BIOMASS PRODUCTION, YIELD AND QUALITY RESPONSE OF SPRING WHEAT TO SOIL TILLAGE, CROP ROTATION AND NITROGEN FERTILISATION IN THE SWARTLAND WHEAT PRODUCING AREA OF SOUTH AFRICA

Safiah Hasan Maali

Dissertation presented for the Degree Doctor of Philosophy (Agriculture) at the University of Stellenbosch

Promotor: Prof. G.A.Agenbag

April 2003

DECLARATION

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

Signature:..S.H.Maali.. Date:..1..3..03..003

S.H.Maali

Abstract

A long-term experiment was conducted at the Langgewens Experimental Farm, near Malmesbury in the Western Cape province of the Republic of South Africa. The effect of soil tillage, crop rotation and nitrogen fertiliser rates on mineral-N levels in the soil, nitrogen levels in plants, wheat growth and yield components, grain yield as well as quality parameters of spring wheat (*Triticum aestivum L.*) were determined. Although the tillage treatments tested were initiated in 1976, present crop rotations and nitrogen application rates were only applied since 1990. Most of the data that are discussed however was recorded during the 1997 to 2001 period.

The trial was designed as a randomised complete block with a split-plot arrangement and four replicates. Main plots were tillage methods namely conventional tillage (CT), tine tillage (TT), minimum tillage (MT) and no tillage (NT). Crop rotations used were continuous wheat (WW) and wheat/lupin/wheat/canola (WLWC). Sub plots (16 x 5 m) consisted of nitrogen fertiliser rates (60, 100 and 140 kg N ha^{-1}) applied as lime stone ammonium nitrate (29 N%). Both soil and crop data were recorded.

The results of this study showed that differences in total mineral-N content of the soil, N-contents of wheat, wheat growth and yield components as well as wheat quality parameters were found between tillage treatments, crop rotations used as well as N-fertiliser rates applied. Response however, varied largely between years due to annual variation in especially total precipitation and distribution of rainfall. The inclusion of a legume crop (lupin) and canola in the rotation with wheat was found to have only a small effect probably due to the fact that lupins were grown once in a four year cycle only.

Application of different nitrogen rates did increase the mineral-N in the soil, but the effect did not last very long in most years due to either N-leaching or plant uptake. To ensure sufficient mineral-N levels, late application of N-fertiliser will therefore be needed. Minimum tillage or reduced tillage preforms better than conventional tillage in low rainfall years. In general these tillage systems should be combined with crop rotation to ensure that yields are comparable to that obtained with conventional tillage.

Uittreksel

Die ontwikkeling, graanopbrengs en bakkwaliteit van koring (*Tritium aestivum L.*) in reaksie teenoor gewasrotasie, metode van grondbewerking en N-bemestingspeil is in 'n lang termyn studie op Langgewens Proefplaas, naby Malmesbury in die Weskaap provinsie van die Republiek van Suid-Afrika, bepaal.

Hoewel die verskillende grond bewerkingsmetodes sedert 1976, en gewasrotasies en stikstofpeile sedert 1990 toegepas is, is daar in hierdie studie gekonsentreer op data wat gedurende die periode 1997-2001 ingesamel is.

Die eksperiment is as 'n randomiseerde blok ontwerp met vier bewerkingsmetodes nl. konvensionele bewerking (CT), tand bewerking (TT), minimum bewerking (MT) en geen bewerking (NT), twee gewasrotasies nl. monokultuur koring (WW) en koring/lupiene/koring/Canola (WLWC) en drie N-peie (60 kg N ha^{-1}, 100 kg N ha^{-1}, 140 kg N ha^{-1} uitgevoer. Alle stikstof is in die vorm van kalksteen-ammoniumnitraat toegedien.

Die reaksie van beide grondfaktore soos die minerale N inhoud en gewaskomponente soos biomassa produksie, opbrengs en kwaliteit teenoor bogenoemde faktore het 'n goeie korrelasie getoon met die heersende klimaatstoestande.

Lae reënval jare (gebiede) sal volgens hierdie studie die grootste voordeel verkry met minder intensiewe grond bewerkingstelsels, terwyl 'n frekwensie van meer as een peulgewas per siklus van 4 jaar nodig sal wees om grondvrugbaarheidsvlakke betekenisvol te verhoog. Stelsels van minder intensiewe grondbewerking is ook tot 'n groter mate deur gewaswisseling bevoordeel as konvensionele metodes van grondbewerking.

Hoewel minerale-N vlakke in grond deur verskillende N-peile beïnvloed is, was die effektiwiteit van toedienings laag en het verdeelde toedienings groot voordele ingehou.

Dedication

It is my privilege to write this heartfelt dedication in memory of my beloved mother, Maryiam Maali, a women of stature, whose example and teaching made me who I am; whose love and vision molded me into what I have become.
I did it, mother! This is for you.

Acknowledgements

I would like to express my grateful thanks to:

Almighty Allah who has provided me with life, intelligence and who has sustained me to accomplish this task.

Professor G.A. Agenbag, who afforded me the benefit of his knowledge and extensive experience in the field of study I choose to undertake.

Dr. P.J. Pieterse, for his invaluable assistance and advice on statistical issues.

The University of Stellenbosch for the support they provided over the past two years.

The staff and technicians at the Department of Agronomy for their help whenever I needed it.

Ms. C.L. Jacobs for proof-reading my dissertation and for her suggestions around grammatical phraseology.

My husband for his encouragement of my work, his support of my studies towards a doctoral degree and for his help with data collection and samplings.

My children for their willingness to entertain themselves while I worked. "Guys, it is over!"

My family: father, brothers and sisters who encouraged me to "go for it" in such amazingly practical way.

"Thank you all. For your support and encouragement."

List Of Abbreviations

BLV	Bread loaf volume
CT	Conventional tillage
C	Organic carbon
°C	Degrees Celsius
DT	Dough development time
DM	Dry mass
g	Gram
ha	Hectare
hl	Hectoliter mass
LSD	Least significant differences
L	Dough extensibility
LAI	Leaf area index
m^2	Square metre
m^{-2}	Per square metre
mg	Milligram
MT	Minimum tillage
N	Nitrogen
NT	No-tillage
P	Dough tenacity
Pp	Pre-planting
P/L	Tenacity-Extensibility
TT	Tine tillage
W	Alveograph index
WW	Wheat/wheat
WLWC	Wheat/lupin/wheat/canola

Contents

Chapter 1

Introduction

Wheat is one of the most domesticated plants and most important food crops in the world. It serves as the staple food for many countries and plays an important part in the fields of economics, politics and culture.

South African wheat farmers on average produce 2 million tons per year on about 1.2 million hectares. The Western Cape Province produces about 29% of the total wheat production (Abstract Agricultural Statistic, 2002). Wheat production has increased consistently during the past 50 years, but with a levelling off during the past decade (SAGIS, 1999). Of this crop on average about 50% is winter wheat produced on dry land, 30% dry land spring wheat and 20 % irrigated spring wheat. The local consumption on average is 2.4 millions tons per annum. Therefore, South Africa is a net importer of wheat along with other Southern Africa Development Community (SADC) countries (Van Niekerk, 2001).

In the Republic of South Africa the majority of spring wheat (*Triticum aestivum L.*) produced in the Swartland (Western Cape Province) is grown under rainfed Mediterranean-type climate (Agenbag & Vlassak, 2000), which is characterised by long, hot, dry summers and short, mild, wet winters with a wide oscillation in the annual rainfall, receiving nearly 80 % of it annually rain during the months April to September (López-Bellido *et al.*, 1996).

The constraints of wheat production vary in Mediterranean environments, but inadequate rainfall is usually the most limiting factor (Fischer, 1979). In general, winter rainfall exceeds crop demand because of mild temperatures, low evaporation, slow growth rates, and the high reliability of the rainfall. During spring, rainfall became less frequent, temperature increase, and soil moisture is usually exhausted by the time the crop reaches maturity (Loss & Siddique, 1994). So rainfall, temperature and the soil type largely determine the length of the growing season, and therefore also crop yields in Mediterranean environments.

Monocropping with wheat is used on more than 60% of all fields sown annually in the Swartland area (Agenbag & Vlassak, 2000), where soils are generally shallow (250-300 mm deep) sandy loams with a high (>30 %) gravel and stone content in the A-horizon.

Very low organic C (< 0.5%) and total N content (< 0.05%) of the soil exacerbate the already low production potential caused by the shallow soils and high gravel and stone content in this area (Agenbag & Vlassak, 2000).

In order to increase yield potential and improve yield stability, it is therefore important for producers to use production techniques which may help to improve fertility of the soil and decrease water deficits towards the end of the growing season. Method of tillage, crop rotation and N application rate are three management practices that have been shown to affect the wheat yield potential and stability (Halvorson, Black, Krupinsky & Merrill, 1999; Bationo & Ntare, 2000; Du-Bing *et al.,* 2000).
Several studies showed that minimum or reduced tillage is more efficient compared to other tillage systems especially in years with below normal precipitation (Lawrence *et al*., 1994; Lafond *et al*., 1996; Strong *et al.* 1996), due to better soil water conservation and higher water use efficiency. Soil responses to method of tillage however vary for different climatic regions and results are therefore not always applicable to all regions (Unger 1994; Riley 1998).

The positive effect of crop rotation on wheat yield due to the increased amount of residual mineral-N in the soil and better water use efficiency is well documented (Dala *et al.,* 1998; Galantini *et al*., 2000) and should therefore help to improve yield potential and stability in the Swartland wheat producing area. Both method of tillage and crop rotations may however have an effect on optimum N-fertiliser rates (Fox & Bandel, 1986; Deng & Tabatabai, 2000). For this reason a long-term study was started to examine the effect of the above-mentioned management practices on spring wheat production and stability as well on soil fertility in Swartland area in the Republic of South Africa. Initial results of this study on the response to tillage had been reported by Agenbag & Maree (1989; 1991). In these reports responses to crop rotation and N-fertiliser rates have not been discussed because these treatments started in 1990 only. This dissertation will therefore focus on the long-term response of different tillage methods as well as interactions between tillage, crop rotation and nitrogen fetiliser rates. Most of the dissertation will concentrate on the years (2000-2001) but for some parameters longer-term data will also be used to take variation in climatic conditions into account.

References

ABSTRACT AGRICULTURAL STATISTICS. 2002. Department of Agriculture, South Africa.

AGENBAG, G.A. & MAREE, P.C.J., 1989. The effect of tillage on soil carbon, nitrogen and soil strength of simulated surface crusts in two cropping systems for wheat (*Triticum aestivum L.). Soil & Tillage Res*. 14, 53-65.

AGENBAG, G.A. & MAREE, P.C.J., 1991. Effect of tillage on some soil properties, plant development and yield of spring wheat (*Triticum aestivum L.*) in stony soil. *Soil & Tillage Res*. 21, 97-112.

AGENBAG, G.A. & VLASSAK, K., 2000. Mineralisation in an agricultural soil of the Swartland wheat producing area of South Africa: field experiments. In: K. Vlassak, G.A. Agenbag & O. Van Cleemput (eds.). Nitrogen dynamics in intensive and extensive agriculture. Leuven, Belgium, pp 39-50.

BATIONO, A. & NTARE, B.R., 2000. Rotation and nitrogen fertiliser effect on pearl millet, cowpea and groundnut yield and soil chemical properties in a sandy soil in the semi arid tropics, *West Africa. J. Agric. Sci*, 134 (3), 277-284.

DALA, R.C., STRONG, W.M., WESTON, E.J., COOPER, J.E., WILDERMUTH, G.B., LEHANE, K.J., KING, A.J. & HOLMES, C.J., 1998. Sustaining productivity of a Vertisol at Warra, Queensland, with fertilisers, no-tillage, or legumes. 5. Wheat yields, nitrogen benefits and water-use efficiency of chickpea-wheat rotation. *Aust. J. of Exp. Agric*. 38, 489-501.

DENG, S.P. & TABATABAI, M.A., 2000. Effect of cropping systems on nitrogen mineralisation in soils. *Biol. Fertil. Soils* 31, 211-218.

DU-BING, DENG-JIAN, LI-WENYING, LIAO-ZHIXI, DU-B, DENG-J, LI-WY & LIAO-ZX, 2000. Field experiment for comparison of winter wheat conservation tillage and conventional tillage. *Journal of China Agricultural University*. 5, 55-58.

FISCHER, R.A. 1979. Growth and water limitations to dry-land wheat yield in Australia: A physiological framework. *J. Aus. Inst. Agric. Sci*. 45, 83-89.

FOX, R.H. & BANDEL, V.A., 1986. Nitrogen utilisation with no-tillage. In: Sprague M. A. & Triplett G. B. (eds.). No-tillage and surface tillage agriculture. John Wiley & Sons, New York, USA, pp 117-143.

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

HALVORSON, A.D., BLACK, L.A., KRUPINSKY, J.M. & MERRILL, S.D., 1999. Dry land winter wheat response to tillage and nitrogen within an annual cropping system. *Agron. J.* 91, 702-707.

LAFOND, G.P., BOYETCHKO, S.M., BRANDT, S.A., CLAYTON, G.W. & ENTZ, M.H., 1996. Influence of changing tillage practices on crop production. *Can. J. Plant Sci.* 76, 641-649.

