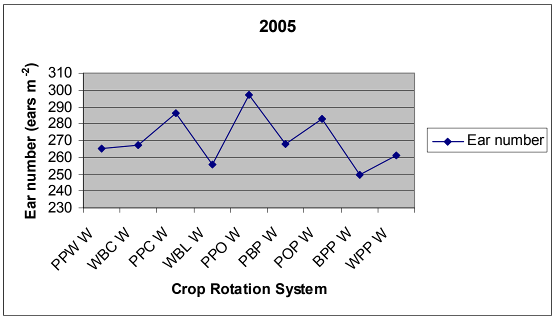












Appendix 6 - Continued