SOIL NITROGEN DYNAMICS AND SPRING WHEAT (*TRITICUM AESTIVUM*) PRODUCTION IN DIFFERENT CROPPING SYSTEMS IN THE SWARTLAND

by

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DECLARATION

I the under-signed declare that the work in this thesis contains my own original work that has never before been submitted as a whole or in part at any other University for the purpose of acquiring a degree.

ABSTRACT

Protein and oilseed production in the winter rainfall region of South Africa (primarily the Southern and Western Cape) is well below the potential for the area. One possible method of increasing production is to convince producers that the inclusion of protein and oilseed rotational crops will enhance the sustainability of wheat production systems. A project to investigate, quantify and elucidate the effect of canola (*Brassica napus*), lupins (*Lupinus angustifolius*) and medics (*Medicago spp.*) on subsequent wheat (*Triticum aestivum*) production as well as their influence on soil fertility in respect to nitrogen was initiated in 1999. The long- term rotational crop system experiment on Langgewens experimental farm near Malmesbury, provided the infrastructure for the project.

During the 1999 and 2000 wheat-growing seasons, 50m^2 plots were demarcated in wheat fields where wheat, lupins, canola or medics were produced in 1998 and 1999 respectively. Each plot was cleared of all vegetation and received no fertilizer N. In these fallow plots, soil samples were collected at three to four week intervals and the available nitrate-N and ammonium-N content of the topsoil (0-15cm depth) and the subsoil (15-30cm depth) were determined.

Additional soil samples were also taken from the topsoil on 09/03/2000 after a summer fallow period. These samples were taken on plots that were subjected to a wheat crop in 1999, but were preceded by either wheat, canola, lupins or medics in 1998. The soil samples were then subjected to a 60-day incubation period at 15°C while being maintained at 75% of their water holding capacity. Mineral N was determined after 0, 3, 7, 15, 30, 45 and 60 days of incubation. Large variation in the nitrogen contents observed made it difficult to always obtain significant differences. The results of the soil investigations however indicate that the inclusion of lupins and medics in wheat cropping systems in the

Swartland could help to limit the decline of mineral N in the soil profile, experienced within a growing season. This will therefore enable farmers to reduce fertilizer inputs without facing soil mineral N depletion.

Plant samples were also collected from wheat plots during the 1999 growing season on three occasions (23/06/99 (growth stage 5), 5/08/99 (growth stage 15), 14/09/99 (growth stage 23)). Plots were selected to represent the same treatments as in the soil sampling procedure during the growing season of 1999 as described above. Plant and tiller numbers of a 0.25m^2 sub sample from each plot were counted and leaf area was determined, whereafter the dry material was weighed. The percentage nitrogen content in the leaves and stems were subsequently determined using Near Infra-Red Spectroscopy. In terms of vegetative growth, little difference was observed. A significant increase in nitrogen content of wheat plants growing in plots where wheat and canola were grown in 1998 was observed in the second plant sampling (growth stage 15) and this was attributed to higher nitrogen topdressing. However, on the third sampling date on 14/9/1999 (growth stage 23), the difference was no longer evident. The most important conclusion to make from this study, is that farmers can probably save on fertilizer inputs when including lupins and medics in their wheat production systems, without risking poorer wheat growth.

At growth stage 28, a 0.25m^2 sub sample of wheat plants was removed at a randomly chosen point in each of the plots described above. Ears and grains were subsequently counted. The wheat remaining on the plots were then harvested at the end of October 1999 using a plot combine. Subsequently the yield, hectolitre mass, thousand grain mass and % crude protein was determined from samples of harvested grain from each plot. The % flour and % bran extraction were then determined whereafter the % flour protein was determined. Micro bread loafs were baked to estimate the loaf volume. Flour and dough properties were also tested using the Falling Number System, mixograph and alveograph. Wheat in cropping systems consisting of legume phases such as lupins and medics, required less nitrogen fertilizer application to achieve statistically the same yield, flour and dough properties. These crop rotations can therefore be considered as more ecologically sustainable and economically viable for the Swartland.

This study was aimed at determining the effect of different crop rotations on soil fertility, and because clear soil fertility trends take time to form, this study was probably too short to obtain fully significant differences.

UITTREKSEL

Proteïen- en oliesaad produksie in die winter reënval streek van Suid Afrika (hoofsaaklik die Suid- en Weskaap) is ver benede die potensiaal vir die streek. Een moontlike manier om die produksie hiervan te verhoog is om produsente in hierdie streek te oortuig dat die insluiting van proteïen en oliesaad gewasse die volhoubaarheid van koring verbouingstelsels sal verhoog. Na aanleiding hiervan, is 'n projek in 1999 van stapel gestuur om die effek van canola (*Brassica napus*), lupiene (*Lupinus angustifolius*) en medics (*Medicago spp.*) op daaropvolgende koring (*Triticum aestivum*) produksie, asook die invloed daarvan op grondvrugbaarheid in terme van stikstofinhoud, te ondersoek. Die langtermyn wisselbouproef op Langgewens proefplaas naby Malmesbury, het as infrastruktuur vir die ondersoek gedien.

Gedurende die 1999 en 2000 koring groeiseisoene is 50m^2 plotte in koringkampe gekies waarop koring, canola, lupiene en medics geproduseer is in onderskeidelik 1998 en 1999. Hierdie plotte is skoon gehou van plantegroei en het ook geen stikstof in kunsmisvorm gekry nie. Met drie tot vier week intervalle is grondmonsters op hierdie plotte versamel in die bogrond (0-15cm diep) en ondergrond (15-30cm diep), waarna die beskikbare nitraat-N en ammonium-N konsentrasie bepaal is. Adissionele grondmonsters van die bogrond is ook geneem op 9/03/2000 na 'n somer braak periode. Hierdie monsters was geneem op persele wat blootgestel was aan 'n koringproduksie in 1999, maar voorafgegaan is deur koring, canola, lupiene en medics in 1998. Hierdie monsters is dan vir 60 dae geïnkubeer teen 15°C en 75% van die grond se water houvermoeë. Minerale N inhoud bepalings is gedoen na 0, 3, 7, 15, 30, 45 en 60 dae van inkubasie. Groot variasie in die minerale stikstof inhoud, het die verkryging van herkenbare tendense en konstante statistiese verskille belemmer. Die resultate wat verkry is dui egter dat die insluiting van lupiene en medics in koring produksie stelsels in die

Swartland, hoër minerale N vlakke in die grond handhaaf en dit kan boere gevolglik in staat stel om kunsmis insette te besnoei sonder dat grondvrugbaarheid verswak.

Op 23/06/99 (groeistadium 5), 5/08/99 (groeistadium 15) en 14/09/99 (groeistadium 23) is plantmonsters versamel van koringpersele. Hierdie persele is gekies om die behandelings van die grondmonsterontledings soos hierbo beskryf, te verteenwoordig. Plante en halms van 'n 0.25m^2 area uit die persele is getel en die blaaroppervlaktes is bepaal, waarna die droëmateriaal massa van die area bepaal is. Die persentasie stikstofinhoud van die blare en stingels was daarna bepaal. In terme van vegetatiewe groei was daar nie groot verskille te bespeur nie. Betekenisvolle hoër stikstof inhoud van koringblare in plotte waar daar in die vorige jaar canola en koring verbou was, is in die tweede planttrekking (groeistadium 15) gevind en dit is toegeskryf aan die hoër stikstof kopbemesting wat daardie behandelings ontvang het. Teen die derde monsterneming op 14/09/99 (groeistadium 23), was hierdie verskille nie meer in die ontledingsdata te sien nie. Die afleiding wat van hierdie studie gemaak is, is dat boere moontlik stikstofbemesting kan verminder as hulle lupiene en medics in hulle koring produksiestelsels inbring, sonder om die risiko van swakker groei te verhoog.

Op 20/10/99 (groeistadium 28) is 0.25m^2 plante van elke koringperseel verwyder waarna die are en die korrels getel is. Die koring wat nog op die persele was is teen die einde van Oktober 1999 met 'n perseelstropertjie geoes. Opbrengs, hektoliter massa, duidendkorrel massa en % ru-proteïene is daarna bepaal. Volgende is die % meel en % semel ekstraksie bepaal waarna die % meelproteïene bepaal is. Mikro broodjies is ook gebak om die broodvolume te bepaal. Meel en deeg eienskappe is ook getoets met die Falling Number System, mixogram en alveogram. Koring in produksiestelsels met peulplant fases (lupien en medics in hierdie geval), het minder N toediening nodig gehad om statisties dieselfde opbrengs, meel- en deeg eienskappe te verkry.

Lupien en medic gebaseerde wisselbou praktyke in die Swartland kan gevolglik as meer ekologies volhoubaar en ekonomies haalbaar bestempel word.

Hierdie studie het gepoog om die invloed van wisselbou op grondvrugbaarheid te ondersoek. Sodanige veranderings neem egter tyd en daarom is dit waarskynlik nog te gou om werklike grondvrugbaarheids verskille waar te neem.

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Thanks to my Creator for giving me the opportunity.

To cherish what remains of the Earth and to foster its renewal
is our only legitimate hope of survival

- Wendell Berry -

CONTENTS

INTRODUCTION

Protein and oilseed production in the winter rainfall region of South Africa (primarily the Southern and Western Cape) is well below the potential for the area (Central Statistical Service, 1998). This is mainly because the mediterranean climate made it very suitable for spring-wheat production and farmers concentrated primarily on wheat production for economic and traditional reasons.

This, together with guaranteed wheat prices and aid from government in the form of fuel subsidies, drought funding-schemes etc. resulted in farmers concentrating on wheat monoculture, fallow-wheat and wheat-pasture cropping systems in these regions. The tendency to go on with this form of land use pattern was encouraged by several factors including low production risks and high product prices. Freely available knowledge and information on these production methods also fuelled this form of land use.

Since the deregulation of the wheat marketing system, the economic picture changed dramatically. Higher input costs, lower product prices, constantly changing prices and an unstable marketing scene have forced farmers to cut inputs such as tillage, fertilizer and chemical disease control in wheat production in an attempt to make a profit. If farming practices are to remain economically viable with less tillage and/or fertilizer, a very good biological soil condition must be sustained.

Monoculture cropping systems are known to result in nutrient exhaustion of the soil (Thomsen & Christensen, 1998) and the increase of weed populations (Arshad, Gill & Izaurralde, 1998). Fallow-wheat systems in turn lead to decreasing soil organic matter (Rasmussen & Collins, 1991; Monreal, Zentner & Robertson, 1997; Rasmussen, Albrecht & Smiley, 1998; Campbell *et al.*, 1999). It is therefore clear that these approaches are not sustainable and in fact will result in decreasing yield of wheat in those systems. This in turn leads to lowering of profit margins and an increase in farmers' financial risk.

Concerning this, crop-pasture rotations became a relative stable pattern of land use in the Western Cape since the 1970's. The control of weeds and diseases that accumulated in a monoculture together with its influence on soil fertility are the main reasons why annual *Medicago spp.* (medics) in wheat-pasture systems were adopted in these regions. Another reason is that this cropping system integrated well with the livestock on these farms.

The same events of system succession restored the productivity of previously degraded soils and the profitability of farming in Southern Australia (Donald, 1963).

Today, however, higher cropping intensity is needed as a result of economic pressures that require increases in farm output. This has placed more pressure on management to maintain at least soil fertility. Clearly the challenge in recent times has been to devise viable farming systems that allow intensive cropping (and largely omit the pasture phases) without the risk of soil degradation, which resulted from the earlier systems of cropping.

However, crop rotation with different crops have indirect advantages and disadvantages, which can vary according to the type of crop used in rotations and the sequence of different crops within a rotation. This includes, amongst other aspects, influences of crop rotation on soil mineral content, soil structure and its capability to compete with weeds. To determine the true value of a crop that is used in a crop rotation, the indirect influence of the crop on soil conditions and the main crop (in this instance, wheat) must be taken into consideration.

The ultimate objective of this study is to investigate, quantify and elucidate the effect of wheat, canola, lupins and medics on subsequent wheat production as well as their influence on soil fertility in respect to nitrogen.

Acceptance of new cropping practices by farmers depends on evidence of increased productivity coupled with some understanding of processes causing the increases. If the results of this study could show that the benefits to be gained from intensification of canola and lupins in rotational cropping systems are improved wheat yields, a reduced dependence on chemical sources of nitrogen fertilizer, a reduction in the risks associated with monocropping and more productive use of land that is currently kept fallow, farmers would incorporate canola and lupin in their systems.

Besides the improved sustainability of cropping systems, a potential result of this study could be increased lupin and canola production, which will then relieve the deficit of protein and oilseed production experienced in South Africa.

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CHAPTER 1

LITERATURE REVIEW

CONVERSION OF NITROGEN IN THE SOIL AND THE FACTORS THAT INFLUENCE THE AVAILABILITY THEREOF DURING THE GROWING PERIOD

From a fertility viewpoint, NH_4^+, NO_2^- and NO_3^- are the most important inorganic forms of nitrogen present in the soil (Tisdale *et al.*, 1993). The nitrogen content of an unfertilised soil is a function of its organic matter content. Inorganic nitrogen is formed and maintained in the soil as a result of decomposing soil organic matter. In turn, the amount of soil organic matter is determined by soil forming factors that are largely influenced by the prevailing climate.

The soil receives N inputs through fertilizer additions and from the atmosphere in precipitation or via biological nitrogen fixation. Inputs are also made through plant and animal residues. Nitrogen is removed in the harvested crop and is lost by leaching and surface run-off of soluble forms, by gaseous transfer as nitrogen gas and nitrogen oxides during nitrification and denitrification processes, and by ammonia volatilisation. In addition to these interactions with the total ecosystem, internal cycles also operate within the soil, so that even if gains and losses are in balance, N continues to cycle in the soil (Tisdale *et al.*, 1993).