LAWRENCE, P.A., RADFORD, B.J., THOMAS, G.A., SINCLAIR, D.P. & KEY, A.J., 1994. Effect of tillage practices on wheat performance in a semi-arid environment. *Soil & Tillage Res.* 28, 347-364.

LÓPEZ-BELLIDO, L., FUENTES, M., CASTILLO, J.E., LÓPEZ-GARRIDO, F.J. & FERNÁNDEZ, E.J., 1996. Long-term tillage, crop rotation, and nitrogen fertiliser effect on wheat yield under rain-fed Mediterranean conditions. *Agron. J.* 88, 783-791.

LOSS, S.P. & SIDDIQUE, H.M., 1994. Morphological and physiological traits associated with wheat yield increases in Mediterranean environments. *Adv. in Agron.* 52, 230-275.

RILEY, H.C.F., 1998. Soil mineral-N and N-fertiliser requirements of spring cereals in two long-term tillage trials on loam soil in southeast Norway. *Soil & Tillage Res.* 48, 265-274.

SAGIS. 1999. South Africa Grain Information Service Annual Reports. Association incorporation under section 21.

STRONG, W.M., DALA, R.C., WESTON, E.J., COOPER, J.E., LEHANE, K.J., KING, A.J. & CHICKEN, C.J., 1996. Sustaining productivity of vertisol at Warra, Queens-land, with fertilisers, no-tillage or legumes 2. Long-term fertiliser nitrogen needs to enhance wheat yields and grain protein. *Aust. J. Exp. Agric*. 36, 665-674.

UNGER, P.W., 1994. Tillage effects on dry-land wheat and sorghum production in the Southern Great Plains. *Agron. J.* 86, 310-314.

VAN NIEKERK, H., 2001. South African wheat pool. In: A.P. Bonjean & W.J. Angus (eds.). The world wheat book. A history of wheat breeding. Limagrain group, Londres, pp 924-936.

Chapter 2

Literature review

Crop production potential is primarily determined by environmental factors such as climate and soil physical, chemical and biological characteristics. Crop production techniques such as crop rotation, methods of tillage used and N-fertiliser rates may however have an effect on these soil characteristics and other biotic factors such as plant establishment, weeds, diseases and pests. Production techniques therefore determined actual yields obtained, quality and sustainability of production.

1. Effect of production techniques on soil properties

1.1 Soil physical properties

According to Dexter & Young (1992) soil physics is the study of the energy state and flux of water in relation to the spatial heterogeneity of the different phases. This heterogeneity is usually referred to as soil structure. Dexter (1997) concluded that soil structure dominates all the physical properties of the soil and it's functioning. Soil physical properties such as bulk density (BD), penetration resistance, aggregate stability, moisture content and temperature, are inter-related and are affected by both the intensity and depth of pre-plant tillage as well as crop rotations used (Hao *et al.*, 2000).

1.1.1 Bulk density

Soil bulk density affects water movements and root growth and sometimes also yield potential of crops. Since the tillage systems vary in depth of tillage and amount of implement traffic, they may also have an effect on soil density in the rooting zone during the growing season. In general direct drilling increased soil bulk density in the upper soil layers, compared to the plough treatments, which may lead to reduced root mass and concentration of roots near the soil surface (Griffith, Mannering & Box, 1986; Malicki, Nowicki & Szwejkowski, 1997; Omer & Elamin, 1997; Varsa *et al.*, 1997; Schjønning & Rasmussen, 2000). In a sandy soil, superficial tillage (disk harrowing) also caused a marked deterioration of soil physical condition, as measured by increases in bulk density and penetration resistance (Bonari, Mazzoncini & Peruzzi, 1995). Salinas-Garcia, Matocha & Hons (1997) found that bulk densities under no-tillage ranged from 5–19 % higher compared to other tillage treatments, while those for mouldboard ranged from 7 to 21% lower. They concluded that more intensive tillage systems resulted in lower bulk densities when compared to shallow tillage and no-tillage treatments. However, after several years of reduced tillage systems, better soil aggregation and more undisturbed large soil pores found with these systems tend to offset the negative effect on water movement and root growth caused by increased density. In another study Evans *et al*. (1996) reported that deep tillage impacted on surface residue accumulation, but did not affect soil bulk density, volumetric soil moisture, or grain yield of corn. In an irrigated cropping study in southern Alberta, Hao *et al*. (2000) also found no adverse effects on bulk density when minimum tillage is used.

1.1.2.Aggregation

Soil aggregation is the cementing or binding together of soil particles into secondary units. A high level of aggregation is considered to be an indication of good soil structure and generally have a positive influence on plant growth. Tillage, or the lack of it, has a major effect on soil aggregation. In a long-term experiment on a clay soil in southeastern Norway, Børresen & Nøjs (1993) found that aggregate stability was better on rotavated as compared to ploughed soil. This could be due to the increase in organic matter in the soil, which had not been ploughed. Agenbag & Maree (1989) in contrast found that reduced tillage decreased the strength of surface crusts on shallow, stony, sandy–loam soils in a Mediterranean-type climate. Sharratt (1996) also found that the percentage non-erodible aggregates, mechanical stability, and penetration resistance were higher for no-tillage compared to conventional tillage on sub-arctic soil. Aggregate stability was however, neither affected by nitrogen rate nor by the interaction between tillage and nitrogen. In an irrigated cropping study in southern Alberta, Hao *et al*. (2000) found that use of minimum tillage in comparison with conventional tillage resulted in higher aggregation and better residue cover, which reduces susceptibility to wind erosion.

Improved aggregation not only helps in water management through better infiltration, but it should help to offset the negative effect of high soil density in untilled soil on rooting. This positive affects, may take several years to develop after implementing reduced tillage (Griffith *et al.,* 1986). Hermawan & Bomke (1997) found that improved aggregate stability with cover crops in wet soil was related to increasing organic carbon levels, while that with tillage was due to alternate wetting and drying of the soil. In addition, the relationships between aggregate stability and carbon content varied with soil water content at sampling.

1.1.3 Moisture content and temperature

In humid regions or for irrigated crops adverse soil physical conditions, which limit soil water infiltration, root development and crop yield, may develop when no-tillage systems are used (Unger, 1996; Hermawan & Bomke, 1997). Ball, Lang, Robertson & Ranklin (1994) obtained similar results, on imperfectly drained loam soils where soil aeration, strength and structure were more favourable under ploughing than under direct drilling. In contrast Krzic, Matie & Arthur (2000) showed that limiting tillage operations to the fall, did not adversely affect soil physical properties for plant growth in humid maritime climates.

Karunatilake, Es Van & Schindelbeck (2000) found that soil strength and soil water content was higher in no-tillage comparing to conventional tillage. They concluded that long–term use of reduced tillage system was beneficial on well–structure clay loam soils if adequate considerations were given to maintain soil structure. In dry and hot regions results of Power & Peterson (1998) showed a higher soil water content and reduced temperature by using no-tillage systems (NT) compared with conventional systems (CT). Similar results were reported by Lafond *et al*. (1996) and Strong *et al.* (1996). Karunatilake *et al*., (2000) on the other hand found that soil properties like soil water content, soil strength and soil temperature did not differ significantly between tillage treatments on a clay loam soil, due to the limited soil degradation and the strong soil structure associated with a high clay content of the soil. In a cold, semiarid climate (Arshad & Gill, 1997), a tendency for increased soil moisture content with decreased tillage intensity was observed on clay soil. Infiltration was also improved by no tillage with surface residue compared to ploughed soil. The authors suggested that better structural stability in the no-tillage with more surface residue enhanced infiltration. Prior *et al*. (2000) suggested that selecting planting equipment that maintains surface residue and minimizes soil disturbance could help to conserve soil water needed for successful seedling establishment in coarse textured soils.

1.2 Soil chemical properties

1.2.1 Soil organic C and total N

Higher levels of soil organic C, total N and extractable P near the soil surface as well as lower concentrations of NO_3^- are directly related to surface accumulation of crop residues in systems of conservation tillage (Salinas-Garcia, *et al*., 1997). Although the levels of both organic carbon and total nitrogen increased with decreased tillage intensity, the C/N ratio was not affected (Ekeberg & Riley, 1997). Increased organic C and N concentration with no-tillage was found to be limited to the 0-75 mm soil profile (Griffith *et al.*, 1986; Campbell *et al.*, 1996). In the semi arid prairies where shallow tillage was practiced, Campbell *et al.* (2000) found that significant soil organic carbon (SOC) changes were unlikely to be found beyond the 150 mm depth, indicating that extrapolation beyond this depth should be avoided. These results are in agreement with Agenbag & Maree (1989), Lòpez-Fando & Almendros (1995) and Potter, Jones, Torbert & Unger (1997). These authors found that a significant increase in soil C in the topsoil with no-tillage in comparison with conventional tillage, suggested increased mineralisation of soil organic matter as a result of ploughing and mixing as reason for this tendency. Contrary results under rainfed Mediterranean conditions showed that no-tillage did not increase the organic matter and the extractable mineral-N content of the soil after six years, due to the small amounts of crop residues returned to the soil annually (Lòpez-Bellido *et al.*, 1997). This is typical for semi-arid climates, suggesting that a longer period will be needed to observe significant changes in the organic matter and N content in the soil under such conditions.

Crop rotation usually increases soil organic matter content, when compared to monoculture. Results of Lòpez-Fando & Almendros (1995) demonstrated the positive effect of crop rotation in combination with both no-tillage and conventional tillage on SOC and N when compared to monoculture. Significant increases in the organic matter content were primarily due to the presence of the legume crops in the rotations in combination with no-tillage (Fettel & Gill, 1995; Stringi & Giambalvo, 1999; Campbell *et al.*, 2000). Grace, Oades, Keith & Hancock (1995) found that soil organic C declined linearly with increasing frequency of fallow and decreasing frequency of pastures in the rotation. Burle, Mielniczuk & Focchi (1997) found that legume cropping systems resulted in the highest soil organic C to a depth of 175 mm. The increase was found to be largest at the 0-25 mm layer. Ekeberg & Riley (1997) on the other hand found that crop rotations, which included legumes, did not increase the organic matter content in the soil when compared to continuous wheat. Campbell *et al.* (2000) also found that SOC content in the legume green manure-wheat system did not differ significantly from the wheat monoculture, and SOC gains with grasses will only occur if weather conditions favour forage production. Lupwayi, Rice & Clayton (1999) reported that neither tillage nor crop rotation had any significant effect on SOC. In sandy soil in the semi-arid tropics of West Africa organic matter showed a decline under continuous millet, cowpea-millet and groundnut-millet rotations (Bationo & Ntare, 2000). The fallow-millet rotation however supplied more mineral-N than the legume-millet rotation. In coarse-textured soils of semi-arid climates, cropping frequency (fallow-wheat vs. continuous wheat) had also no effect on organic C or N content in the soil (Campbell *et al.*, 1999).

1. 2. 2 Cation exchange capacity (CEC) and soil pH

The effect of tillage on soil CEC appeared to be dependent on the mechanical mixing of soil by the mouldboard plough and conventional tillage treatments, which may bring clay to the surface layer from lower depths (Campbell *et al.*, 1996). Higher N fertilisation increased organic C, total N, and extractable P, in the 200 mm depth under sub humid climates, while no-tillage decreased cation exchange capacity and soil pH as compared to other tillage systems (Salinas-Garcia *et al.*, 1997).

Ekeberg & Riley (1997) reported that reduced tillage lowered the pH about 0.1-0.3 units when compared to plough tillage in a long-term trial on loam soils of southeast Norway. Børresen & Nøjs (1993) reported that the pH decreased 0.006 units per year in the upper 200 mm of the soil profile after rotary cultivation as compared to ploughing. Legume cropping systems also resulted in higher cation exchange capacity (CEC) Burle *et al.* (1997). Although the increases were found to be largest in the 0-25 mm layer, higher CEC values were shown to a depth of 175 mm. Clover based systems however resulted in the highest soil acidification in the 25-175 mm soil profile

1.3. Soil biological properties

Tillage operations affect the soil environment by altering the geometry. In addition, tillage determines the placement of crop residues. These effects influence many physical, chemical and biological properties of the soil and thereby the conditions for crop growth. Young & Ritz (2000) pointed out that physical disturbance of the soil profile can have profound effects on microbial dynamics of the soil systems.

Both soil structure and soil microbial processes changed when annual tillage practices were altered. On a weakly structured clay soil, cultivation to 120 mm depth instead of mouldboard ploughing (200-250 mm) improved soil structure and increased the microbial activity in the upper 120 mm (Stenberg, 1998). Lupwayi *et al.* (1999) found that soil microbial biomass was often significantly higher under zero tillage when compared to conventional tillage, while the lowest microbial biomass and CO_2 evolution were found after summer fallow, especially under conventional tillage. Legume crops also resulted in higher microbial biomass compared to other treatments which did not include legume crops. They concluded that zero tillage and legume-based rotations are more sustainable crop management systems than conventional tillage in gray Luvisolic soils of northern

Alberta. Pankhurst *et al.* (1995) showed that tillage, stubble management, crop rotation and N fertilisation significantly affected microbial biomass in a long-term field trial. Tillage with stubble management significantly affected mycorrhizal fungi, protozoa, collembola, earthworms and cellulose decomposition. Crop rotation affected only mycorrhizal fungi protozoa and soil peptidase activity, while N fertiliser had a significant effect on mycorrhizal fungi, and cellulose decomposition. Moore, Klose & Tabatabai (2000) study the impacts of crop rotations and N fertilisation on microbial biomass C (C mic) and N (N mic) and concluded that the C mic and N mic values were significantly affected by crop rotation and plant cover, but not by N fertilisation. In general, the highest C mic and N mic contents were found in the multi-cropping systems and the lowest found in monoculture systems.

