THE EFFECT OF CROP ROTATION AND TILLAGE PRACTICE ON SOIL MOISTURE, NITROGEN MINERALISATION, GROWTH, DEVELOPMENT, YIELD AND QUALITY OF WHEAT PRODUCED IN THE SWARTLAND AREA OF SOUTH AFRICA

by
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Declaration

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Abstract

This study was done during 2010 and 2011 as a component study within a long-term crop rotation/soil tillage trial that was started in 2007 at the Langgewens Research Farm near Moorreesburg in the Western Cape Province of South Africa. The aim of this study was to determine the effect of crop rotation and soil tillage on the soil moisture content, mineral-N levels of the soil, leaf area index, chlorophyll content of the flag leaf, biomass production, grain yield and grain quality of spring wheat (*Triticum aestivum* L).

The experimental layout was a randomised complete block design with a split-plot treatment design replicated four times. Wheat monoculture (WWWW), lupin-wheat-canola-wheat (LWCW) and wheat-medic (McWMcW) crop rotation systems were included in this study and allocated to main plots. This study was confined to wheat after medic/clover, wheat after canola and wheat monoculture. Each main plot was subdivided into four sub-plots allocated to four tillage treatments namely: Zero-till (ZT) – soil left undisturbed until planting with a star-wheel planter No-till (NT) – soil left undisturbed until planting and then planted with a no-till planter Minimum-till (MT) – soil scarified March/April and then planted with a no-till planter Conventional-till (CT) – soil scarified March/April, then ploughed and planted with a no-till planter.

Soil samples were collected every two weeks from just before planting until before harvest, from which gravimetric soil moisture and total mineral-N (NO_3^--N and NH_4^+-N) were determined. Plant samples were collected every four weeks until anthesis, starting four weeks after emergence. From these leaf area index and dry-matter production were determined. Chlorophyll content and light interception were measured at anthesis. At the end of the growing season the total biomass, grain yield and grain quality was determined.

Crop rotations which included medics (McWMcW) or canola/lupins (LWCW) led to higher mineral-N content of the soil at the start of the 2011 growing season when compared to wheat monoculture, but did not have an effect on soil moisture. Conservation tillage (minimum- and no-till) practices resulted in higher soil moisture whilst conventional-till resulted in the highest mineral-N content for 2010. There was

however no differences in mineral-N content between tillage methods for 2011, whilst soil moisture content was affected in the same way as the previous year.

Both crop rotation and tillage influenced crop development and biomass production. In general, increased soil disturbance together with wheat after medics and wheat after canola resulted in better development of the wheat crop with regards to dry matter production and leaf area index. The positive effect of medic and canola rotations was also evident on chlorophyll content and light interception.

Grain yield was positively influenced by wheat after medics and wheat after canola, with both systems out-yielding wheat monoculture in 2010 and 2011. Minimum- and no-till resulted in the highest grain yield in both years. Crop rotation and tillage practice showed no clear trends with regards to grain quality. This illustrated the important effect of environmental conditions during grain-filling.

Environmental factors such as rainfall and temperature had significant effects in both years of the study, but the importance and advantages of crop rotation, especially with a legume crop such as medics included, was evident even though this component study was done early in terms of the long-term study. The positive effect of implementing conservation tillage practices such as minimum- and no-till were also clearly shown in results obtained throughout this experiment.

Uittreksel

Die studie is gedurende 2010 en 2011 uitgevoer as 'n deelstudie van 'n langtermyn grondbewerking- en wisselbouproef op die Langgewens proefplaas naby Moorreesburg in die Wes-Kaap Provinsie van Suid-Afrika. Die doel van hierdie studie was om die effek van grondbewerking en wisselbou op grondvog, minerale stikstof in die grond, blaaroppervlakindeks, chlorofilinhoud van die blare, graanopbrengs en -kwaliteit van lente koring (*Triticum aestivum* L) te kwantifiseer.

Die eksperiment is uitgelê as 'n volledig lukrake blokontwerp met 'n verdeelde perseel ontwerp met vier herhalings. Wisselboustelsels wat aan hoofpersele toegeken is sluit koring monokultuur (WWWW), lupien-koring-kanola-koring (LWCW) en medic-koring (McWMcW) in. Grondbewerking is toegeken aan subpersele. Die grondbewerkingsbehandelings het ingeslui:
Zero-bewerking (ZT) – die grond is onversteurd gelaat en koring is met 'n sterwielplanter geplant, Geen-bewerking (NT) – die grond is onversteur gelaat tot en met planttyd waar koring met 'n geenbewerking (no-till) planter geplant is, Minimum-bewerking (MT) – die grond is in Maart/April met 'n tandimplement bewerk en met 'n geen-bewerking planter geplant, Konvensionele-bewerking (CT) – die grond is in Maart/April met 'n tandimplement bewerk die grond is in Maar/April geploeg met 'n skaarploeg en met 'n geenbewerking planter geplant.

Grondmonsters is elke twee weke versamel van net voor plant tot net voor oes. Vanaf die versamelde monsters is die grondwaterinhoud grawimetries bepaal en ook die totale minerale stikstofinhoud (NO_3^--N en NH_4^+-N). Plantmonsters is vierweekliks versamel beginnende vier weke na opkoms tot en met antese. Blaaroppervlakindeks en biomassaproduksie is bepaal. Die chlorofilinhoud en ligonderskepping is tydens antese bepaal. Aan die einde van die groeiseisoen is totale biomassa, graan opbrengs asook graankwaliteit bepaal.

Wisselboustelsels, wat medics (McWMcW) of kanola/lupine (LWCW) ingesluit het, het 'n hoër minerale stikstofinhoud aan die begin van die 2011 groeiseisoen getoon. Wisselbou het egter geen effek op grondvog gehad nie. Minimum- en geen-bewerking het 'n hoër grondvoginhoud tot gevolg gehad, terwyl die persele onder konvensionele bewerking 'n hoër minerale stikstof inhoud gehad het in 2010. In 2011 was daar geen verskille in die minerale stikstofinhoud tussen verskillende die

bewerkingsmetodes nie en grondvog gedurende 2011 is op dieselfde wyse as in 2010 beïnvloed.

Beide wisselbou en bewerkingsmetode het 'n invloed gehad op gewasontwikkeling en biomassaproduksie. Die algemene tendens was dat, soos grondversteuring toegeneem het in die koring na medics en koring na kanola, het beter gewasontwikkeling plaasgeving met betrekking tot droëmassaproduksie en blaaroppervlakindeks. Die positiewe effek van wisselbou is ook waargeneem in die chlorofilinhoud van die blare en die ligonderskeppingspotensiaal van die blaredak.

Graanopbrengs is positief beïnvloed deur die wisselboustelsel, met beide koring na medics en koring na kanola wat hoër graanopbrengste as koring monokultuur vir beide jare gelewer het. Die hoogste graanobrengs is ook gekry onder die minimum- en geen-bewerkingsbehandelings vir 2010 en 2011. Wisselbou en bewerkingsmetodes het geen duidelike invloed op koringkwaliteit gehad nie. Dit is 'n weerspieëling van die belangrike invloed van omgewingsfaktore gedurende die korrelvulstadium van koring.

Omgewingsfaktore soos reënval en temperatuur het betekenisvolle effekte in beide jare van die studie gehad, maar die belang van 'n wisselbou wat 'n stikstofbinder soos medics insluit, was reeds in hierdie vroeë stadiums van die langtermynproef opvallend. Die positiewe effek van minimum- en geen-bewerking was ook duidelik sigbaar gedurende die verloop van die studie.

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List of Abbreviations

B	Boron
°C	Degrees Celsius
C	Carbon
Ca	Calcium
cm	Centimeter
cm^2	Square centimeter
CT	Conventional-till
Cu	Copper
g	Gram
g^{-1}	Per gram
ha	Hectare
ha^{-1}	Per hectare
HLM	Hectolitre mass
K	Potassium
kg	Kilogram
kg^{-1}	Per kilogram
kg hl^{-1}	Kilogram per hectolitre
LAI	Leaf area index
LWCW	Lupin-wheat-canola-wheat
m	Meter
m^{-1}	Per meter
m^{-2}	Per square meter
McWMcW	Medics-wheat-medics-wheat
Mg	Magnesium
mg	Milligram
mm	Millimeter
Mn	Manganese
MT	Minimum-till
N	Nitrogen
Na	Sodium
NH_4^+	Ammonium

NO_3^-	Nitrate
NT	No-till
OM	Organic matter
P	Phosphorus
S	Sulfur
s	seconds
SPAD	Soil plant analysis development
TKW	Thousand kernel weight
WWWW	Wheat-wheat-wheat-wheat
Zn	Zinc
ZT	Zero-till

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Chapter 1

1. Literature review

The Western Cape produces about 41 % of the RSA wheat crop of 1.8 million tons per annum (Crop estimates committee 2012). The climate of the Swartland wheat producing area of the Western Cape is typical Mediterranean and the majority of the annual rain is received during winter (Sim 1958). Although the soils are shallow and stony with weakly structured A horizons and low organic carbon content which result in a low water storing capacity, Sim (1958) came to the conclusion that high yielding wheat crops can be produced because of a reliable long-term winter rainfall of 300–400 mm per annum.

Knowledge of wheat production in the Western Cape is based on research results obtained mainly from wheat grown under monoculture and conventional tillage practices. During the last 10 - 15 years many farmers adopted conservation agriculture strategies. Crop rotation (diversification), retaining of surface stubble and reduced tillage were phased in and are currently important management strategies aimed at increasing profit margins and securing sustainability of crop production in the Western Cape. Ever-increasing production costs in combination with low produce prices result in narrowing of profit margins and force farmers to increase the yield per hectare and/or improve the management of these factors that influence wheat yield and quality.

Conventional tillage influences soil characteristics and therefore the growth and development of crops (Triplett and Dick 2008). According to these researchers, conventional tillage has a number of negative effects on soil properties. It destroys soil structure and thereby the soil porosity. Conventional tillage removes all crop residues from the soil surface and exposes the soil surface to raindrops and thereby enhances soil erosion. With very little cover (residue) on the soil surface, soil temperature will fluctuate and drying of the soil will increase. Conventional tillage also disrupts and destroys beneficial organisms in the soil and causes compaction which will require larger inputs of fuel and energy. When soil is tilled on a regular basis it improves oxidation and breakdown of soil organic matter resulting in decreases in soil carbon (C) content.

Introduction of conservation agricultural practices on the other hand will decrease soil erosion as a result of higher plant residue cover on the soil surface (Doran 1987). No-till practices that result in accumulation of crop residues on the soil surface will also affect soil temperature, due to the fact that soils will not be exposed to the same temperature extremes experienced by bare soils. In addition to this, residue mulches also tend to keep soils moist for longer periods due to a reduction in evaporation (Doran 1987). In tropical (hot) areas, lower soil temperatures, due to minimum- and zero-till practices can be beneficial to the production of cool weather crops, but the opposite may be true in cold, high rainfall areas (Ramakrishna et al. 2006, Wang et al. 2009) where seedling emergence may be delayed.

One of the most important factors that will influence crop yield is soil water availability and use efficiency (French and Schultz 1984). The adoption of no-till (NT) allows more intensive cropping sequences (Halvorson et al. 2000, Peterson et al. 2001), because NT results in increased rainwater infiltration and retains more water in the potential root sone compared to conventional-till. Farhani et al. (1998) concluded that NT conserved more surface residue, resulting in less evaporation loss. The result is crops that use soil water more efficiently under NT (Peterson et *al.* 2001) and by this increasing the growing period (Farhani et al. 1998).

Studies by Farhani *et al.* (1998) showed that the effect of different tillage practices on crop growth differed due to differences in climate and soil conditions under Mediterranean climatic conditions. Although no-till practices resulted in improved soil conditions such as improved soil moisture content, less fluctuations in soil temperature, reduced soil erosion and increased soil N content, it did not always result in higher yields (Eck and Jones 1992).

Tillage practice also influences the organic matter (OM) content of the soil. The use of a mouldboard plough in conventional-till systems will accelerate OM breakdown in the soil (Doran 1987). The lower soil C content will result in less diverse and culturable microbial populations when compared to systems where NT is practiced.

Conservation agriculture and especially no-till will also reduce inputs in terms of fuel and energy because less cultivation takes place and soil is not ploughed (Triplett and Dick 2008).

Method of soil tillage may also affect soil chemical properties and soil processes such as N mineralisation (Deng and Tabatabai 2000) which determines the N supply from the soil. Nitrogen is an essential plant nutrient and is the mineral element required in the largest quantity for crop development and growth (Maali 2003). Because N mineralisation is affected by soil nitrogen content, temperature and soil moisture (Power and Peterson 1998), it will be important to determine the effect of crop rotation and tillage practice on N mineralisation. Adopting conservation tillage may initially require increased application rates of N fertiliser, but differences in fertiliser needs will decrease over time (Phillips et al. 1980). When soil is disturbed on a regular basis, nutrients tend to be immobile. This is due to the fact that application zones are destroyed and the nutrients are exposed to new binding sites. When the soil is undisturbed, application zones stay intact and become saturated to such a degree that nutrients such as P and K are more freely available to the crop (Triplett and Dick 2008).

Crop rotation is practised in large areas of the world. Crop rotation involves growing different crops, normally alternating grasses and broadleaf species, in a pre-determined sequence on the same field/camp in subsequent years. Rotational cycles are typically extended over several years without annual changes unless dictated by unforeseen circumstances (Leighty 1938). The concept of crop rotation also includes the use of cover crops that can be used as green manure. Crop rotation has been practised in Europe since the 18th century to intensify food production and eliminate the need for a fallow period (Grigg 1974).

In rotational crop production it has been found that higher yields were obtained with wheat when planted in rotation with lupins and canola compared to wheat monoculture (Chan and Heenan 1996). Higher yields after legume crops such as medic pastures or feed crops such as lupins, may be the result of higher plant available nitrogen content in the soil because of the nitrogen fixing abilities of the legume crops. These legumes may also act as a break crop to reduce soil borne diseases in wheat and enable more efficient weed control because of a wider range of herbicides that can be used (Arshad et al. 2002).

Canola is a deep rooted crop. It has been found that soil on which canola has been grown tends to be more porous. A higher concentration of cations and a higher C content in the soil have also been found after a canola crop (Chan and Heenan 1996). This may be due to a recycling of nutrients from deeper soil layers to the topsoil when canola residues decompose in the topsoil. These factors may be the reason why wheat develops deeper rooting systems and produces more wheat ears per unit area when planted after a canola crop (Rieger et al. 2008).

Crop rotation has a significant effect on sustainability (Arshad et al. 2002). These rotations of crops can influence different aspects of the soil-plant continuum, which involves beneficial interrelationships among individual crops. These interrelationships include the incidence of weed cycles being broken, insects and plant disease being reduced, the improvement and/or maintenance of soil productivity, increase in organic matter content, increase in water holding capacity, the seasonal requirements for resources being met and soil nutrients being replenished (El-Nazer and McCarl 1986, Haylin et al. 1990, Liebig et al. 2004). Crop rotations also increase diversity and reduce the risk of adverse climatic conditions during a specific season, and therefore stabilises farm income and crop performance.

Large areas of the Swartland have been converted to conservation agriculture since the early nineties. This includes crop rotation systems, stubble management and reduced tillage practices. Crops in the Swartland include wheat, canola, lupins and medic, mostly grown under no-till. The aim of this study was to develop a better understanding of how the different crop rotation systems and soil tillage will influence soil water content, in-season nitrogen mineralisation potential and the subsequent growth, yield and quality response of the wheat crop to these soil properties. The information gathered will increase the knowledge pool essential to develop effective and sustainable production practices.

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Chapter 2

2. Material and methods

The influence of crop rotation and tillage on the N mineralisation potential and the subsequent response of wheat were studied within a crop rotation/tillage trial that was initiated in 2007.

2.1. Experimental site

This research was done as a two year component study within a long-term crop rotation/soil tillage trial that was started in 2007 at the Langgewens Research Farm, near Moorreesburg (-33.27665°; 18.70463°; altitude 191 m) in the Western Cape Province of South Africa during 2010 and 2011. The aim of the long-term study was to quantify the effects of crop rotation and soil tillage on the physical, chemical and biological properties of the soil to develop a better understanding of soil parameters that will improve sustainability in crop production systems on the shale derived soils of the Western Cape.

2.2. Soil

The soil at the experimental site derived from Malmesbury and Bokkeveld shales and consisted of shallow sandy-loam soil with a clay content of 10 - 15 % and a high stone content in the A horizon (Table 2.1). The estimated effective rooting depth varied between 30 - 90 cm. Due to the area covered by the trial and the variability of the soil which is typical for the soils in the Western Cape, three soil forms (Oakleaf, Swartland and Glenrosa) were identified within the boundaries of the trial. These soils tend to have poor vertical drainage, but rapid lateral drainage along the off-horizontal fractures in the shale layers giving rise to rapid saturation of low-lying areas. Water retention of these soils also tends to be low due to restricted soil depth and high stone content (Anon. 2010).

Table 2.1: The physical properties of the soil at the Langgewens Research Farm (Anonymous 2010)

Formation	Clay Content (%)	Stone (%)	Effective depth (cm)
Oakleaf	**10-15**	**36**	**60**
Swartland	**10-15**	**40**	**90**
Glenrosa	**10-15**	**76**	**60**

The chemical composition of the soil four years after initiation of the trial is summarised in Table 2.2. In general, lower pH values were recorded in the wheat monoculture (WWWW) compared to the systems which included legume crops (LWCW and McWMcW), while conventional-till (CT) resulted in lower % C values. Although differences were shown with regards to both macro- and trace elements due to the crop rotation and tillage practice used, it is unlikely that these differences would have any effect on the growth, yield and quality of the wheat crop.

Table 2.2: Chemical properties of the soil at the beginning of the 2011 growing season: wheat monoculture (WWWW), lupin-wheat-canola-wheat (LWCW) and medics-wheat (McWMcW) and four tillage practices [conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT)] at Langgewens Research Farm (Anonymous 2010)

		pH	Resistance	Acidity	Ca	Mg	Na	K	T-value	P	Cu	Zn	Mn	B	S	C
		(KCl)	(ohm)	(cmol/kg	(cmol/kg)	(cmol/kg)	(mg/kg)	(mg/kg)	(cmol/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(%)
WWWW	**CT**	5.0	455.0	0.71	2.66	0.55	49.8	137.3	4.48	67.5	1.91	3.69	146.7	0.19	12.50	0.79
	MT	5.3	647.5	0.63	3.60	0.64	22.0	169.5	5.40	88.0	1.37	5.88	133.8	0.20	5.12	1.41
	NT	5.1	790.0	0.65	3.51	0.66	28.8	165.0	5.36	105.5	1.56	6.79	166.9	0.20	7.37	1.32
	ZT	4.7	1102.5	0.97	2.39	0.50	25.8	155.0	4.37	94.8	1.47	4.99	114.3	0.17	5.05	1.19
	Mean	**5.0**	**748.8**	**0.74**	**3.04**	**0.59**	**31.6**	**156.7**	**4.90**	**88.9**	**1.58**	**5.34**	**140.4**	**0.19**	**7.51**	**1.18**
LWCW																
	CT	5.5	650.0	0.36	4.37	0.59	26.0	167.8	5.87	79.0	1.50	4.17	182.9	0.21	8.04	0.95
	MT	5.3	547.5	0.57	3.56	0.69	29.8	182.8	5.42	77.0	1.64	5.35	219.1	0.27	8.16	1.12
	NT	5.4	790.0	0.46	3.58	0.61	18.0	184.5	5.21	75.8	1.29	7.39	147.8	0.23	5.35	1.21
	ZT	5.2	710.0	0.63	3.06	0.53	27.0	182.5	4.80	70.5	1.29	3.84	154.9	0.24	7.27	1.09
	Mean	**5.3**	**674.4**	**0.50**	**3.64**	**0.61**	**25.2**	**179.4**	**5.32**	**75.6**	**1.43**	**5.19**	**176.2**	**0.24**	**7.20**	**1.09**
McWMcW																
	CT	5.1	410.0	0.70	3.16	0.58	34.0	154.8	4.98	78.0	1.41	3.81	141.5	0.20	7.37	1.07
	MT	5.6	560.0	0.37	4.49	0.71	27.8	180.8	6.15	93.5	1.65	6.56	146.1	0.27	6.77	1.36
	NT	5.5	800.0	0.22	4.18	0.68	27.5	177.0	5.64	87.8	1.42	4.90	150.4	0.24	4.96	1.22
	ZT	5.4	922.5	0.52	3.61	0.61	23.8	195.5	5.35	75.0	1.21	3.88	131.3	0.22	6.05	1.33
	Mean	**5.4**	**673.1**	**0.45**	**3.86**	**0.64**	**28.3**	**177.0**	**5.53**	**83.6**	**1.42**	**4.79**	**142.3**	**0.23**	**6.29**	**1.25**

2.3. Climate

The total monthly rainfall recorded for 2010 and 2011 are presented in Figure 2.1. The total rainfall recorded in 2010 was 16 % higher than the long-term average whilst rainfall recorded for 2011 was the same. The long-term average rainfall at Langgewens is 396.9 mm per annum whilst in 2010 and 2011, 461.6 mm and 396.8 mm were recorded respectively.