Nutrient cycling is a function of the nature of organic substrates entering the soil, the diversity and activity of soil microbes and fauna mediating decomposition of these substrates, weather conditions that regulate the rates of reaction, physical and chemical properties of the soil and crop management factors (tillage, fertilizers and crop rotation) (Tidale *et al.*, 1993). In the case of nitrogen the processes of mineralization, nitrification, immobilization and denitrification are important.

MINERALIZATION

Mineralization is the process where organic nitrogen is transformed to NH_4^+-N. According to Tisdale *et al.* (1993) the actual transformation consists of two reactions namely amination and ammonification. Heterogenic microorganisms cause both reactions. According to these researchers, mineralization rate does increase as temperature rises given that soil water and oxygen are readily available. Mineralization was found to continue under anaerobic waterlogged soil conditions, but it is much less effective than under aerobic conditions (Tisdale *et al.,* 1993).

NITRIFICATION

A fraction of the NH_4^+-N, which is released in the soil during mineralization, is transformed through the process of nitrification and produces NO_3^--N as a result. This reaction takes place in two defined steps (Tisdale *et al.,* 1993): NH_4^+ is transformed to NO_2^- and then to NO_3^- by *Nitrosomona*- and *Nitrobacter*-bacteria respectively. Conditions must be suitable for the mineralization reaction to produce enough NH_4^+-N for the nitrification reaction. It is therefore obvious that factors influencing mineralization can have an indirect influence on this reaction. On top of that, the microorganism population sizes also influence the process. Although nitrification can occur in a wide pH range (4,5 to 10), a pH of 8,5 is considered optimal. Sufficient aeration of the soil is also required to supply the *Nitrobacter* bacteria with enough O_2 to continue producing NO_3^--N. According to Fillery and McInnes (1992), nitrification is more sensitive to soil aeration than ammonification and immobilization.

Soil water content higher than field capacity has a negative influence on nitrification due to the shortage of O_2 developing under such soil conditions. Optimum temperatures for nitrification are between 25 and 33 °C. The nitrification process can however still take place under temperature conditions between 5 and 40 °C.

IMMOBILIZATION

Immobilization is the inverse of mineralization. It is the transformation of inorganic NH_4^+-N and NO_3^--N to organic N due to the activity of microorganisms in the soil (Tisdale *et al.*, 1993). This process is promoted by a high C:N ratio of organic material in the soil. When the organic material, which serves as food for the microorganisms, has a high C content relative to N, all the plant available N in the soil is used by the organisms to produce protein for bodies.

Further, it was found that the microorganisms compete very effectively for NH_4^+ and NO_3^- during immobilization. This often happens to such an extent that plants may experience N shortages. This phenomenon can be described as a nitrogen deficit period. Sufficient N in the organic material left on the soil surface after harvesting can limit immobilization. After the organic material has been consumed, the microorganism activity slows down until immobilization stops. As soon as the microorganisms die, organic N in their bodies will be converted back to inorganic N through mineralization.

DENITRIFICATION

Denitrification is the inverse reaction to nitrification (Tisdale *et al.*, 1993), and can also be influenced by several factors involved in the soil. Firstly, the superabundance of fresh organic material may create a suitable environment for denitrification. Secondly, waterlogged soil can be advantageous to denitrification due to insufficient O_2 supplies available to the microorganisms involved in nitrification. Soil does not have to be waterlogged to experience O_2 shortages. General shortages of O_2 in the soil will also lead to denitrification. This may occur when the demand for O_2 in the soil is high due to large microorganism populations together with limited aeration of the soil.

Soils with a pH higher than five may develop extensive NO_3^- losses due to accelerated denitrification. Rises in temperatures from 2 – 25 °C also leads to accelerated denitrification. Temperatures higher than 60 °C inhibits this process. Above-average amounts of NO_3^- in the soil can result in N losses in the N_20 and N_2 form, all because of accelerated denitrification.

Aerobic microbe activity and nitrification increase with higher soil water content between wilting point and field capacity (Broder *et al.*, 1984). With water in the soil exceeding field capacity, the aerobic nitrification activity decreases while the anaerobic denitrification increases as a result of improper aeration of the soil.

UPTAKE AND ROLE OF NITROGEN ON THE GROWTH AND PRODUCTION OF WHEAT

Generally, nitrogen is the most limiting nutrition element of wheat production when water supply is sufficient. Its availability is very important in wheat production (Hay & Walker, 1992). Nitrogen plays an essential role in biochemical reactions in plants and is part of every plant component in the form of nucleonic acids, proteins and chlorophyll. Chlorophyll is important in the plant for photosynthesis.

According to Tisdale *et al.* (1993), wheat plants absorb only NH_4^+-N and NO_3^--N from the soil as sources of nitrogen. The uptake of nitrate is encouraged by low pH conditions (Laubscher & Du Preez, 1991; Tisdale *et al.*, 1993), while NH_4^+ uptake occurs mainly under neutral pH conditions. Some researchers found that NH_4^+ is more important for growth and production of wheat in the early growth stages. NO_3^- on the other hand plays a more important role in later growth stages (Taylor, Lill & McNeill, 1988; Joseph & Prasad, 1993). According to Cox and Reisenauer (1973) there is no difference in growth of young wheat seedlings that received NH_4^+ or NO_3^-. This is however only true at low rates of N application.

Influence on the vegetative growth of wheat

The yield potential of wheat is determined relatively early in its growth period. Development of vegetative growth components like tillers plant^{-1}, above ground dry mass and leaf area are important and nitrogen plays a significant role in this regard (Khalifa, 1973).

According to Beathgen and Alley (1989), a low yield is associated with small numbers of tillers plant^{-1}. It is therefore important that enough nitrogen is available for development and vegetative growth, because increased organic growth will help to maximise the plant's use of available radiation, water and other minerals.

Growth analyses have shown that a high leaf area index leads to higher final dry mass and yield of wheat. Hay and Walker (1992) found that higher N-application (N availability) lead to increased leaf area, leaf area duration, tiller production and the survival thereof. Austin (1982) found that an increase in leaf area index and the grain filling period resulted in higher yield of wheat. Nitrogen fertilizer did not increase the number of leaves tiller^{-1}, but it did influence leaf growth and help to maintain a higher leaf area index (Khalifa, 1973).

Pearman, Thomas and Thorne (1978) showed that photosynthesis per unit leaf area decreased as leaf area index increased in reaction to nitrogen fertilizer. However, productivity of photosynthesis still increased. The effect of nitrogen availability on photosynthesis is mainly indirect through its influence on increasing leaf size and leaf area duration and therefore photosynthetic active material.

Photosynthesis provides the metabolic energy to ultimately enable the wheat plant to produce a harvest (Evans & Wardlaw, 1976). In the early stages of plant growth, the leaves are the most important organs for photosynthesis. Towards the end of its growing season photosynthesis by the stems, leaf-sheath and ears becomes more important.

Influence on reproductive growth and yield of wheat

Wheat yield was defined by Hammes *et al.* (1986) as the product of number of grains and mass grain^{-1}. The number of ears m^{-2} and the number of grains ear^{-1} determines the number of grains. The number of grains ear^{-1} is a result of the number of spikelets ear^{-1} and grains spikelet^{-1}.

The overwhelming contribution of the number of tillers m^{-2} to yield is well known (Evans, Wardlaw & Fisher, 1975), but the grains ear^{-1} and grain weight ear^{-1} also contributes to the final yield (Mossedaq & Smith, 1994).

Nitrogen fertilizer (N-availability) influence all the factors determining yield, directly as a building brick of protein and indirectly through photosynthesis which produce carbohydrates. The latter is indirectly influenced by nitrogen, due to its effect on the increase in leaf area and leaf area duration. Nitrogen availability at planting and during the early growth stages of plant development increases the number of tillers, while availability during and after flowering increases the grain mass spikelet^{-1}, provided moisture is not limiting (Pearman *et al*, 1978).

Hay and Walker (1992) also found that the nitrogen application rate and the time of application influence the development and survival of yield determining components. Spiertz (1978) found that late **N** application resulted in a prolonged photosynthetic period, which resulted in a higher yield due to an increase in the number of grains ear^{-1}.

Generally, it can be concluded that nitrogen availability contributes to both the vegetative and reproductive growth and development of wheat. Although several researchers (Evans & Wardlaw, 1976; Pearman *et al.*, 1978) reported yield increases due to nitrogen fertilizer, the principle of declining responses to increasing fertilizer applications is also well documented. Optimum application rates will be determined by the climate, potential of the soil and the type of cropping system that is followed.

Influence on wheat quality

Wheat quality is determined by the protein content, protein composition and other properties of the flour. The protein content in wheat grain is largely dependent on genotype (Stoddard & Marshall, 1990) but is also influenced by environment (Rao *et al.*, 1993). Prominent among environmental factors is climate, residual **N** in the soil (Olson *et al.*, 1976), the rate and time of fertilizer **N** application (Fowler & Brydon, 1989), crop rotation (Borghi *et al.*, 1995) and interactions among them. Gluten consists of gliadin and glutenin and contributes to about 80% of the protein composition in wheat flour. Gluten is mainly responsible for the breadmaking quality properties of wheat flour (Pyler, 1973). A positive correlation between loaf volume and protein content of wheat is generally found (Holbrook & Ridgeman, 1989).

Protein content of grain is the product of translocated nitrogen containing compounds from the leaves and stems to the ear (McMullann, McVetty & Urquhart, 1988). According to Hay and Walker (1992), nitrogen influences the quality of wheat due to its positive effect on grain protein content. Crop rotation may also influence the protein content and bread making quality of wheat (Zentner *et al.*, 1990). López-Bellido *et al.* (1998) found that rotations including legume crops, increased wheat yield and grain protein content, and improved the rheological properties of the resulting dough.

THE RESPONSE OF CEREAL CROPS TO DIFFERENT ROTATION SYSTEMS

Several studies indicate a predominantly positive influence of crop rotation on the following cereal crop (Munyinda, Karamanos & O'Halloran, 1988; Rowland, Mason & Hamblin, 1988; Bourgeois & Entz, 1996; López-Bellido *et al.*, 1996; Singer & Cox, 1998). This phenomenon is usually referred to as a "rotation effect".

Responses in grain yield of cereals to previous crops of grain legumes varied between +0.20 and +3.68 t ha^{-1} compared to cereal–cereal monocropping yields, with relative increases being in the range of 16 – 353% (Peoples & Herridge, 1990). Schultz (1995) concluded from results obtained in Australia that the best wheat yields were always obtained in rotations that included a legume crop or a legume pasture. This effect of legume based rotations was more prominent in drier years, probably due the soil's improved water holding capacity (López-Bellido *et al.*, 1996). In an experiment comparing yield of winter wheat as a test crop, yields obtained after winter wheat (7.2 t ha^{-1}) averaged 1.5 t ha^{-1} less than averaged yield obtained after break crops such as lupins, oilseed rape and fieldbeans (McEwen *et al.*, 1989).

Cereals showed yield increases between 40 and 84% if preceded by crops such as chickpeas, fababeans, lupins and other legumes (Strong *et al.*, 1986). López-Bellido *et al.* (1996) have found that wheat yields obtained in a wheat–fallow crop rotation did not differ from wheat yields obtained in a wheat–fababean rotation, but outyielded that obtained in other legume based rotation systems. Arshad, Gill & Izaurralde (1998) and Campbell *et al.* (1996), however, observed that the replacement of fallow with a crop increased total crop production and amount of organic material returned to the soil, improving soil structure and minimizing NO_3^--N leaching potential.

The data of Strong *et al.* (1986) also show that the uptake of N by wheat was higher in the legume-wheat rotation systems compared to the cereal-wheat or oilseed-wheat systems. The relative increases in N yield (74 – 185%) were in general considerably higher than the relative increase in grain yield (40 – 84%), suggesting that factors other than N were limiting grain yield. Bourgeois and Entz (1996) computed field data from farmers in Canada to compare the yield of wheat that followed different crops. These data were generated from 1982 until 1993. A wheat-wheat monoculture was used as a comparative basis. The data, averaged across years, indicated that yield of wheat following peas, canola, and flax was significantly higher than the yield of wheat following wheat. The yield increase was likely due to the interaction of several factors.

Some researchers have listed the probable reasons for crop rotation effects on cereal crop production. Karlen *et al.* (1994) list more than a dozen possible benefits accruing from crop rotation and concluded that analysis of individual factors generally does not explain the entire yield response associated with crop rotation. Campbell *et al.* (1990) reviewed crop rotation studies in the Canadian prairies and concluded that influence of a crop on a following crop in a rotation was largely dependent on its residual effect on soil moisture, soil fertility and pest populations. A number of factors can operate in this respect, the relative importance of each dictated by site, season, and crop sequence (Peoples & Herridge, 1990).

Higher crop yield of cereals following legumes have been mostly attributed to the release of N from legume residues, although harvesting legumes for seed may create a negative soil N budget (Peoples & Herridge, 1990). Stevenson and Van Kessel (1996) attributed 8% of the field pea effect on grain yield of subsequent wheat to N benefits and 92% to non-N benefits.

Non-N benefits of legumes have been attributed to: (a) control of cereal diseases and insect pests (Reeves, Ellington & Brooke, 1984), (b) improvements in soil structure and physical conditions (Peoples & Herridge, 1990), (c) reduced weed populations (Blackshaw, 1994) and release of growth promoting substances and increased population of microorganisms favourable for crop growth (Fyson & Oaks, 1990).