2. Effect of production techniques on crop biotic factors

2.1 Crop establishment

Crop establishment are affected by soil temperature, soil moisture, seeding depth, seed quality, fertiliser placement and soil packing. Most of these factors are largely affected by tillage systems (Lafond *et al.*, 1996). In a wheat lupin rotation under reduced tillage, rough seedbed conditions imposed by this treatment resulted in uneven sowing depth and relatively low wheat establishment (Heenan, Taylor, Cullis & Lill, 1994). In a semi-arid environment, no-tillage however, resulted in higher plant establishment of wheat when compared to conventional and reduced tillage (Lawrence *et al.*, 1994). On sandy clay soil in arid dry land in Sudan, Omer & Elamin (1997) showed moisture storage gains due to chisel and 100 mm discing, which were reflected in better crop establishment. They also showed the rate and extent of crop establishment were not adversely affected by conservation tillage provided that seeding is shallow and adequate seed to soil contact is achieved. Çarman (1997) showed that tillage method had a significant effect on emergence rate of wheat in a study in central Anatolia. The highest emergence rate index was obtained with a stubble cultivator followed by disc harrowing and the lowest for a rotary tiller. Crop establishment, which is critical in crop production, can be therefore improved with conservation tillage (Lafond *et al.*, 1996).

2.2 Yield

Long-term effects of tillage, crop rotation and nitrogen fertiliser on wheat yield under rainfed Mediterranean conditions showed that differences in rainfall during the growing season had a marked effect on wheat yield (López-Bellido *et al.* 1996). In dry years, wheat yield was higher under no-tillage compared to conventional tillage. Results of many researchers proved that no-tillage is more efficient compared to other tillage systems especially in years with below normal precipitation. Lawrence *et al.* (1994) reported that no-tillage showed consistent advantages in wheat grain yield in all four years tested compared to conventional tillage. The increase in yield from no-tillage is believed to be related to better soil water conservation and greater water use efficiency under no-tillage (NT) compared to other tillage. Mcandrew, Fuller & Wetter (1994), Lafond *et al.* (1996), Strong *et al.* (1996) and Du-Bing *et al.* (2000) obtained similar results, while Pratley (1995) showed that wheat grain yield was significantly better with direct drilling compared to conventional and reduced tillage in New South Wales in Australia. Agenbag & Maree (1991) emphasised that the yield of spring wheat, under no-tillage (NT) on shallow, stony soil in Mediterranean climates were limited by high cone resistance of the soil, less mineral nitrogen in the soil at seeding and lower plant densities. Crop responses to tillage are also affected by soil characteristics. Bonari, Mazzoncini & Peruzzi (1995) initially found no significant differences, in the yield of rapeseed between conventional tillage (CT) and minimum tillage (MT) on a sandy soil. They therefore recommended minimum tillage for up to three years for this type of environment because of time and energy savings as well as cost reduction. For longer periods of time, it might be necessary to include an occasional conventional tillage treatment to reduce soil compaction. In a study on Morainic loam soil in southeast Norway, Ekeberg & Riley (1997) found that the yield levels of cereals and potatoes showed consistent increases of 2–8% with declining tillage intensity, whereas yields of fodder beet were highest after plough tillage.

Çarman (1997) showed that in central Anatolia, the highest yields were obtained with a stubble cultivator followed by disc harrowing and the lowest with a rotary tiller. Crop responses to tillage were in some cases very confusing. Omer & Elamin (1997) obtained higher yields by using chisel plough compared to other tillage systems. They are of the opinion that crop yield stability, rather than higher yield, is very important in the arid dry-land farming systems. Giorgio *et al.* (1996) showed that the highest grain yield of emmer wheat (*Triticum dicoccom*) was obtained with traditional tillage and the lowest with minimum tillage, while Kirkegaard (1995) on the other hand showed that the overall effect of tillage on wheat yield was small. López-Fando & Almendros (1995) also suggested that NT had little or no effect on crop parameters in semi-arid environments. Unger (1994) showed that grain yields of winter barley under long and short term direct drilling were comparable, but lower than those under conventional ploughing and drilling. Problems associated with straw residues, grass weeds and seedbed compaction, on imperfectly drained loam soils were mentioned as reasons for this tendency (Ball *et al.*, 1994). Arshad & Gill (1997) on the other hand suggested that conservation tillage practices might be used on fine-texture soils in cold, semi-arid climates without any significant loss in crop productivity.

The favourable effect of crop rotation on yield has long been known. Crop rotation increase yield relative to monoculture (Heenan *et al.*, 1994; Grace *et al.*, 1995; López-Fando & Almendros, 1995; West *et al.*, 1996; Bationo & Ntare, 2000). The effect of the previous rotations on wheat productivity, however changes with seasonal rainfall during the wheat and the previous legume years (Heenan, McGhie & Collins, 1998). Heenan *et al.* (1994) reported that average grain yields of wheat in legume rotations were higher than continuous wheat with added N fertiliser. In semi-arid environments, no-tillage in combination with crop rotation also led to an improvement, compared to barley monoculture (López-Fando & Almendros, 1995). The wheat yield obtained with NT was found to be higher than with conventional tillage in continuous wheat, wheat–fababean, and wheat-fallow rotations (López-Bellido *et al.*, 1996). Similar results were reported by Burle *et al.* (1997) in legume–based systems of maize production. Maize yielded 17% higher in the soybean-wheat/red clover–maize rotation under low chemical input compared to continuous maize under high chemical input (Katsvairo & Cox, 2000). Crop responses to N-fertiliser rates also differ with climatic conditions and crop rotations. In Mediterranean climates wheat did not respond to N fertiliser when rainfall was below 450 mm during the growing seasons (López-Bellido *et al.*, 1996). Under semi-arid tropic conditions (Bationo & Ntare, 2000) found that N fertiliser increased the yield of pearl millet, cowpea and groundnut significantly. Canola yields also responded positively to N fertilisers applied at either sowing or bud stage (Ramsey & Callinan, 1994). Although, wheat grain yield increased with the addition of N fertiliser to continuous wheat, yields from continuously cropped wheat were usually lower than those after a lupin crop (Heenan *et al.*, 1998).

2.3 Quality parameters

The effect of tillage methods on durum wheat quality is determined by soil characteristics, soil moisture at time of tillage and climatic conditions during grain filling (Pisante *et al.*, 2000). The results of Heenan *et al.* (1994) showed lower grain protein of wheat with no-tillage, compared to conventional cultivation. This is attributed to a lower number of ears, higher harvest index and grain size, because of more efficient use of rainfall. Tillage methods were also found to effect grain protein content, test weight and some grain quality indices, because of the effect on nitrate-N in the soil (López-Bellido, Fuentes, Castillo &

López-Garrido, 1998). Total nitrogen up-take in both grain and straw of wheat and barley was found to be about 20% higher after minimum tillage than after annual ploughing, whilst other quality parameters, such as phosphorus and potassium concentrations as well as grain size and weight, were unaffected by tillage methods (Ekeberg & Riley, 1997). In contrast to this, a study done in Italy showed that no-tillage reduces wheat grain protein content (Giambalvo *et al.* 1999). In another study the nitrogen content in the cereals increased when grown on rotavated soil, while phosphorus, potassium, calcium and magnesium content of the grain were not affected by the tillage systems (Børresen & Njøs, 1993).

Crop rotations, which included legume crops, improved the protein content and the rheological properties of the dough, when compared to continuous wheat. (Heenan *et al.*, 1994; Løpez-Bellido *et al.*, 1998; Heenan *et al.*, 1998; Giambalvo *et al.*, 1999; Galantini *et al.*, 2000). This effect can be ascribed to the biological fixed residual N in the soil profile, which increases N supply and up-take, by the wheat crop. Wheat grain N yields following lupins were also some 20% higher than after field pea and chickpea and three times more than after barley (Armstrong, Heenan, Pate & Unkovich, 1997).

Protein and gluten content in the wheat grain and flour are both increased by both nitrogen application rate (Randall *et al.*, 1990; Zentner, Bowren, Edwards & Campbell, 1990; Ayoub, Guertin, Fregeau-Reid & Smith, 1994; Gyori *et al.*, 1994; Strong *et al.*, 1996; Agenbag, De Volder & Vlassak, 1998; Lomako, 1998) and time of application (Nakatsu, Watanabe & Okumura, 1999).

With canola it was found that the highest seed protein was obtained with the highest application of N, but the percentage of the oil in seed generally decreased with increasing N fertiliser (Ramsey & Callinan, 1994).

2.4 Diseases, insects and weeds

One of the components altered by changes in tillage practices is the soil physical environment. Changes in soil physical properties may affect plant diseases by influencing the survival and activity of the pathogen, host susceptibility and the prevalence of other soil microorganisms. Increased soil water content as a results of tillage may reduce diseases, because water stressed plants may be more susceptible to diseases. Flooded conditions which reduce soil aeration and temperature, increase soil water above the field capacity or compaction may predispose the host to disease infection. High soil water content may also increase diseases through increasing mobility of the pathogen or diffusion of the exudates. Reduced soil pore size as found with high soil densities on the other hand may limit activity or movement of the pathogen (Rothrock, 1992).

In conservation tillage, the lack of soil disturbance and the presence of surface crop residue provide a more favourable habitat for pests, compared to the bare soil environments of ploughed tillage (All & Musick, 1986). A change from conventional tillage to direct-drill planting may result in an increase in the cereal root diseases such as *Rhizocotonia* root rot and take-all, but a decrease in cereal cyst nematode (Roget, Neate & Rovira, 1996).

In the northwestern United States, no differences have however been observed among most pests, with the exception of the Hessian fly, which seems to increase in conservation tillage systems where spring wheat follows winter wheat (All & Musick, 1986). Reduced and no-tillage which provide surface residues needed for the survival of *Pyrenophora trichostoma*, a fungal pathogen which induces tanspot of wheat, may contribute to the distribution and establishment of this disease (Boosalis, Doupnik & Atkins, 1986). Surface tillage may, on the other hand lessen or have no effect on the incidence of some diseases. Boosalis *et al.* (1986) found that minimum tillage decreased the incidence of take-all of wheat caused by *Gaeumannomyces graminis var.Tritici*; decreased or had no effect on eyespot of wheat induced by *Pseudoscercosporella herpotrichoides*, and had no effect on sharp eyespot and brown rot of wheat caused by *Rhizoctonia solani Kuhn* and *Fusarium spp*., respectively. In southern Queensland, crown rot caused by *Fusarium graminerum* was also not affected by the type of tillage used (Wildermuth *et al*., 1997). The incidence of dead head caused by crown rot was on the other hand found to be the lowest in the no-tillage plots (4.3%) and highest in the reduced tillage (19.3%) and conventional disc tillage (12.2%).

Crop rotation is especially important for controlling diseases when surface tillage is used. Planting a crop into residue of the same crop from the previous season (monoculture) is more likely to increase certain plant diseases than a crop rotation system where a crop is planted into the residue of a non-related crop (Boosalis *et al*., 1986).

Surface tillage may decrease the variety of annual weed species, but increase the variety of biennial and especially perennial weed species (Burnside, 1981). Such changes in weed species may also change the type and the incidence of crop diseases associated with weeds. Klaij & Hoogmoed (1996) reported that the pre-sowing tillage reduced seasonal weed growth and increased Pearl millet yields in a sandy soil of the West African Sahelian Zone. In a long-term study on clay soil in southeastern Norway, Børresen & Njøs (1993) found that the infestation of couch grass and other weeds were higher on the rotavated soil and more pronounced than on the ploughed soil during the early stages of the experiment. Rotating crops helps to prevent the build up of problem weeds. Equally, if not more important, the herbicides will normally also be rotated with the crops (Triplett & Worsham, 1986).

Crop rotation, crop competition, and crop allelopathy are also forms of biological control. These methods plus defoliation by grazing or mowing should be equally effective in plough or no-tillage systems (Triplett & Worsham, 1986). When both tillage and herbicides are used for weed control, the number of problem weeds is reduced, but if any of these practices is omitted, the number of weeds causing problems often increases due to inadequate control (Witt, 1984; Georgieva, 1997).

References

AGENBAG, G.A. & MAREE, P.C.J., 1989. The effect of tillage on soil carbon, nitrogen and soil strength of simulated surface crusts in two cropping systems for wheat (*Triticum aestivum*). *Soil & Tillage Res.* 14, 53-65.

AGENBAG, G.A. & MAREE, P.C.J., 1991. Effect of tillage on some soil properties, plant development and yield of spring wheat (*Triticum aestivum L.*) in stony soil. *Soil & Tillage Res.* 21, 97-112.