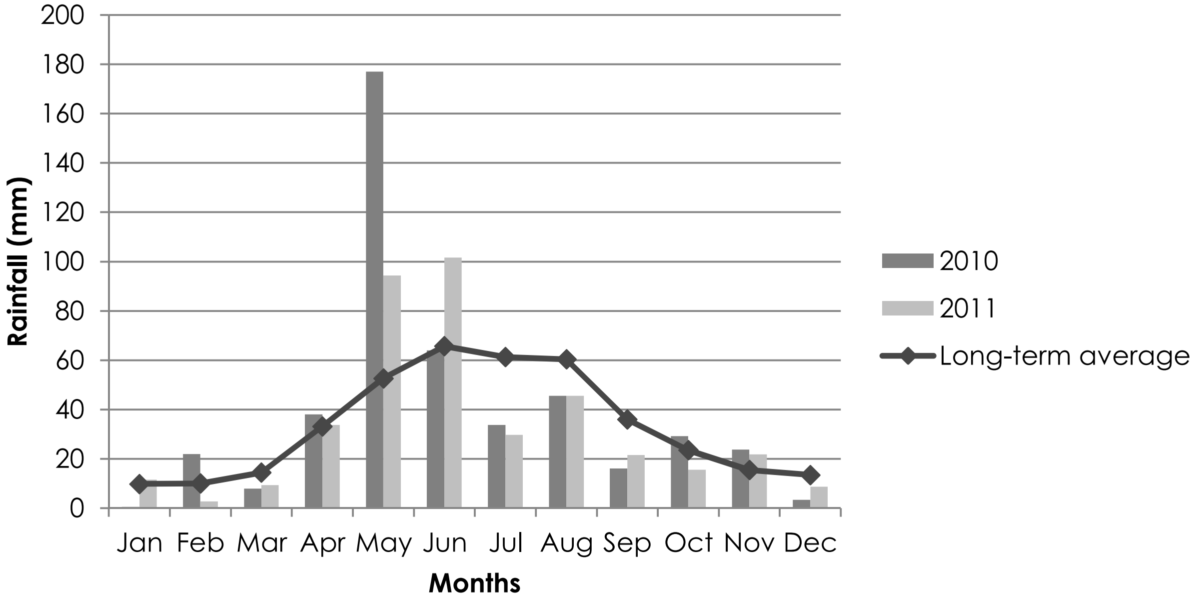

Figure 2.1: The long-term average rainfall compared to the 2010 and 2011 seasons' rainfall at the Langgewens Research Farm (Data from the ARC-ISCW)

Rainfall recorded during May 2010 was 240 % higher than the long-term average and 80 % more in 2011 compared to the long-term average. The long-term average rainfall for May is 52.7 mm while 177 mm and 94.4 mm rain were recorded during May 2010 and 2011 respectively. Losses of fertiliser (especially N) applied at planting could have been a possibility as a result of the high rainfall recorded early in the season. In 2011 rainfall received in June was 55 % higher, compared to the long-term average. The long-term average for June is 65.7 mm while in 2011 101.6 mm was recorded. Lower than average rainfall was recorded for July, August and September in both 2010 and 2011. The drier mid- and late seasons could have resulted in some degree of water stress during anthesis and grain filling.

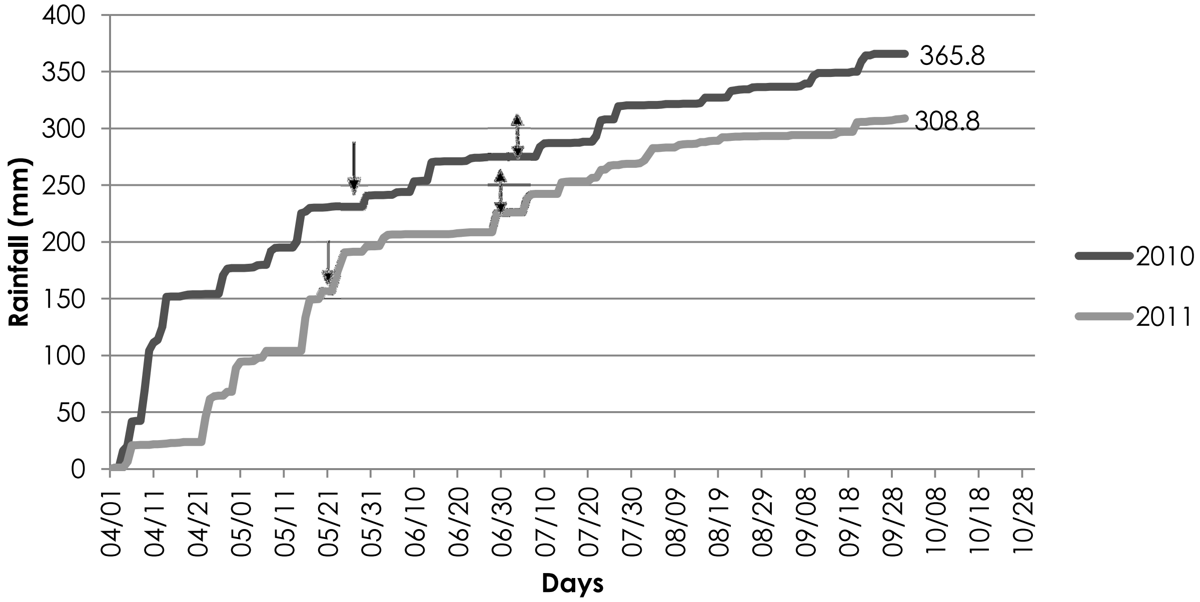

Figure 2.2: Accumulation of rainfall during the 2010 and 2011 growing season (1st of May to 31st of October) on the Langgewens Research Farm. Planting took place the 25/05/2010 and 20/05/2011 respectively and N top dressing was done on 02/07/2010 and 30/06/2011 respectively. (Planting date: ; Top dressing:) (Data from the ARC-ISCW)

Figure 2.2 shows the accumulative rainfall recorded from April 1st to October 31st. Early season rainfall received during the 2010 growing season was higher than in 2011. In both 2010 and 2011 rain was recorded after planting. In both 2010 and in 2011, significant amounts of rain were recorded within five days after planting took place. This could have affected the mineralisation of N and also leaching of nitrate. No periods of high rainfall were recorded after top dressing N in both years.

The temperatures recorded and the rainfall occurrences for the 2010 and 2011 production seasons are summarised in Figures 2.3 and 2.4 respectively.

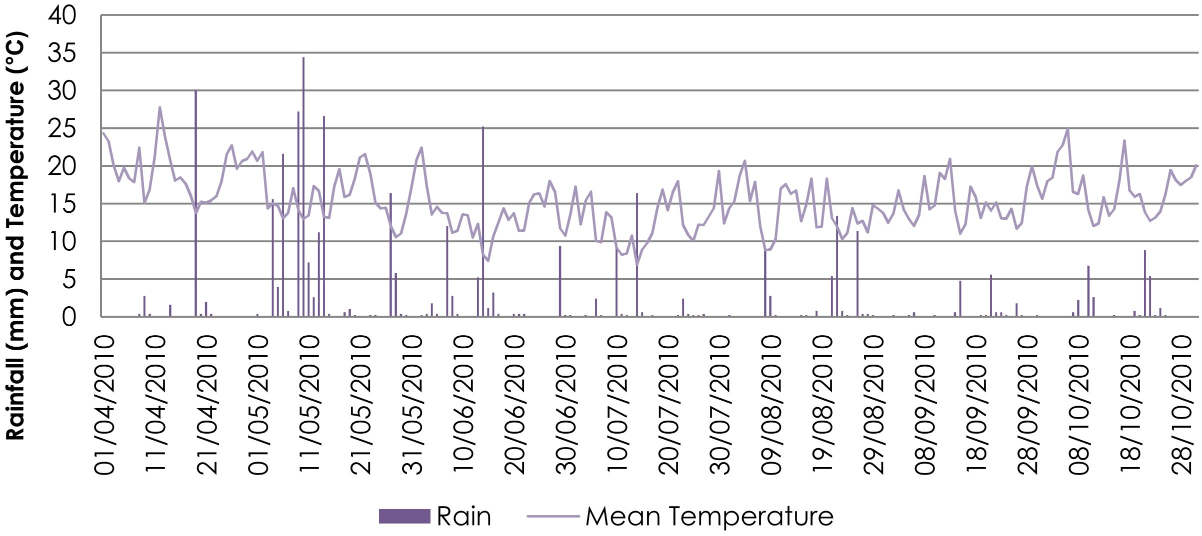

Figure 2.3: Daily rainfall (mm) and mean daily temperatures (°C) recorded for the period April to November 2010 at Langgewens Research Farm (Data from the ARC-ISCW)

The high intensity of rainfall events during the first two weeks of May 2010 (Figure 2.4) could have resulted in leaching losses of mineral nitrogen mineralised after 30 mm rain measured on April 19th. The 16.4 mm recorded on May 27th, could have caused some losses of the nitrogen band-placed during planting on May, 25th. Mean daily temperatures for 2010 remained between 10 ° and 17 °C from planting until late September followed by an increase towards harvesting. Although temperatures during September were moderate, rainfall was low, a factor that might have influenced nitrogen mineralisation during September.

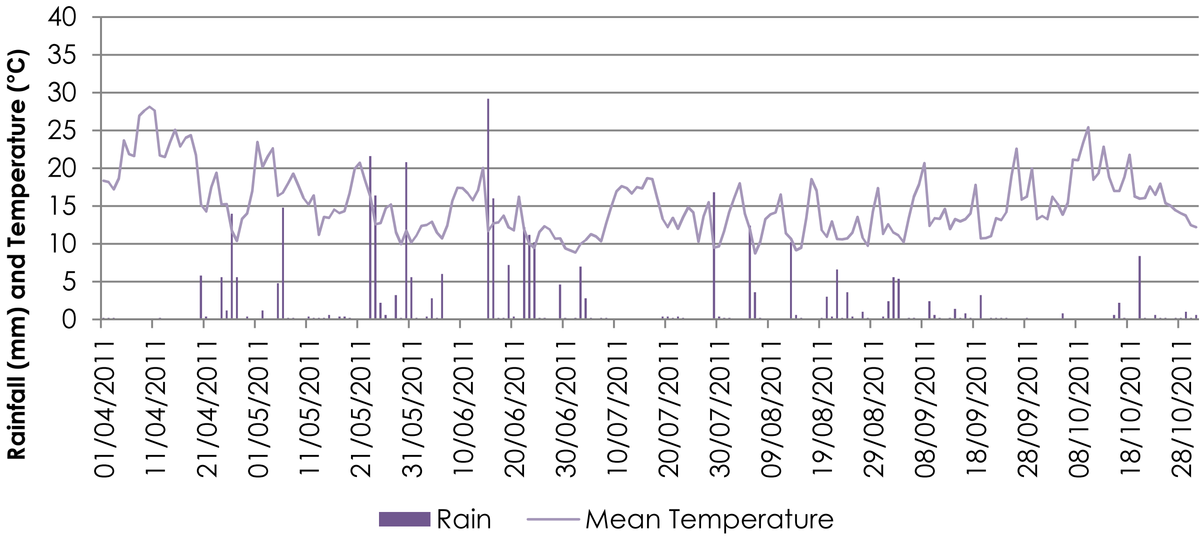

Figure 2.4: Daily rainfall (mm) and mean daily temperatures (°C) recorded for the period April to November 2011 at Langgewens Research Farm (Data from the ARC-ISCW)

The pre-plant rainfall incidents for 2011 were fewer compared to 2010 and less leaching of mineralised N, if any, was expected during the month prior to planting that took place on May 20th. The 38 mm of rain recorded four days after planting could have caused leaching losses of N fertiliser band-placed during planting. The mean daily temperature for the 2011 growing season remained between 10 ° and 17 °C for most of the growing season until late September.

2.4. Maintenance of experimental plots

General management of the experimental site was in accordance with protocol prescribed by a Technical Committee that included experts covering all aspects of wheat production.

Wheat, cultivar SST 027, was planted, using a no-till Ausplow fitted with knife-openers and presswheels (in all treatments except for zero-till where a star-wheel planter was used), at 90 kg seed ha^{-1} on May 25th and May 20th in 2010 and 2011 respectively. Wheat plots received 25 kg N ha^{-1} and 12.5 kg P ha^{-1}, band-placed with planting, except the zero-till where fertiliser was broadcast. On the wheat plots 40 kg N ha^{-1} was top-dressed 40 days after emergence of the crop. A broad spectrum herbicide (active ingredient of glyphosate) was applied three days before planting to ensure a weed free seedbed. In an effort to reduce annual ryegrass (*Lolium spp*), a herbicide containing the active ingredient, trifluralin, was applied during the planting process on the no-, minimum- and conventional-till treatments. Effective use of this herbicide in the zero-till treatment was not possible, because the planting method used (star-wheel planter) was not able to ensure a herbicide free band in the planting furrow. Post-emergence weed control included Axial® (pinoxaden) for grass control in both years and Buctril DS® (3.5-dibromo-4-hydroxybenzonitrile) in 2010 and Harmony M® (metasulfuron-methyl/thifensulfuron) in 2011 for broadleaf weed control. Mospilan® (acetamiprid) and Duett® (carbendazim/epoxiconazole) were applied to control insects and fungi in both years covered by the study. All crop residues remained on the soil surface as zero-grazing and no baling was practised.

2.5. Experimental layout and treatments

The interaction between three crop rotation systems and four tillage practices was studied. The experimental layout was a randomised complete block design with a split-plot treatment design replicated four times (Snedecor and Cochran 1967). Wheat monoculture (WWWW), lupin-wheat-canola-wheat (LWCW) and wheat-medic rotation

(McWMcW) were included in this study and allocated to main plots. Gross sub-plot size measured 25 m x 10 m of which 1.61 x 25 m was harvested. This study was confined to wheat after medic/clover, wheat after canola and wheat monoculture. Each main plot was subdivided into four sub-plots allocated to four tillage treatments namely:

Zero-till (ZT) – soil left undisturbed until planting with a star-wheel planter
No-till (NT) – soil left undisturbed until planting and then planted with a no-till planter
Minimum-till (MT) – soil scarified March/April and then planted with a no-till planter
Conventional-till (CT) – soil scarified March/April, then ploughed and planted with a no-till planter.

Except for harvesting that was done with a "small plot combine", commercial implements were used for all other actions on the trial.

2.6. Data collection

2.6.1. Soil Moisture (g g^{-1})

Soil samples were collected at 14 day intervals, 0 - 150 mm deep, starting one day before seeding (before any fertiliser was applied) until harvesting. Four sub-samples were collected per treatment combination, bulked and placed in pre-weighed tins. The tins were sealed immediately to prevent any moisture loss due to evaporation. The soil was weighed within 2-3 hours after sampling. Total weight of the tin plus soil was recorded and dried at 60 °C for at least 72 hours. After subtracting the weight of the tin, the soil weight was used to calculate the gravimetric soil moisture content using the formula: Gravimetric water content = (soil wet weight – soil dry weight)/(soil dry weight)*(100) (Brady and Weil 1999).

2.6.2. Soil mineral Nitrogen (mg kg^{-1})

The soil sample used to calculate soil moisture content was sieved through a 2 mm sieve and soil mineral nitrogen (NH_4^+-N and NO_3^--N) content was determined using the indophenol-blue (Pace et al. 1982) and salicylic acid (Cataldo et al. 1975) methods.

2.6.3. Flag leaf chlorophyll content

A portable Opti-Sciences CCM 200 chlorophyll meter was used to record the chlorophyll content of the flag leaf at anthesis. Five readings per treatment combination were logged and the mean value noted. Readings were taken one third of the flag leaf's length from the stem and the midrib avoided.

2.6.4. Light interception

Light interception by the plant canopy was measured using an AccuPAR LP-80 PAR/LAI ceptometer. The light intensity was measured in sets, five readings directly above the wheat canopy accompanied by five readings directly below the canopy on ground level to determine the total light intercepted by the canopy as a whole.

2.6.5. Leaf area (cm^2)

Leaf area (cm^2) was determined by sampling 20 green plants per treatment combination. Sampling commenced four weeks after emergence and thereafter at 28 day intervals until the end of the growing season. When leaves started to colour from green to yellow, with all leaves being more than 50 % yellow, it was accepted that the growing season had ended. After leaves were separated from the stems, the leaf area was determined using a Li-Cor, LI-3100 Area Meter.

2.6.6. Biomass production (kg ha^{-1})

The same plant material used to determine leaf area was used to determine biomass production. After the roots were removed, the stems and leaves were oven-dried at 60 °C for at least 72 hours and biomass recorded.

2.6.7. Seedling and tiller survival

The number of seedlings m^{-2} was determined three weeks after crop emergence by counting the number of seedlings per meter row length. Fifteen 1m row counts per treatment combination were done and the mean number of seedlings m^{-1} calculated. Mean number of seedlings m^{-2} was calculated using the formula: Seedlings m^{-2} = (mean seedlings m^{-1} row length)*(10000)/(0.3). The same procedure as described for seedling survival was used to determine the number of ear bearing tillers at harvest, the only difference being that the plants were cut at soil level and the tillers counted.

2.6.8. Final biomass produced

The plant material used to calculate the final number of ear bearing tillers m^{-2} was oven dried at 60 °C and final biomass production (kg ha^{-1}) calculated. For the determination of total biomass produced per plot, 10 rows of one meter each were cut and weighed one week before harvest. Total biomass = total biomass m^{-1} row length*(10000)/(0.3)

2.6.9. Yield components

Twenty ears were selected at random from the sample used to determine final biomass production. Spikelets per ear, number of kernels per spikelet and mean kernel weight were recorded.

2.6.10. Grain yield

A plot harvester (small combine) was used to harvest the grain produced. Yield was determined by the following equation: Grain yield = 10 000 m^2/(area of sampling plot)*(kg of wheat harvested from sampling plot).

2.6.11. Quality parameters of the grain

Grain samples were collected from each treatment combination and subjected to quality analysis. Protein content (%), thousand kernel weight (g), falling number (s) and hectolitre mass (kg hl^{-1}) were determined as described by Nel et al. (1998, 2000).

2.7. Statistical analyses

An appropriate analysis of variance (ANOVA) was performed, using SAS/STAT software, Version 9.2 (SAS 2008). The Shapiro-Wilk (1965) test was used to test normality of residuals and least significant difference (LSD) was calculated at the 5 % confidence level to compare treatment means using Student's t-test (Ott 1998). Only results showing statistically significant differences were presented and discussed.

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Chapter 3

3. Soil water and mineral-N content as influenced by crop rotation and tillage practice in the Swartland sub-region of the Western Cape

Abstract

Soil water content and nitrogen mineralisation can be influenced by amongst others crop rotation and tillage practices. This study assessed the effect of crop rotation and tillage practice on the soil water (g g^{-1}) and mineral-N content (mg kg^{-1}) during the 2010 and 2011 growing seasons. Research was conducted as a component study within a long-term crop rotation and soil tillage trial. Three crop rotation systems, wheat monoculture (WWWW), lupin-wheat-canola-wheat (LWCW) and wheat-medic rotation (McWMcW) and four tillage treatments namely conventional- (CT), minimum– (MT), no- (NT) and zero-till (ZT) were included in the study. Soil moisture and mineral-N content (NH_4^+-N + NO_3^--N) were determined every two weeks from before planting until just before harvesting. Soil moisture content did not differ due to crop rotation system. Tillage treatment influenced soil water content with a tendency of higher levels in the NT and MT treatments. The soil water content in CT tended to be lower compared to the other tillage treatments tested. The low soil water content recorded for the ZT could be ascribed to high herbicide-resistant ryegrass infestation rather than a treatment effect. A tendency of higher mineral-N in CT was observed, although not for all sampling dates. Mineral-N content did not differ between ZT, NT and MT treatments. It can be concluded that tillage practice influenced soil water and mineral-N content, while crop rotation only influenced mineral-N by including a legume-crop (medic). Results obtained in this study could be valuable in developing management strategies for wheat grown under different production systems.