Felton *et al.* (1998) found that wheat yielded 0,1 to 1,7 tons ha^{-1} more on locations where it was rotated with chickpeas. In this instance, he also found that wheat plants had a higher dry material production and partly attributed it to a decreased occurrence of diseases in the rotation systems. Different legume crops influenced the following cereal differently. Heenan, McGhie & Collins (1998) for example found that lupins as a rotation crop had a more positive effect on disease control and wheat yield than subterranean clover. Canola also resulted in a higher yield and protein content of wheat compared to wheat monocropping. This shows the great break-crop effect of canola in rotation systems (Kirkegaard *et. al.*, 1997)

The most consistent effect of the legumes, however, is to increase plant-available nitrogen in the soil (Rowland *et al.,* 1988; Evans *et al.,* 1989; Chalk *et al.,* 1993). Legume crops may add N to the soil because of symbiotic N_2 fixation, and may also remove less inorganic N from the soil compared to a cereal crop because its N requirement is partly met by N_2 fixation. The latter has been termed the "N sparing" or "N conserving" effect. Either one or both of these factors may contribute to an N benefit (Keatinge, Chapanian & Saxena, 1988).

Where barley was grown after lupins in comparison with barley after wheat (Chalk *et al.*, 1993), N content in the latter was less. This was equally attributed to the "N sparing" effect in the lupin phase and the availability of fixed N after the mineralization of lupin residue with a low C:N ratio.

A grain legume will only add to the soil N pool if the proportion of N in the total plant, which is derived from N_2 fixation, is more than the N harvest index (Peoples & Herridge, 1990). This is frequently, but not always, the case. It can therefore be possible for a grain legume to decrease the size of the soil N pool, but at the same time allocate an N benefit to a succeeding cereal due solely to the "N sparing" effect. Evans *et al.* (1991) provided evidence that N spared under lupins and field peas were the major contributor to the average N benefit to wheat over 15 sites.

CONCLUSION

Some aspects of crop rotation are yet to be understood. This includes the full scientific explanation of the rotation effect, the effect of different sequences of crops on the sustainability of the soil and the interaction of the abovementioned with the soil type and climate. However, the benefits of crop rotation on the productivity of subsequent cereal crops have been readily shown in the literature.

Economic considerations have and presumably will always influence land use decisions, such as adoption of crop rotation (Karlen *et al.*, 1994). The yield-effects of crop rotation can have big implications on the economic viability of a farm. Crooksten (1984) showed that because cereal crops are continuously being cultivated at a lower profit margin, a 5% increase in yield could mean up to 50% higher profit.

Considering all this, crop rotations have a major role in future agriculture to ensure economically viable, environmentally sustainable and socially acceptable practices.

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CHAPTER 2

SOIL N MINERALIZATION: THE EFFECT OF DIFFERENT ROTATION CROPS IN THE PRECEDING YEAR

INTRODUCTION

Wheat monoculture, fallow–wheat and wheat–pasture cropping systems dominate the agricultural land use patterns in the Swartland (Western Cape Province) wheat producing area of South Africa (Agenbag & Vlassak, 2000).

Monoculture is known to result in nutrient exhaustion of the soil (Thomsen & Christensen, 1998) while fallow-wheat systems in turn lead to decreasing soil organic matter (Rasmussen, Albrecht & Smiley, 1998). It is clear that these approaches are not sustainable and will eventually decrease soil fertility in those systems. The inclusion of wheat-annual medic (*Medicago spp.*) pasture rotations currently used on some farms is a more stable form of land use. Benefits of the wheat-medic pasture rotations include improved weed control and improved soil fertility, particularly increased mineral N availability. These benefits have encouraged farmers to adapt wheat-medic pasture rotation systems. This system also provides grazing to the livestock on these farms.

In spite of wheat yields of more than 3000 kg ha^{-1} often obtained on farms in the Swartland, profit margins are at present very small due to low product prices and high production costs. These economic pressures are forcing farmers to reduce production costs including for example, tillage, fertilization and chemical disease control, and to raise the cropping intensity in an attempt to increase farm output. Greater emphasis must therefore be placed on management to maintain soil fertility. One way of achieving a low input, sustainable approach to wheat production and therefore remain a viable wheat producing area, is the implementation of rotational cropping systems.

Mineral N in the soil, consisting of exchangeable NH_4^+-N and No_3^--N, constitutes the nitrogen reserve that can be directly used by crops. The nitrogen content of an unfertilized soil is a function of its organic matter content. Inorganic nitrogen is therefore formed and maintained in an unfertilized soil as a result of decomposing soil organic matter. In turn, the amount of soil organic matter is determined by soil forming factors that are largely influenced by the prevailing climate and agronomic practices. Crop rotation generally increases soil organic matter content relative to monocultures (Havlin *et al*., 1990), but Varvel (1994) found that this is only true for certain crop sequences. Rasmussen *et. al*. (1998) found that soil organic matter could be maintained or increased in most semi-arid soils if they are cropped every year, crop residues are returned to the soil and erosion is kept to a minimum. Hossain *et. al.* 1996 also found that the soil N status was significantly improved after the legume phase in all legume based systems as indicated by total N as well as several N availability indices.

Where soils typically have low organic matter content, the role of legumes in terms of economy and nitrogen dynamics, become important to promote efficient, stable agriculture. Including legumes in cropping systems lowers the C:N ratio of the residues incorporated into the soil, thereby altering N dynamics. The results of Strong *et. al*. (1986) also emphasize the likely effect of grain legumes in dryland crop rotations on the accumulation of available N in the subsoil for use by subsequent cereal crops.

While there are potentially several factors contributing to the positive effect of rotational crops, it is widely recognized that the most consistent effect of the legumes is to increase plant-available nitrogen in the soil (Rowland, Mason & Hamblin, 1988; Evans *et al.,* 1989; Chalk *et al.,* 1993). The legume may potentially add to the soil N pool because of symbiotic N_2 fixation, and it may also remove less inorganic N from the soil compared to a cereal because part of its N requirement may be met by N_2 fixation. The latter has been termed the "N sparing" or "N conserving" effect. Either one or both of these factors may contribute to a N benefit (Keatinge, Chapanian & Saxena, 1988) and at least limited the decline of soil N fertility associated with intensive cereal cropping.

In this study, the introduction of annual medic pastures (*Medicago spp.*), canola (*Brassica napus*) and lupins (*Lupinus angustifolius*) as rotation crops into wheat production systems, was investigated with regard to soil N mineralization.

The objectives of the study were to monitor and assess (i) changes of NH_4^+-N and NO_3^--N in the soil without any nitrogen fertilizer application (*i.e.* determining the inherent capability of the soil to produce plant available nitrogen during the growing season following either wheat, canola, lupins or medic pastures in the preceding year);
(ii) the influence of different crops on the mineralization potential of the soil after one season under wheat cultivation.

MATERIALS AND METHODS

Locality

The experimental site was located at Langgewens Experimental Farm of the Department of Economic Affairs, Agriculture and Tourism of the Provincial Administration: Western Cape, north of Malmesbury (18º43'E; 33º06'S). The depth of the sandy loam soil was 250-300 mm. The soil characteristics of the experimental site are summarized in Table 2.1.

Total monthly rainfall and mean daily temperature distributions from seasons 1999 to 2000 measured at Langgewens are shown in Figure 2.1. Below average rainfall was experienced in both years during the months of April – June,

Table 2.1. Soil characteristics at the experimental site (Dec. 1998)

Depth of A–horizon	250 – 300 mm
Material underlying A-horizon	Saprolite grading into fragmented shale and phyllite
Bulk density	1 400 kg m^{-3}
Sand (%)	64 – 81
Silt (%)	8 – 15
Clay (%)	12 – 18
C (%)	0.8 – 1.30
pH (KCl)	5.3 – 6.2
P (mg kg^{-1})	52 –130
Na (mg kg^{-1})	16 – 42
K (mg kg^{-1})	129 - 195

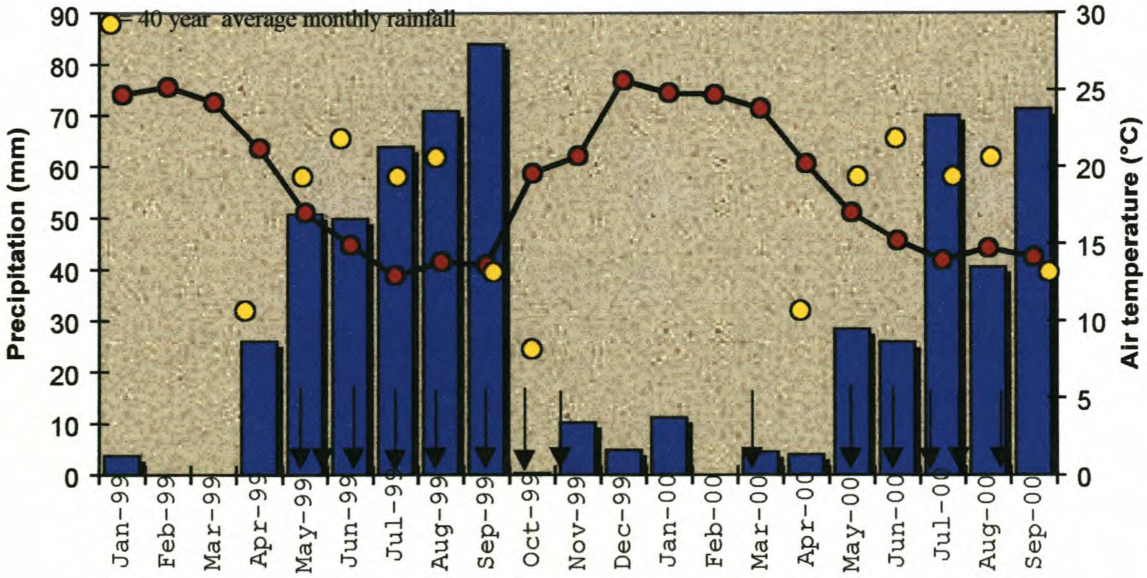

Figure 2.1. Total monthly precipitation (columns) and mean air temperatures (line) during the experimental period. Arrows indicate soil sampling events.

with above average rainfall in July, August and September during 1999 and in July and September during 2000. These above average rainfall measurements indicate that very wet and even waterlogged conditions could have been experienced for short periods in both years.

Experimental techniques

Field experiments have been conducted at the trial site during the 1999 and 2000 seasons. The experiments included four treatments: In each year, fields where the crops in the preceding year were 1) wheat (*Triticum aestivum*), 2) canola (*Brassica napus*), 3) lupins (*Lupinus angustifolius*) and 4) medics (*Medicago spp*) were selected. Agronomic techniques used in the rotation trial were in accordance with contemporary farm practices. The experimental design was a completely randomized design with uneven number of replicates.

A 50m^2 plot was identified in each of the above mentioned fields. All plots were tilled with a tine cultivator to a depth of 15 cm after the first rains in autumn, but kept free of vegetation throughout the sampling period, using a chemical herbicide. No N fertilizer was applied. Soil sampling started within 10 days after the soil had been tilled, and was done at the following dates: 14/05/1999, 28/05/1999, 22/06/1999, 22/07/1999, 17/08/1999, 13/09/1999, 6/10/1999 and 1/11/1999. Two soil samples were taken randomly in each plot and divided into topsoil (0-150mm) and subsoil (150-300mm). The samples were immediately transported to the laboratory and subsequently dried at 40°C for 48 hours, sifted (2mm mesh) and analyzed for available NH_4^+-N and NO_3^--N. The mineral N content was measured using the indophenol blue method for ammonium (Pace, Miller & Keeney, 1982) and the salicylic acid method (Cataldo *et. al.*, 1975) for nitrate-N. Differences between treatment means for each sampling date were compared by using the PROC GLM command of the SAS statistical package (SAS Institute Inc., 1985).

In 2000, the same measurements and analyses were done on plots with similar treatments as described above. The samples were taken on 10/05/2000, 8/06/2000, 5/07/2000, 26/07/2000, and 22/08/2000.

Incubation study

Additional soil samples were taken at the same experimental site on 9/03/2000 after a summer fallow period. The samples were taken on plots that were subjected to a wheat crop in 1999, but were preceded by 1) wheat, 2) canola, 3) lupins and 4) medics in 1998. During the wheat year in 1999, agronomic practices were applied based on accepted production techniques used in the Swartland. Techniques that differed according to the preceding crop were the following:

Wheat as preceding crop: Stubble was burned before seedbed preparation and a total of 90 kg N ha^{-1} was applied as ammonium nitrate fertilizer.

Canola as preceding crop: Stubble was retained but fractured with a tyre roller. In this case, the wheat crop also received a total of 90 kg N ha^{-1} during the growing season.

Lupins as preceding crop: Stubble was retained and 60 kg N ha^{-1} was applied to wheat during the growing season.

Medics as preceding crop: Stubble was retained and 60 kg N ha^{-1} was applied to wheat during the growing season.

All the plots were tined to a depth of 15 cm before planting.

After the soil was sampled it was dried and sifted before one hundred grams of soil was weighed into 250 ml plastic screw top containers. The soil was then wetted up to 50% of its water holding capacity (WHC), determined with the pressure pan method at 100 kPa (3.7ml H_2O, 100 g soil)(Coessens, Agenbag & Vlassak, 2000). The containers were sealed and preincubated for seven days at 15°C. Thereafter, the soil was wetted to 75 % WHC and incubated for 0, 3, 7, 15, 30, 45 and 60 days before analyzed for NO_3^--N and NH_4^+-N.

Differences between treatment means for each analysis were compared by using the PROC GLM command of the SAS statistical package.