AGENBAG, G.A., DE VOLDER, B.P., VLASSAK, K., 1998. Effect of crop residue management, soil tillage and N fertilisation on yield and quality of spring wheat (*Triticum aestivum* L.). *Applied Plant Sci.*12, 67-71.

ALL, J.N. & MUSICK, G.J., 1986. Management of vertebrate and invertebrate pests. In M.A. Sprague & G.B. Triplett (eds.). No tillage and Surface tillage Agriculture. John Wiley & Sons. New York.

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

ARSHAD, M.A. & Gill, K.S., 1997. Barley, canola and wheat production under different tillage-fallow-green manure combinations on a clay soil in a cold, semiarid climate. *Soil & Tillage Res.*, 43, 263-275.

AYOUB, M., GUERTIN, S., FREGEAU-REID, J. & SMITH, L., 1994. Nitrogen fertiliser effect on bread-making quality of hard red spring wheat in Eastern Canada. *Crop Sci*. 34, 346-1352.

BALL, B.C., LANG, R.W., ROBERTSON, E.A.G. & RANKLIN, M.F., 1994. Crop performance and soil conditions on imperfectly drained loams after 20-25 years of conventional tillage or direct drilling. *Soil & Tillage Res*. 31, 97-118.

BATIONO, A. & NTARE, B.R., 2000. Rotation and nitrogen fertilizer effect on pearl millet, cowpea and groundnut yield and soil chemical properties in a sandy soil in the semi arid tropics, *West Africa. J. Agric. Sci*, 134 (3), 277-284.

BONARI, E., MAZZONCINI, M. & PERUZZI, A., 1995. Effect of conventional and minimum tillage on winter oilseed (*Brassica Napus L.*) in a sandy soil. *Soil & Tillage Res*. 33, 91-108.

BOOSALIS, M.G., DOUPNIK, B. L. & ATKINS, J.E., 1986. Effect of surface tillage on plant diseases. In M.A. Sprague & G.B. Triplett (eds.). No tillage and Surface tillage Agriculture. John Wiley & Sons. New York.

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

BURNSIDE, O.C., 1981. Changing weed problems with conservation tillage. Conference on crop production with conservation in the 80' s. ASAE Publication. 7-81, St.Joseph, MI, pp. 161-174.

BØRRESEN, T. & NJØS, A., 1993. Ploughing and rotary cultivation for cereal production in a long–term experiment on a clay soil in southeastern Norway. 2-Yields and weed infestation. *Soil & Tillage Res*. 28, 109-121.

CAMPBELL, C.A., MCCONKEY, B.G., ZENTNER, R.P., SELLES, F. & CURTIN, D., 1996. Tillage and crop rotation effects on soil organic C and N in a coarse-textured typic haploboroll in southwestern Saskatchewan. *Soil & Tillage Res*, 37, 3-14.

CAMPBELL, C.A., ZENTNER, R.P., LIANG, B.C., ROLOFF, G., GREGORICH, E.C. & BLOMERT, B., 1999. Organic C accumulation in soil over 30 years in semiarid southwestern Saskatchewan-Effect of crop rotations and fertilizers. *Can. J. Soil. Sci*. 80, 179-192.

CAMPBELL, C.A., ZENTNER, R.P., SELLES, F., BIEDERBECK, V.O., MCCONKEY, B.G., BLOMERT, B. & FERSON, P.G., 2000. Quantifying short-term effect of crop rotations on soil organic carbon in southwestern Saskatchewan. *Can. J. Soil Sci*. 80, 193-202.

ÇARMAN, K., 1997. Effect of different tillage systems on soil properties and wheat yield in Middle Anatolia. *Soil & Tillage Res*. 40, 201-207.

DEXTER, A. R., 1997. Physical properties of tilled soils. *Soil & Tillage Res.* 43, 41-63.

DEXTER, A.R. & YOUNG, I. M., 1992. Soil physics towards 2000. *Soil & Tillage Res*. 24, 101-106.

DU-BING, DENG-JIAN, LI-WENYING, LIAO-ZHIXI, DU-B, DENG-J, LI-WY & LIAO-ZX, 2000. Field experiment for comparison of winter wheat conservation tillage and conventional tillage. *Journal-of-China-Agricultural –University*. 5, 55-58.

EKEBERG, E. & RILEY, H.C.F., 1997. Tillage intensity effects on soil properties and crop yields in a long-term trial on morainic Loam soil in southeast Norway. *Soil & Tillage Res.* 42, 277-293.

EVANS, S.D., LINDSTROM, M.J., VOORHEES, W.B., MONCRIEF, J.F. & NELSON, G.A., 1996. Effect of sub-soiling and subsequent tillage on soil bulk density, soil moisture, and corn yield. *Soil & Tillage Res.* 38, 35-46.

FETTEL, N.A. & GILL, H.S., 1995. Long-term effect of tillage, stubble, and nitrogen management on properties of a red–brown earth. *Aust. J. Exp. Agric*. 35, 923-928.

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

GEORGIEVA, H., 1997. Effect of the soil tillage, fertilisation and herbicides on weed infestation and productivity of the stands in a four-course rotation. *Pochvoznanie, Agrokhimiya Ekologiya.* 32, 98-101.

GIAMBALVO, D., STRINGI, L., FRENDA, A.S., MICELI, D.I. & DIMICELI, G., 1999. Effect of crop rotation and soil tillage techniques on wheat production and quality in a Sicilian hilly environment. *Rivista-di Agronomia*. 33 (4), 202-208.

GIORGIO, D.DI., RINALDI, M.,RIZZO, V., PINTO, F., LAUDADIO, V. & DE-GIORGIO, D., 1996. Effect if soil tillage methods and nitrogen fertilizer rates in yield and biometric and quality characteristics of emmer (*Triticum dicoccum Shubler*). *Rivista-di-Agronomia.* 30 (2), 154-159.

GRACE, P.R., OADES, J.M., KEITH, H. & HANCOCK, T.W., 1995. Trends in wheat yield and soil organic carbon in the permanent rotation trial at the Waite Agricultural Research Institute, South Australia. *Aust. J. Exp. Agric.* 35, 857-64.

GRIFFITH, D.R., MANNERING, J.V. and BOX, J.E., 1986. Soil and moisture management with reduced tillage. In: Sprague, M.A. and Triplett, G.B. (eds.). No tillage and Surface tillage Agriculture. John Wiley-Inter Science, New York, pp.19-58.

GYORI, Z., BENEDEK, A., OLAH, A.Z., KOVACS, B., PROKISCH, J., BORBELY, M., BORIN, M. & SATTIN, M., 1994. Effect of different factors on wheat quality. Proceeding of the third congress of the European Society for Agronomy, Padova University, Abano-Padova, Italy.

HAO, X., CHANG, C., LARNEY, F.J., NITSCHELM, J. & REGITNIG, P., 2000. Effect of minimum tillage and crop sequence on physical properties of irrigated soil in southern Alberta. *Soil & Tillage Res.* 57, 53-60.

HEENAN, D.P., MCGHIE, W.J. & COLLINS, D., 1998. Impact of lupins, grazed or un-grazed subterranean clover, stubble retention, and lime on soil nitrogen supply and wheat nitrogen uptake, grain yields, and grain protein. *Aust. J. Agric. Res.* 49, 487-94.

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

HERMAWAN, B. & BOMKE, A.A., 1997. Effect of winter cover crops and successive spring tillage on soil aggregation. *Soil & Tillage Res.* 44, 109-120.

KARUNATILAKE, U., ES VAN, H.M. & SCHINDELBECK, R.R., 2000. Soil and maize response to plow and no-tillage after alfalfa- to maize conversion on a clay loam soil in New York. *Soil & Tillage Res.* 55, 31-42.

KATSVAIRO, T.W. & COX, W.J., 2000. Tillage X Rotation X Management Interaction in Corn. *Agron. J* .92, 493-500.

KIRKEGAARD, J.A., 1995. A review of trends in wheat yield responses to conversation cropping in Australia. *Aust. J. Exp. Agric*. 35, 835-48.

KLAIJ, M.C. & HOOGMOED, W.B., 1996. Weeding method and pre-sowing tillage effects on weed growth and pearl millet yield in a sandy soil of the West African sahelian zone. *Soil & Tillage Res.* 39, 31-43.

KRZIC, M., MATIE, C.F. & ARTHUR, A.B., 2000. Short–term responses of soil physical properties to corn tillage–planting systems in a humid maritime climate. *Soil & Tillage Res*. 54, 171-178.

LAFOND, G.P., BOYETCHKO, S.M., BRANDT, S.A., CLAYTON, G.W. & ENTZ, M.H., 1996. Influence of changing tillage practices on crop production. *Can. J. Plant Sci*. 76, 641-649.

LAWRENCE, P.A., RADFORD, B.J., THOMAS, G.A., SINCLAIR, D.P. & KEY, A.J., 1994. Effect of tillage practices on wheat performance in a semi-arid environment. *Soil & Tillage Res.* 28, 347-364.

LOMAKO, E.I., 1998. The effect of application rates and timing of nitrogen dressing on yield and grain quality of winter wheat. *Agrokhimiya* 11, 31-38.

LÓPEZ-FANDO, C.L & ALMENDROS, G., 1995. Interactive effect of tillage and crop rotation on yield and chemical properties of soils in semi-arid central Spain. *Soil & Tillage Res.*36, 45-57.

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

LÓPEZ-BELLIDO, L., FUENTES, M., CASTILLO, J.E., LÓPEZ-GARRIDO, F.J. & FERNÁNDEZ, E.J., 1996. Long-term tillage, crop rotation, and nitrogen fertilizer effect on wheat yield under rain fed Mediterranean conditions. *Agron. J.* 88, 783-791.

LÓPEZ-BELLIDO, L., GARRIDO, F.J., FUENTES, M., CASTILLO, J.E. & FERNANDEZ, E.J., 1997. Influence of tillage, crop rotation and nitrogen fertilization on soil organic matter and nitrogen under rain-fed Mediterranean conditions. *Soil & Tillage Res*. 43, 277-293.

LUPWAYI, N.Z., RICE, W.A. & CLAYTON, G.W., 1999. Soil microbial biomass and carbon dioxide flux under wheat as influenced by tillage and crop rotation. *Can. J. Soil Sci.* 79, 273-280.

MALICKI, L., NOWICKI, J. & SZWEJKOWSKI, Z., 1997. Soil and crop responses to tillage systems: a Polish perspective. *Soil & Tillage Res.* 43, 65-80.

MCANDREW, D.W., FULLER, L.G. & WETTER, L.G., 1994. Grain and straw yields of barley under four tillage systems in northeastern Alberta. *Can. J. Plant Sci.* 74, 713-722.

MOORE, J.M., KLOSE, S. & TABATABAI, M.A., 2000. Soil microbial biomass carbon and nitrogen as effected by cropping systems. *Bio. & Feri. Of Soils.* 31, (3,4), 200-210.

NAKATSU, S., WATANABE, Y. & OKUMURA, S., 1999. Effects of nitrogen fertiliser application and pre-harvest rainfall on grain quality of wheat (*Triticum aestivum L.*). *Japanese J. Soil Sci. & Plant Nutrition* 70 (4), 514-520.

OMER, M.A. & ELAMIN, E.M., 1997. Effect of tillage and contour diking on sorghum establishment and yield on sandy clay soil in Sudan. *Soil & Tillage Res.* 43, 229-240.

PANKHURST, CE; HAWKE, BG; MCDONALD, HJ; KIRKBY, CA; BUCKERFIELD, JC; MICHELSEN, P; BRIEN, KA; GUPTA, VVSR. & DOUBE, BM., 1995. Evaluation of soil biological properties as potential bioindicators of soil health. *Aust. J. Exp. Agric.*35, 1015-1028.

PISANTE, M., BASSO, F., ROYO, C., NACHIT, M.M., FONZO, N. & ARAUS, J.L., 2000. Influence of tillage systems on yield and quality of durum wheat in Southern Italy. Durum wheat improvement in the mediterranean region; new challenges. Proceedings of a seminar, Zaragoza, Spain.

POTTER, K.N., JONES, O.R., TORBERT, H.A. & UNGER, P.W., 1997. Crop rotation and tillage effects in organic carbon sequestration in the semiarid southern greatplains. *Soil Sci.* 162, 140-147.

POWER, J.F. & PETERSON, G.A., 1998. Nitrogen transformation, utilization, and conservation as affected by fallow tillage method. *Soil & Tillage Res.* 49, 37-47.

PRATLEY, J.E., 1995. Long term investigations of the effect of tillage practices on crop production at Wagga Wagga, New South Wales. *Aust. J. Exp. Agric.*, 35, 885-92.

PRIOR, S.A., REICSKY, D.C., REEVES, D.W., RUNION, G.B. & RAPER, R.L., 2000. Residue and tillage effects on planting implement-induced short–term CO2 and water loss from a loamy sand soil in Alabama. *Soil & Tillage Res*. 54, 197-199.

RAMSEY, B.R. & CALLINAN, P. L., 1994. Effect of nitrogen fertiliser on canola production in north central Victoria. *Aust. J. Exp. Agric*. 34, 789-96.