Keywords: crop rotation, nitrogen mineralisation, soil tillage, soil water content

3.1. Introduction

The Swartland sub-region of the Western Cape is one of the most important wheat producing areas in Southern Africa with ±260 000 ha planted annually to wheat under rain-fed conditions (Crop estimates committee 2012). The long-term annual rainfall for the central Swartland is 397 mm. The climate of the Swartland is typically Mediterranean with ±80 % of the rainfall occurring between April and September (López-Bellido et al. 1996). Although wheat yields differ annually, yields of 3 t ha^{-1} are often recorded.

Nitrogen is one of the most important plant nutrients contributing to crop yield and is needed in large quantities by the wheat plant to ensure high grain yields of good quality (Jarvis et al. 1996). Nitrogen is mainly added to the soil through application of chemical or organic fertilisers, biological nitrogen fixation by preceding legume crops and the mineralisation of soil nitrogen reserves (Carpenter-Boggs et al. 2000). Factors that will influence the activity of soil microbes and for this reason also the amount of nitrogen mineralised, include, amongst others, soil temperature (Fabrizzi et al. 2005), soil moisture content (Garabet et al. 1998), physical condition of the soil (Mahboubi et al. 1993), organic matter and C content (Haylin et al. 1990) as well as the previous crop (Carpenter-Boggs et al. 2000, López-Bellido et al. 1997). Most of these factors are also affected by soil tillage (Chang and Lindwall 1989). The crop response to nitrogen fertiliser is also influenced by many factors, including soil type, method of tillage, crop sequence, nitrogen application rate and the amount of plant available nitrogen (López-Bellido and López-Bellido 2001).

Reduced tillage leave more plant material on the soil surface resulting in increased infiltration of water, less surface crusting and less evaporation loss (Sprague and Triplett 1986, Unger et al. 1991). Chang and Lindwall (1989) found, in an experiment running for 28 years, that the water holding capacity in the upper 150 mm layer of soil was higher in NT compared to conventional tillage. Less intensively tilled soils usually have larger pores compared to intensively tilled soils, resulting in higher infiltration rates throughout the growing season. Contrary to the advantages of reduced tillage, conventional till resulted in soils with higher initial water infiltration rate, but this rate decreased rapidly due to surface sealing from rainfall (Triplett et al. 1968).

Carpenter-Boggs et al. (2000) found that initial inorganic N was often poorly correlated with N mineralisation potential in crop rotation systems, because residual N from fertiliser applied in previous seasons also affected initial levels of inorganic N in the soil. This finding suggests that crop rotation may play a lesser role in determining N mineralisation potential than generally expected. Various scientists reported the beneficial effects of some crop rotations on soil water content. Larney and Lindwall (1995) reported higher soil water contents in wheat after lentils/flax compared to wheat monoculture. But they also recorded lower soil water levels in wheat that followed canola compared to wheat monoculture. Hulugalle et al. (2007) measured higher soil water contents in wheat when rotated with cotton, compared to cotton monoculture.

It is therefore anticipated that crop rotation and tillage practice will influence nitrogen mineralisation potential and thereby influence the amount of N available for crop absorption in a specific system. The aim of this study was to investigate the effect of crop rotation and tillage practice on moisture and mineral-N content of the soil during the growing season of a wheat crop. Quantifying and development of a better understanding of N mineralisation potential in different crop rotation systems and tillage practices may contribute to the development of more efficient N fertiliser programmes for wheat produced under different management scenarios in the Swartland.

3.2. Material and methods

3.2.1. Locality and treatments

This research was conducted during 2010 and 2011 as a component study within a long-term crop rotation and soil tillage trial on the Langgewens Research Farm near Moorreesburg (-33.27665°; 18.70463°; altitude 191 m). Soil properties at the experimental site and climatic conditions (rainfall and temperature) during the experimental period were discussed in Chapter 2. The experimental layout was a randomised complete block design with a split-plot treatment design, replicated four times. Three cropping systems, wheat monoculture (WWWW), lupin-wheat-canola-wheat (LWCW) and wheat-medic rotation (McWMcW) were allocated to main plots. Each main plot was subdivided into four sub-plots allocated to four tillage treatments namely, zero-till (ZT) – soil left undisturbed until planting with a star-wheel planter; no-till (NT) – soil left undisturbed until planting with a no-till planter; minimum-till (MT) – soil scarified March/April; and then planted with a no-till planter and conventional-till (CT) – soil scarified March/April, then ploughed and planted with a no-till planter.

Crops were managed in accordance to recommendations by a Technical Committee consisting of experts in all fields of crop production as explained in Chapter 2. Except for the treatments, all agronomic practices were the same on all treatment combinations.

3.2.2. Data collected

Data were collected during the wheat phase of the WWWW, LWCW (wheat after canola) and McWMcW systems. The McWMcW system was included in the study from September 2010. Soil samples were collected every two weeks, to a depth of 150 mm, from just before planting until harvesting. Soil water content and nitrogen mineralisation potential were determined. Samples were placed in pre-weighed tins and closed immediately to prevent moisture loss through evaporation and to slow down nitrogen mineralisation. After the wet weight of each sample was recorded, samples were oven-dried for at least 72 hours at 60 °C. This temperature was much lower than the temperature recommended for measuring of gravimetric soil water content, but was used on purpose to minimise the negative effect of high temperature on mineral-N and especially the NH_4^+-N content of the soil. Soil water content was expressed gravimetrically (g g^{-1}) using the equation: Gravimetric soil water content = (soil wet weight - soil dry weight)/(soil dry weight). After drying, the samples were sieved (2 mm) and NH_4^+-N and NO_3^--N determined using the indophenol-blue (Pace et al. 1982) and salicylic acid (Cataldo et al. 1975) methods respectively. Mineral nitrogen was calculated as the sum of ammonium-N and nitrate-N content.

3.2.3. Statistical analyses

An appropriate analysis of variance (ANOVA) was performed, using SAS/STAT software, Version 9.2 (SAS 2008). The Shapiro-Wilk test (Shapiro and Wilk 1965) was used to test normality of residuals and least significant difference (LSD) was calculated at the 5 % confidence level to compare treatment means using Student's t-test (Ott 1998).

3.3. Result and discussion

3.3.1. Soil water content

Gravimetric soil water content (g g^{-1}) for all treatment combinations tended to decrease from planting to harvesting during 2010 (Figures 3.1 and 3.2). As a result of low rainfall in August 2010, low levels of soil water content were recorded on August 4th and 20th in all systems studied. Significant differences between tillage treatments within systems were inconsistent and it was very difficult to identify any trends. Soil water content did not differ ($P=0.05$) between NT and MT in 2010 in both the WWWW and LWCW systems. A tendency of lower soil water in the CT compared to NT was recorded in 2010, although significantly only on July 8th, July 22nd and September 9th in WWWW and June 23rd, July 8th and July 22nd in LWCW. The relatively low water content in the CT treatment is in accordance with results published by Sprague and Triplett (1986) who found that conventional tillage negatively affected surface runoff, evaporation and infiltration, resulting in less plant available soil water. The higher soil water content in ZT, NT and MT in June 2010 could possibly be attributed to reduced evaporation and better water infiltration due to the stubble retained in the treatments subjected to reduced tillage (Triplett et al. 1968). As the 2010 season progressed soil water content of ZT in WWWW decreased to levels comparable to CT, possibly the result of a higher transpiration demand by the high population of herbicide-resistant ryegrass in ZT. The increase in soil water content at the end of the season could be an indication that the ryegrass matured earlier than the wheat crop. Heenen and Chan (1992) recorded higher penetration resistance and bulk density in the 0-50 mm of the soil under zero-till compared to CT, which could cause a reduction in water infiltration (more runoff) under ZT practices.

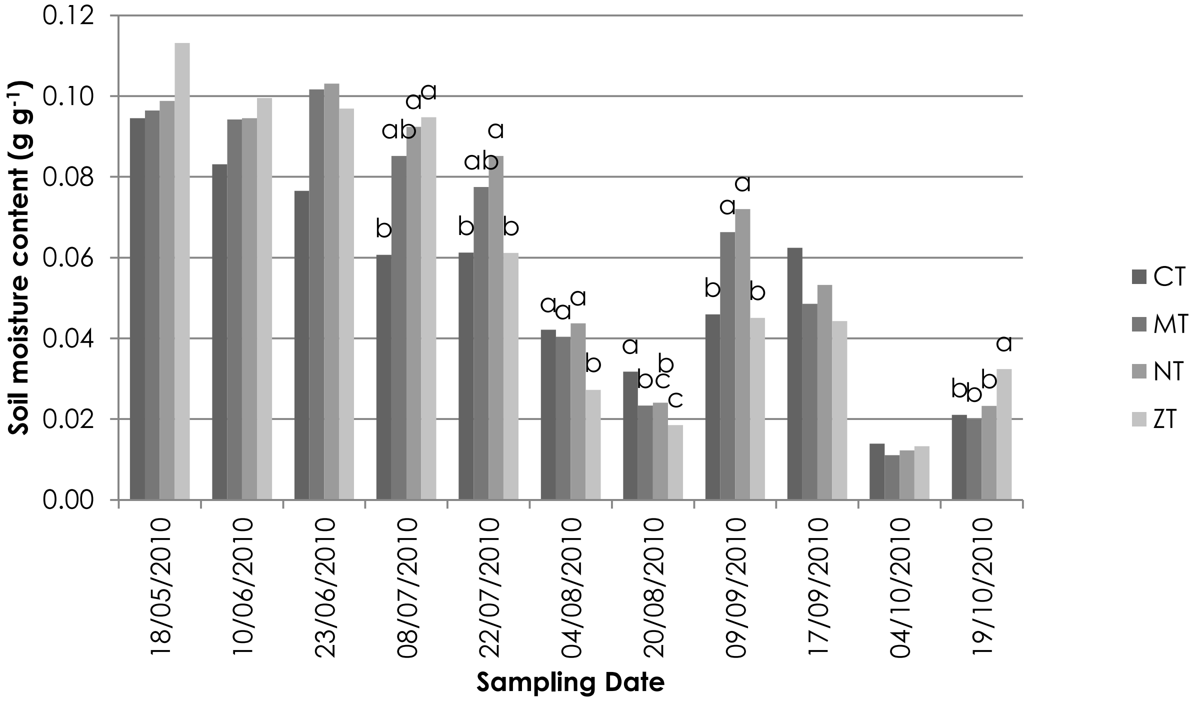

Figure 3.1: Soil water content (g g^{-1}) in the wheat monoculture (WWWW) treatment as influenced by conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) during the 2010 growing season at Langgewens Research Farm

Bars with the same letter at the same date are not significantly different at 0.05 probability level

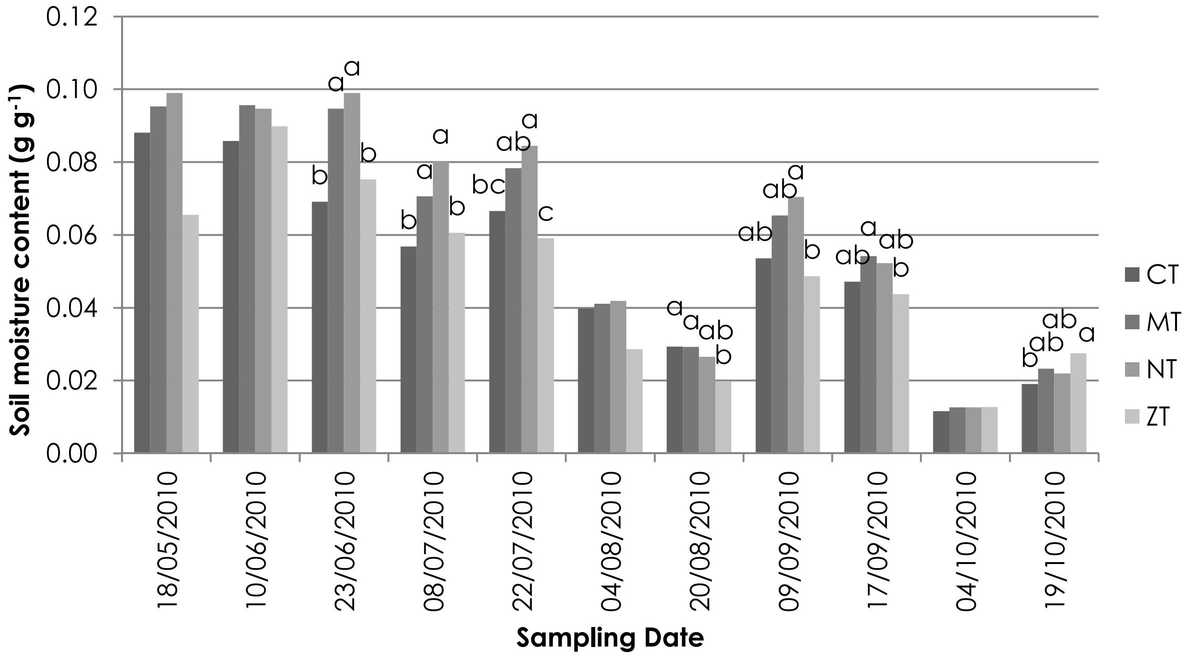

Figure 3.2: Soil water content (g g^{-1}) in the lupin-wheat-canola-wheat (LWCW) rotation as influenced by conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) during the 2010 growing season at Langgewens Research Farm

Bars with the same letter at the same date are not significantly different at 0.05 probability level

The low soil water content prior to planting in 2011 is indicative of relatively dry conditions before planting (Figures 3.3–3.5). Except for relatively low moisture contents on July 18th 2011, soil water content after planting increased and remained at values between 0.08-0.1 g g^{-1} followed by a gradual decrease towards harvesting. A short dry spell between July 4th and August 1st resulted in a decrease in soil water content. Except for November 8th in LWCW, no differences in soil water content were recorded from September 27th until harvesting for all tillage treatments tested during 2011. Although differences in soil water content were less pronounced in 2011 compared to 2010, a tendency of higher soil water levels for NT and MT in 2011 for all systems tested was observed. A tendency of lower soil water for the CT compared to NT was also recorded in 2011, although significantly only on May 16th, August 15th in WWWW and May 16th and August 15th in McWMcW. These results are similar to those reported by Franzluebbers et al. (1995) who reported that water-filled pore spaces in NT soil planted with wheat retained 19 % more water in the top 200 mm of the soil profile compared to soil in a conventional till system. Differences (P=0.05) in soil water content between NT and MT were only recorded in the McWMcW system on May 16th, July 18th, August 1st, August 15th and September 12th (Figure 3.5). If the observation in the McWMcW system is repeatable, it can be concluded that the positive results related to no-till will develop sooner in McWMcW compared to WWWW and LWCW.

Fabrizzi et al. (2005) however showed that NT had a significant higher bulk density and a lower total porosity in the 30 - 80 and 130 - 180 mm soil profile, indicating that a lack of disturbance increased soil compaction, resulting in lower soil moisture levels due to a reduced water holding capacity.

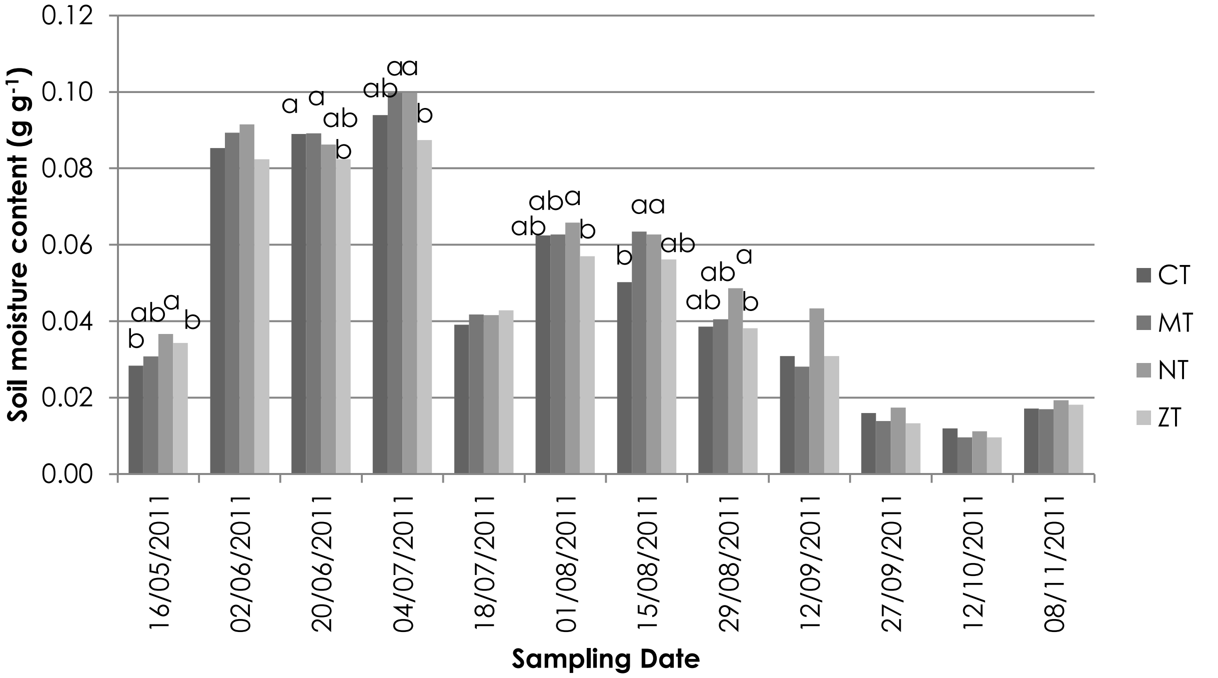

Figure 3.3: Soil water content (g g^{-1}) in the wheat monoculture (WWWW) treatment as influenced by conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) during the 2011 growing season at Langgewens Research Farm

Bars with the same letter at the same date are not significantly different at 0.05 probability level

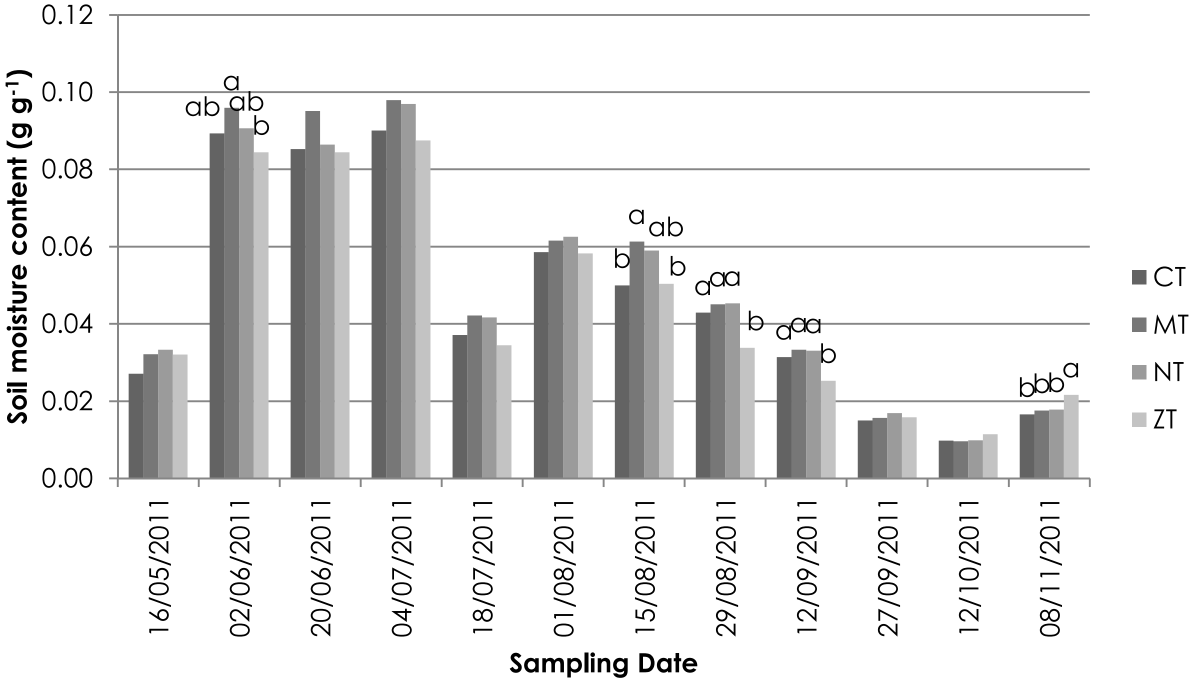

Figure 3.4: Soil water content (g g⁻¹) in the lupin-wheat-canola-wheat (LWCW) rotation as influenced by conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) during the 2011 growing season at Langgewens Research Farm

Bars with the same letter at the same date are not significantly different at 0.05 probability level

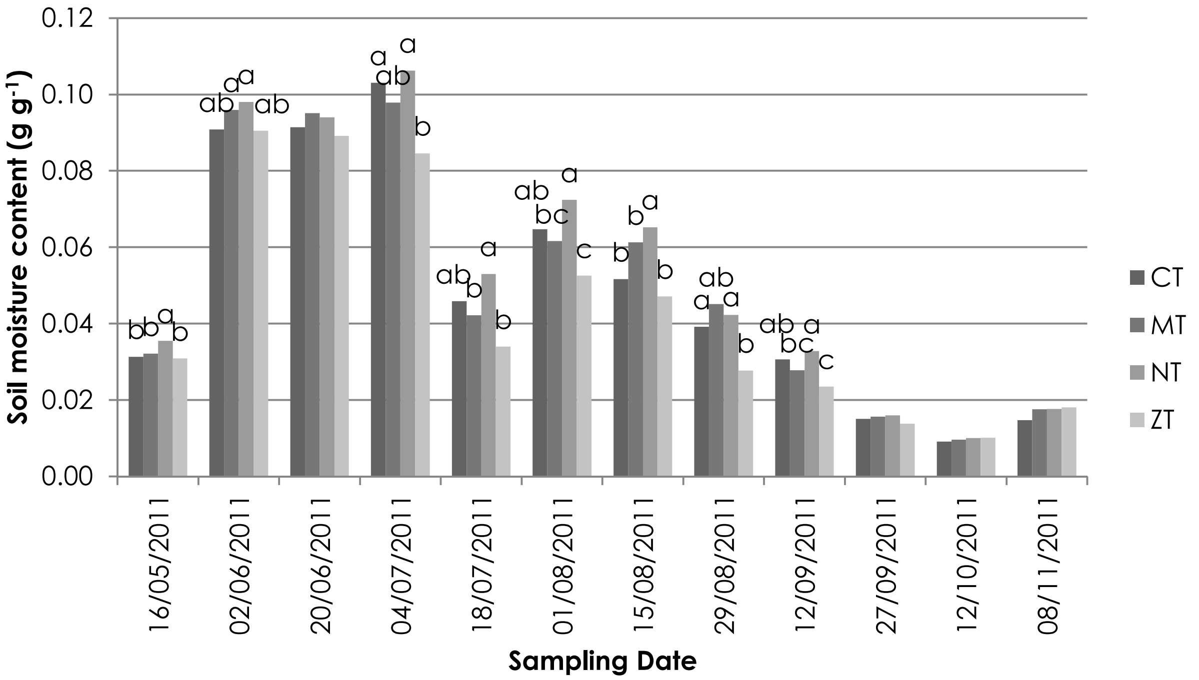

Figure 3.5: Soil water content (g g⁻¹) of the wheat after medics (McWMcW) rotation as influenced by conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) during the 2011 growing season at Langgewens Research Farm

Bars with the same letter at the same date are not significantly different at 0.05 probability level

To summarise, soil water content generally did not differ between WWWW and LWCW during both 2010 and 2011. Tillage treatment influenced soil water content with a tendency of higher levels in the NT and MT and lower in CT. In contrast to WWWW and LWCW, NT in McWMcW resulted in higher soil water content compared to MT at all five sampling dates during 2011. It can also be concluded that the lower water content recorded in ZT is not only a treatment effect, but rather the result of high infestation of herbicide-resistant ryegrass in ZT that increased transpiration losses.