RESULTS AND DISCUSSION

Plant available nitrogen

Ammonium-N concentration in the topsoil (0-150mm) did not differ significantly (P=0.05) between crop rotations during the 1999 growing season. In 2000 significant differences were obtained at most sampling dates (Table 2.2(a)). In general lowest values were found in the soil after a wheat crop. Differences between other crop rotations were however inconsistent. Ammonium-N concentration in the subsoil (150-300mm) was less than that of the topsoil on most sampling dates for both 1999 and 2000 (Table 2.3(a)). Although significant differences did occur in both years, results during 1999 were inconsistent, showing no clear tendency. During 2000 significant differences were only obtained at the first two sampling dates with the highest values in the soil after lupins and the lowest values in the soil after wheat and canola. Intermediate values were found after medics.

The high NH_4^+-N concentration initially found in the topsoil after lupins and especially canola during 2000 may be attributed to the poor yields obtained with these crops in 1999, which could result in a large carry-over effect. In general, NH_4^+-N concentrations found were very low so that differences most probably would not have any practical or economical value.

Nitrate-N concentrations during 1999 and 2000 differed significantly (P=0.05) between treatment means for both sampling soil depths (Table

Table 2.2. Effect of previous crop on (a) NH_4^+-N and (b) NO_3^--N content in the 0-150mm soil profile during 1999 and 2000

(a) NH_4^+-N (mg kg^{-1})

Year	Previous crop	14/5/99	28/5/99	22/6/99	22/7/99	17/8/99	13/9/99	6/10/99	1/11/99
1999	Wheat	4.11a*	4.09a	6.16a	9.25a	6.14a	4.2a	2.71a	3.56a
	Canola	7.32a	5.85a	6.82a	9.53a	5.97a	4.46a	3.21a	3.67a
	Lupin	5.21a	6.73a	6.36a	11.10a	5.40a	3.83a	2.81a	2.82a
	Medics	6.94a	6.44a	6.35a	8.01a	6.26a	4.01a	2.72a	3.01a
		10/5/00	**8/6/00**	**5/7/00**	**26/7/00**	**22/8/00**			
2000	Wheat	5.49b	5.58a	4.29c	4.13a	4.74b			
	Canola	14.92a	10.19a	5.84b	4.212a	5.94a			
	Lupin	10.83ab	12.01a	8.41a	5.07a	5.65ab			
	Medics	6.92b	12.24a	3.26c	4.93a	6.13a			

(b) NO_3^--N (mg kg^{-1})

Year	Previous crop	14/5/99	28/5/99	22/6/99	22/7/99	17/8/99	13/9/99	6/10/99	1/11/99
1999	Wheat	43.78ab	28.38a	31.53a	24.14a	17.56a	10.76a	7.30a	23.84a
	Canola	49.05ab	25.56a	19.73a	27.26a	13.09a	5.26b	12.37a	6.49b
	Lupin	39.25b	39.34a	36.05a	30.34a	22.10a	12.56a	13.06a	16.50ab
	Medics	68.35a	45.17a	25.17a	29.65a	11.16a	4.95b	8.78a	11.56b
		10/5/00	**8/6/00**	**5/7/00**	**26/7/00**	**22/8/00**			
2000	Wheat	57.04b	46.10ab	65.54ab	18.30a	33.92a			
	Canola	81.20a	63.43a	77.08a	26.17a	29.88a			
	Lupin	26.74c	58.74ab	43.28bc	32.69a	41.19a			
	Medics	52.7abc	32.3b	34.47c	13.29a	35.78a			

***Different letters in the same column indicate statistical significant differences at the 5% level.**

Table 2.3. Effect of previous crop on (a) NH_4^+-N and (b) NO_3^--N content in the 150-300mm soil profile during 1999 and 2000

(a) NH_4^+-N (mg kg^{-1})

Year	Previous crop	14/5/99	28/5/99	22/6/99	22/7/99	17/8/99	13/9/99	6/10/99	1/11/99
1999	Wheat	2.93ab*	2.64a	2.93a	8.19a	4.78ab	2.73a	2.04a	2.11a
	Canola	2.08b	2.33a	2.65a	9.28a	5.25ab	3.06a	2.11a	2.15a
	Lupin	2.99ab	2.45a	2.95a	9.05a	4.16b	2.48a	2.20a	1.76a
	Medics	5.74a	3.40a	3.21a	8.61a	5.37a	2.49a	2.15a	1.85a
		10/5/00	**8/6/00**	**5/7/00**	**26/7/00**	**22/8/00**			
2000	Wheat	1.98b	2.18ab	1.86a	1.92a	2.59a			
	Canola	2.31b	1.93b	1.99a	2.67a	3.26a			
	Lupin	6.78a	4.03a	2.81a	1.04a	3.01a			
	Medics	2.93b	3.01ab	3.08a	1.83a	3.06a			

(b) NO_3^--N (mg kg^{-1})

Year	Previous crop	14/5/99	28/5/99	22/6/99	22/7/99	17/8/99	13/9/99	6/10/99	1/11/99
1999	Wheat	29.00a	22.54b	23.16a	20.47b	11.22a	11.04a	6.65a	6.77a
	Canola	17.21a	18.70b	20.51a	22.67ab	12.42a	5.20b	6.75a	7.63a
	Lupin	29.42a	52.75a	24.31a	35.78a	19.24a	10.51a	10.90a	10.82a
	Medics	44.67a	52.15a	34.53a	32.77a	10.14a	4.65b	5.69a	6.59a
		10/5/00	**8/6/00**	**5/7/00**	**26/7/00**	**22/8/00**			
2000	Wheat	16.71ab	24.87b	30.37a	32.87a	23.67a			
	Canola	17.85ab	35.40ab	34.78a	23.29a	13.50b			
	Lupin	7.96b	38.80ab	51.40a	32.77a	22.18ab			
	Medics	22.88a	55.26a	45.45a	27.28a	17.54ab			

***Different letters in the same column indicate statistical significant differences at the 5% level.**

2.2 and Table 2.3). Differences between treatments were very inconsistent, but all treatments showed a decline in NO_3^--N content during the sampling period, which coincides with rainfall patterns.

Total mineral N content (NO_3^--N + NH_4^+-N) in the 0-300mm soil profile, however, provides a much clearer picture (Figure 2.2). During 1999, high mineral N content's were found at the initial samplings, which may be attributed to the increased microbial activity as generally found when a soil has been cultivated (Fox & Bandell, 1984). In general higher values were obtained in the soil after a lupin and medic crop compared to a wheat or canola crop in 1999. This tendency was however not repeated during 2000 (Figure 2.3). High values, with the exception of lupins on the 10 May sampling date, for all crop rotations were obtained during samplings at 10 May, 8 June and 5 July 2000.

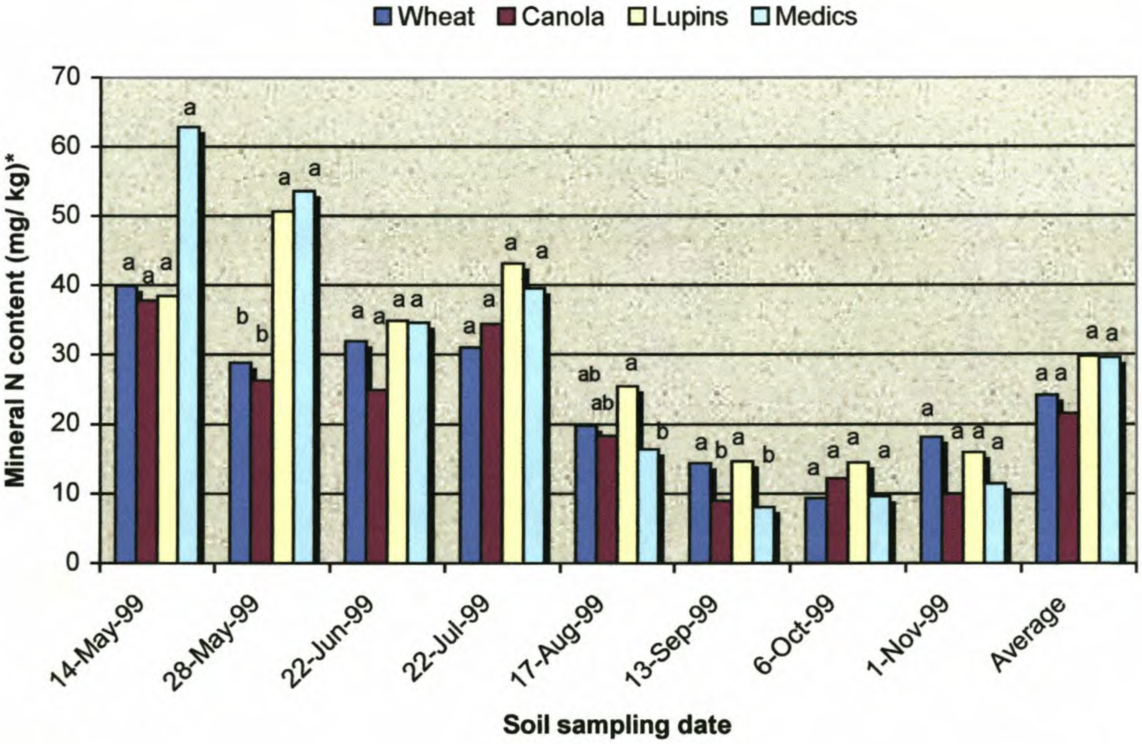

Figure 2.2. Mineral-N (NH_4^+-N + NO_3^--N) content in 0-300mm soil profile (mg kg^{-1}) during 1999 in plots that were under different crops (wheat, canola, lupins and medics) in 1998. *Letters on the graph represent significant differences at the 5% level within sampling events.

These high values indicate either a carry-over effect from 1999 or optimum conditions for mineralization during 2000. Because of the low rainfall experienced during the early winter of 2000, the latter is very doubtful. This and the uncertainty of applied N recovery in grain (Doyle & Leckie, 1992) call for further investigation whether wheat after lupins or medics really needs nitrogen fertilizer at sowing.

After July 1999 the mineral N content in the 0-300mm soil profile of all treatments showed a gradual decrease, diminishing all differences between treatments. Small increases found during the last sampling date in November were probably due to late occurring rain in combination with an increase in soil temperature.

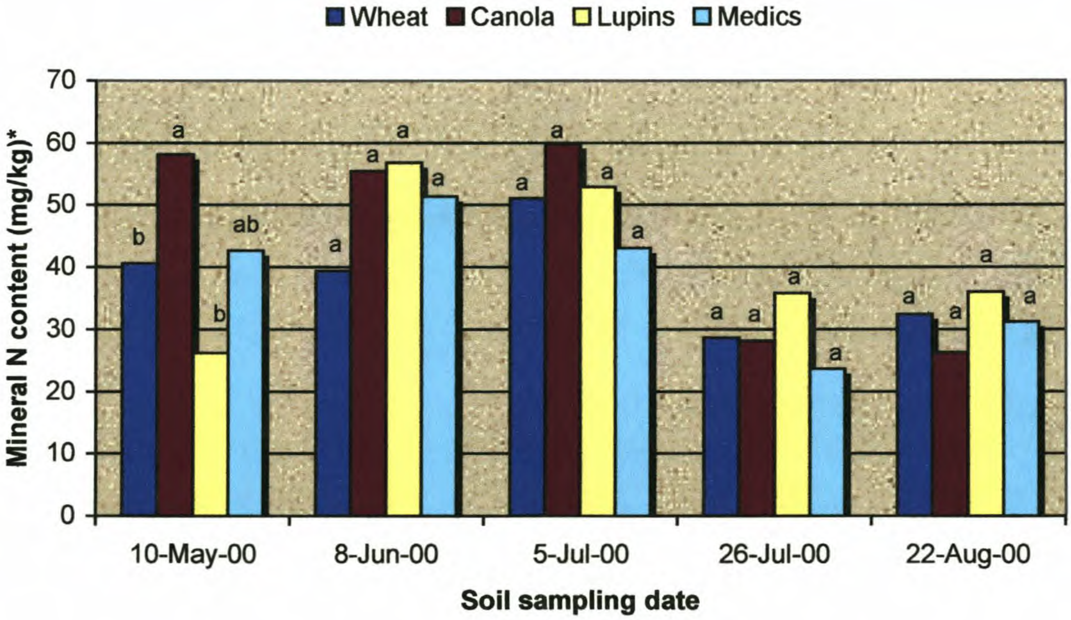

Figure 2.3. Mineral-N (NH_4^+-N + NO_3^--N) content in 0-300mm soil profile (mg kg^{-1}) during 2000 in plots that were under different crops (wheat, canola, lupins and medics) in 1999. *Letters on the graph represent significant differences at the 5% level within sampling events.

Because all the plots were kept fallow for the duration of the experiment, lower values for the months August and September must be a result of immobilization and N losses due to leaching. From Table 2.2 and Table 2.3 it is clear that NO_3^--N is the greater component of the mineral N. It is also the component that is vulnerable to leaching.

Above average rainfall from July 1999 – September 1999 probably played a big role in the detrimental effects to mineral-N content. This effect on the mineral content can also be seen in the data of 2000 after the rain prior to 26 July 2000 (Figure 2.3).

Incubation

Results obtained from the incubation study are summarized in Table 2.4. Significant differences between crop rotations were obtained for both the NH_4^+-N and NO_3^--N content of the soil. Large variations found between different measurements (incubation period) for the same crop rotation, made it very difficult to identify specific trends.

NH_4^+-N content in the lupin-wheat soil were initially (0-7 days) very low compared to the contents in the soil from other crop rotations, but did not decrease with time. All other crop rotations showed a decline in NH_4^+-N content during incubation. NH_4^+-N concentration was the highest for the medics-wheat treatment during the first 45 days of incubation, but differences were not significant. Measurement throughout the incubation period showed that concentrations of exchangeable NH_4^+ remained low, indicating that conditions favoured nitrification.