RANDALL, P.J., FRENEY, J.R., SMITH, C.J., MOSS, H.J., WRIGLEY, C.W. & GALBALLY, I.E., 1990. Effect of additions of nitrogen and sulfur to irrigated wheat at heading on grain yield, composition and milling and baking quality. *Auts. J. Exp. Agri.* 30, 95-101.

ROGET, D.K., NEATE, S.M. & ROVIRA, A.D., 1996. Effect of sowing point design and tillage practice on the incidence of rhizoctonia root rot, take all and cereal cyst nematode in wheat and barley. *Aust. J. Exp. Agric*. 36, 683-93.

ROTHROCK, C.S., 1992. Tillage systems and plant disease. *Soil Sci.* 154 (4), 308-314.

SALINAS-GARCIA, J.R., MATOCHA, J.E. & HONS, F.M., 1997. Long-term tillage and nitrogen fertilisation effects on soil properties of An Alfisol under dry land corn/cotton production. *Soil & Tillage Res*. 42, 79-93.

SCHJØNNING, P. & RASMUSSEN, K.J., 2000. Soil strength and soil pore characteristics for direct drilled and ploughed soils. *Soil & Tillage Res*. 57, 69-82.

SHARRATT, B.S., 1996. Tillage and straw management for modifying physical properties of a subarctic soil. *Soil & Tillage Res.* 38, 239-250

SPRAGUE, M.A. & TRIPLETT, G.B., 1986. No tillage and Surface tillage Agriculture. John Wiley & Sons, New York.

STENBERG, M., 1998. Soil tillage influences on nitrogen conservation. *Acta-Universitatis Agriculturae Sueciae–Agraria.* 129, 39 pp.

STRINGI, L. & GIAMBALVO, D., 1999. Agronomic, energetic and economic aspects of different cropping systems in a Sicilian hilly environment. *Rivista-di-Agronomia.* 33 (4), 191-201.

STRONG, W.M., DALA, R.C., WESTON, E.J., COOPER, J.E., LEHANE, K.J., KING, A.J. & CHICKEN, C.J., 1996. Sustaining productivity of a vertisol at Warra, Queensland, with fertilisers, no-tillage or legumes 2. Long-term fertiliser nitrogen needs to enhance wheat yields and grain protein. *Aust. J. Exp. Agric*. 36, 665-74.

TRIPLETT, G.B. & WORSHAM, A.D., 1986. Principles of weed management with surface–tillage systems. In: M.A. Sprague, & G.B. Triplett, (eds.). No tillage and Surface tillage Agriculture. John Wiley & Sons, New York.

UNGER, P.W., 1994. Tillage effects on dry and wheat and sorghum production in the Southern Great Plains. *Agron. J*. 86, 310-314.

UNGER, P.W., 1996. Soil bulk density, penetration resistance, and hydraulic conductivity under controlled traffic conditions. *Soil & Tillage. Res*. 37, 67-75.

VARSA, E. C., CHONG, S.K., ABOLAJI, J.O., FARQUHAR, D.A. & OLSEN, F.J., 1997. Effect of deep tillage on soil physical characteristics and corn (*Zea mays L.*) root growth and production. *Soil & Tillage Res*. 43, 219-228.

WEST, T.D., GRIFFITH, D.R., STEINHARDT, G.C., KLADIVKO, E.J. & PARSINS, S.D., 1996. Effect of tillage and rotation on agronomic performance of corn and soybean: twenty–year study on dark silty clay loam soil. *J. Prod. Agric*. 9, 241-248.

WILDERMUTH, G.B., THOMAS, G.B., RADFORD, B.J., MCNAMARA, R.B. & KELLY, A., 1997. Crown rot and common rot in wheat grown under different tillage and stubble treatments in southern Queensland, Australia. *Soil & Tillage Res*. 44, 211-224.

WITT, W.W., 1984. Response of weeds and herbicide under no–tillage conditions. In Ronald E. Phillips and Shirley H. Phillips (eds.). No Tillage Principles and Practices. Van Nostrand Reinhold Co., New York, pp. 152-170.

YOUNG, I.M. & RITZ, K., 2000. Tillage habitat space and function of soil microbes. *Soil & Tillage Res*. 53, 201-213.

ZENTNER, R.P., BOWREN, K.E., EDWARDS, W. & CAMPBELL, C.A., 1990. Effects of crop rotations and fertilisation on yields and quality of spring wheat grown on a black chernozem in North–Central Saskatchewan. *Can. J. Plant Sci*. 70, 383-397.

Chapter 3

Experimental procedure

A long term experiment was used to measure the effect of soil tillage, crop rotation and nitrogen fertiliser rates on mineral-N levels in the soil, nitrogen levels in plants, wheat growth and yield components, grain yield as well as quality parameters of spring wheat (*Triticum aestivum L.*). Although the tillage treatments tested were initiated in 1976, present crop rotations and nitrogen application rates were only applied since 1990. Most of the data that will be discussed was however recorded during the 1997-2001 period.

3.1 Locality

The trial was conducted at the Langgewens Experimental Farm, near Malmesbury in the Western Cape province of the Republic of South Africa. This wheat producing area is characterised as a Mediterranean-type climate and is located at 33°17`S and 18°42`E. The soil at the experimental site was a shallow (250-300 mm deep) sandy loam with a gravel and stone content of 44.6% in the A-horizon. Organic C and total N content of the soil varied between 0.2 and 0.4 % and 0.04–0.05 % respectively (Table 3.1). The low soil pH recorded throughout the trial necessitated regular applications of agricultural lime. During the experimental period an application of 2000 kg agricultural lime per hectare was applied to all plots in November 1999.

Table 3.1 General description of physical and chemical characteristics of the soil (A-horizon) at the experimental site

Depth			250-300(mm)
Particle size distribution	Clay	(< 0.002 mm)	14.7%
	Silt	(0.02- 0.002 mm)	15.2%
	Sand	(0.02-0.2 mm)	47.5%
		(0.2-0.5 mm)	8.8%
		(0.5-2.0 mm)	13%
Gravel and stone (>2.0 mm) content			44.6%
Bulk density			1400 kg. m^{-3}
Chemical analysis		**0-150 mm**	**150-300 mm**
pH (KCl)		4.60	4.40
Organic C (%)		0.40	0.20
Total N (%)		0.05	0.04

3.2 Climate

Rainfall data for the 1997-2001 growing seasons are presented and compared with long-term averages in Figure 3.1. Total April-October rainfall of 222, 295, 346, 250 and 450 mm were recorded for the 1997, 1998, 1999, 2000 and 2001 growing seasons respectively. Above long-term average rainfall (334 mm) occurred during the 1999 and 2001 growing seasons only. In the 1997 growing season total April-October rainfall of 220 mm was well below the long-term average with dry conditions throughout the growing season except in June. In 1998 below the long-term averages was also recorded throughout the season except in May. Although above average rainfall occurred during the 1999-growing season, only the months July, August and September showed above average rainfall while extremely low rainfall occurred in October. In the 2000 growing season total April-

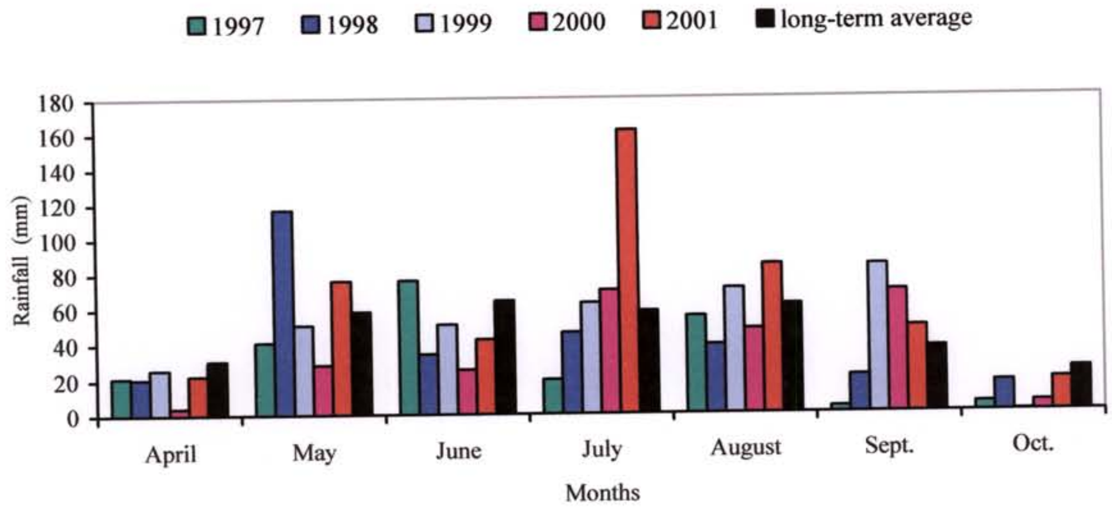

Figure 3.1 Monthly rainfall (mm) data from April to October during the 1997-2001 growing seasons compared with 40-year long-term averages at Langgewens Experimental Farm

October rainfall of 250 mm was again below the long-term average of 334 mm with extremely dry conditions during April and October, while above average rainfall occurred during the months of July and September. In contrast to this, the 2001 growing season was characterised by a very high rainfall of 450 mm, with above long-term average rainfall in most of the months between April and September, especially during May, July and August.

Ten days cumulative rainfall (mm) from 1 April to 30 October during the 2000 and 2001 growing seasons (when crop development data was recorded), relative to the dates of planting and time of nitrogen applications are presented in Fig. 3.2. During the 2000 growing season the amount of rainfall before planting (early June) was less than 50 mm. In the 2001 growing season, on the other hand, more than 100 mm occurred before planting in the later half of May. During the 2000 growing season about 60 mm rainfall between the first and second top dressing, while about 171 mm occurred during the same

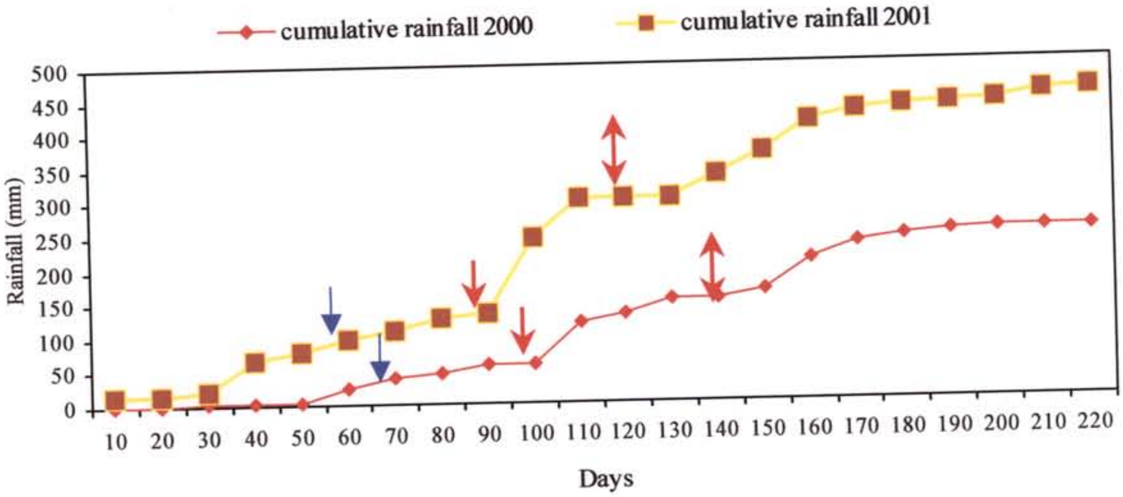

Figure 3.2 Planting dates and dates for N-top-dressing relative to ten days cumulative rainfall (mm) from 1 April to 31 of October during the 2000 and 2001 growing seasons at Langgewens Experimental Farm

↓ Planting date, ↓ first N top-dressing, ↕ second N top-dressing

period during 2001. During the 2000-growing season, only 12 mm of rainfall occurred within 30 days after the second N top-dressing, while about 21 mm occurred within 30 days after the second N top-dressing during 2001. These differences may have an effect on N-use efficiency.

Mean monthly temperatures for the months April to October in 1997-2001 growing seasons are presented and compared with the long-term average in Figure 3.3. From this figure it became clear that mean daily temperature decreases from about 20 °C in April to about 14 °C during the months June to August where-after it start to increase again. In the 2000 growing season higher than long-term average temperatures occurred in all the months except in September. Similar trends occurred for the 2001-growing season except in August when normal temperatures (long-term average) were experienced.