3.3.2. Soil mineral nitrogen content

Although both NH_4^+-N and NO_3^--N content were measured only total mineral-N (NH_4^+-N + NO_3^--N) as indicator of inorganic N content will be presented and discussed as changes from NH_4^+-N to NO_3^--N may occur very rapidly under field conditions (Wienhold and Halvorson 1999).

Soil mineral nitrogen content (mg kg^{-1}) showed a gradual increase from planting until July 22nd for all treatments during the 2010 growing season (Figures 3.6, 3.8 and 3.10). Unfortunately sampling in the McWMcW system only started in September 2010 (Figure 3.10). Data recorded during the 2011 season (Figures 3.7, 3.9 and 3.11) showed that the initial amount of mineralised N was higher for all crop rotation systems in 2011, compared to 2010. This could be the result of less N leaching in 2011 as less rain was recorded in the two weeks before planting in 2011 or lower N mineralisation as a result of drier pre-plant conditions (Chapter 2, Figure 2.4). Except for August 1st 2011, where an unexplainable sharp increase in mineral-N was observed in all systems tested, mineral-N content tended to decrease as season progressed in WWWW, LWCW and McWMcW in 2011.

Nitrogen fertiliser applied as a top-dressing on July 2nd (2010) and June 30th (2011) did not result in a sharp increase in soil nitrogen levels in any of the treatment combinations tested. Mineral-N content of CT in WWWW tended to be higher than NT and MT, however only significantly on August 20th and September 9th in 2010 and June 20th and August 15th 2011 (Figures 3.6 and 3.7). Except for higher (P=0.05) mineral-N levels found in NT compared to MT in WWWW on May 18th (2010), August 29th (2011) and September 27th (2011), no differences in soil N content were recorded between NT and MT. The increase in mineralised N content recorded on September 9th 2010 could be the result of relatively high temperatures measured mid to late August (Chapter 2, Figure 2.3). Wang et al. (2006) reported significant increases in N mineralisation from a laboratory study as air temperature increased above 15 °C. The sharp decrease in soil N content from the beginning of September onwards could be expected as N requirement of the wheat crop during September and October (flag leaf to early grain filling stage) is very high. The increase in mineral-N at the end of the 2010 season (19th October) could be the result of the crop reaching maturity with no more need for mineral-N from the soil, while increasing temperatures could result in increased N mineralisation rates in the soil.

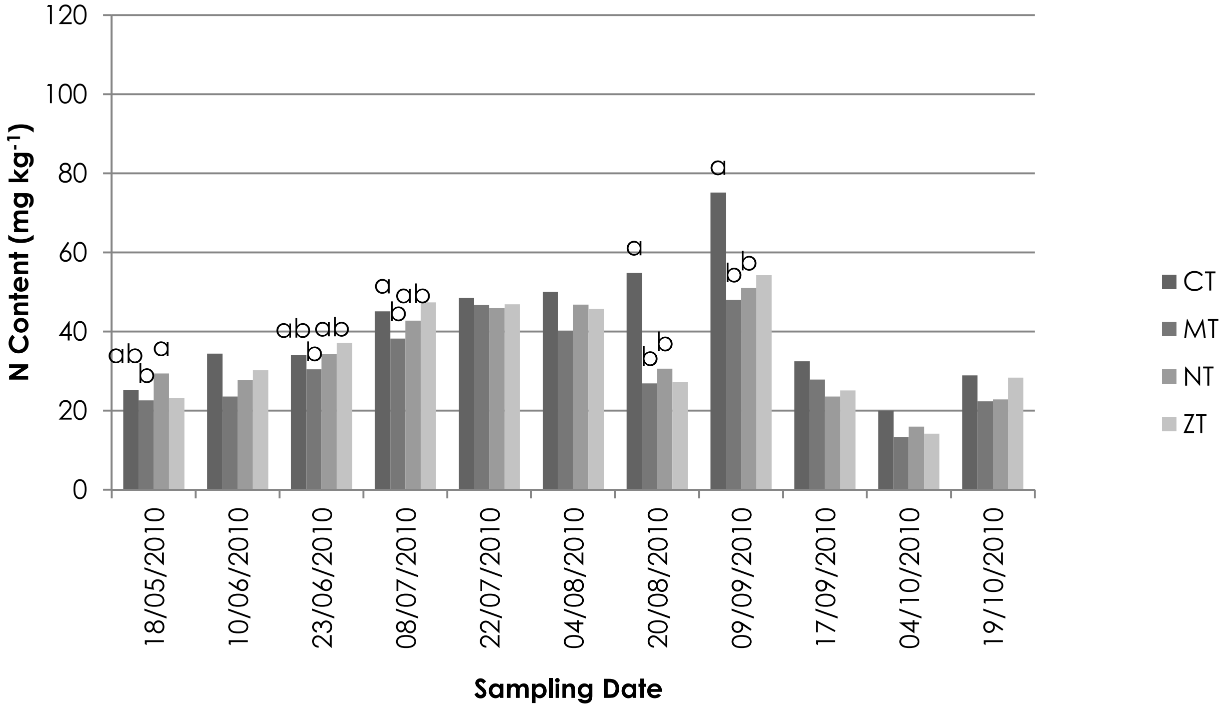

Figure 3.6: Soil mineral-N content (mg kg^{-1}) in the wheat monoculture (WWWW) system as influenced by conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) during the 2010 growing season at Langgewens Research Farm

Bars with the same letter at the same date are not significantly different at 0.05 probability level

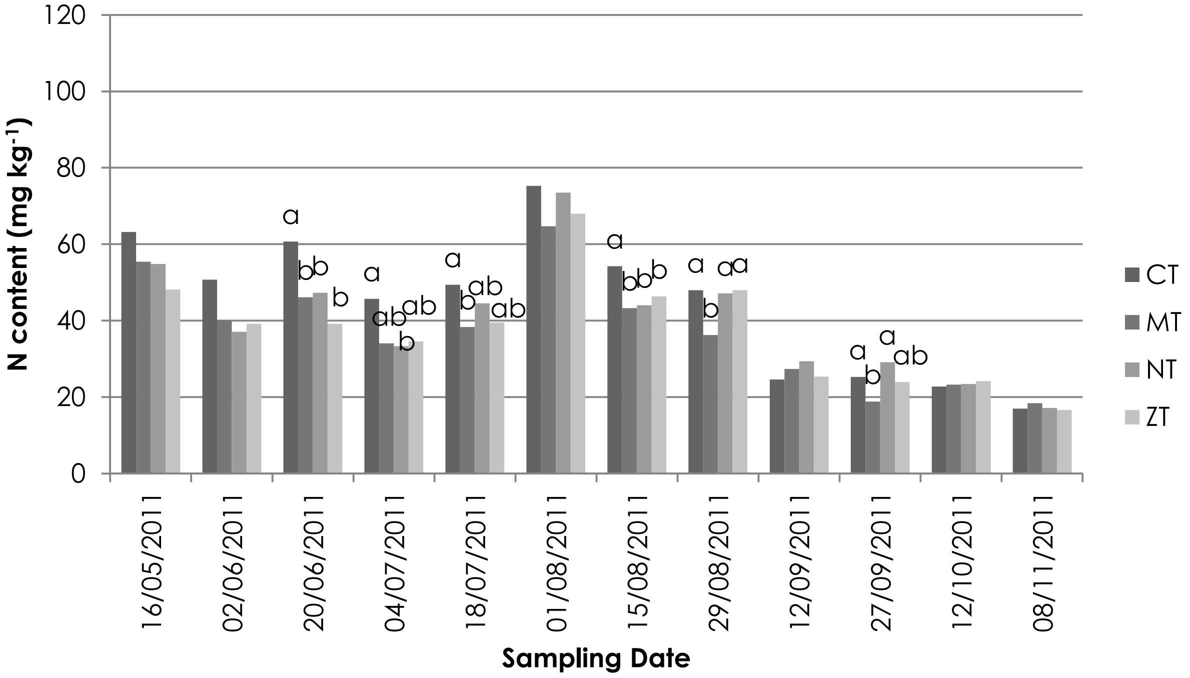

Figure 3.7: Soil mineral-N (mg kg^{-1}) content in the wheat monoculture (WWWW) system as influenced by conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) during the 2011 growing season at Langgewens Research Farm

Bars with the same letter at the same date are not significantly different at 0.05 probability level

The mineral-N content of the soil recorded during 2010 and 2011 in the LWCW system is shown in Figures 3.8 and 3.9. Except for an increase in soil mineral-N content in CT and MT on July 22nd 2010, results were similar to those in WWWW during 2010. This spike in mineral-N levels in CT and MT where wheat followed canola (LWCW), could be indicative of differences in decomposition patterns between wheat (WWWW) and canola residues. The only significant difference due to tillage practice in the LWCW system was recorded on October 4th 2010 when the mineral-N content in CT was higher compared to MT, NT and ZT. Mineral-N content did not differ between NT and MT in LWCW for 2010 and 2011.

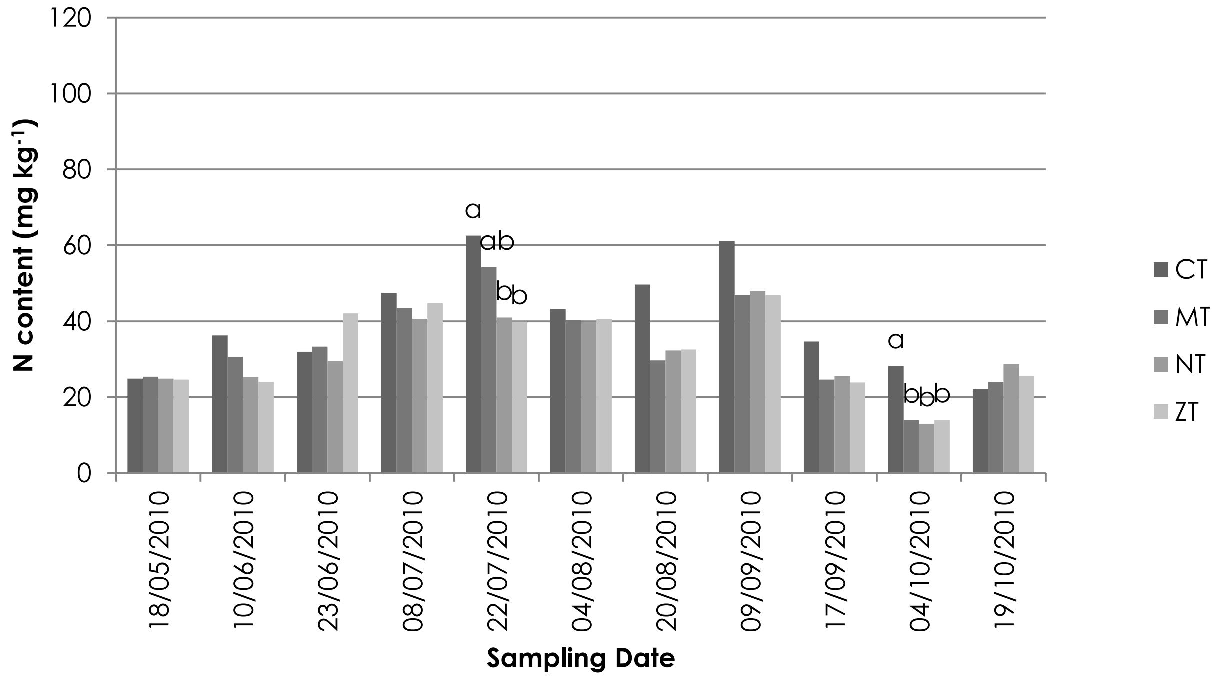

Figure 3.8: Soil mineral-N (mg kg^{-1}**) content in the lupin-wheat-canola-wheat (LWCW) rotation as influenced by conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) during the 2010 growing season at Langgewens Research Farm**

Bars with the same letter at the same date are not significantly different at 0.05 probability level

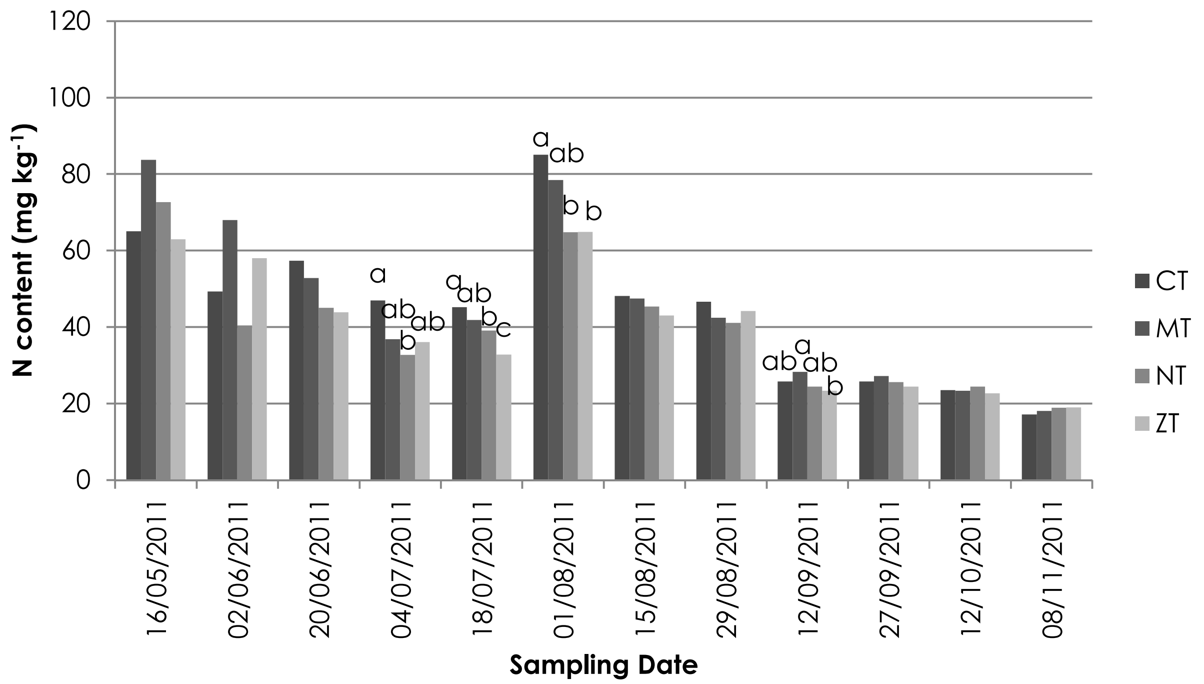

Figure 3.9: Soil mineral-N (mg kg^{-1}**) content in the lupin-wheat-canola-wheat (LWCW) rotation as influenced by conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) during the 2011 growing season at Langgewens Research Farm**

Bars with the same letter at the same date are not significantly different at 0.05 probability level

Figures 3.10 and 3.11 summarises the effect of tillage practice on mineral-N content in the McWMcW system during the 2010 and 2011 growing seasons.