In general NO_3^--N content showed an increase during incubation to coincide with the decline in NH_4^+-N. In general, highest NO_3^--N values were found in the lupin-wheat soil. Differences were however only significant on day 15. Although NO_3^--N content in the medic-wheat soil initially proved to be the lowest, high values towards the end of the incubation period indicated that mineralization in this soil needed more time to reach its maximum rate. This may be due to a wider C:N ratio in this soil.

Table 2.4. Mineralization potential in mg NH_4^+-N (a) and NO_3^--N (b) per kg soil sampled from different crop rotations (0-150mm soil profile).

(a) NH_4^+-N (mg kg^{-1})

Treatment		**Incubation period (days)**						
1998	**1999**	**0***	**3**	**7**	**15**	**30**	**45**	**60**
Wheat	Wheat	5.61a**	4.67a	3.94a	3.49ab	1.95ab	1.57a	3.21a
Canola	Wheat	5.85a	5.14a	4.06a	2.24b	1.38b	2.93a	1.55a
Lupin	Wheat	1.75a	1.66a	1.41a	1.70ab	1.37ab	1.41a	1.75a
Medics	Wheat	9.06a	8.11a	8.23a	7.32a	6.15a	3.49a	2.74a

(b) NO_3^--N (mg kg^{-1})

Treatment		**Incubation period (days)**						
1998	**1999**	**0***	**3**	**7**	**15**	**30**	**45**	**60**
Wheat	Wheat	36.24a**	31.5a	32.43a	42.49ab	45.27a	31.36a	45.24a
Canola	Wheat	36.67a	31.9a	33.14a	28.37b	43.53a	38.58a	53.85a
Lupin	Wheat	58.12a	55.18a	30.92a	66.00a	46.68a	32.61a	41.89a
Medics	Wheat	30.30a	25.50a	31.84a	38.64ab	50.24a	45.45a	59.67a

*** 11 April 2000**

**** Different letters in the same column indicate statistical significant differences at the 5% level.**

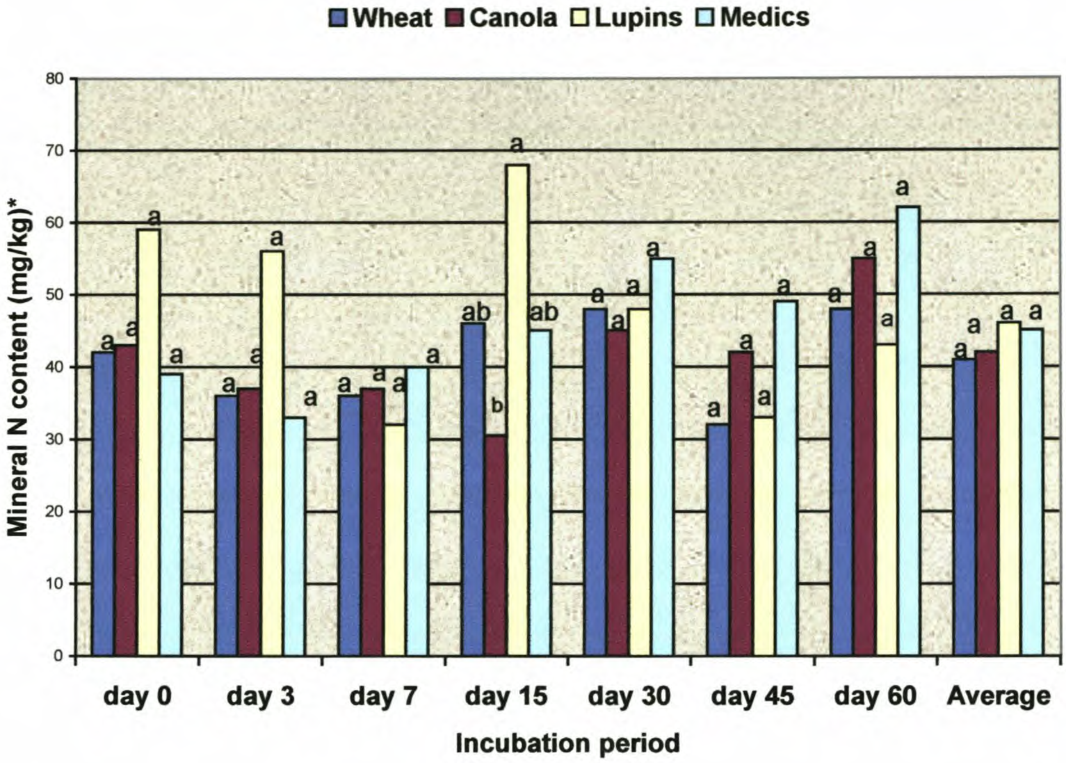

Figure 2.4. Mineral-N (NH_4^+-N + NO_3^--N) content in 0-150mm soil profile (mg kg^{-1}) during incubation of the soil for 60 days at 15°C and at 75% of its water retention capacity. The samples were taken on 9/3/2000 in plots that were subjected to a wheat crop in1999, but were preceded by wheat, canola, lupins and medics in 1998. *Letters on the graph represent significant differences at the 5% level within sampling events.

This higher average mineral N content in the topsoil over the 60 day incubation period (Figure 2.4) for the systems that include a legume phase in comparison with the systems that included canola and wheat are supported by earlier results in Australia (Shultz, 1995). The fact that the two latter systems received more nitrogen fertilizer in the year previous to the incubation and still showed a lower mineral N content is further proof of their lower mineralization potential. The burning of wheat stubble, before sowing the 1999 wheat crop, in the wheat-wheat system could also attributed to its poorer mineralization potential realized.

CONCLUSIONS

The pool of mineral N is never constant. It is increased by mineralization of organic nitrogen and diminished by denitrification and immobilization, while the nitrate component may leach during winter. This makes N measurements very variable and therefore difficult to obtain statistical differences between treatments.

The results of this study indicate that inclusion of lupins and medics in continuous wheat cropping systems in the Swartland could help to limit the decline of mineral N in the soil profile, experienced within a growing season. This ability have been attributed to amongst other things, the carry-over effect of biologically fixed nitrogen, less N immobilized during decomposition due to a lower C:N ratio, lower utilization of soil derived N or combinations of the factors.

Higher mineral N concentrations can therefore be maintained in these soils with the adoption of cropping systems that include lupins and medics. Farmers will then be able to cut fertilizer inputs without facing soil mineral N depletion.

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CHAPTER 3

THE EFFECT OF DIFFERENT CROPS IN THE PRECEDING YEAR ON THE VEGETATIVE GROWTH AND NITROGEN CONTENT OF THE WHEAT PLANT

INTRODUCTION

Development of vegetative growth components like tillers plant^{-1}, above ground dry mass and leaf area are important in determining wheat yield and nitrogen plays a significant role in this regard (Khalifa, 1973).

Nitrogen is often the most limiting nutrition element of wheat production when water supply is sufficient (Hay & Walker, 1992). It is therefore important that enough nitrogen is available for development and vegetative growth, because this will help to optimize the wheat plant's use of available radiation, water and other minerals.

Photosynthesis provides the metabolic energy to ultimately enable the wheat plant to produce a harvest. Pearman, Thomas & Thorne (1978) showed that photosynthesis per unit leaf area decreased as leaf area index increased in reaction to nitrogen fertilizer (nitrogen availability). However, productivity of photosynthesis still increased. The effect of nitrogen availability on photosynthesis is mainly indirect through its influence on increasing leaf size and leaf area duration and therefore photosynthetic active material.

High input costs, low wheat prices and an unstable marketing scene are forcing farmers to cut inputs in wheat production in the form of tillage, fertilization and chemical disease and weed control. For farming practices to remain economically viable with less tillage and/or fertilizer the soil needs to be in a very good biological condition and must be held at that level. One way of achieving such a goal, is the implementation of rotational cropping systems (see chapter 2).

The data of Strong *et al.* (1986) show that the uptake of N by wheat was greater in legume-wheat rotations compared to the cereal-wheat or oilseed-wheat rotations. The relative increases in N yield (74 – 185%) were in general considerably higher than the relative increase in grain yield (40 – 84%), suggesting that factors other than N were limiting grain yield. Mason and Rowland (1990) found that the apparent average increases in N available in wheat dry matter, without added N, were 10.9 kg ha^{-1} from clover and 13 kg ha^{-1} from lupins. Researchers have listed the probable reasons for crop rotation effects on cereal crop production. Karlen *et al.* (1994) list more than a dozen possible benefits accruing from crop rotation and concluded that analysis of individual factors generally does not explain the entire yield response associated with crop rotation.

Campbell *et al.* (1990) reviewed crop rotation studies in the Canadian prairies and concluded that influence of a crop on a subsequent crop in a rotation was largely dependent on its residual effect on soil moisture, soil fertility and pest populations. A number of factors can operate in this respect, the relative importance of each dictated by site, season, and crop sequence (Peoples & Herridge, 1990).

The most consistent effect of the legumes, however, is to increase plant-available nitrate-N in the soil (Rowland, Mason & Hamblin, 1988; Evans *et al.*, 1989; Chalk *et al.*, 1993). The legume may potentially add to the soil N pool because of symbiotic N_2 fixation, and it may also remove less inorganic N from the soil compared to a cereal because part of its N requirement may be met by N_2 fixation. The latter has been termed the "N sparing" or "N conserving" effect. Either one or both of these factors may contribute to a N benefit that may result in increases in above ground dry material production of subsequent wheat (Evans *et. al.*, 1991).

The objective of this study was to investigate the effect of different crops on the vegetative growth and nitrogen content of wheat plants grown during the subsequent season.

MATERIALS AND METHODS

Locality

The experimental site was located at Langgewens Experimental Farm of the Department of Economic Affairs, Agriculture and Tourism of the Provincial Administration: Western Cape, north of Malmesbury (18°43'E; 33°06'S). Some properties of the sandy loam soil (250-300mm deep) at the experimental site are summarized in Table 2.1. The long-term mean annual rainfall during the growing season (April-October) is 334 mm. Total monthly rainfall and mean temperature distributions from seasons 1999 to 2000 measured at Langgewens are shown in Figure 2.1.

Procedure

Field experiments were carried out during the 1999 wheat-growing season. The experiments included four treatments: fields where the crops in the preceding year were 1) wheat (*Triticum aestivum*), 2) canola (*Brassica napus*), 3) lupins (*Lupinus angustifolius*) and 4) medics (*Medicago spp*), were selected in 1999. These treatments will subsequently be referred to as 1) WW, 2) CW, 3) LW and 4) MW. The experimental design was a completely randomized design with uneven number of replicates.

Plant measurements

In each selected field, a 50m^2 plot was selected to represent the same treatments as described for soil sampling procedures during the 1999 growing season (Chapter 2). During the 1999 growing season, 0.25m^2 areas of wheat plants were randomly sampled on 23/06/1999 (growth stage 5), 5/08/1999 (growth stage 15) and14/09/1999 (growth stage 23).

Plant and tiller numbers were counted and leaf area was determined for each sub-sample. Plant material was then dried at 60°C, weighed to determine dry material production. After milling with a Falling Number 3100 mill, percentage nitrogen content in the leaves and stems were determined using Near Infra-Red Spectroscopy (Technikon Infraalyzer 400).

Statistical analysis was performed using the PROC GLM command of the SAS statistical package (SAS Institute Inc., 1985). Differences between the treatments were considered significant at LSD$_{0.05}$.

Agronomic management

Relevant production techniques for different crop rotations to obtain maximum economic in stead of biological yield, were used in this study. Therefore wheat was not chemically treated against pests and diseases unless an economical threshold was reached; the cultivar choice were based on a cultivar that proved to maintain productivity and give a stable yield in the Swartland; soil was fertilized according to soil analysis and general recommended fertilizer programs for different crop rotations (mineral-N content of the soil is at present not used in N-recommendations to either maize or wheat in South-Africa). Tillage, sowing and application of chemical substances were done using standard farm implements and machinery.

General practices recommended and followed in commercial agricultural management of wheat in the Swartland differ according to the preceding crop. Practices used were as follows:

Wheat as preceding crop (WW): Stubble was burned on 17/03/99, before any seedbed preparations started. Weeds were controlled with a knockdown herbicide application (1l glyphosate (Sting) ha^{-1}), once (5/05/99) before sowing. Primary tillage was done with a chisel plough to a depth of about 20cm after the first rains in autumn, 1½ weeks before sowing. This commenced after the opening rains in autumn. Wheat was planted on 12/05/99 at the recommended rate of 100kg seed ha^{-1}. Limestone ammonium nitrate (at 30 kg N ha^{-1}) was incorporated at sowing. The most prominent weeds at the trial site were annual ryegrass (*Lolium rigidum*), wild oats (*Avena spp*) and a range of broad leaf annual weeds including *Emex australis*. Topic (clodinafop-propargyl, 250ml product ha^{-1}) and Harmony M (metsulfuron methyl/thifensulfuron, 30g product ha^{-1}) was therefore sprayed on 11/06/99. Dimethoate (at 0.5l product ha^{-1}) was applied as an insecticide. A topdressing of 60 kg N ha^{-1} on 23/06/99, in the form of Limestone ammonium nitrate fertilizer, brought the total nitrogen application to 90 kg N ha^{-1}. A fungicide was applied on two of the plots at 7/07/99, where eyespot (*Pseudocercosporella herpotrichoides)* was identified.

Canola as preceding crop (CW): Stubble was retained but fractured with a tyre roller. Similar tillage and crop protection techniques were applied as described for the WW treatment, except that no fungicide was applied on any of the CW plots. The wheat crop also received a total of 90 kg N ha^{-1} during the growing season, similar to the WW treatment.

Lupins as preceding crop (LW): Stubble was retained. Similar tillage and crop protection techniques were used as described for the CW treatment. In this case, the wheat crop received a total of 60 kg N ha^{-1} during the growing season, 30 kg of which was applied at sowing and the rest applied as topdressing on 23/06/99 (growth stage 6).