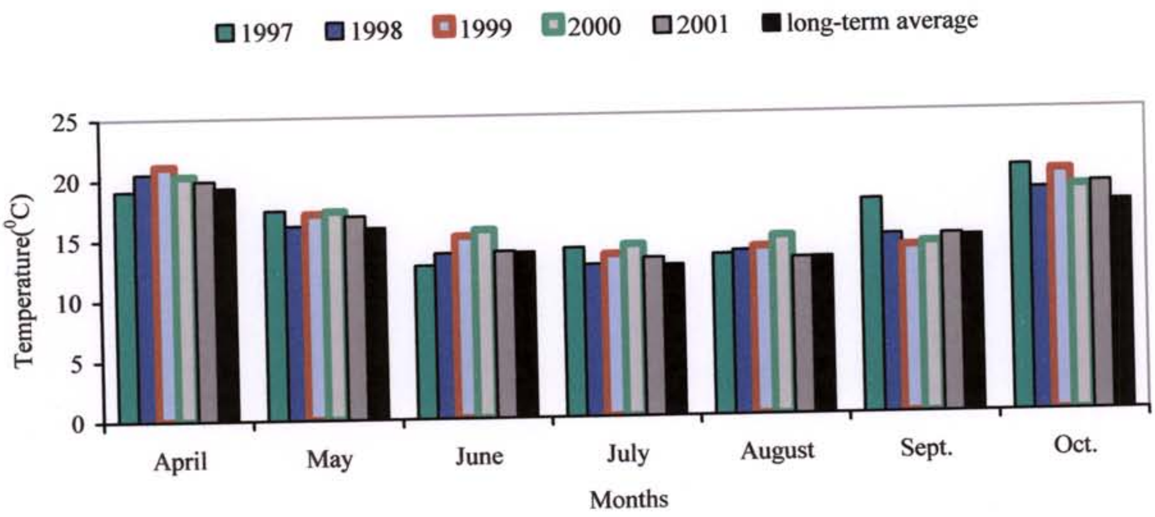

Figure 3.3 Mean monthly temperatures (°C) from April to October during the 1997-2001growing seasons compared with the 40- year averages at Langgewens Experimental Farm

3.3 Experimental layout and treatments

The trial was designed as a randomised complete block with a split-plot arrangement and four replicates. Main plots were tillage methods namely conventional tillage (CT), tine tillage (TT), minimum tillage (MT) and no tillage (NT). Crop rotations used were continuous wheat (WW) and wheat/lupin/wheat/canola (WLWC). In the latter wheat was planted every second year and canola and lupins were rotated in the alternating year. Sub plots (16 x 5 m) consisted of nitrogen fertiliser rates (60, 100 and 140 kg N ha^{-1}) applied as lime stone ammonium nitrate (29 N%).

The CT treatment involved a primary tillage with a chisel plough after the first autumn rains, followed by mould board plough (200 mm deep) and field cultivator in May before seeding. The TT treatment involved primary tillage with a chisel plough (150 mm deep) after the first autumn rains, followed by a field cultivator in May before seeding, while MT involve a primary tillage with chisel plough (75 mm deep) after the first autumn rains followed by non-selective herbicide application before seeding. In the NT treatment, non-selective herbicides were used to control the weeds and volunteer wheat plants before seeding. Plots were sown with a Moore (No-till) drill. However, during 1999 all plots were cultivated to a depth of 75 mm at the end of November to mix the agricultural lime (2000 kg ha^{-1}) in to the soil. The N fertiliser were applied as follows: 1) The 60 N-treatment received 60 kg N ha^{-1} at sowing. 2) The 100 N-treatment received a further 40 kg N ha^{-1} as top-dressing at the onset of the tillering stage (approximately 40 days after planting). 3) The 140 kg N ha^{-1} treatment received a further 40 kg N ha^{-1} as a second top-dressing at stem elongation stage (approximately 70 days after planting).

Spring wheat (cv. SST57) was sown in the later half of May to early June in all years at a rate of 300 seeds per m^2, and harvested in October. P and K fertilizers as well as post-emergence herbicides and fungicides were applied as needed.

3.4 Data collection and analysis

In this study soil data was collected during the 1997-2000 growing seasons to measure the mineral-N (NO_3^--N and NH_4^+-N) content. Soil sampling was done annually at 14-day intervals, starting on the day of planting (before any N-fertiliser was applied) and continued till harvesting. Sub-samples (8 per treatment) were gathered from the 0-150 mm and 150-300 mm soil profile of different plots. Soil samples for CT, TT and NT treatments in die WW systems were sampled from 1997-2000. In the WLWC system, tillage treatments were sampled in 2000 only (See Chapter 4).

Plant growth and development were measured during the 2000 and 2001 growing seasons. Wheat plants were sampled at the following growth stages: The first sampling at tillering stage (S_1). The second sampling at stem elongation (S_2). The third sampling at flag leaf (S_3) and the fourth sampling at anthesis (S_4). Ten plants were taken from each sub-plot at each sampling date. The following plant growth components were measured: Plant numbers, Tiller numbers; leaf area index and the total dry mass (See Chapter 5), as well as nitrogen levels in the leaves, stems and ears (See Chapter 6).

Wheat yield components were measured during the 2000 and 2001 growing seasons, but grain yield for this period was compared to yields obtained during the period 1992-2001, (See Chapter 7).

Most quality parameters were measured in the 2000-growing season only, but results of some parameters were compared with long-term averages (See Chapter 8).

Parameters and years of data collection are summarised in (Table 3.2)

Data was subjected to an analysis of variance (ANOVA), using the PROC GLM command of the SAS statistical package (SAS Institute Inc., 1990). The LSD T test was used to compare treatment means at the 5% level. Discussion of results will focus on the effects of main factors. However if significant interactions do occur, these interactions will be discussed.

Table 3.2 Summary of data collection through out the study.

Parameters	Years of data collection
Soil data	
Mineral–N (No_3^- and NH_4^+-N)	1997 - 2000
Plant data	
Wheat growth and development	2000 - 2001
Nitrogen levels in leaves, stems and ears	2000 - 2001
Wheat grain yield	1992, 1994, 1996, 1998, 2000 and 2001
Wheat yield components	2000 - 2001
Quality data	
Milling characteristics	
Hectoliter mass	Mean values for 1992 – 1998; and 2000
Flour yield	2000
Baking characteristics	Mean values for 1992 –1998; and 2000
Dough development characteristics	2000

Chapter 4

Effect of soil tillage, crop rotation and nitrogen application rates on soil mineral-N levels in the Swartland wheat producing area of South Africa

Abstract

Studies on nitrogen (N) levels in soil were conducted from 1997-2000 in a long-term tillage and crop rotation trial, which started in 1979. Three tillage methods namely conventional tillage (CT), tine tillage (TT), and no-tillage (NT) were compared. Crop rotation systems used were continuous wheat (WW) and wheat/lupin/wheat/canola (WLWC). Three rates of N-fertilisers (60, 100 and 140 kg N ha^{-1}) were applied. All treatments received 60 kg N ha^{-1} at planting, while the 100 and 140 kg N ha^{-1} treatments received additional top-dressings of 40 kg N ha^{-1} at tillering and stem elongation stages respectively. Soil samplings were done at 14-day intervals, starting immediately before planting and continued till harvesting each year. Samplings at planting were done before N-fertiliser was applied and therefore regarded as pre-planting (Pp).

The effect of tillage methods on mineral-N was variable and inconsistent among the soil samplings and years. During the four years period of this study, higher values of total mineral-N were found with conventional tillage at the pre-planting (Pp) samplings. Crop rotation did not significantly influence total mineral-N, which may be explained by the cultivation of a legume crop (lupins) once every four years only. In general the application of N-fertiliser resulted as expected in an initial increase in the mineral-N content of the soil. However, this was soon followed by a rapid decline as crops start to utilise the added nitrogen, resulting in values of less than 10 mg kg^{-1} soil during the grain filling stages with application rates of 60 and 100 kg N ha^{-1}. These values may be regarded as deficient for grain yields of 4000 to 5000 kg ha^{-1}.

Keywords: Conventional tillage, crop rotation, mineral-N, no-tillage, tine tillage.

Introduction

Nitrogen (N) is considered one of the most important plant nutrients and is the mineral element required in the largest quantity for growth and development of plants. It is an important component of protein and chlorophyll and application usually result in yield increases (Jarvis, Stockdale, Shepherd & Powlson, 1996; Otto, Kilian, Agenbag & Vlassak, 2000; Vlassak & Agenbag, 2000).

Nitrogen is added to the soil as a result of chemical or organic fertilisers, mineralisation of N-reserves and via biological fixation. Nitrogen is removed by the harvest crop, lost by leaching and surface run-off in soluble forms or by gaseous emissions as N-gas, N-oxides as a result of denitrification and by ammonia volatilisation (Jarvis *et al*., 1996). Plants absorb N mainly as nitrates and uptake as ammonium-N is usually limited (Borghi, 1999).

Cropping intensity, method of tillage, crop rotation and N application rate are four management practices that have been shown to affect the total mineral-N (Franzluebbers, Hons & Zuberer, 1994; Wienhold & Halvorson, 1999). Results of Power & Peterson (1998) showed that tillage significantly affected total N content of the 0-100 mm soil depth. The higher content found with no-till (NT) compared to conventional tillage (CT) was related to the higher soil water content and reduced temperature in dry and hot regions. These results are supported by several other studies (Stein, Sageman, Fischer & Angus, 1987; Kingery, Wood & William, 1996; Wienhold & Halvorson, 1999). However, Agenbag & Maree (1989) found that initially NO^{-}_{3}-N was less in tined (TT) and no till (NT) soils compared to conventional tilled soil, but differences gradually decreased after a number of years under mediterranean conditions. Similar results were obtained by other researchers (Goss *et al*., 1993; Jarvis *et al*., 1996), who found that mineralisation is reduced in NT soil, compared to ploughed soil. This was most probably due to the effect of climatic conditions on mineralisation, as evident from a study by Riley (1998) who found no consistent effect on soil mineral-N status and N-fertiliser requirements under cool climatic conditions due to reduced tillage.

In high rainfall areas, higher soil water content in NT soils may result in greater denitrification rates when compared to ploughed soils, resulting in a loss of plant available NO_3^--N (Doran, Elliott & Paustian, 1998).

In general it may therefore be assumed that mineralisation and thus mineralised-N content of the soil will benefit from minimum and no tillage in semi arid and hot regions because of improved soil moisture conditions. In cool areas with high rainfall, the opposite may be true due to the suppressing effect of low temperature and anaerobic soil conditions on the soil N-mineralisation processes.

The beneficial effect of legumes on soil N content is well established and has been observed for generations. Inclusion of a legume, particularly alfalfa in the rotation increased N-mineralisation (Carpenter-Boggs, Pikul, Vigil & Riedell, 2000). Research showed that N-mineralisation may be increased in plots receiving no N-fertiliser compared to soil with a history of N fertilisation (Carpenter-Boggs *et al*., 2000). Kolberg, Westfall & Peterson (1999), in contrast reported that total mineralised-N increased by 0.2 kg ha^{-1} for each kg N ha^{-1} of previously applied nitrogen.

Chalk (1998) suggested that cereals benefit from the reserved N when rotated with grain legumes compared to cereal monoculture, resulting in higher yields. The positive effect could be attributed to biological N fixation or to less N used by the legume crops and a decline in immobilisation of N during decomposition.

Nitrogen fertilisation increased total N content in the top 300 mm soil for no-till, but decreased total N of ploughed soils (Power & Peterson, 1998). The authors related this to more rapid N-mineralisation and nitrification in ploughed soil, possibly increasing N leaching from the surface 300 mm of fertilised ploughed soils when compared to NT soils.

The results of De Wever, Agenbag & Vlassak (2000) showed that when wheat straw and N-fertiliser were applied to the soil, available N was immobilised. They therefore recommended not to incorporate plant residues shortly before planting but to keep them on the soil surface or to incorporate them long before planting to avoid N immobilisation.

Although important, little research has been previously done on mineral-N contents of the soil in the wheat producing area of the Swartland. The aim of this study was therefore to determine the effect of tillage method, crop rotation and N-fertilisation on mineral-N content of these soils.

Materials and methods

Studies on N levels in soil were conducted from 1997-2000 in a long-term tillage and crop rotation trial initiated in 1976. The trial was conducted at the Langgewens Experimental Farm, near Malmesburry in the Western Cape province of the Republic of South Africa. This wheat (*Triticum aestivum* L.) producing area is characterised as a Mediterranean-type climate and is located at 33°17`S and 18°42`E. Description of the locality, climate, experimental layout and treatments as well as data analysis are presented in Chapter 3.

Soil nitrogen analysis

Soil sampling was done annually at 14-day intervals, starting on the day of planting (before any N-fertiliser was applied) and continued till harvesting. Sub-samples (8 per treatment) were gathered from the 0-150 mm and 150-300 mm soil profile of different plots. Soil samples for CT, TT and NT treatments in die WW system were sampled from 1997-2000. In the WLWC system, tillage treatments were sampled in 2000 only.

After sampling, soil samples were immediately put in a cool-box to keep the temperature at approximately 4 °C and brought to the laboratory to dry in the oven at 40 °C for 48 hours. Afterwards samples were sifted through a 1.0 mm sieve, put into plastic bottles and stored till analysed for NH^{+}_{4}-N and NO^{-}_{3}-N using the indophenal-blue (Pace, Miller & Keeney, 1982), and salicylic acid (Cataldo, Haroon, Schrader & Young, 1975) methods respectively.

Results and discussion

Compared to NO_3^--N, NH_4^+-N content of the soil was low (1-5 mg kg^{-1} soil) throughout this study and did not varied significantly between treatments (results not shown). Differences between years and treatments were dominated by differences in NO_3^--N content of the soil. For this reason and since NH_4^+-N is mineralised to NO_3^--N rapidly in most soils (Fox & Bandel, 1986; Wienhold & Halvorson, 1999), only data on total mineralised-N (NH_4^+-N + NO_3^--N) is presented.