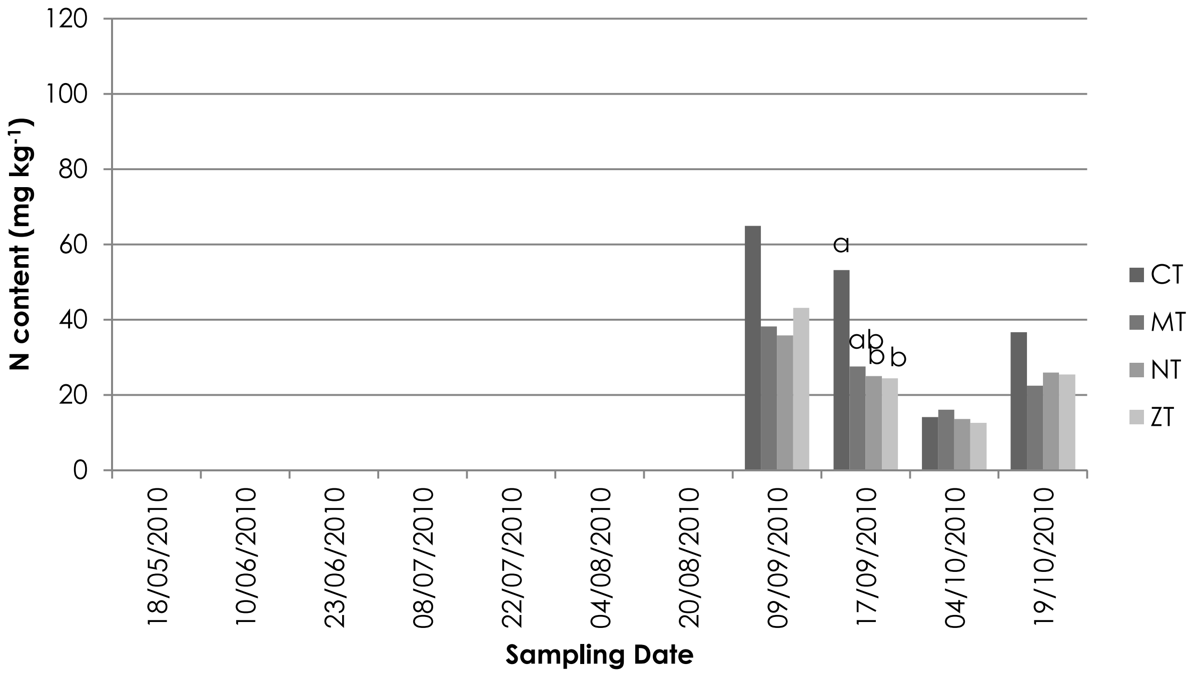

Figure 3.10: Soil mineral-N (mg kg^{-1}) content in the wheat after medics (McWMcW) rotation as influenced by conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) during the 2010 growing season at Langgewens Research Farm

Bars with the same letter at the same date are not significantly different at 0.05 probability level

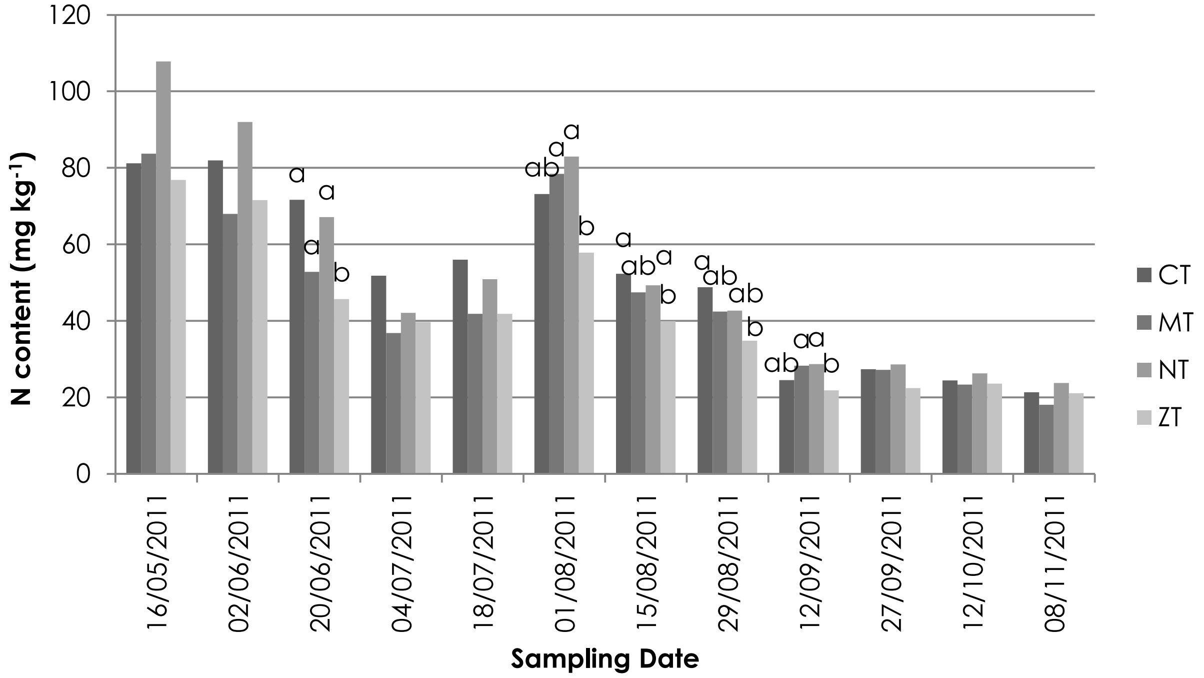

Figure 3.11: Soil mineral-N (mg kg^{-1}) content in the wheat after medics (McWMcW) rotation as influenced by conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) during the 2011 growing season at Langgewens Research Farm

Bars with the same letter at the same date are not significantly different at 0.05 probability level

The mineral-N content of the McWMcW system was generally higher during 2011 compared to the other two systems included in the study (Figure 3.11). This could partially be ascribed to the carry-over effect of nitrogen from the legume crop (medic/clover) to the following crop. Soon et al. (2001) found that nitrogen uptake by the subsequent wheat crop was greatest for field pea and red clover, both being legume crops.

The reason for the relatively high levels of mineral-N measured in the CT treatment could be the result of better conditions for nitrogen mineralisation as the soil was ploughed, a practice that increases initial drainage and aeration (Rice et al. 1987). When a soil is ploughed or tilled, and crop residues are mixed into the soil, the release of residue N tends to be faster than that of surface-placed residue (House et al. 1984, Varco et al. 1993). Some degree of nitrogen immobilisation in the conservation tillage treatments could also contribute to the initial lower mineral-N levels, as soil microbes use mineral-N to break down plant residues during the initial stages of decomposition (Soon et al. 2001). The fact that the increase in mineral-N content was caused by an increase in NO_3^--N (data not shown) serves as proof of higher nitrification rates in the CT treatments. The mineral-N content tended to be lower in the ZT treatment compared to the other tillage treatments tested. It could be ascribed partially to the high herbicide-resistant ryegrass infestation which increased mineral-N absorption.

3.4. Conclusion

The study has shown that differences in soil water and mineral-N content can mainly be ascribed to the effect of tillage. Although not always significant, the highest water content was recorded under conditions of NT and MT within the crop rotations studied. Crop rotations included in the study did not influence soil water content. The low soil water content recorded in the ZT was the result of high herbicide-resistant ryegrass infestation resulting in a much higher demand for water compared to NT, MT and CT.

Although the initial soil mineral-N content differed between growing seasons due to differences in rainfall, mineral-N showed a general decrease during the growing season in all crop rotation systems with surprisingly little difference between the WWWW system and systems with legumes included (LWCW and WMcWMc). The effect of increased soil disturbance, amongst others, increased aeration caused CT to contain higher mineral-N compared to ZT, NT and MT at some sampling dates. With the exception of three sampling dates during the duration of the study, mineral-N content of NT and MT did not differ significantly. It can therefore be concluded that crop rotation and tillage practice influenced soil water and mineral-N content. This data could be valuable in developing management strategies for wheat grown under different production systems.

3.5. References

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Chapter 4

4. The influence of crop rotation and soil tillage on the vegetative development of wheat under rain-fed conditions in the Swartland sub-region of the Western Cape

Abstract

Grain yield of crops is influenced by vegetative parameters such as leaf area development, photosynthetic activity of leaves and partitioning of dry matter. These factors may be affected by growth conditions as influenced by crop rotation and soil tillage.

Research was conducted as a component study within a long-term crop rotation and soil tillage trial to quantify the effect of three crop rotations, wheat monoculture (WWWW), lupin-wheat-canola-wheat (LWCW) and wheat-medic rotation (McWMcW) and four tillage treatments, namely: conventional- (CT), minimum– (MT), no- (NT) and zero-till (ZT) on vegetative development of wheat. High populations of herbicide-resistant ryegrass negatively influenced ZT during 2010 and 2011. Leaf development as measured by leaf area index (LAI) tended to increase as degree of soil disturbance increased in WWWW and LWCW. The light interception within treatment combinations tended to be higher in McWMcW and lower under CT mainly in WWWW and McWMcW. The chlorophyll content which may influence the photosynthetic activity did not differ between crop rotation systems for both years and the only difference due to tillage was a higher (P=0.05) chlorophyll content in CT compared to ZT in 2010. Differences in dry matter production were inconsistent although a weak trend of increased dry matter production as soil disturbance increased was shown. Total biomass production tended to be higher in McWMcW compared to LWCW and WWWW.

It is concluded that early season vegetative development tended to be enhanced with the inclusion of medics and also under conditions of intensive soil disturbance (CT). However, total biomass production tended to increase in systems where NT was used in rotations that include medic pastures.

Keywords: biomass production, chlorophyll, crop rotation, leaf area index, light interception, soil tillage

4.1. Introduction

Wheat production under rain-fed conditions in the Swartland sub-region of the Western Cape is largely influenced by plant available soil water (Agenbag and Maree 1991). The relatively low soil water storage capacity and erratic seasonal rainfall can cause variation in wheat grain yield and quality. Management practices such as fertilisation, tillage, crop rotation and residue cover could modify the soil/root environment and thereby influence crop productivity (Wilhelm and Mielke 1988, López-Bellido et al. 1996).

Leaf area index (LAI) has been shown to be a good indicator of differences in growth conditions and may be used to determine yield potential during the vegetative growth stages (Agenbag and Maree 1991). Leaf area index will also affect light penetration within the crop canopy and may, together with measurements of the chlorophyll content of leaves, be used as an indication of the photosynthetic potential during different growth stages. The chlorophyll concentration in the uppermost leaves (flag leaves) of the wheat plant is also believed to be directly affected by the nitrogen status of the wheat plant (Olesen et al. 2003, Ziadi et al. 2010). Sufficient amounts of nitrogen available for translocation from plant tissue (leaves and stems) to the grain kernel are important to ensure high grain yield of good quality. For this reason the chlorophyll content of the flag leaf at anthesis can be related to potential grain protein content as a result of translocation of tissue N to the filling kernels harvested (López-Bellido et al. 2004). These authors also found that chlorophyll content (Soil plant analysis development – SPAD - values) of the flag leaf at anthesis was significantly correlated with shoot-, leaf- and grain protein content. Increases in leaf N concentration may also result in crops less susceptible to disease infections and can therefore be used as a decision support system for fungicide application (Olesen et al. 2003). Production of biomass is the result of photosynthetic capacity and efficiency of crops. Grain yield is the result of very complex plant processes and total dry matter produced often gives a good indication of growth conditions during the crop cycle (Watson 1968). Production of more dry matter ensures better competitiveness against weeds (Balyan et al. 1991), however proliferous vegetative growth may enhance diseases because of a favourable microclimate (Olesen et al. 2003). Borghi (1999) showed that increases in dry mass was associated with larger leaves that stayed green for longer, taller stems and larger numbers of ear bearing tillers per unit area.

Degree of soil disturbance (caused by tillage) and rooting patterns of crops will influence a range of soil physical (Martinez et al. 2008), chemical (Chan et al. 1992) and biological characteristics (TebruÈgge et al. 1991). Degree of soil disturbance will influence soil structure and organic matter/carbon content and subsequently plant available soil water, a principle factor that influences crop productivity (biomass production)(Garabet et al. 1998). Nitrogen supply to crops is also affected by factors such as soil type, soil tillage and crop rotation (López-Bellido and López-Bellido, 2001).

Nitrogen uptake is a function of development stage of the wheat crop (Van Biljon 1987) and can vary considerably between different stages. Nitrogen N uptake also depends on soil mineral-N availability and root distribution (Gastal and Lemaire 2002). The nitrogen index of a crop is a plant-based diagnostic method for characterising the N status of a crop throughout the growing season by measuring the chlorophyll content in the uppermost leaves of the crop, from which the crop N status can be determined (Lemaire and Gastal 1997, Ziadi et al. 2010).

Because crop rotation systems and tillage practices affect soil conditions which may influence LAI, chlorophyll content and total dry matter, this study was done to develop a better understanding of the effect of different crop rotation systems and tillage practices on the physiological parameters which can serve as important management tools to ensure high yield of acceptable quality.

4.2. Material and methods

This study was conducted on the Langgewens Research Farm (-33.27665°; 18.70463°; altitude 191 m), in the Western Cape Province of South Africa. The study was done during the 2010 and 2011 growing seasons as a component study, within a long-term crop rotation and soil tillage research programme initiated in 2007. Detailed discussions of the soil at the experimental site as well as climatic conditions during 2010 and 2011 were done in Chapter 2. In summary it can be said that above-average rainfall was recorded during May 2010 and 2011 as well as June 2011, while below-average rainfall was recorded during July, August and September as well as October 2011 (Figure 4.1).

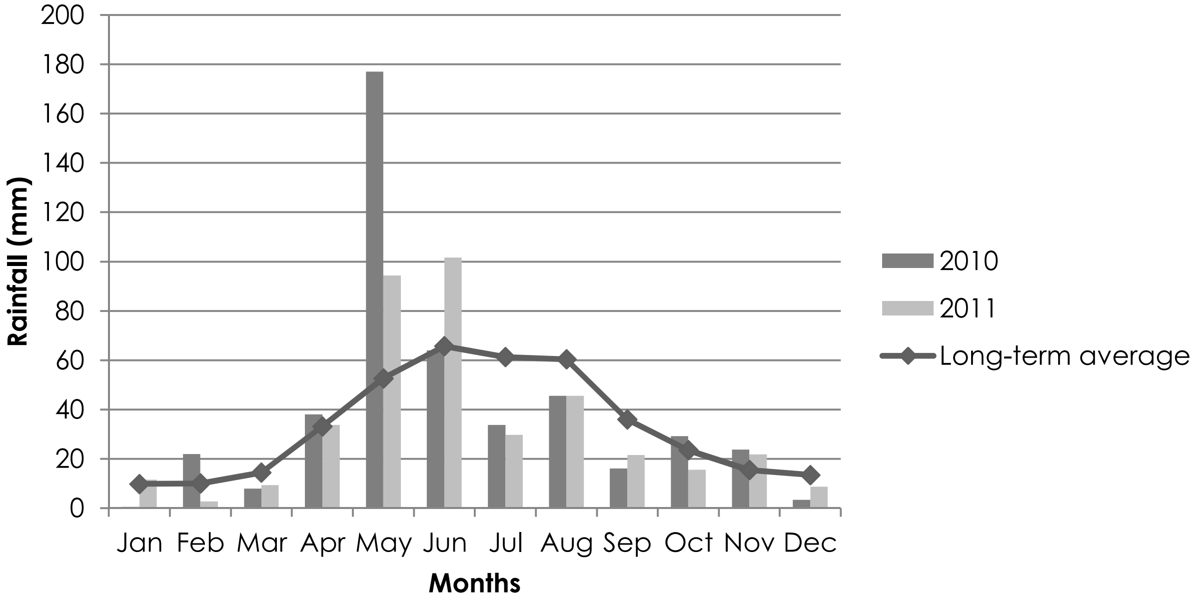

Figure 4.1: The long-term average rainfall compared to the 2010 and 2011 seasons' rainfall at the Langgewens Research Farm (Data from the ARC-ISCW)

The experimental layout was a randomised complete block design with a split-plot treatment design replicated four times (Snedecor and Cochran 1967). The effect of three crop rotation systems, namely: wheat monoculture (WWWW), lupin-wheat-canola-wheat (LWCW) and wheat-medic-wheat-medic (McWMcW) in combination with four tillage treatments, conventional- , minimum- , no- and zero-till (see Chapter 2 for detail on tillage treatments and other agronomic practices) on biomass production, leaf area-index (LAI), light interception and chlorophyll content of the wheat during the wheat phase, were studied.

Leaf area (cm^2) was determined by sampling 20 green plants per treatment combination. Sampling commenced four weeks after emergence and thereafter at about 28 day intervals until the end of the growing season. After leaves were separated from the stems, the leaf area was determined using a Li-Cor, LI-3100 Area Meter. Leaf area index (LAI) was calculated using the formula: LAI = (Mean leaf area measured for an individual plant in cm^2)*(plants m^{-2})/10000 cm^2.

A portable Opti-Sciences CCM 200 chlorophyll meter was used to record the chlorophyll content of the flag leaf at anthesis. Five readings per treatment combination were logged and the mean value noted. Readings were taken one third of the leaf's length from the stem.

Light interception by the plant canopy was measured using an AccuPAR LP-80 PAR/LAI ceptometer. The light intensity was measured in sets, five readings directly above the wheat canopy accompanied by five readings at ground level below the canopy at anthesis during 2010 and 2011. From these two readings the percentage of light intercepted was calculated as follows: (Intensity reading above the canopy - intensity reading at ground level)/(intensity reading above the canopy)*100.

The same plant material used to determine leaf area was used to determine biomass production. After the roots were removed, the stems and leaves were oven-dried at 60 °C for at least 72 hours and biomass calculated as follows:

Biomass m^{-2} = plants m^{-2} *mass of 20 plants/20

Total biomass production was determined by sampling the week before the anticipated harvesting date.

4.3. Result and discussion

4.3.1. Leaf Area Index (LAI)

Leaf area index (LAI) is one of the critical factors determining light interception and as a result also crop yield (Milthorpe and Moorby 1974). Higher LAI values are an indication of increased leaf surface area available for photosynthesis and a product of plant density and plant size (Agenbag and Maree 1991). An increase in leaf area can however increase water loss through transpiration and subsequently result in water stress during anthesis and grain filling during relatively dry years. Hulugalle et al. (2006) found that wheat in rotation with cotton resulted in higher leaf area index (LAI) and higher transpiration loss compared to monoculture.

Figures 4.2 and 4.3 summarise the effect of tillage on the leaf area index (LAI) during the 2010 and 2011 seasons in the WWWW crop rotation system.

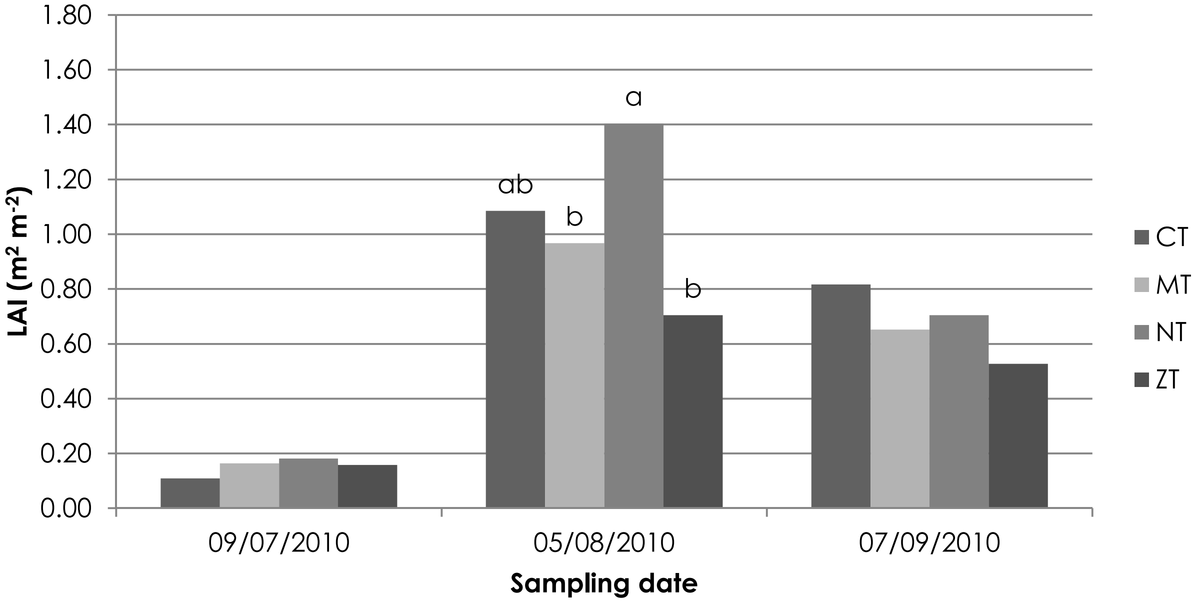

Figure 4.2: Leaf Area Index (LAI) in the wheat monoculture (WWWW) as influenced by conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) at the Langgewens Research Farm during the 2010 growing season

Bars with the same letter at the same date are not significantly different at 0.05 probability level

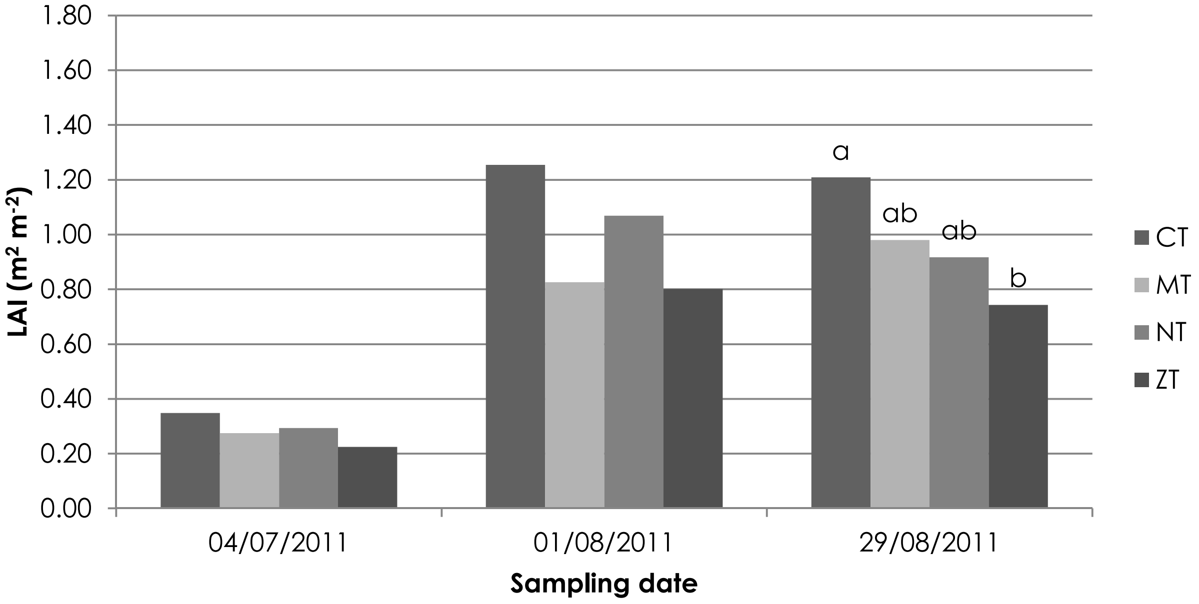

Figure 4.3: Leaf Area Index (LAI) in the wheat monoculture (WWWW) as influenced by conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) at the Langgewens Research Farm during the 2011 growing season

Bars with the same letter at the same date are not significantly different at 0.05 probability level

The LAI increased during the period between the first sampling date in July and the second sampling date in August in both years, whereafter it decreased during 2010 or stayed more or less the same in 2011. Except for August 5th 2010 and August 29th 2011, no significant differences due to tillage practice were shown in the WWWW system. In 2010 no differences were shown between CT, MT and NT, while no differences were shown between CT and NT in 2011. In both years lowest LAI was recorded under ZT. This could have been ascribed to LAI being calculated from individual plants and the poor growth of wheat plants in the ZT due to the competition effect from the severe ryegrass infestations.