Medics as preceding crop (MW): Stubble was retained. The same tillage and crop protection techniques were used as described for previous treatments, except that no pre-sowing chemical weed control was done and no fungicide was applied. A total of 60 kg N ha^{-1} was applied to wheat, as was done in the LW treatment.

RESULTS AND DISCUSSION

Growth and yield of a crop are the result of the interactive response of plants to weather and soil factors. These responses may be modified by the occurrence of pests, weeds and diseases (Spiertz & De Vos, 1983). Assuming optimum crop protection, crop growth is governed by environmental conditions and availability of water and nutrients.

During the 1999 production season the climatic conditions was very favourable for wheat growth and production. The rainfall (Figure 2.1) was evenly distributed throughout the months from April to September with above average monthly rainfall experienced in July-September.

Mean plant and tiller numbers determined at 23/06/99 (S1), 5/08/99 (S2) and 14/09/99 (S3) for different crop rotations are summarized in Table 3.1. No statistical differences (P=0.05) between treatment means on any of the sampling dates were obtained.

Table 3.1. Effect of previous crop on mean plant and tiller numbers of a following wheat crop. Values represent a 0.25m^2 area that was sampled on 23/06/1999 (S1), 5/08/1999 (S2) and 14/09/1999 (S3).

Preceding crop	PLANTS			TILLERS	
	S1	S2	S3	S2	S3
Wheat (WW)	115a*	97a	98a	165a	143a
Canola (CW)	127a	115a	71a	194a	135a
Lupins (LW)	121a	119a	73a	157a	145a
Medics (MW)	90a	96a	96a	156a	132a

***Different letters in the same column indicate statistical significant differences at the 5% level.**

The plant numbers for all treatments except the MW treatment showed a decrease as the season developed, with WW and MW plant numbers being the highest at S2 and S3. The tiller numbers at the third sampling was however quite similar, ranging from 132 (MW) – 145 (LW) between treatments. This indicates that the treatments experienced similar growth conditions, which resulted in similar numbers of potential ear bearing tillers.

Figure 3.1 also shows no significant differences in leaf area measured on a 0.25m^2 area of wheat following different rotation crops. At the first sampling (23 June 1999), results indicate a higher leaf area of wheat following rotation crops in the LW and MW treatments.

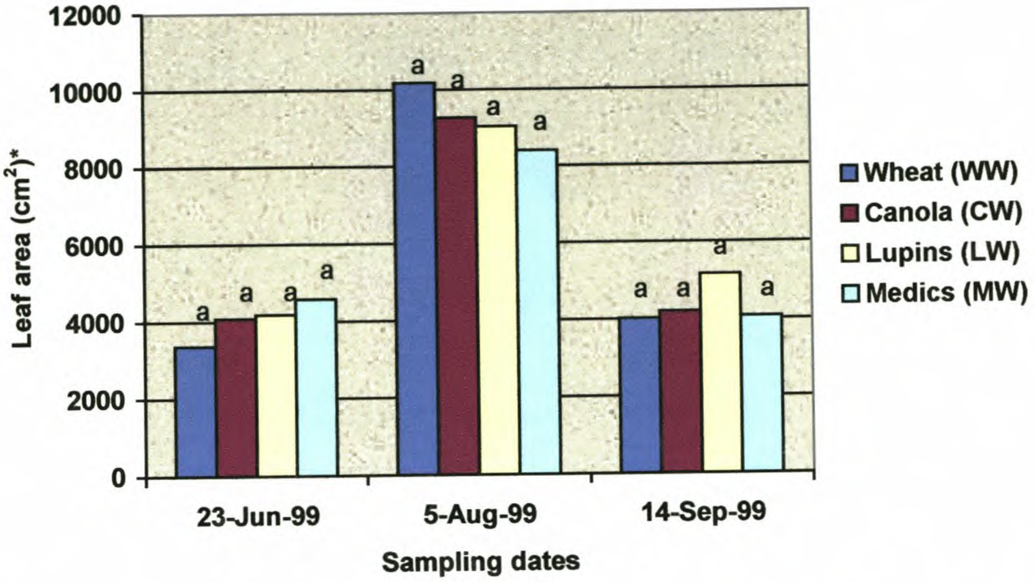

Figure 3.1. Effect of previous crops on the leaf area of a 0.25m^2 area of wheat in the following year (1999). *Letters on the graph represent significant differences at the 5% level within sampling events.

This could be attributed to the higher mineral N content experienced in these treatments (Figure 2.2). At the second sampling (5 August 1999) the results showed the opposite trend, probably due to the N topdressing applied to the CW and WW treatments. On 14 September 1999 LW had the highest leaf area which is an indication that leaf area duration were prolonged. Although not significant, this could be a result of the continuous higher mineral N in the soil profile of the LW treatment during that time of the growing season (Figure 2.2).

Statistical differences (P=0.05) was found between the total dry mass (roots excluded) of the treatments at the first sampling date (Figure 3.2). MW showed the highest total dry mass due to the significantly

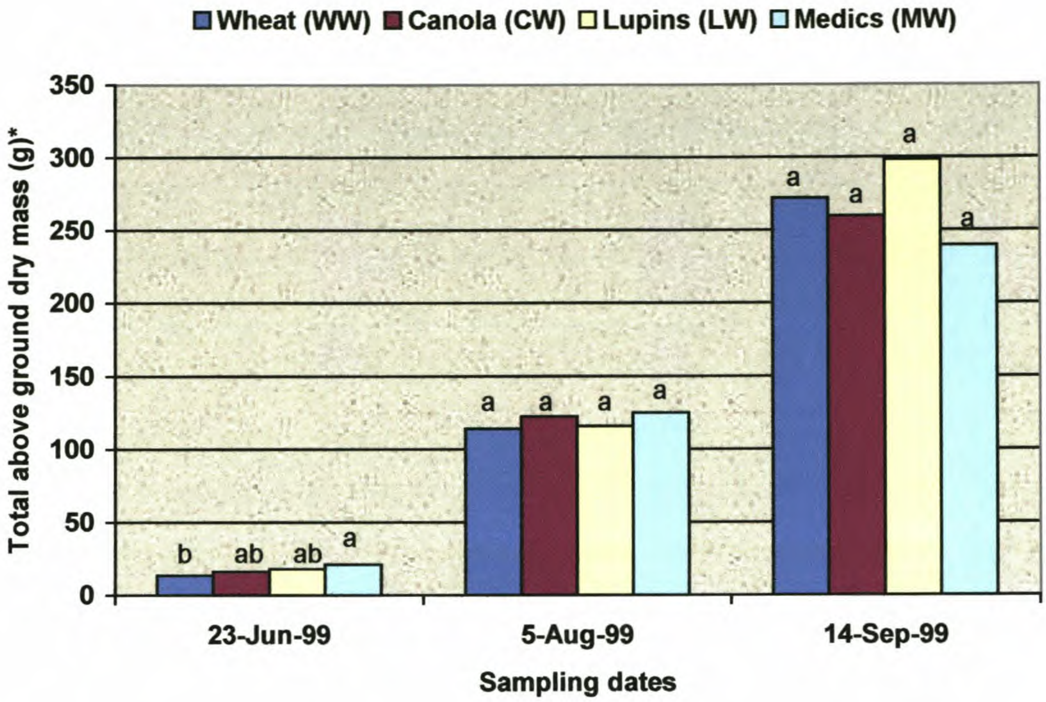

Figure 3.2. Effect of previous crops on the total above ground dry mass (g) of a 0.25m^2 area of wheat in the following year (1999). *Letters on the graph represent significant differences at the 5% level within sampling events.

higher leaf dry mass on 23/06/99 (Figure 3.3). No statistical differences between the stem dry mass of treatments were found (Figure 3.4). At the end of the growing season (Figure 3.2), the LW treatment showed the highest total dry mass. However, these differences were not statistically significant (P=0.05).

Statistical differences (P=0.05) obtained between treatment means for % nitrogen of wheat stems and leaves after different preceding crops, are shown in Table 3.2.

Nitrogen concentration (%N) in both stems and leaves decreased for all treatments towards maturity of the crops (Table 3.2). These results indicate that all treatments experienced N-shortages due to either a low concentration in the soil or inefficient uptake. High mineral-N contents found at planting (Figure 2.2) supports the latter. During the early growth

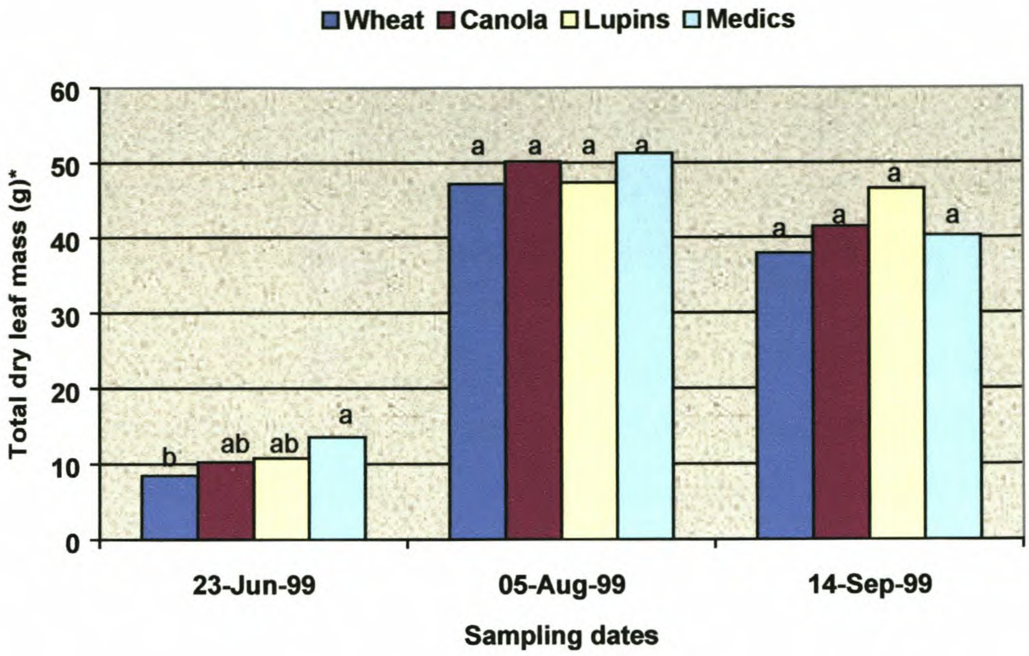

Figure 3.3. Effect of previous crops on the dry leaf mass (g) of a 0.25m^2 area wheat in the following year (1999). *Letters on the graph represent significant differences at the 5% level within sampling events.

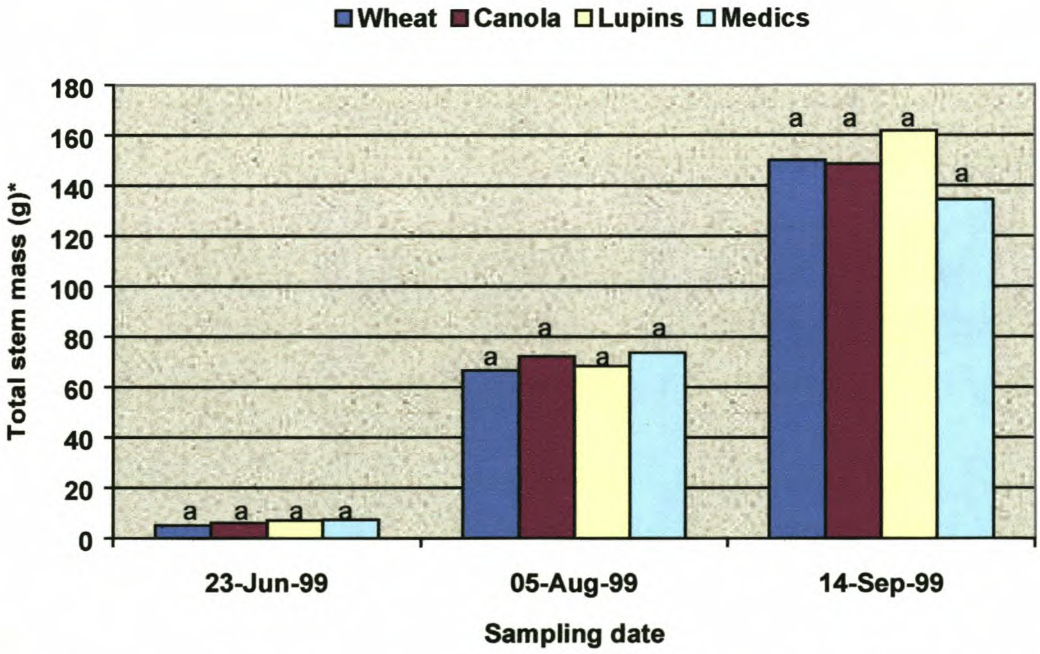

Figure 3.4. Effect of previous crops on the dry stem mass (g) of a 0.25m^2 area wheat in the following year (1999). *Letters on the graph represent significant differences at the 5% level within sampling events.

stages this may be the result of a dilution effect caused by the increased vegetative dry mass. At the end of the growing season it most significant differences between crop rotations were found for the first and third sampling dates. At the second sampling the WW and CW treatment had a significantly higher % nitrogen content in their stems than LW and MW. The higher N topdressing received in the CW and WW treatments at 23/06/1999 (growth stage 6) could account for that.

Table 3.2. Effect of previous crops on the % nitrogen of the stems and leaves of a following wheat crop. Values represent a 0.25 m^2 area that was sampled on 23/06/1999, 5/08/1999 and 14/09/1999.