Effect of soil depth on total mineral-N in the soil

In general all tillage treatments showed an initial increase in mineral-N content due to the application of 60 kg of N ha^{-1} at planting, followed by a gradual decrease towards the end of the growing season in both the 0-150mm and 150-300mm soil depths (Table 4.1). However, large differences in total mineral-N occurred between seasons due to climatic factors such as rainfall and temperature. Extremely high values were found in 2000. This was most probably due to the tillage done in November 1999 to incorporate the lime. Contributing to this may be the termination of crop growth with a non-selective herbicide application in early October 1999 due to a severe weeds infestation. This may have limited N-uptake and increase N content in the soil. Lowest values were found in 1997, which were probably due to the low rainfall experienced during the growth season (Fig. 3.1).
Generally mean mineral-N content was found to be slightly higher in the 0-150 mm soil profile, compared to the 150-300 mm soil profile. This tendency was especially true for the less intensive tillage treatments (NT and TT), reflecting possible differences in leaching potential or differences in N-mineralisation as shown by Fox & Bandel (1986) as well as Deng & Tabatabai (2000). Differences in total N content with soil depth also varied between years, most probably due to differences in the rainfall. Due to these inconsistencies, which made comparisons between treatments very difficult it was decided to use mean values for the 0-300 mm soil profile in the discussion of responses to tillage, fertiliser and crop rotations.

Table 4.1 Total mineral-N (mg kg^{-1} soil) in the 0-150 and 150-300 mm soil profiles at different soil samplings (Pp-S_{10}) for the period 1997-2000 in response to different tillage treatments and at nitrogen application of 60 kg N ha^{-1} at planting

		1997		1998		1999		2000	
Tillage	Samplings	0-150	150-300	0-150	150-300	0-150	150-300	0-150	150-300
CT	Pp	25.5	7.4	20.3	6.8	14.2	20.2	71.9	27.0
CT	S_1	17.3	27.4	20.2	14.7	18.9	18.0	134.7	53.7
CT	S_2	12.9	17.7	24.1	21.1	24.2	24.9	61.6	63.7
CT	S_3	5.6	8.9	26.7	15.9	30.2	23.2	46.2	36.3
CT	S_4	7.1	7.9	22.8	9.6	26.7	19.2	27.3	33.8
CT	S_5	7.2	7.5	18.1	6.7	24.2	17.6	21.7	19.7
CT	S_6	6.0	7.0	8.5	5.6	8.6	12.5	26.9	21.5
CT	S_7	4.9	5.3	5.0	5.5	8.2	11.0	20.0	20.4
CT	S_6	5.3	5.6	6.8	4.7	6.8	7.3	13.9	16.7
CT	S_9	6.2	5.8	4.7	3.9	5.6	6.1	_	_
CT	S_{10}	8.5	6.6	4.3	5.4	_	_	_	_
Mean		9.7	9.7	14.6	9.08	16.8	16.0	47.1	32.5
TT	Pp	22.6	10.6	8.7	6.8	16	8.7	65.8	23.1
TT	S_1	23.9	24.8	15.6	14.7	24.4	17.9	107.7	64.0
TT	S_2	21.6	21.3	21.3	21.1	36.0	18.9	86.5	66.0
TT	S_3	10.7	12.9	16.8	15.9	23.0	8.9	39.1	32.7
TT	S_4	8.8	7.5	11.4	9.6	20.7	15.2	24.5	19.7
TT	S_5	6.1	5.5	8.9	6.7	12.5	8.0	30.1	32.0
TT	S_6	6.0	5.5	8.9	5.6	8.4	6.3	17.1	9.0
TT	S_7	5.9	5.7	6.0	5.5	11.1	8.8	15.5	15.0
TT	S_6	4.9	4.6	5.2	4.7	11.9	8.5	9.5	9.0
TT	S_9	6.0	4.8	5.0	3.9	10.1	7.8	_	_
TT	S_{10}	6.7	6.3	5.8	5.4	_	_	_	_
Mean		11.2	10.0	17.4	9.08	17.4	10.9	44.0	30
NT	Pp	20.1	6.0	8.4	7.5	11.9	12.3	58.0	22.9
NT	S_1	20.7	19	35	23.5	30.9	12.1	75.0	75.0
NT	S_2	23.1	12.9	39	33.5	38.3	19.1	66.0	59.9
NT	S_3	10.4	14.1	39	25.7	36.2	21.1	53.0	40.0
NT	S_4	6.7	4.1	25.5	22.1	41.6	23.2	42.0	23.0
NT	S_5	5.1	4.6	18.9	13.6	24.2	15.4	18.0	15.0
NT	S_6	5.3	4.8	8.9	9.9	10.4	8.0	19.9	12.6
NT	S_7	6.3	5.0	5.8	5.5	13.3	9.3	14.0	12.0
NT	S_6	7.2	5.9	6.4	5.0	12.0	8.7	9.5	8.9
NT	S_9	5.6	6.1	4.9	3.9	7.4	4.6	_	_
NT	S_{10}	7.7	5.2	4.8	4.0	_	_	_	_
Mean		10.7	7.9	17.1	14	11.7	13.4	39.5	29.9
G. Mean		10.5	9.2	14.4	10.7	15.3	13.4	43.5	30.8

CT= Conventional tillage, TT= Tine tillage, NT= no-tillage, Pp= sampling done at day of planting, S_1-S_{10}= samples taken every 14 days during growth period
_ No measurements

Effect of tillage methods on total mineral-N in the soil

Total mineral-N for different soil samplings as affected by tillage methods during the period 1997-2000 are presented in Figure 4.1. The effect of tillage methods on mineral-N was variable and inconsistent among the soil samplings (S_1-S_{10}) and years. During the 2000 growing season for instance, significant differences were found at 6 of the 9 sampling dates between tillage treatments, but the ranking order of tillage treatments varied between

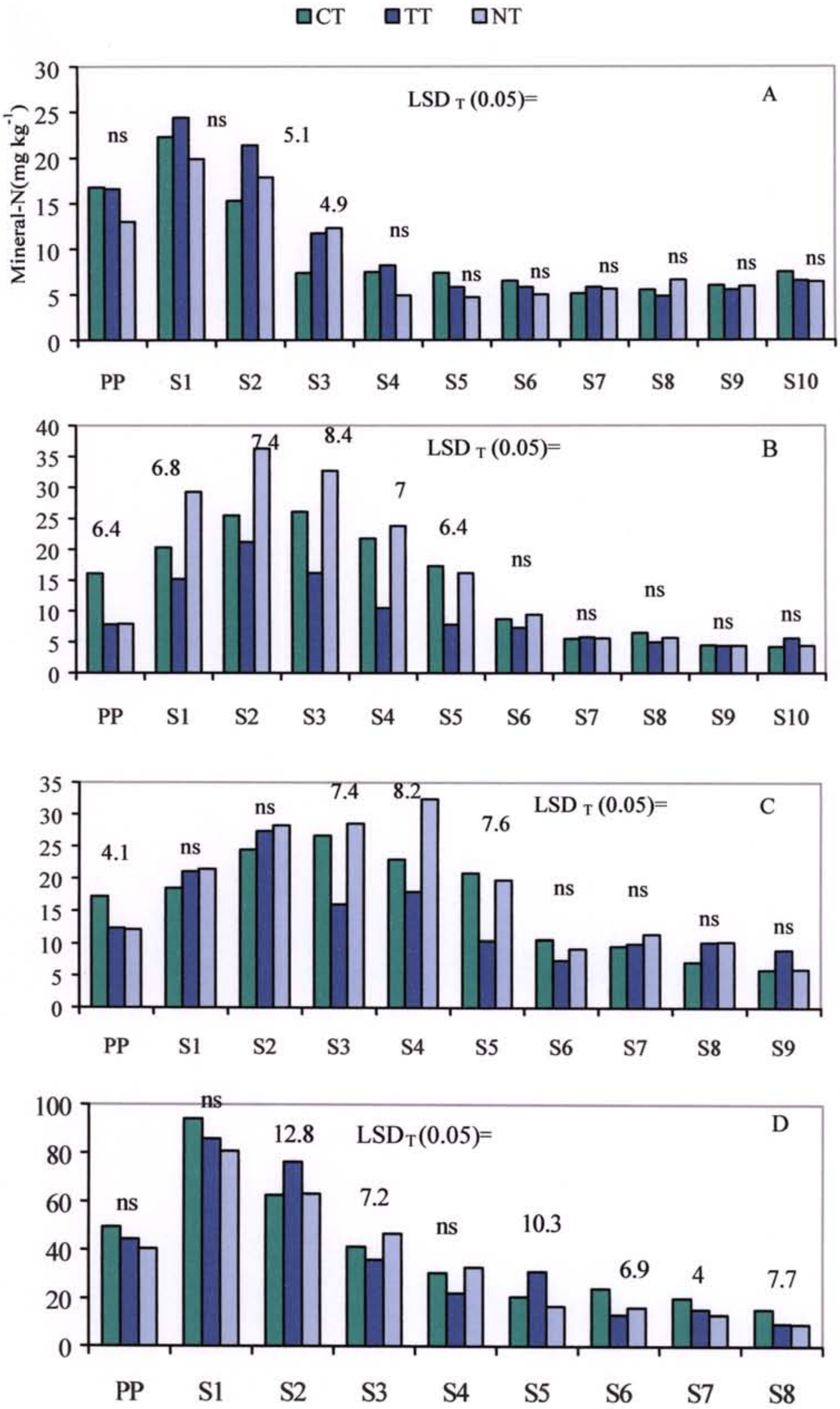

Figure 4.1 Effect of conventional tillage (CT), tine tillage (TT), and no-tillage (NT) on total mineral-N content (mg kg^{-1}soil) at different soil samplings (Pp= pre-planting; S_1-S_{10} every 14 day interval) in the A) 1997, B) 1998, C) 1999 and D) 2000 growing seasons at a nitrogen application of 60 kg ha^{-1}

samplings. The same tendency applied for 1997-1999, with the result that mean annual values of 22.5, 16.0 and 18.1 mg N kg^{-1} soil for CT, TT and NT respectively did not differ significantly. This may be explained by an interaction between soil properties and climatic conditions, which effected N-mineralisation and leaching (Fox & Bandel, 1986; Goss *et al.*, 1993; Jarvis *et al.*, 1996), differences in N uptake as a result of different plant populations, rooting depth (Agenbag & Maree, 1991), or sampling errors. At the Pp samplings took after tillage, but before N-fertiliser was applied or crops have been planted, higher values were found with conventional tillage throughout the study (Fig.4.1). Similar results were obtained by Agenbag & Maree (1989) in an earlier study on the same locality. With the exception of 2000 growing season, mineral-N content at Pp sampling varied between 16 to 17 mg N kg^{-1} soil for CT plots and between 7 and 13 for NT plots. At a soil bulk density of 1400 kg m^{-3} these values showed that plant available N at planting varied between 74.6 kg ha^{-1} and 79.3 kg ha^{-1} for CT and between 32.7 kg ha^{-1} and 60 kg ha^{-1} for NT.

At present mineral-N content of the soils are not measured and therefore not taken in consideration in N-fertiliser programmes for wheat in the Western Cape. The differences found between years and method of tillage may thus result in either sub or super-optimal fertilisation if the same N-rate is applied irrespective of the year and tillage method.

Effect of crop rotation on total mineral-N content in the soil

The effect of crop rotation on mineral-N content in the soil was measured in 2000 only. Significant differences were found at samplings S_3, S_7 and S_8 (Fig. 4.2). Although a significantly higher mineral-N content was found with monoculture wheat compared to crop rotation at sampling S_3, this may be attributed to experimental error as all other samplings showed similar or higher values in the soil where wheat was rotated with canola and lupins. At samplings S_7 and S_8 significantly higher values were obtained with crop rotation compared to wheat monoculture. These results are in agreement with earlier results by Chalk (1998). The smaller than expected benefits from the inclusion of a legume crop in the rotation may be due to the fact that lupins were grown once in a four-year cycle only. However, the results showed that N supply to wheat may be improved by the N fixing abilities of legume crops grown in rotation. From this study it become clear that the largest benefits in N supply from the legume crop are obtained towards the end of the growing season (S_7 and S_8). This tendency may help to improve N-supply during the very important grain filling stage of the succeeding wheat crop.