The LAI for LWCW during the 2010 and 2011 growing seasons are summarised in Figures 4.4 and 4.5.

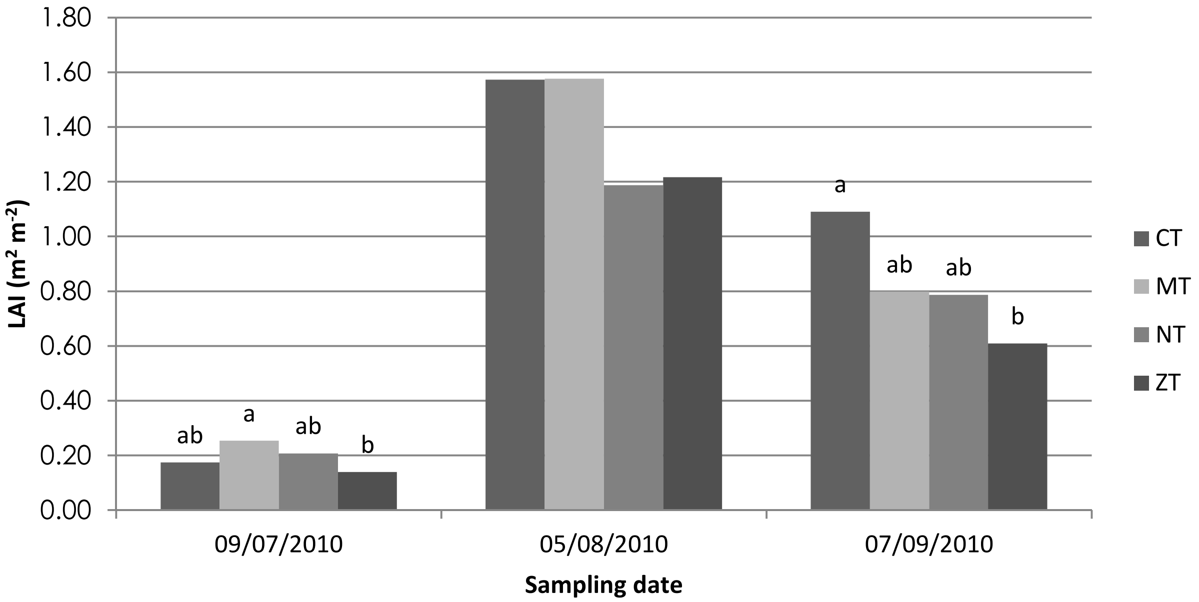

Figure 4.4: Leaf Area Index (LAI) in the lupin-wheat-canola-wheat (LWCW) rotation as influenced by conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) during the 2010 growing season at Langgewens Research Farm

Bars with the same letter at the same date are not significantly different at 0.05 probability level

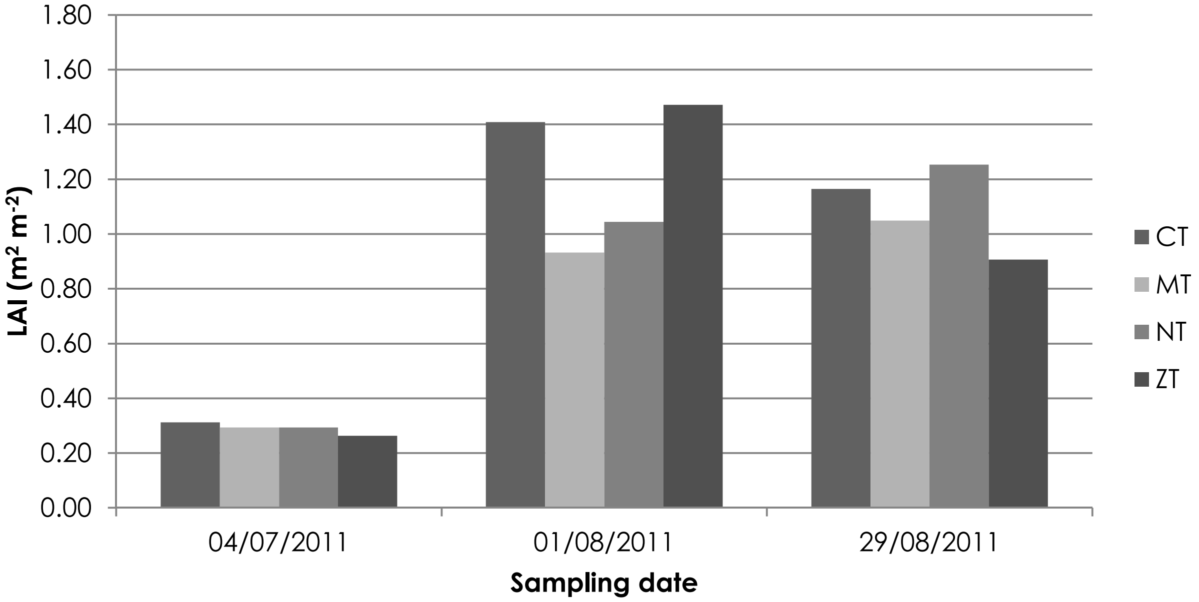

Figure 4.5: Leaf Area Index (LAI) in the lupin-wheat-canola-wheat (LWCW) rotation as influenced by conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) during the 2011 growing season at Langgewens Research Farm

Tillage did not influence LAI significantly (P=0.05) on August 8th 2010 and at all sampling dates in 2011 in the LWCW system. During the first sampling (09/07) and last sampling (07/09) in 2010, no significant differences were recorded for CT, MT and NT. Similarly to WWWW ZT recorded the lowest LAI, most likely due to the allelopathic effect ryegrass had on surrounding crops (personal communication: Mike Ferreira, Western Cape Department of Agriculture, Elsenburg). Wilhelm (1998) also found no differences in leaf area due to conventional-, sub- and no-till treatments. Agenbag and Maree (1991) found LAI to be higher for NT compared to CT and tine tillage at the end of a six year trial period, but higher values for CT during the initial years.

During 2010, a higher LAI was recorded with WWWW at the first sampling date (09/07/2010) compared to LWCW, but the opposite was true for the second sampling date (05/08/2010) and no differences were recorded at the third sampling date (07/09/2010) according to Table 4.1.

Table 4.1: The mean Leaf Area Index (m m^{-2}) for the two cropping systems, wheat monoculture (WWWW) and lupin-wheat-canola-wheat (LWCW) during the 2010 growing season at Langgewens

	Crop Rotation	
Sampling Date	**WWWW**	**LWCW**
09/07/2010	0.194 a	0.153 b
05/08/2010	1.062 b	1.388 a
07/09/2010	0.685 a	0.821 a

Values followed by the same letter at the same date are not significantly different at 0.05 probability level

Leaf area index in the McWMcW crop rotation system was not calculated during the 2010 season because of the late inclusion of this system in the study. During 2011, tillage treatments did not have any significant effect on LAI in the McWMcW system (Figure 4.6), but in contrast to WWWW and LWCW, LAI tended to be lower with CT compared to the other tillage treatments during samplings at the 1st and 29th of August 2011. The reason for the lower LAI in the CT cannot be explained at this stage.

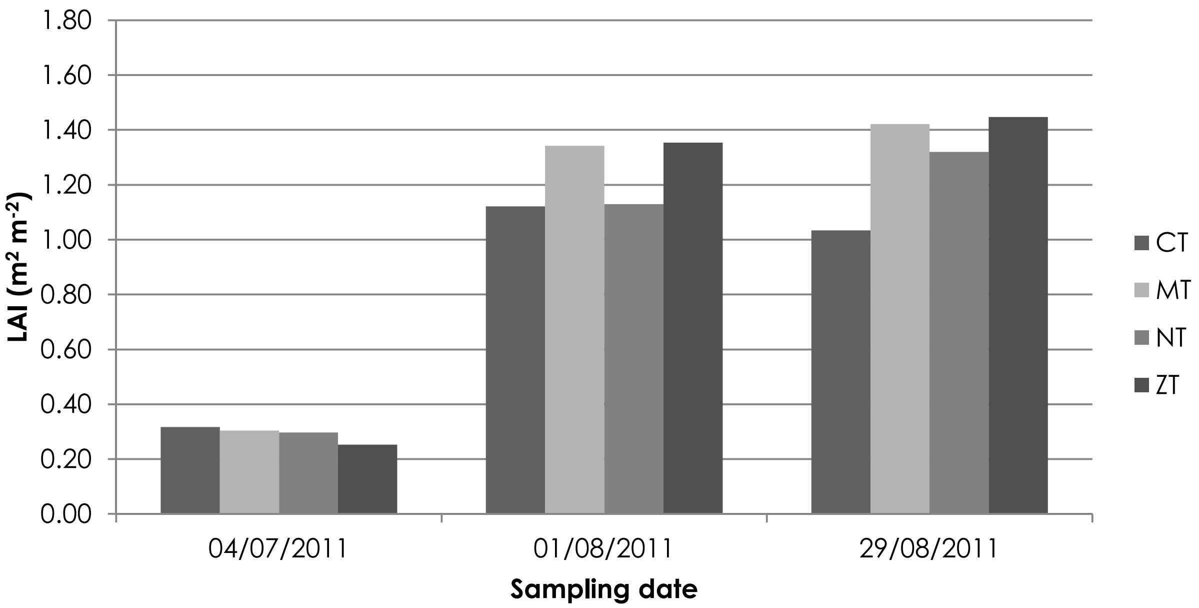

Figure 4.6: Leaf Area Index (LAI) in the wheat after medics (McWMcW) rotation as influenced by conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) during the 2011 growing season at Langgewens Research Farm

During 2011 no significant differences due to the crop rotation system were recorded at the first (04/07/2011) and second (01/08/2011) sampling dates, but at the third sampling date (29/08/2011) a significant higher LAI was recorded for McWMcW compared to WWWW (Table 4.2).

Table 4.2: The mean Leaf Area Index (m m^{-2}) for the three crop rotation systems (wheat monoculture (WWWW), lupin-wheat-canola-wheat (LWCW), wheat after medics (McWMcW) during the 2011 growing season at Langgewens

	Crop Rotation		
Sampling date	**WWWW**	**McWMcW**	**LWCW**
04/07/2011	0.285 a	0.292 a	0.291 a
01/08/2011	0.988 a	1.237 a	1.214 a
29/08/2011	0.962 b	1.305 a	1.093 ab

Values followed by the same letter at the same date are not significantly different at 0.05 probability level

The LAI recorded for LWCW (1.093) however, did not differ from the other two systems tested. The 2011 results supported those recorded during 2010, suggesting that crop rotation systems that include legume crops resulted in higher LAI values.

4.3.2. Percentage Light Interception

Leaf area development is a critical factor determining light interception and as a result photosynthetic potential and crop yield (Milthorpe and Moorby 1974). Light interception within a crop canopy also reflects crop growth (Olesen et al. 2003). The percentage values reported in Tables 4.3 and 4.4 summarise the percentage of light intercepted by the crop canopy at anthesis for the 2010 and 2011 growing seasons. Higher interception values represent denser crop canopies and therefore higher potential active photosynthetic areas.

Table 4.3: Percentage Light Interception (%) at anthesis as influenced by wheat monoculture (WWWW), wheat after canola in a lupin-wheat-canola-wheat rotation (LWCW) and wheat after medics in rotation (McWMcW) and tillage namely: conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) for the 2010 growing season at Langgewens Research Farm

Tillage practice	Cropping rotation			Mean (Tillage)
	WWWW	**McWMcW**	**LWCW**	
Conventional-till (CT)	72.5	79.6	86.6	**79.6 b**
Minimum-till (MT)	89.1	89.1	92.0	**90.1 a**
No-till (NT)	81.7	89.3	90.1	**87.0 a**
Zero-till (ZT)	87.1	91.3	91.3	**89.9 a**
Mean (System)	**82.6**	**87.3**	**90.0**	

Values followed by the same letter in columns are not significantly different at 0.05 probability level

Crop rotation did not influence light interception in 2010. CT resulted in significantly lower light interception compared to MT, NT and ZT.

Table 4.4 summarises the results for the percentage light intercepted in experimental plots at anthesis for the 2011 growing season.

Table 4.4: Percentage Light Interception (%) at anthesis as influenced by wheat monoculture (WWWW), wheat after canola in a lupin-wheat-canola-wheat rotation (LWCW) and wheat after medics in rotation (McWMcW) and tillage namely: conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) for the 2011 growing season at Langgewens Research Farm

Tillage practice	Cropping rotation			Mean (Tillage)
	WWWW	McWMcW	LWCW	
Conventional-till (CT)	88.9	93.3	89.4	**90.4 b**
Minimum-till (MT)	87.6	90.8	85.5	**88.0 c**
No-till (NT)	85.2	91.0	87.4	**87.9 c**
Zero-till (ZT)	92.0	94.2	92.5	**92.9 a**
Mean (System)	**88.4 b**	**92.3 a**	**88.7 b**	

Values followed by the same letter in rows and columns are not significantly different at 0.05 probability level

Crop rotation influenced canopy density in 2011 with McWMcW developing significantly denser canopies compared to WWWW and LWCW. Mean canopy density in ZT was higher (P=0.05) compared to the other tillage treatments tested. The lowest canopy densities were recorded in MT and NT. A tendency observed for the 2011 growing season was a denser canopy for wheat that followed medics. A dense canopy will also increase the competitive ability of the wheat crop to suppress weeds (Korres and Froud-Williams 2002). The difference in canopy density might also influence the canopy micro-climate and therefore crop protection management strategies. Oleson et al. (2003) reported a positive correlation between the severity of crop disease and canopy density. Thus the measurement of the leaf canopy could be a good indication of general susceptibility to disease.

The mean percentage of light intercepted for the cropping systems differed from the mean for the LAI under the same crop rotation systems. This could be ascribed to the fact that LAI was determined for individual plants, whilst the light interception was influenced by canopy density and thus a better indicator of biomass production. Therefore the LAI is an indication that individual plants performed better in this particular case.

4.3.3. Flag Leaf Chlorophyll Content

The chlorophyll content of the flag leaf at anthesis is a reliable indicator of the nitrogen status of the plant/crop (Ziadi et al. 2010) and can be related to potential grain protein content as a result of translocation of tissue N to the kernels (grains) during the grain filling stages (López-Bellido et al. 2004).

Ziadi et al. (2010) found that high levels of plant available soil N increased the chlorophyll content of the uppermost leaf of the wheat plant during different growth stages. They also reported that leaf chlorophyll content increased as N application rates were increased. Spaner et al. (2005) also reported that the chlorophyll content of the uppermost collared leaf increased with increasing N fertiliser application rates while López-Bellido et al. (2004) reported an increase in chlorophyll content from 33.5 SPAD (Soil plant analysis development - values) for 0 kg of N applied, to values reaching a plateau of 50 SPAD at fertiliser rates of 250 kg N ha^{-1}. Table 4.5 and 4.6 summarises the effect of treatment combinations on the chlorophyll content of the flag leaves during the 2010 and 2011 growing season at anthesis.

Table 4.5: Chlorophyll content (Soil plant analysis development – SPAD - values) of the flag leaf of wheat plants at anthesis as influenced by wheat monoculture (WWWW) and wheat after canola in a lupin-wheat-canola-wheat rotation (LWCW) and tillage namely: conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) for the 2010 growing season at Langgewens Research Farm

Tillage practice	Crop Rotation		Mean (Tillage)
	WWWW	LWCW	
Conventional-till (CT)	51.05	49.65	**50.35 a**
Minimum-till (MT)	47.95	49.95	**48.95 ab**
No-till (NT)	47.25	48.78	**48.01 ab**
Zero-till (ZT)	46.38	46.88	**46.63 b**
Mean (System)	**48.16**	**48.81**	

Values followed by the same letter in columns are not significantly different at 0.05 probability level

Mean chlorophyll content was not influenced by crop rotation system during 2010. Tillage treatments resulted in significant differences (P=0.05) in mean chlorophyll content with higher values with CT compared to ZT. Within individual crop rotation system and on average chlorophyll content increased as soil disturbance increased from ZT to CT. Prior to the measuring date of the chlorophyll content (06/09/10), the mineral-N content in the soil (Chapter 3, Figure 3.6 and 3.8) was shown to be higher in the CT plots compared to other tillage systems in both the WWWW and the LWCW. The significant lower chlorophyll content recorded with ZT may again be ascribed to the herbicide-resistant ryegrass infestations which competed with the wheat crops with regards to resources such as fertiliser and water.

Table 4.6: Chlorophyll content (Soil plant analysis development – SPAD - values) of the flag leaf of wheat plants at anthesis as influenced by wheat monoculture (WWWW), wheat after canola in a lupin-wheat-canola-wheat rotation (LWCW) and wheat after medics in rotation (McWMcW) and tillage namely: conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) for the 2011 growing season at Langgewens Research Farm

Tillage practice	Crop Rotation			Mean (Tillage)
	WWWW	McWMcW	LWCW	
Conventional-till (CT)	47.95	51.78	46.48	**48.73**
Minimum-till (MT)	47.30	50.38	51.03	**49.57**
No-till (NT)	47.08	50.08	50.93	**49.36**
Zero-till (ZT)	47.83	46.98	47.03	**47.28**
Mean (System)	**47.54**	**49.80**	**48.86**	

No significant differences due to crop rotation system or tillage practice were recorded for the 2011 growing season (Table 4.6). As in 2010, a tendency of increased chlorophyll content with increased soil disturbance was noted in 2011, but in contrast to 2010 differences were not significant. According to Follett et al. (1992) chlorophyll readings can be expected to increase as soil N availability increases. Spaner et al. (2005) found that chlorophyll meter readings were influenced by soil moisture availability and tillage practices. The above results supported these findings, as a trend started to develop with CT, MT and NT being the highest in McWMcW and also for MT and NT in the LWCW crop rotation for both seasons. These treatments also tended to result in higher soil moisture contents (Chapter 3, Figure 3.4 and 3.5).

4.3.4. Biomass production

Crop rotation system and tillage practice may have an effect on soil properties (root environment) and as a result also on the growth and development of the wheat crop (Martinez et al. 2008). Grain yield is the product of biomass at maturity and the proportion of biomass that is partitioned to the grain. The effect of tillage has been seen on biomass production and the following yield (Kumudini et al. 2008), therefore difference in biomass could be a possible indicator of yield.

Figures 4.7 to 4.11 summarise the influence of crop rotation and tillage on biomass production m^{-2} during the 2010 and 2011 growing seasons.