Preceding crop	Sample1 23/06/1999		Sample2 5/08/1999		Sample3 14/09/1999	
	Stems	Leaves	Stems	Leaves	Stems	Leaves
Wheat(WW)	8.54a*	4.63a	6.19a	2.22b	4.0a	2.75a
Canola(CW)	8.54a	4.76a	5.86a	2.24b	4.18a	2.78a
Lupins(LW)	8.69a	4.16a	4.86b	2.46a	4.03a	2.70a
Medics(MW)	8.18a	4.49a	5.02b	2.20b	4.12a	2.84a

***Different letters in the same column indicate statistical significant differences at the 5% level.**

The higher % nitrogen in the leaves of sample 3 relative to sample 2 could be explained by the fact that only green leaves were subjected to % nitrogen content analysis.

Despite higher nitrogen fertilizer in the WW and CW treatments, there was no statistical differences in % nitrogen content of the stems or leaves of wheat in all of the treatments of sample three. This gives proof that N yield in the LW and MW treatments were better and can almost solely be attributed to the more readily plant available nitrogen found to be present in these soils (Figure 2.2). This supports the important role of legume species as a partial substitute for N fertilizer.

CONCLUSIONS

Wheat growth components are affected by physical, chemical and biological soil properties and climatic conditions. Since the latter was no limiting factor to wheat production during the 1999 growing season, soil properties must have played an important role in the production of above ground plant material.

Because more nitrogen fertiliser were applied to the WW and CW treatments, it is considered responsible for the lack of differences observed in eventual above ground plant production when compared to the MW and LW treatments

However the most important conclusion to make from this study, is that farmers can probably save on fertiliser inputs when including lupins and medics in their wheat production systems, without risking poorer wheat growth.

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CHAPTER 4

THE EFFECT OF DIFFERENT CROPS IN THE PRECEDING YEAR ON THE YIELD AND QUALITY OF WHEAT GRAIN

INTRODUCTION

Factors such as high input costs and low product prices necessitate a low input, sustainable approach to wheat production. One way of achieving such a goal, is the implementation of rotational cropping systems.

Responses in grain yield of cereals to previous crops of grain legumes varied from +0.20 to +3.68 t ha^{-1} compared with cereal–cereal monocropping yields, with relative increases being in the range 16 – 353% (Peoples & Herridge, 1990). Schultz (1995) concluded from results obtained in Australia that the best wheat yields were always in rotations that included a legume crop or a legume pasture. Bourgeois and Entz (1996) computed field data from farmers in Canada to compare the yield of wheat that followed different crops. These data were generated from 1982 until 1993. A wheat-wheat monoculture was used as a comparative basis. The data, averaged across years, indicated that yield of wheat following peas, canola, and flax was significantly higher than the yield of wheat following wheat. The yield increase was likely due to the interaction of several factors.

Higher crop yield of cereals following legumes have been mostly attributed to release of N from legume residues, although harvesting legumes for seed may create a negative soil N budget (Peoples & Herridge, 1990).

Non-N benefits of legumes have been attributed to: (a) control of cereal diseases and insect pests (Reeves, Ellington & Brooke, 1984), (b) improvements in soil structure and physical conditions (Peoples & Herridge, 1990), (c) reduced weed populations (Blackshaw, 1994) and d) release of growth promoting substances and increased population of microorganisms favourable for crop growth (Fyson & Oaks, 1990).

The most consistent effect of the legumes, however, is to increase plant-available nitrogen in the soil (Rowland, Mason & Hamblin, 1988; Evans *et al.,* 1989; Chalk *et al.,* 1993). The legume may potentially add to the soil N pool because of symbiotic N_2 fixation, and it may also remove less inorganic N from the soil compared to a cereal because part of its N requirement is met by N_2 fixation. The latter has been termed the "N sparing" or "N conserving" effect. Either one or both of these factors may contribute to a N benefit (Keatinge, Chapanian & Saxena, 1988). A grain legume will only add to the soil N pool if the proportion of N in the whole plant, which is derived from N_2 fixation, is greater than the N removed when it is harvested (Peoples & Herridge, 1990). This is frequently, but not always, the case. It can therefore be possible for a grain legume to decrease the size of the soil N pool, but at the same time confer a N benefit to a succeeding cereal due solely to the N sparing effect. Evans *et al.* (1991) provided evidence that N spared under lupins and field peas were the major contributor to the average N benefit to wheat over 15 sites.

Nitrogen fertilizer (N-availability) influences all the factors determining yield, directly as a building brick of protein and indirectly through photosynthesis which produces carbohydrates.

Wheat quality is determined by its protein content, protein composition and properties of the flour. The protein content in wheat grain is largely dependent on genotype (Stoddard & Marshall, 1990) but is also influenced by environment (Rao *et al.*, 1993). Prominent among environmental factors is climate, residual N in the soil (Olson *et al.*, 1976), the rate and time of fertilizer N application (Fowler & Brydon, 1989), crop rotation (Borghi *et al.*, 1995) and interactions among them.

The ultimate objective of this study was to investigate the effect of wheat, canola, lupins or medics on the yield and quality of a subsequent wheat crop.

MATERIALS AND METHODS

Locality

The experimental site was located at Langgewens Experimental Farm of the Department of Economic Affairs, Agriculture and Tourism of the Provincial Administration: Western Cape, north of Malmesbury (18°43'E; 33°06'S). Some properties of the 250-300mm deep sandy soil of the experimental site are summarized in Table 2.1. The long-term mean annual rainfall during the growing season (April-October) is 334 mm. Total monthly rainfall and mean temperature distributions of the 1999 and 2000 seasons measured at Langgewens are shown in Figure 2.1.

Procedure

Field experiments were carried out in 1999, which was the fourth year since introduction of the long term rotational cropping systems established on the farm. For this particular study, wheat fields (*Triticum aestivum* cv. SST57) where the crops in the preceding year were 1) wheat, 2) canola (*Brassica napus*), 3) lupins (*Lupinus angustifolius*) and 4) medics (*Medicago spp.*) were selected in 1999. These treatments will subsequently be referred to as 1) WW, 2) CW, 3) LW and 4) MW. The experimental design was a completely randomized design with uneven number of replicates.

Plant measurements

In each selected field a $50m^2$ plot was selected to represent the same treatments as used for soil sampling procedure during the growing season of 1999 (Chapter 2).

On 20/10/99 (growth stage 28), wheat plants on a $0.25m^2$ sub sample were removed at randomly chosen points in the plots. Ears were counted and then thrashed to determine the number of grains. The wheat was harvested at the end of October using a plot combine (2 x $12m^2$ per plot). Yields were determined using an electronic scale and were converted to kg ha^{-1}. Representative seed samples of approximately 3 kg each were collected from the final yield of each plot and subjected to the following quality tests:

The hectolitre mass was determined according to the standard Two Level Funnel Method. The thousand grain mass was computed after a "Numigral" electronic grain counter was used to select 1000 grains from a representative sample before it was weighed.

The % kernel protein was determined using Near Infra-Red Spectroscopy (Technikon Infralyzer 400). Flour and bran were determined of a 100g sample (14% moisture), by using a Brabender Quadrumat Senior mill whereafter the % flour protein was determined using the Technikon Infralyzer 400.

Micro bread loafs were subsequently baked from 10g flour using the baking formula developed by Shorgen & Finney (1984). After the loaves had cooled down at room temperature (25°C), loaf volume was estimated through the displacing of rapeseed (Shorgen & Finney, 1984).

To determine the degree of alpha-amylase activity the Hagberg Falling Number System was used where a viscometer-stirrer is automatically released in a tube of heated flour (7±0.05g)/water suspension. When the viscometer has fallen the set distance through the suspension, the falling number value is calculated (seconds) which is then a direct measurement of the alpha-amylase activity. A falling number value of less than 250 seconds indicate a high alpha-amylase activity and is not desirable because it results in sticky bread.

Dough development time of the flour was determined using mixograph. The Alveograph was used to measure the rheological properties of dough prepared from flour and water. The dough was formed into disc-shaped pieces that were inflated into bubbles. The pressure variation inside each bubble was recorded in graphical form presented as an "alveograph" (Borghi *et. al.*, 1995). The maximum height of the curve provides an estimate of dough tenacity (P) and its length is a measure of dough extensibility (L). To be suitable for breadmaking, wheat should have a tenacity-to-extensibility ratio (P/L)of less than 1.0. Finally, the area under the curve is proportional to the energy required to cause the test piece (or dough bubble) to burst (W is the alveograph index, in J x 10^{-4}), with values $200>W>100$ required for wheat used for breadmaking.

Statistical analysis was performed using the PROC GLM command of the SAS statistical package (SAS Institute Inc., 1985). Differences between the treatments were considered significant at $LSD_{0.05}$.

Agronomic management

Relevant production techniques for different crop rotations to obtain maximum economic in stead of biological yield, were used in this study. Therefore wheat was not chemically treated against pests and diseases unless an economical threshold was reached; the cultivar choice were based on a cultivar that proved to maintain productivity and give a stable yield in the Swartland; soil was fertilized according to soil analysis and general recommended fertilizer programs for different crop rotations (mineral-N content of the soil is at present not used in N-recommendations to either maize or wheat in South-Africa). Tillage, sowing and application of chemical substances were done using standard farm implements and machinery.

General practices recommended and followed in commercial agricultural management of wheat in the Swartland differ according to the preceding crop. Practices used were as follows:

Wheat as preceding crop (WW): Stubble was burned on 17/03/99, before any seedbed preparations started. Weeds were controlled with a knockdown herbicide application (1l glyphosate (Sting) ha^{-1}), once (5/05/99) before sowing. Primary tillage was done with a chisel plough to a depth of about 20cm after the first rains in autumn, 1½ weeks before sowing. This commenced after the opening rains in autumn. Wheat was planted on 12/05/99 at the recommended rate of 100kg seed ha^{-1}. Limestone ammonium nitrate (at 30 kg N ha^{-1}) was incorporated at sowing. The most prominent weeds at the trail site were annual ryegrass (*Lolium rigidum*), wild oats (*Avena spp*) and a range of broad leaf annual weeds including *Emex australis.* Topic (clodinafop-propargyl, 250ml product ha^{-1}) and Harmony M (metsulfuron methyl/thifensulfuron, 30g product ha^{-1}) was therefore sprayed on 11/06/99. Dimethoate (at 0.5l product ha^{-1}) was applied as an insecticide. A topdressing of 60 kg N ha^{-1} on 23/06/99, in the form of Limestone ammonium nitrate fertilizer, brought the total nitrogen application to 90 kg N ha^{-1}. A fungicide was applied on two of the plots at 7/07/99, where eyespot (*Pseudocercosporella herpotrichoides)* was identified.

Canola as preceding crop (CW): Stubble was retained but fractured with a tyre roller. Similar tillage and crop protection techniques were applied as described for the WW treatment, except that no fungicide was applied on any of the CW plots. The wheat crop also received a total of 90 kg N ha^{-1} during the growing season, similar to the WW treatment.

Lupins as preceding crop (LW): Stubble was retained. Similar tillage and crop protection techniques were used as described for the CW treatment. In this case, the wheat crop received a total of 60 kg N ha^{-1} during the growing season, 30 kg of which was applied at sowing and the rest applied as topdressing on 23/06/99 (growth stage 6).

Medics as preceding crop (MW): Stubble was retained. The same tillage and crop protection techniques were used as described for previous treatments, except that no pre-sowing chemical weed control was done and no fungicide was applied. A total of 60 kg N ha^{-1} was applied to wheat, as was done in the LW treatment.

RESULTS AND DISCUSSION

Figure 4.1 shows the yield achieved by a wheat crop as affected by different rotation crops in the preceding year. No statistical difference (P=0.05) was found between wheat monocropping and the CW, LW and MW in terms of yield but wheat after lupins clearly outyielded all other crop rotations. This comes as no surprise, as the LW treatment also had the highest total dry mass at 14/9/1999 (growth stage 23) as indicated in Figure 3.2. Although not significant, this could be a result of the continuous higher mineral N in the soil profile of the LW treatment during that time of the growing season (Figure2.2).

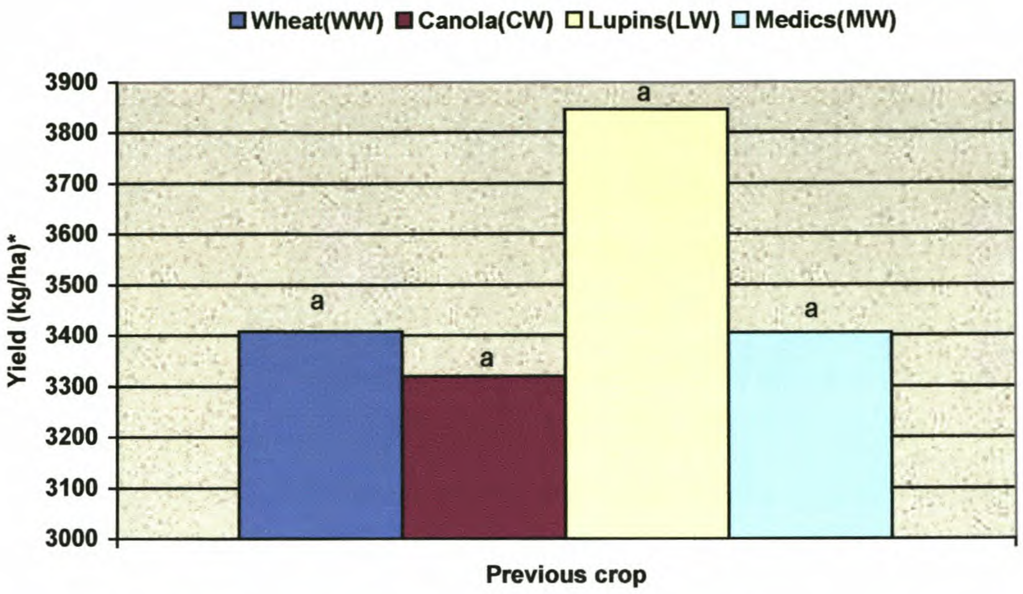

Figure 4.1. Effect of previous crops on the yield (kg ha^{-1}) of wheat in the following year (1999). *Letters on the graph represent significant differences at the 5% level.