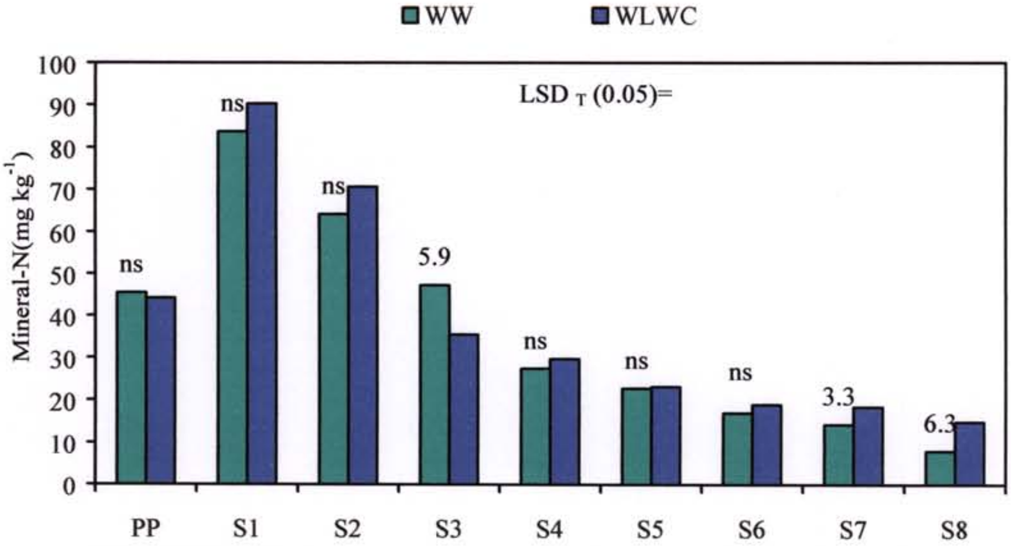

Figure 4.2 Effect of wheat/wheat (WW) and wheat/lupin/wheat/canola (WLWC) crop rotation on mineral-N content (mg kg^{-1} soil) at different soil samplings (Pp =pre-planting; S_1-S_8= 14 day intervals) during the 2000-growing season at a nitrogen application of 60 kg ha^{-1}

Effect of nitrogen application rate on total mineral-N content in the soil

As expected from results of Kolberg *et al.* (1999), mineral-N content of the soil initially increased (with the exception of the 140 kg N ha^{-1} treatments in 2000) for all treatments after N was applied (Fig.4.3). However, this was soon followed by a decrease as crops started to utilise the nitrogen. The 60 kg N ha^{-1} treatment which received fertiliser at planting only, resulted in mineral-N contents of less than 10 mg kg $^{-1}$ of soil during samplings at heading and grain filling (S_6-harvest) annually except 2000. At a bulk density of 1400 kg m^{-3}, this N concentration implies a value of 46 kg N ha^{-1} plant available N in the 0-300 mm soil profile during grain filling. Assuming that wheat needed about 30 kg of N to produce 1000 kg of grain (Borghi, 1999) and about 30% of this is taken up during heading and grain filling (Hagin & Tucker, 1982), these values may have restrict grain yield and reduced kernel protein content in high yielding (4000-5000 kg ha^{-1}) areas or years. Treatments which received a top-dressing of 40 kg N ha^{-1} at approximately 40 days after planting (100 kg N ha^{-1}) or top-dressing at both 40 and 70 days after planting (140 kg N ha^{-1}) also showed a decline in the mineral-N content of the soil towards the end of the growth period. With the exception of 2000, mineral-N contents of the soil for the 100 kg N ha^{-1} treatments also declined to values of 10 mg N kg^{-1} soil or less, during the last sampling. It is therefore suggested that applications of 140 kg N ha^{-1}, with top-dressings at 40 and 70 days after planting may be needed to ensure a sufficient plant–available N supply in the soil for maximum yields and good bread-making quality in high yielding production areas and years.

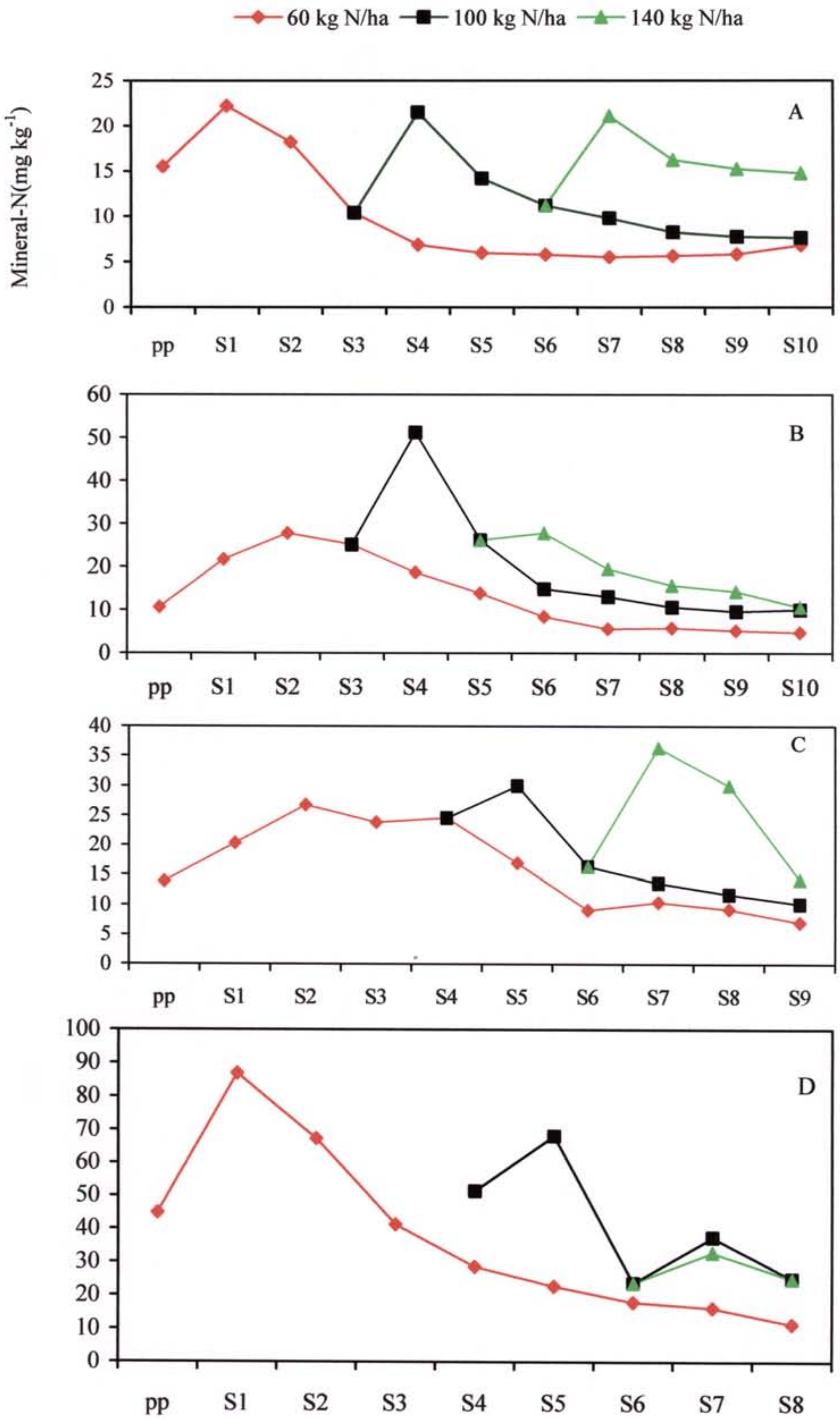

Figure 4.3 Effect of nitrogen fertiliser rates on total mineral-N content (mg kg^{-1} soil) at different soil sampling (Pp=pre-planting; S_1-S_{10}=14 day intervals) in the A) 1997, B) 1998, C) 1999, D) 2000 growing seasons

Conclusion

Differences in total mineral-N content of the soil were found between tillage treatments, crop rotations used as well as N-fertiliser rates applied. Response however, varied largely between years due to annual variation in especially total and distribution of rainfall.

Significant differences between tillage treatments at pre-planting (Pp) sampling in some years showed that the use of the same N-fertiliser application rate, irrespective of tillage methods used and climatic conditions prevailing during that specific year, may result in serious over or under fertilisation in some years.

Although the use of crop rotations which include legumes may improved the mineral-N content of the soil, results of this study showed that the beneficial effect will be relative small if the legume crop is planted only once in a four year cycle.

Results also showed that although the application of N fertiliser did increase the mineral-N content of the soil, the effect did not last very long in most years. Late application (70 days after planting) of N fertiliser may therefore be needed to ensure sufficient N supply during the very critical grain filling stage of the wheat crop.

References

AGENBAG, G.A. & MAREE, P.C.J., 1989. The effect of tillage on soil carbon, nitrogen and soil strength of simulated surface crusts in two cropping systems for wheat (*Triticum aestivum L.). Soil & Tillage Res*. 14, 53-65.

AGENBAG, G.A. & MAREE, P.C.J., 1991. Effect of tillage on some soil properties, plant development and yield of spring wheat (*Triticum aestivum L.*) in stony soil. *Soil & tillage Res*. 21, 97-112.

BORGHI, B., 1999. Nitrogen as determinant of wheat growth and yield. In E.H. Satorre and G.A. Slafer (eds.): Wheat: Ecology and physiology of yield determination. Food Products Press. New York.

CARPENTER-BOGGS, L., PIKUL, J.L., VIGIL, M.F. & RIEDELL, W.E., 2000. Soil nitrogen mineralisation influence by crop rotation and nitrogen fertilisation. *Soil Sci. Soc. Am. J.* 64, 2038-2045.

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

CHALK, P.M., 1998. Dynamic of biological fixed N in legume-cereal rotations: a Review. *Aust. J. Agric. Res*. 49, 303-316.

DENG, S.P. & TABATABAI, M.A., 2000. Effect of cropping systems on nitrogen mineralisation in soils. *Biol. Fertil. Soils* 31, 211-218.

DE WEVER, H., AGENBAG, G.A. & VLASSAK, K., 2000. Mineralisation potential and denitrification of South Africa soils. Proceedings of a workshop N-dynamics in intensive and extensive agriculture. Laboratory for Soil Biology and Soil Fertility K. U. Leuven, Belgium.

DORAN, J.W., ELLIOTT, E.T. & PAUSTIAN, K., 1998. Soil microbial activity, nitrogen cycling, and long-term changes in organic carbon pools as related to fallow tillage management. *Soil & Tillage Res*. 49, 3-18.

FRANZLUEBBERS, A.J., HONS, F.M. & ZUBERER, D.A., 1994. Long-term changes in soil carbon and nitrogen pools in wheat management systems. *Soil Sci. Soc. Am. J.* 58, 1639-1645.

FOX, R.H. & BANDEL, V.A., 1986. Nitrogen utilisation with no-tillage. In: Sprague M. A. & Triplett G. B. (eds). No-tillage and surface tillage agriculture. John Wiley & Sons, New York, USA.

GOSS, M.K., HOWSE, K.R., LANE, P.W., CHRISTIAN, D.G. & HARRIS, G.L., 1993. Losses of nitrate nitrogen in water draining from under autumn-sown crop established by direct drilling or mouldboard ploughing. *J. Soil Sci*. 44, 35-48.

HAGIN, J. & TUCKER, B. (eds.), 1982. Fertilisation of dryland and irrigated soils. Springer-Verlag, New York.

JARVIS, C.S., STOCKDALE, A.E., SHEPHERD, A. M. & POWLSON, S.D., 1996. Nitrogen mineralisation in temperate agricultural soils: Processes and measurement. *Adv. In Agron.* 57, 187- 235.

KINGERY, W.L., WOOD, C.W. & WILLIAM, J.C., 1996. Tillage and amendment effects on soil carbon and nitrogen mineralisation and phosphorus release. *Soil & Tillage Res*. 37, 239-250.

KOLBERG, R.L., WESTFALL, D.G. & PETERSON, G.A., 1999. Influence of cropping intensity and nitrogen fertiliser rates on in situ nitrogen mineralisation. *Soil Sci. Soc. Am. J.* 63 (1), 129-134.

OTTO, W.M., KILIAN, W.H., AGENBAG, G.A. & VLASSAK, K., 2000. Laboratory and field measurement of nitrogen mineralisation in a duplex soil following straw and nitrogen applications. Proceedings of the workshop N-dynamics in intensive and extensive agriculture. Laboratory for Soil Biology and Soil Fertility K.U. Leuven, Belgium.

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

POWER, J.F. & PETERSON, G.A., 1998. Nitrogen transformation, utilization, and conservation as affected by fallow tillage method. *Soil & Tillage Res* .49, 37-47.

RILEY, H.C.F., 1998. Soil mineral-N and N-fertiliser requirements of spring cereals in two long-term tillage trials on loam soil in southeast Norway. *Soil & Tillage Res.* 48, 265-274.

STEIN, J.A., SAGEMAN, A.R., FISCHER, R.A. & ANGUS, J.F., 1987. Soil nitrogen supply of wheat in relation to method of cultivation. *Soil & Tillage Res.* 10, 243-258.

SAS, 1990. SAS/STAT User's Guide, Version 6, Fourth Edition, Volume 2. SAS Institut Inc, SAS Campus Drive, Cary, NC 27513.

VLASSAK, K. & AGENBAG, G.A., 2000. Nitrogen dynamic in intensive and extensive agriculture. Proceeding of a workshop N-dynamics in intensive and extensive agriculture. Laboratory for Soil Biology and Soil Fertility K.U. Leuven Belgium.

WIENHOLD, B.J. & HALVORSON, A.D., 1999. Nitrogen mineralisation responses to cropping, tillage, and nitrogen rate in the Northern great plains. *Soil Sci. Soc. Am. J.* 63, 12-196.