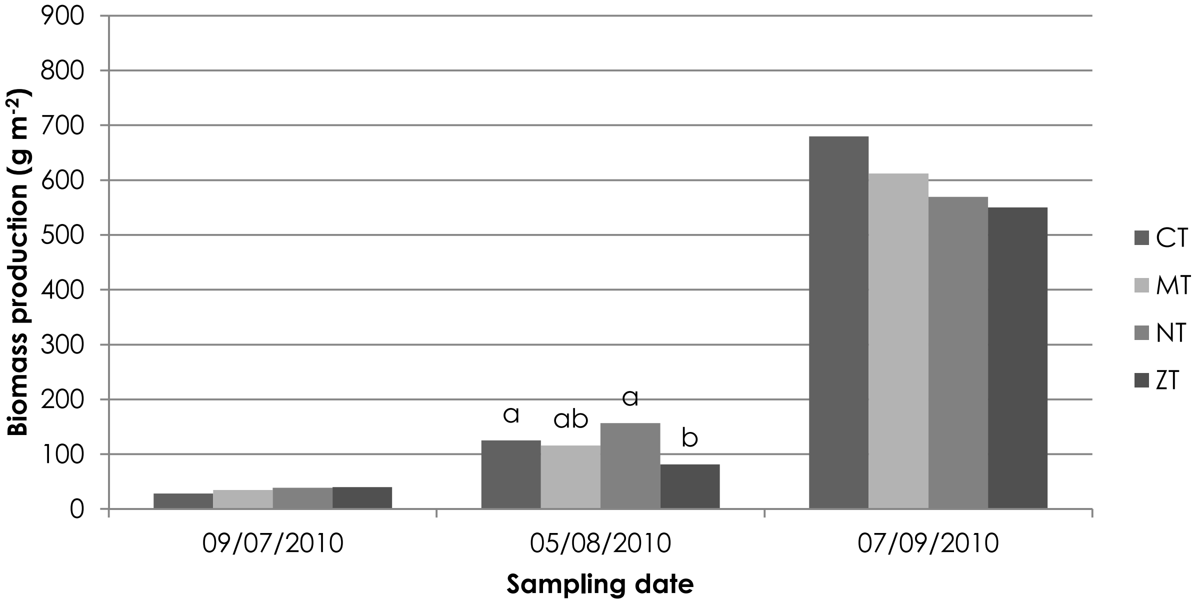

Figure 4.7: Biomass production (g m^{-2}) in the wheat monoculture (WWWW) as influenced by conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) at the Langgewens Research Farm during the 2010 growing season

Bars with the same letter at the same date are not significantly different at 0.05 probability level

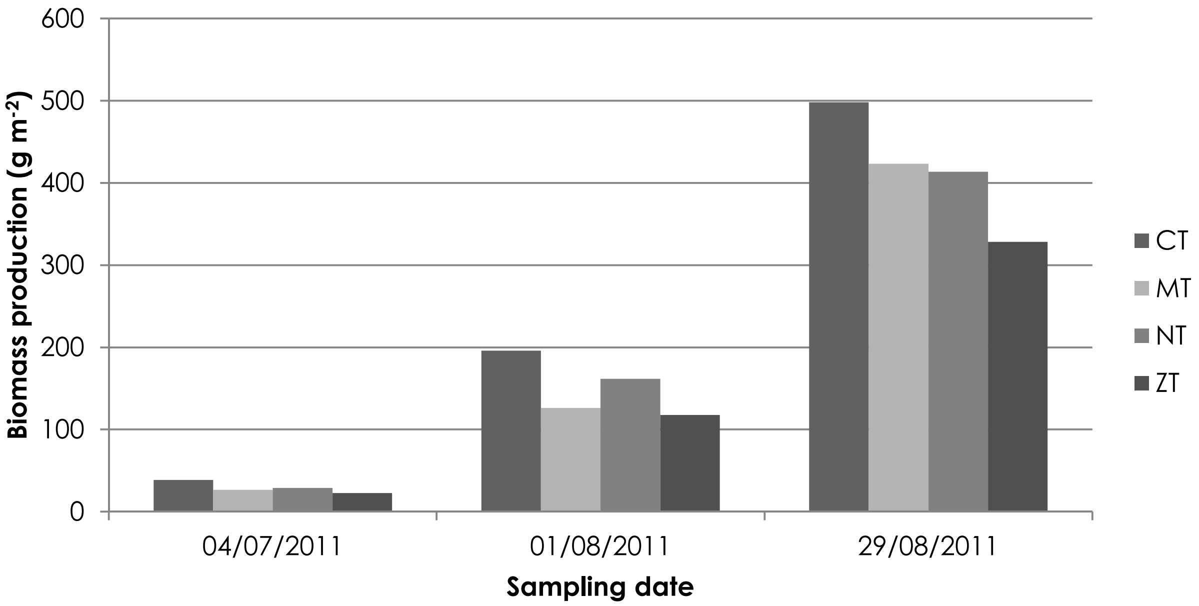

Figure 4.8: Biomass production (g m^{-2}) in the wheat monoculture (WWWW) as influenced by conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) at the Langgewens Research Farm during the 2011 growing season

The only difference due to tillage practice recorded in the WWWW system during 2010 and 2011 was lower biomass production in ZT compared to CT and NT on 5/8/2010 (Figures

4.7 and 4.8). The third sampling date for both years covered by the study showed a tendency of a reduction in biomass production in the WWWW system as degree of soil disturbance decreased, most probably due to the tendency of higher mineral-N content observed under CT and progressively lower mineral-N content as the degree of soil disturbance decreased (Chapter 3, Figure 3.6). These results supported earlier studies (Rieger et al. 2008) which also showed higher rates of biomass production in CT, compared to MT and especially NT, but in contrast, Wilhelm (1998) found no differences in biomass production of wheat due to tillage practice.

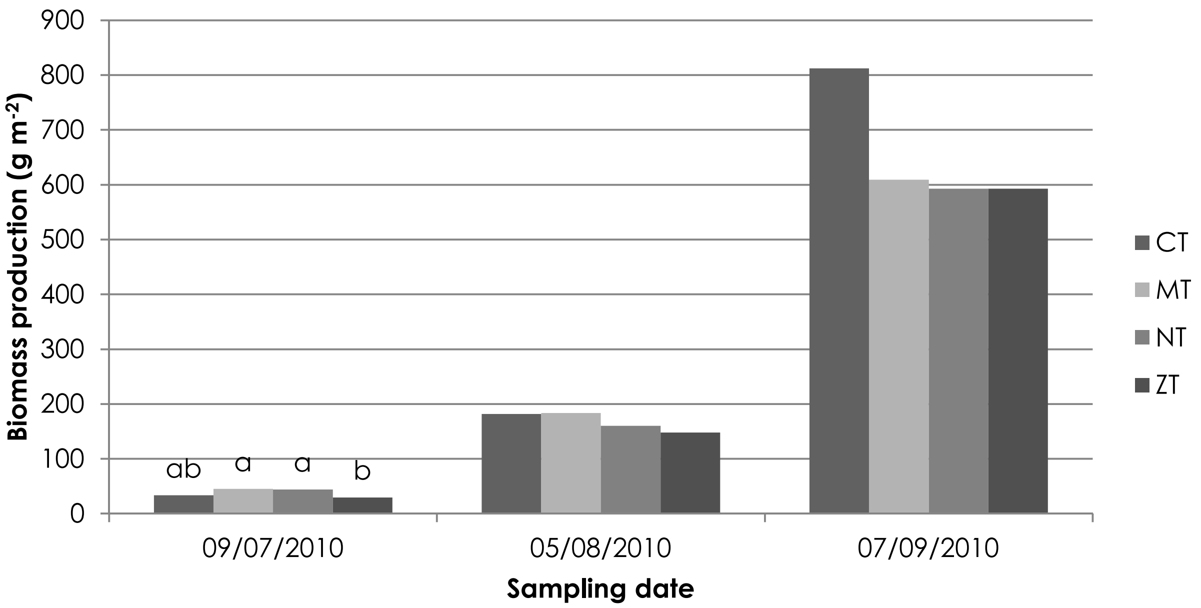

Figure 4.9: Biomass production (g m^{-2}) in the lupin-wheat-canola-wheat (LWCW) rotation as influenced by conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) during the 2010 growing season at Langgewens Research Farm

Bars with the same letter at the same date are not significantly different at 0.05 probability level

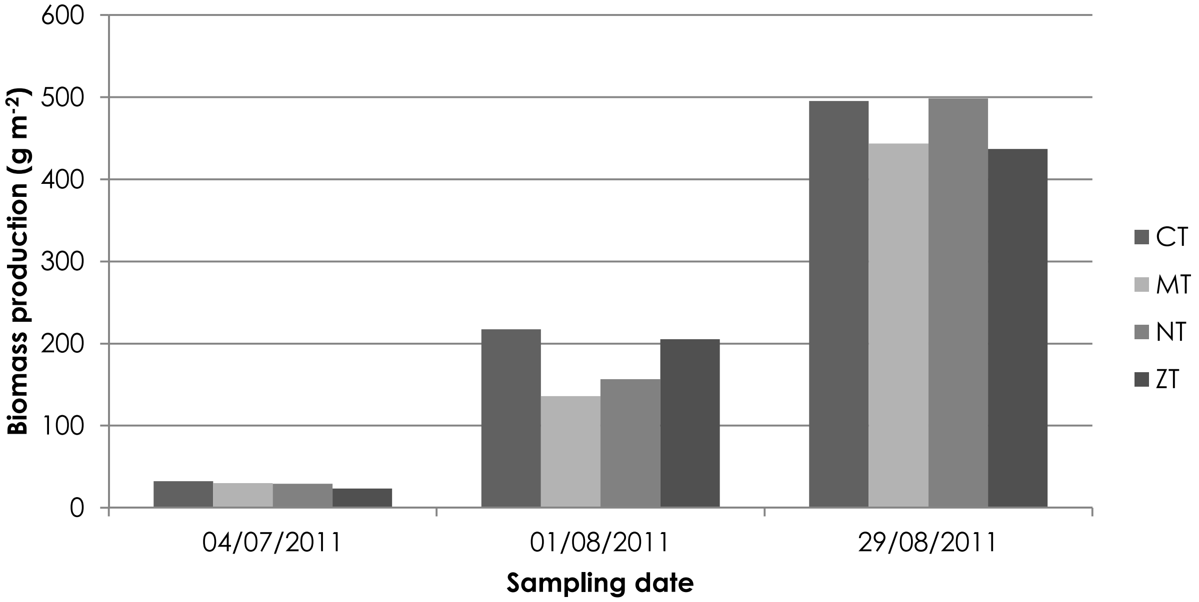

Figure 4.10: Biomass production (g m^{-2}) in the lupin-wheat-canola-wheat (LWCW) rotation as influenced by conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) during the 2011 growing season at Langgewens Research Farm

Although MT and NT showed a significant higher biomass compared to ZT during the first sampling in 2010 (Figure 4.9), no tendency was identified regarding the effect of tillage on biomass production in LWCW during 2010 and 2011.

These results are in contrast with those of Hemmat and Eskandari (2006) who found that NT produced more biomass per unit area than CT in drier years and ascribed it to higher water availability under NT. For years with above average precipitation they found the opposite to be the result with CT yielding more biomass than NT. This again is in accordance with results obtained by Rieger et al. (2008) who also found an increase in biomass production as degree of soil disturbance increased.

Table 4.7: The mean biomass production (g m^{-2}) for the two cropping systems, wheat monoculture (WWWW) and lupin-wheat-canola-wheat (LWCW) during the 2010 growing season at Langgewens

	Crop Rotation	
Sampling Date	**WWWW**	**LWCW**
09/07/2010	35.12 a	38.06 a
05/08/2010	122.45 b	168.44 a
07/09/2010	606.26 a	651.59 a

Values followed by the same letter at the same date are not significantly different at 0.05 probability level

With the exception of a lower biomass in the WWWW crop system at the 05/08/2010 sampling date, no differences in biomass due to the crop rotation system was recorded in 2010 (Table 4.7). Although not significant at other sampling dates a higher biomass was recorded in LWCW compared to WWWW at all sampling dates, suggesting a higher potential for wheat in crop rotation systems compared to monoculture.

Tillage treatments did not influence biomass production in McWMcW during 2011 (Figure 4.11).

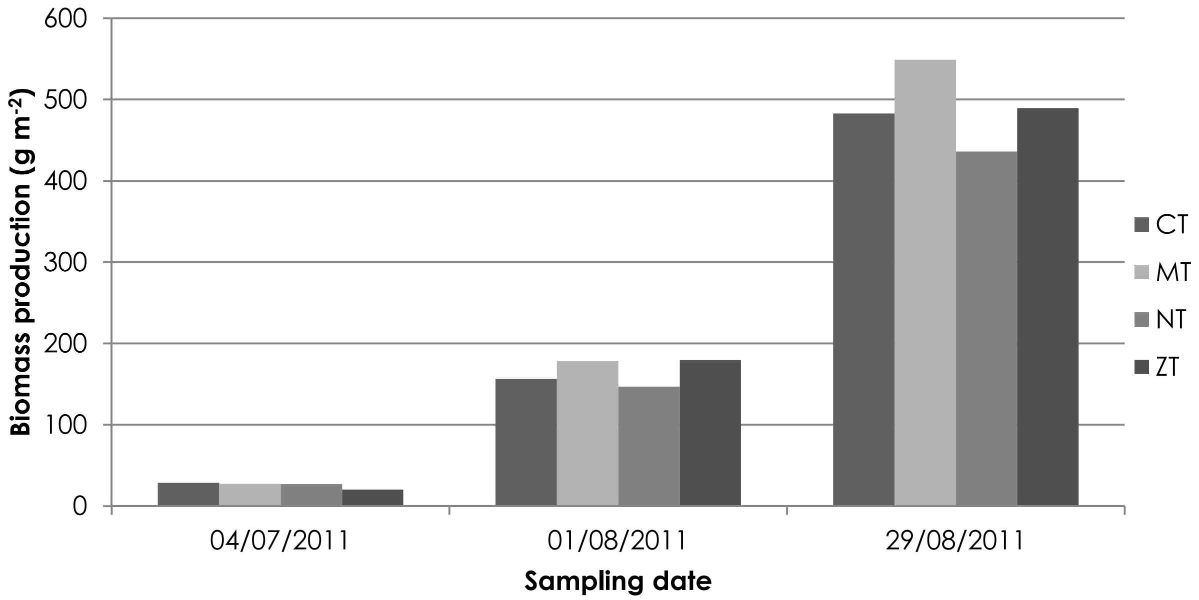

Figure 4.11: Biomass production (g m^{-2}) in the wheat after medics (McWMcW) rotation as influenced by conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) during the 2011 growing season at Langgewens Research Farm

No differences in mean dry matter production were recorded between crop rotation systems during 2011 (Table 4.8).

Table 4.8: The mean biomass production (g m^{-2}) for the three crop rotation systems (wheat monoculture (WWWW), lupin-wheat-canola-wheat (LWCW), wheat after medics (McWMcW) during the 2011 growing season at Langgewens

	Crop Rotation		
Sampling date	**WWWW**	**McWMcW**	**LWCW**
04/07/2011	29.14	25.84	28.96
01/08/2011	150.36	165.34	178.76
29/08/2011	415.67	489.44	468.34

Total biomass production (kg ha^{-1}) as influenced by crop rotation system and tillage practice for the 2010 and 2011 growing seasons is summarised in Tables 4.9 and 4.10.

Table 4.3: Total biomass production (kg ha^{-1}) as influenced by wheat monoculture (WWWW), wheat after canola in a lupin-wheat-canola-wheat rotation (LWCW) and wheat after medics in rotation (McWMcW) and tillage namely: conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) for the 2010 growing season at Langgewens Research Farm

Tillage practice	Crop Rotation			Mean (Tillage)
	WWWW	McWMcW	LWCW	
Conventional-till (CT)	8033	7650	7217	**7633 a**
Minimum-till (MT)	6917	8167	8217	**7767 a**
No-till (NT)	7134	8883	7984	**8000 a**
Zero-till (ZT)	4317	5650	3244	**4509 b**
Mean (System)	**6600 a**	**7587 a**	**6893 a**	

Values followed by the same letter in rows and columns are not significantly different at 0.05 probability level

Total biomass produced during the 2010 growing season varied between 3244 and 8883 kg ha^{-1} (Table 4.9), while a slightly lower biomass of between 2439 and 7559 kg ha^{-1} was produced in 2011 (Table 4.10). No significant differences in total biomass were recorded between CT, MT and NT treatments in either 2010 or 2011, but significantly less biomass was produced by ZT in both years, possibly due to the high levels of herbicide-resistant ryegrass.

Table 4.4: Total biomass production (kg ha^{-1}) as influenced by wheat monoculture (WWWW), wheat after canola in a lupin-wheat-canola-wheat rotation (LWCW) and wheat after medics in rotation (McWMcW) and tillage namely: conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) for the 2011 growing season at Langgewens Research Farm

Tillage practice	Crop Rotation			Mean (Tillage)
	WWWW	McWMcW	LWCW	
Conventional-till (CT)	5958	6813	6468	**6413 a**
Minimum-till (MT)	4775	7222	6232	**6062 a**
No-till (NT)	5664	7559	6910	**6711 a**
Zero-till (ZT)	2439	2764	3860	**3021 b**
Mean (System)	**4709 b**	**6089 a**	**5843 a**	

Values followed by the same letter in rows and columns are not significantly different at 0.05 probability level

Although no significant differences in total biomass due to crop rotation system were recorded in 2010, higher total biomass was produced in the McWMcW and LWCW compared to the WWWW crop system in 2011 (Tables 4.9 and 4.10).

4.4. Conclusion

The study showed that LAI, canopy coverage (light interception), flag leaf chlorophyll content, biomass production through the season and total biomass production were influenced by crop rotation and tillage practice at some sampling dates and growing seasons. LAI tended to increase as degree of soil disturbance increased in WWWW and LWCW. Light interception tended to be higher in McWMcW and lower under CT mainly in WWWW and McWMcW. The chlorophyll content did not differ between crop rotation systems for both years and the only difference in tillage was CT being significantly higher compared to ZT in 2010. Dry matter production was inconsistent although a weak trend of increased dry matter production was noticed as soil disturbance increased. Total biomass production was not influenced by CT, MT or NT. Total biomass production tended to be higher in McWMcW and LWCW compared to WWWW. High populations of herbicide-resistant ryegrass negatively influenced ZT during 2010 and 2011. From this data the anticipated positive effects of conservation agriculture on crop performance does not show clear trends yet. These positive effects do not follow instantaneously on the applied treatments and requires time, as many processes in the soil are slow and requires years to deliver the anticipated results.

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Chapter 5

5. The influence crop rotation and soil tillage on seedling survival, crop development and grain production of wheat grown under rain-fed conditions in the Swartland sub-region of the Western Cape

Abstract

Soil chemical, physical and biological characteristics are influenced by, amongst others, crop rotation and tillage practice and subsequently influence crop development and productivity. The purpose of this study was to investigate the effect of cropping systems and tillage practices on crop establishment, yield component development and grain yield of wheat. This research was conducted as a component study within a long-term crop rotation and soil tillage trial. Three crop rotation systems: wheat monoculture (WWWW), lupin-wheat-canola-wheat (LWCW) and wheat-medic rotation (McWMcW) and four tillage treatments namely: conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) were included in the study. Seedling survival, number of ear-bearing tillers m^{-2} at maturity, number of spikelets per ear, number of grains per ear, mass of individual kernels and grain yield were recorded.

In both 2010 and 2011 the seedling survival rate was affected by tillage. The ZT treatments resulted in the highest mean survival rate for both years, with CT having significantly fewer seedlings surviving in 2010 and the NT and MT treatments having significantly fewer seedlings surviving in 2011. Both crop rotation and tillage affected mean number of ear bearing tillers in 2010 and 2011. In 2010 the ZT had fewer ear bearing tillers compared to all the other tillage treatments and the McWMcW crop rotation system had the highest number of ears. For the 2011 season the ZT had fewer ears compared to MT, which had fewer ears compared to NT. The mean number of ears was significantly lower in the WWWW for 2011. The number of spikelets per ear was only affected by tillage in 2010 with CT being the highest and ZT being the lowest for both years. The crop rotation system McWMcW had the highest mean for 2011. The number of kernels per ear had a crop rotation and tillage interaction for 2010 with CT in all three crop rotation systems and the MT in LWCW and McWMcW being the highest. In 2011 only tillage had an influence with ZT that had the lowest number of kernels per ear compared to the other tillage treatments. Only tillage affected the mean kernel mass for both years with ZT significantly the highest in 2010 and significantly the lowest in 2011. The grain yield was only affected by tillage with MT and NT being the highest in 2010 and NT being the highest in 2011 together with a tendency of McWMcW having the highest grain yield.

The results give an indication that a crop rotation system gives an advantage with regards to yield components and that NT and MT are very advantageous tillage practices for the reigning climatic conditions.

Keywords: crop rotation, ear bearing tillers, grain yield, harvesting index, kernel mass, kernels per ear, seedling survival, soil tillage, spikelets per ear

5.1. Introduction

It is a well-known fact that crop rotation and soil tillage will influence the chemical (Deng and Tabatabai 2000, Liebig et al. 2004), physical (Chang and Lindwall 1989, Izaurralde et al. 1986) and biological properties (Johnston 1986, Haylin et al. 1990) of cultivated soils. It is anticipated that changes to soil quality parameters as a result of crop rotation and/or soil tillage will influence crop development and grain production.

To understand the effect of external factors, such as degree of soil disturbance and crop rotation, knowledge about the growth and development of the wheat plant is crucial. Potential photosynthetic area is determined during the leaf initiation period that takes place during the early vegetative growth stages of wheat. The reproductive stage comprises of various periods namely spikelet initiation, floret initiation, active spike and stem growth, anthesis and pollination as well as floret senescence. The final stage is grain set and grain filling. Final yield is therefore the result of various yield components that individually and in combination contribute to grain production and quality. Yield components include ear bearing tillers m^{-2}, spikelets per ear, grains per ear and weight of individual grains (Anonymous, 2012).