During the 1999 production season the climatic conditions favoured wheat growth and production. The rainfall (Figure 2.1) was evenly distributed throughout the months of April-September with above average monthly rainfall experienced in July-September. This resulted in above average yields.

Strong *et.al.* (1986) found that the presence of mineral N in the subsoil layers following legumes was considered responsible for relatively high grain yields of the following wheat crop during seasons of limited growing-season rainfall. As a trend of higher mineral-N concentrations in the subsoil after legumes was detected in this study (Table 2.3), it can be argued that the "rotation-effect" of the legume treatments on the subsequent wheat crop could be diluted by the favouring weather (rainfall) conditions. This may explain why yield differences was not significant.

Table 4.1. Effect of previous crops on the number of ears, grains and grains per ear of a subsequent wheat crop. Values represent a 0.25 m^2 area that was sampled on 20/10/99 (growth stage 28).

Previous crop	Ears	Grains	Grains/ear
Wheat(WW)	115a*	4239a	37a
Canola(CW)	109a	3641b	33b
Lupins(LW)	113a	3957ab	35ab
Medics(MW)	119a	4184ab	34ab

***Different letters in the same column indicate statistical significant differences at the 5% level.**

More grains per ear were produced in the WW treatment than the CW treatment (Table 4.1), although it did not differ (P=0.05) from LW and MW. Larger grains in LW as shown in Figure 4.2 was therefore the reason for the higher yield achieved with wheat after lupins.

A greater leaf area duration in the LW treatment (Figure 3.1) could explain the higher yield, because more photosynthetic substrates will be produced as a result of longer radiation interception (Khalifa, 1973). This is however only true when soil moisture is no limiting factor, as was the case during the 1999 wheat-growing season (Figure 2.1) when the above average rainfall experienced during August and September 1999 ensured that soil moisture was no limiting factor. The higher hectolitre mass found in the LW treatment supports the higher yield realized (Figure 4.3).

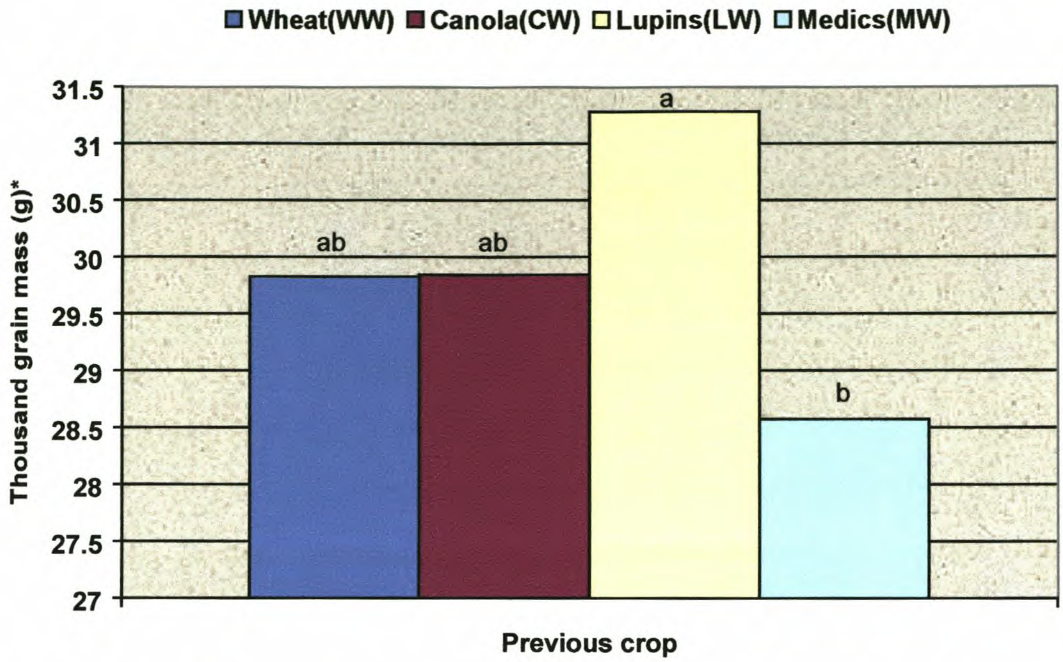

Figure 4.2. Effect of previous crops on the thousand grain mass (g) of wheat in the following year (1999). *Letters on the graph represent significant differences at the 5% level.

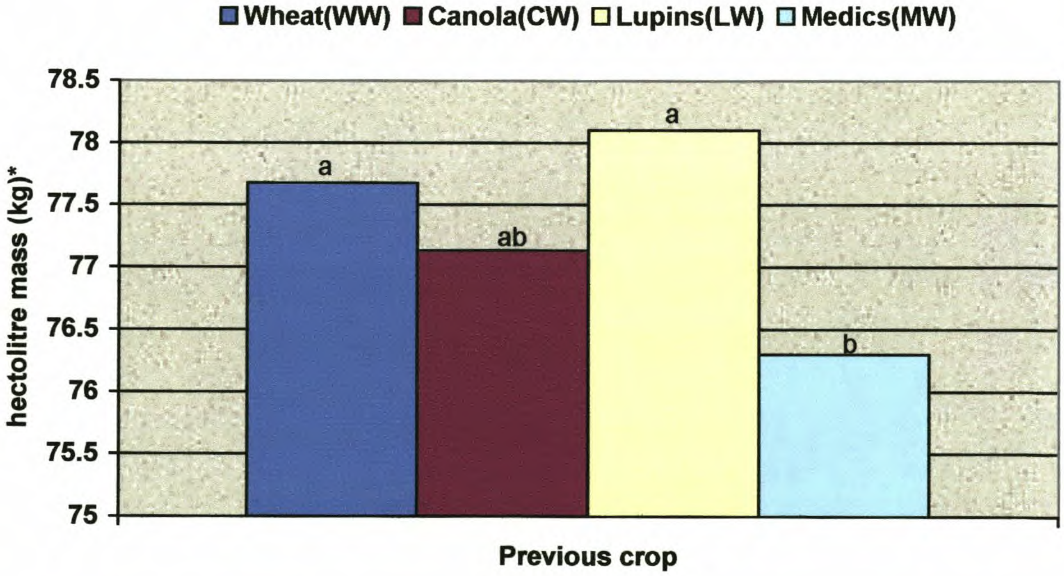

Figure 4.3. Effect of previous crops on the hectolitre mass (kg/100l) of wheat in the following year (1999). *Letters on the graph represent significant differences at the 5% level.

The kernel protein content, flour protein content as well as flour yield (%) and bran yield (%), as affected by the previous crop are summarized in Table 4.2.

No statistical difference (P=0.05) was found in the flour or bran yield, while differences between means of treatments for % kernel protein (CP%) and % flour protein (FP%) were found. Both CP% and FP% of the LW and WW treatments had the lower protein content, while the CW and MW treatments resulted in the highest protein content of the flour.

Table 4.2. Effect of previous crops on the percentage kernel protein (CP%), flour protein (FP%) and the flour yield (F%) and bran yield (B%).

Preceding Crop	CP%	FP%	F%	B%
Wheat	12.83b*	11.4b	72.92a	26.95a
Canola	13.13a	11.83ab	73.38a	26.5a
Lupins	12.85ab	11.4b	73.8a	26.25a
Medics	13.35a	12a	73.07a	26.78a

***Different letters in the same column indicate statistical significant differences at the 5% level.**

The protein content of the flour plays an important role in the baking quality of wheat (Finney *et. al.*, 1987) and this can be seen in Figure 4.4 where the volume of experimental micro loafs baked, are presented. WW and MW treatments resulted in the bread with the highest volume.

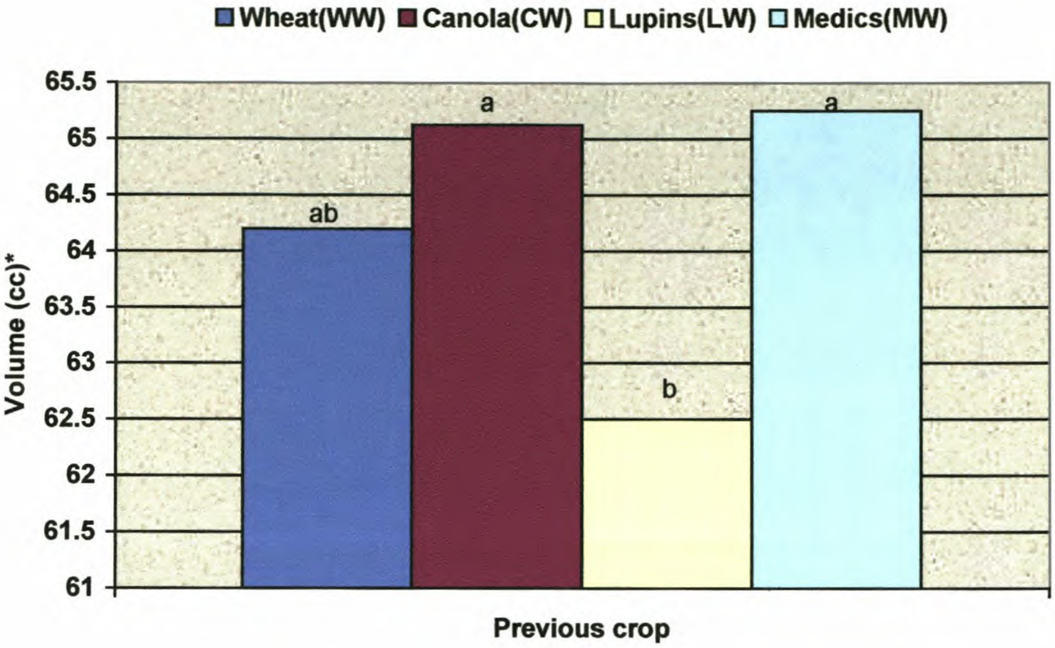

Figure 4.4. Effect of previous crops on the volume of experimental loafs (cc) of wheat flour in the following year (1999). *Letters on the graph represent significant differences at the 5% level.

Table 4.3 shows the alpha amylase activity of the wheat, the mixing time in minutes together with the rheological properties of the dough. No statistical difference (P=0.05) were reached in all of the measurements between treatment means. All the parameters for a good quality bread making wheat was met.

Table 4.3. Effect of previous crops on the falling number (measuring alpha amylase activity in seconds), mixing time of the flour to get to dough (in minutes), W value (the alveograph index measured in Jx10^{-4}) and the P/L value (tenacity-to-extensibility ratio) of a subsequent wheat crop.

Preceding crop	Falling number	Mixing time	W value	P/L value
Wheat	415.63a*	2.65a	184.5a	0.86a
Canola	422.67a	2.46a	192.2a	0.85a
Lupins	415.0a	2.65a	164.1a	0.90a
Medics	448.5a	2.53a	170.0a	0.88a

***Different letters in the same column indicate statistical significant differences at the 5% level.**

The most important conclusion to make from Table 4.3, is that good flour and dough properties of wheat cultivated after legumes such as medics and lupins can be maintained with less fertilizer N applied.

CONCLUSION

Wheat in cropping systems consisting of legume phases such as lupins and medics, required less nitrogen fertilizer application to achieve statistically the same yield, flour and dough properties. These crop rotations can therefore be considered as more ecologically sustainable and economically viable for the Swartland.

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CHAPTER 5

CONCLUSION

The results of this study indicate that the inclusion of lupins and medics in continuous wheat cropping systems in the Swartland could help to limit the decline of mineral N experienced within a growing season. Since the climatic conditions were not a serious limiting factor to wheat production during the 1999 growing season, these better chemical soil properties played an important role in the production of above ground plant material, yield and quality of wheat studied.

The weather conditions, which favoured growth and production of wheat, together with higher nitrogen fertilizer application to the "wheat after wheat" and "wheat after canola" rotations, prevented the positive effect of crop rotation on soil conditions, pests and diseases to become evident. Agronomic benefits of rotations are likely to become evident in less favourable wheat growing conditions when the disease breaking capability of canola, lupins and medics as rotational crops may play a more important role.

The most important conclusion to make from this study, is that the cropping systems involving wheat and annual legumes required 30 kg N ha^{-1} less to achieve statistically the same wheat yield and quality in the Swartland region and these rotations can therefore be considered as more ecologically sustainable and economically viable.

The mineral N content of the soil is at present not used in N recommendations to wheat and N fertilizer rates in the Swartland are currently determined by rainfall (expected yields) while minor adjustments are made due to differences in soil texture, cropping history and method of soil tillage used. This method of N recommendations can underestimate the available N present in the soil and this study also call for investigation on the effectivity of applied nitrogen fertilizer at sowing to wheat planted subsequent to lupins and medics. This is needed because high mineral N concentrations were found in the soil profile after these legumes during the first third of the growing season without receiving any nitrogen fertilizer.

Key objectives to strive for will be the synchronization between N supply from the soil and demand for N in soil-crop systems, and conservation of N mineralized outside normal crop growth periods. Consequently, management of active soil organic N in coordination with added N sources will give coupling knowledge of controls on mineralization of soil organic N with appropriate cropping systems and soil management practices.

This study was aimed at determining the effect of different crop rotations on soil fertility, and because clear soil fertility trends take time to form, this study was probably to short to obtain fully significant differences.