The seeding rate and seedling survival rate differ between farms and even camps on the same farm. Higher seeding rates are recommended for wheat production under reduced tillage (Grove et al. 2000, Carter and Rennie 1985, Weisz and Bowman 1999) mainly because the crop residue on the soil surface may interfere with the optimal placement of seeds during the seeding action. No-till may also have an impact on crop establishment as residues on the soil surface cause changes in topsoil characteristics, amongst others reduction of evaporation and less fluctuation of soil temperatures (Johnson and Lowery 1985). These relatively cool soils could retard emergence, slow down seedling development and also delay onset of tillers (Rasmussen et al. 1997). The lack of tillage, especially during first years of adopting conservation agriculture, can also result in soil compaction and increased bulk density (Gantzer and Blake 1978). These factors may have an influence on root development and therefore water absorption and nutrient uptake.

Reduced tillage accompanied by crops high in biomass production will increase crop residue accumulation on the soil surface. Over time the carbon content will increase in the topsoil. Crop residues will not only protect the soil surface from wind and water erosion; it will also increase the soil water content, improve the water use efficiency of crops, improve the organic matter content of the soil and provide a source of plant nutrients (Chastain et al. 1995, Grove et al. 2000). Research by Merrill et al. (1996) proved that reduced tillage will improve soil structure, increase water use efficiency, stimulate the development of an extensive root system and improve water and nutrient uptake resulting in increases in grain yield.

Crop rotations influence different aspects of the soil-plant continuum. These include the incidence of weed cycles being broken, insects and plant disease being reduced, the improvement and/or maintenance of soil productivity, increase in organic matter content, increase in water holding capacity, the seasonal requirements for resources being met, soil nutrients being replenished and stability of whole farm income (El-Nazer and McCarl 1986). Larney and Lindwall (1995) found in an 11 year trial that soil water content was between 1.3 and 1.6 times higher in continuous wheat and where wheat followed lentils/flax respectively, compared to where canola preceded wheat. Soil water content was on average three times higher after fallow than after canola. Hulugalle et al. (2007) found that water infiltrated deeper if crop rotation was practised compared to monoculture, even under conditions of increased soil compaction as a result of intensive cultivation.

Grain yield is normally positively related to plant biomass production due to partitioning of biomass to the harvested components. Low biomass production could be the result of poor establishment, reduced tillering or adverse environmental conditions, such as drought. The partitioning of biomass to the grain can be affected by number of tillers per m^{-2}, the number of kernels per ear bearing tiller, or kernel (grain) weight (Kumudini et al. 2008). Van Biljon (1987) found that the application of N at early growth stages significantly influenced the yield components of wheat.

Galantini et al. (2000) found that wheat after a legume crop resulted in more ears per square meter as well as a higher number of kernels per spike. The same results were found by Heenan et al. (1994) who reported that wheat after lupins resulted in more ears per square meter compared to wheat after wheat. With regards to tillage practice, conflicting results were reported. Bahrani et al. (2002) found the number of ears per square meter to be lower under NT when compared to CT, whilst Kumudini et al. (2008)

found the opposite to be true. They regarded the higher number of ears under NT to be due to the physiological response of wheat to NT production practices. Thousand kernel weight was found to be greater under NT when compared to CT (De Vita et al. 2007, Carr et al. 2003).

The high cost of wheat production necessitates research to develop a better understanding of how crop rotation and tillage practice will influence the reproductive development of the wheat plant. This study was done in an effort to quantify the effect of different crop rotation systems and tillage practices on the establishment, initiation, development and survival of yield components and finally grain production of wheat.

5.2. Material and methods

This study was conducted as a component study within a long-term crop rotation and soil tillage research programme at the Langgewens Research Farm (-33.27665°; 18.70463°; altitude 191 m) near Moorreesburg, Western Cape, South Africa. The study focused on the effect of three crop rotation systems and four tillage treatments on the establishment, initiation and development of yield components and grain yield during the wheat phase of the crop rotation systems included in the study. The experimental layout was a randomised complete block design with a split-plot treatment design, replicated four times. Three cropping systems namely: wheat monoculture (WWWW), lupin-wheat-canola-wheat (LWCW) and wheat-medic rotation (McWMcW) were allocated to main plots. Each main plot was subdivided into four sub-plots allocated to four tillage treatments namely, zero-till (ZT) – soil left undisturbed until planting with a star-wheel planter; no-till (NT) – soil left undisturbed until planting with a no-till planter; minimum-till (MT) – soil scarified March/April; and then planted with a no-till planter and conventional-till (CT) – soil scarified March/April, then ploughed and planted with a no-till planter.

All production practices such as application of fertiliser and herbicides as well as seeding density were determined by a technical team as discussed in Chapter two.

Number of seedlings was counted three weeks after emergence of the crop to determine the emergence and survival rate, while the number of ear-bearing tillers was counted at maturity before harvesting. Fifteen 1m plant row lengths per treatment combination were randomly selected and the number of seedlings determined as follow three weeks after emergence: Seedlings m^{-2} = (mean seedlings m^{-1} row length)*(10000)/(0.3). The same procedure was followed to calculate the number of ear-bearing tillers and converted to seedlings or ear-bearing tillers m^{-2}. To study the other yield components, 20 ears were collected randomly before harvesting and dissected to count the number of spikelets per ear, number of kernels per ear and mass per kernel. Grain harvesting was done as discussed in Chapter two. Grain yield was determined as follows: (10 000m^2)/(area of the experimental plots)*(yield in kg from the harvested plot). The statistical analysis was performed as described in Chapter two.

The Harvest Index of wheat was determined using the following equation: Harvest Index = (Total Grain Yield in kg)/(Total Biomass produced in kg)

5.3. Result and discussion

The non-availability of effective pre- and post-emergence herbicides for grass control in wheat resulted in high ryegrass infestation in plots of the ZT treatment especially in the WWWW system, a situation that caused poor crop development and low grain yields. The major contributor to low yields with ZT was therefore not the non-disturbance of soil, but the suppressive effect of high herbicide-resistant ryegrass infestations.

5.3.1. Seedling emergence and survival

The number of seedlings that emerge and survive is an important early indicator of yield potential. Environmental conditions such as temperature, plant available soil water and mineral nitrogen supply will however influence the final number of ear bearing tillers produced per plant (Kumudini et al. 2008). Soil conditions, planting method and crop rotation system will influence the optimum plant population for a specific field. Depending on the crop rotation system, 120-175 seedlings m^{-2} are recommended for a no-till system at Langgewens (Personal communication: Langgewens Technical Committee Protocol, 2012).

Seedling emergence and survival for different treatment combinations varied between 66 and 143 seedlings m^{-2} in 2010 and between 77 and 128 seedlings m^{-2} in 2011, but were not significantly affected by crop rotation system. There were no interaction between crop rotation system and tillage practice (Tables 5.1 and 5.2).

Table 5.1: Seedling emergence and survival (seedlings m^{-2}) as influenced by wheat monoculture (WWWW), wheat after canola in a lupin-wheat-canola-wheat rotation (LWCW) and wheat after medics in rotation (McWMcW) and tillage namely: conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) for the 2010 growing season at Langgewens Research Farm

Tillage practice	Crop rotation			Mean (Tillage)
	WWWW	McWMcW	LWCW	
Conventional-till (CT)	66	82	84	**77 c**
Minimum-till (MT)	88	98	94	**93 b**
No-till (NT)	97	92	95	**95 b**
Zero-till (ZT)	135	143	114	**130 a**
Mean (System)	**97**	**104**	**97**	

Values followed by the same letter in columns are not significantly different at 0.05 probability level

Table 5.2: Seedling emergence and survival (seedlings m^{-2}) as influenced by wheat monoculture (WWWW), wheat after canola in a lupin-wheat-canola-wheat rotation (LWCW) and wheat after medics in rotation (McWMcW) and tillage namely: conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) for the 2011 growing season at Langgewens Research Farm

Tillage practice	Crop rotation			Mean (Tillage)
	WWWW	McWMcW	LWCW	
Conventional-till (CT)	80	77	79	**79 c**
Minimum-till (MT)	79	80	77	**79 c**
No-till (NT)	92	82	91	**88 b**
Zero-till (ZT)	112	128	127	**122 a**
Mean (System)	**91**	**92**	**93**	

Values followed by the same letter in columns are not significantly different at 0.05 probability level

Tillage treatments influenced mean emergence and seedling survival significantly in both years of the study. The significantly higher number of seedlings m^{-2} recorded for the ZT treatment in both years needs further investigation. In both years the CT resulted in the lowest (P=0.05) seedling counts, namely 77 seedlings m^{-2} in 2010 and 79 seedlings m^{-2} in 2011, although not significantly lower than MT (93 and 79 seedlings m^{-2} in 2010 and 2011 respectively). These results are in contrast with results found by Rieger et al., (2008) and Fabrizzi et al. (2005) who reported lower seedling survival rates under NT compared to CT and MT.

The low emergence and survival rate of the CT treatments could be the result of loose friable soil, due to the plough treatment prior to seeding. This loose topsoil prevented even and accurate seed placement and caused loose herbicide (Trifluralin) contaminated soil to partially fill the planter furrow causing germinating seedlings to be killed by the herbicide. The low number of seedlings that emerged and survived under CT in 2010 could also be the result of crust formation as 16 mm of rain was received two days after seeding (visual observation). The occurrence of a hard soil crust was less evident during crop emergence in the CT treatments in 2011 (visual observation).

From this data it is clear that seedling survival is less influenced by crop rotation system than tillage practice. Important to note is a trend (not significant) of lower seedling survival rate as degree of soil disturbance increased from minimum disturbance in NT to maximum in the CT treatment.

5.3.2. *Ear-bearing tillers m^{-2}*

The number of ear-bearing tillers m^{-2} (ears m^{-2}) is one of the most important components that influence final grain yield. Rieger et al. (2008) found that tiller formation and survival are positively correlated with N supply to the wheat crop. The number of ear-bearing tillers is also influenced by, amongst others, the number of plants m^{-2} (Kumudini et al. 2008, Norwood 2000).

Ears m^{-2} for different treatment combinations varied between 110 and 227 in 2010 and between 78 and 241 in 2011 (Tables 5.3 and 5.4). In both years ears m^{-2} were significantly affected by cropping system and tillage treatment. In both years the highest (P=0.05) number of ears m^{-2} was produced in McWMcW, however in 2011 it was not significantly higher than in LWCW.

Table 5.3: The number of ears m^{-2} that reached maturity as influenced by wheat monoculture (WWWW), wheat after canola in a lupin-wheat-canola-wheat rotation (LWCW) and wheat after medics in rotation (McWMcW) and tillage namely: conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) for the 2010 growing season at Langgewens Research Farm

Tillage practice	Crop rotation			Mean (Tillage)
	WWWW	McWMcW	LWCW	
Conventional-till (CT)	187	180	153	**173 a**
Minimum-till (MT)	142	207	142	**164 a**
No-till (NT)	165	227	172	**188 a**
Zero-till (ZT)	110	126	129	**121 b**
Mean (System)	**151 b**	**185 a**	**150 b**	

Values followed by the same letter in rows and columns are not significantly different at 0.05 probability level

Table 5.4: The number of ears m^{-2} that reached maturity as influenced by wheat monoculture (WWWW), wheat after canola in a lupin-wheat-canola-wheat rotation (LWCW) and wheat after medics in rotation (McWMcW) and tillage namely: conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) for the 2011 growing season at Langgewens Research Farm

Tillage practice	Crop rotation			Mean (Tillage)
	WWWW	McWMcW	LWCW	
Conventional-till (CT)	178	198	185	**187 ab**
Minimum-till (MT)	130	216	172	**173 b**
No-till (NT)	158	241	200	**204 a**
Zero-till (ZT)	78	97	143	**106 c**
Mean (System)	**134 b**	**188 a**	**175 a**	

Values followed by the same letter in rows and columns are not significantly different at 0.05 probability level

These results support those of Lopez-Bellido et al. (2000) who also found that the number of ears m^{-2} was the highest in cropping systems that included legume crops. The results obtained with the WWWW and LWCW systems in 2010 agree with results reported by Weisz and Bowman (1999) who concluded that the number of the tillers was generally not affected by the tillage system in the absence of a legume crop.

Except for ZT which produced the lowest number of ears (121 ears m^{-2}), no differences due to tillage practice were recorded during the 2010 growing season. In 2011, the lowest mean number of ears m^{-2} was again produced in the ZT treatment (mean), while the highest number of ears m^{-2} in 2011 was reported for NT (204 ears m^{-2}), although not significantly higher than the CT treatment (187 ears m^{-2}).

Kumudini et al. (2008) reported similar results with significantly higher numbers of fertile tillers under NT compared to CT practices. Hemmat and Eskandari (2006) also found that more ears m^{-2} were present under NT compared to other tillage treatments and they ascribed this observation to higher soil-moisture content under NT practices. This result is supported by Halvorson et al. (2000) who suggested better water holding capacity as a contributing factor to more tillers m^{-2} produced under NT. Maali (2003) also found that the highest number of tillers in NT occurred for years with below-average rainfall, but no differences due to tillage practice in high rainfall years. This was ascribed to more efficient soil moisture conservation and utilisation in NT under drier climatic conditions. Results obtained from the current study however, differed from results reported by Lopez-Bellido et al. (2000) who found higher number of ears.m^{-2} in CT compared to NT. In contrast to seedling emergence and survival the ZT treatments resulted in the lowest number (121 and 106 ears.m^{-2} for 2010 and 2011 respectively) of ear-bearing tillers, which can most probably be ascribed to the competitive effect of the severe herbicide-resistant ryegrass infestation in ZT.

5.3.3. Spikelets per ear

The number of spikelets per ear reflects the influence of environmental conditions and crop response during spikelet initiation (Van Biljon 1987). The number of spikelets per ear also affects the potential number of grains per ear. Satorre and Slafer (1999) concluded that the highest rate of assimilate partitioning related to ear formation takes place three weeks prior to anthesis. They also found that high LAI and high photosynthetic rate produced more assimilates available for ear formation. Fewer spikelets per ear is therefore indicative of less favourable conditions during the initiation and growth phases of the spikelets.

In this study, mean number of spikelets was not influenced by crop rotation systems during the 2010 growing season and no interactive effect with tillage practice was shown in 2010 or 2011 (Tables 5.5 and 5.6). However, during 2011, spikelet numbers were significantly higher in the McWMcW (17.7) compared to 17.2 and 16.9 spikelets per ear in the WWWW and LWCW systems respectively.

Table 5.5: Number of spikelets per ear as influenced by wheat monoculture (WWWW), wheat after canola in a lupin-wheat-canola-wheat rotation (LWCW) and wheat after medics in rotation (McWMcW) and tillage namely: conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) for the 2010 growing season at Langgewens Research Farm

Tillage practice	Crop rotation			Mean (Tillage)
	WWWW	McWMcW	LWCW	
Conventional-till (CT)	19.1	19.2	17.6	**18.6 a**
Minimum-till (MT)	17.4	18.3	18.2	**17.9 b**
No-till (NT)	17.5	17.8	17.1	**17.5 bc**
Zero-till (ZT)	16.3	17.6	17.1	**16.9 c**
Mean (System)	**17.6**	**18.2**	**17.5**	

Values followed by the same letter in columns are not significantly different at 0.05 probability level

Table 5.6: Number of spikelets per ear as influenced by wheat monoculture (WWWW), wheat after canola in a lupin-wheat-canola-wheat rotation (LWCW) and wheat after medics in rotation (McWMcW) and tillage namely: conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) for the 2011 growing season at Langgewens Research Farm

Tillage practice	Crop rotation			Mean (Tillage)
	WWWW	McWMcW	LWCW	
Conventional-till (CT)	18.1	18.7	17.8	**18.2 a**
Minimum-till (MT)	17.1	18.3	17.9	**17.7 a**
No-till (NT)	17.5	18.2	17.1	**17.6 b**
Zero-till (ZT)	16.1	15.5	14.9	**15.5 c**
Mean (System)	**17.2 b**	**17.7 a**	**16.9 b**	

Values followed by the same letter in rows and columns are not significantly different at 0.05 probability level

Tillage treatments resulted in significant differences in the mean number of spikelets produced per ear in both 2010 and 2011 seasons with an increase in spikelet numbers as degree of soil disturbance increased, resulting in the highest number of spikelets per ear in CT plots. No significant differences were however shown between CT and MT in 2011. This agrees with results obtained by Kumudini et al. (2008) who found that the number of spikelets per ear was less in NT plots compared to CT. In both years, ZT resulted in the lowest numbers of spikelets per ear, although not significantly lower than the NT in 2010. Low spikelet numbers with ZT were again most probably due to the competitive effect of the severe herbicide-resistant ryegrass infestation.

5.3.4. Kernels per ear

Kernels per ear are the result of the number of spikelets per ear multiplied by the number of kernels per spikelet. Crop rotation system did not influence the mean number of kernels per ear in 2010 and 2011(Tables 5.7 and 5.8). There was however a tendency for a lower number of spikelets per ear in the WWWW and LWCW crop rotation systems compared to McWMcW. These results illustrated the ability of the wheat plant to compensate (within limits) for unfavourable conditions that might prevail during different stages of yield development.

Table 5.7: The number of grains per ear as influenced by wheat monoculture (WWWW), wheat after canola in a lupin-wheat-canola-wheat rotation (LWCW) and wheat after medics in rotation (McWMcW) and tillage namely: conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) for the 2010 growing season at Langgewens Research Farm

Tillage practice	Crop rotation			Mean (Tillage)
	WWWW	McWMcW	LWCW	
Conventional-till (CT)	58.8 a	55.1 a	50.2 a	**54.7 a**
Minimum-till (MT)	49.4 b	52.7 ab	50.8 a	**51.0 b**
No-till (NT)	47.7 bc	50.1 bc	47.5 ab	**48.4 c**
Zero-till (ZT)	43.9 c	48.4 c	44.6 b	**45.6 d**
Mean (System)	**49.9**	**51.5**	**48.3**	

Values followed by the same letter (not bold) are not significantly different at 0.05 probability level

Values followed by the same letter (bold) in columns are not significantly different at 0.05 probability level

Table 5.8: The number of grains per ear as influenced by wheat monoculture (WWWW), wheat after canola in a lupin-wheat-canola-wheat rotation (LWCW) and wheat after medics in rotation (McWMcW) and tillage namely: conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) for the 2011 growing season at Langgewens Research Farm

Tillage practice	Crop rotation			Mean (Tillage)
	WWWW	McWMcW	LWCW	
Conventional-till (CT)	49.9	50.6	48.7	**49.7 a**
Minimum-till (MT)	47.4	51.0	51.1	**49.8 a**
No-till (NT)	46.5	50.9	47.2	**48.2 a**
Zero-till (ZT)	41.8	40.0	38.5	**40.1 b**
Mean (System)	**46.4**	**48.2**	**46.4**	

Values followed by the same letter in columns are not significantly different at 0.05 probability level

A tendency, similarly to the tendency which occurred for the spikelets per ear, namely more kernels per ear as soil disturbance increased, was found in 2010 and 2011. Kernels per ear in 2010 showed a significant interaction between cropping system and tillage. This interaction was due to significantly higher number of grains per ear with ZT in the LWCW cropping system compared to WWWW and McWMcW systems and also with MT in LWCW and McWMcW compared to WWWW. In contrast to 2010, no interaction was found in 2011 and no significant differences in number of grains per ear were reported between the CT, MT and NT treatments.

The results obtained in the current study differed from the findings of Rieger et al. (2008) who reported no differences in the number of grains per ear as a result of crop rotation or soil tillage - an indication of the effect of growing conditions of plant growth responses to cultivation practices.

5.3.5. Grain Mass (mass per individual kernel)

Grain mass (mass per individual kernel) is an indication of growing conditions after anthesis. Except for ZT in the WWWW system which was significantly lower compared to all other treatment combinations, no differences were found between treatment combinations in 2010 (Table 5.9). This low value however, resulted in the mean value for ZT to be also significantly lower than other tillage treatments.

Table 5.9: Grain mass (g) as influenced by wheat monoculture (WWWW), wheat after canola in a lupin-wheat-canola-wheat rotation (LWCW) and wheat after medics in rotation (McWMcW) and tillage namely: conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) for the 2010 growing season at Langgewens Research Farm

Tillage practice	Crop rotation			Mean (Tillage)
	WWWW	McWMcW	LWCW	
Conventional-till (CT)	0.039 a	0.038 a	0.040 a	**0.039 a**
Minimum-till (MT)	0.041 a	0.039 a	0.040 a	**0.040 a**
No-till (NT)	0.039 a	0.039 a	0.039 a	**0.040 a**
Zero-till (ZT)	0.027 b	0.037 a	0.036 a	**0.033 b**
Mean (System)	**0.037**	**0.038**	**0.039**	

Values followed by the same letter (not bold) are not significantly different at 0.05 probability level

Values followed by the same letter (bold) in columns are not significantly different at 0.05 probability level

In 2011, mean grain mass was significantly influenced by cropping system with WWWW (0.042 g) producing larger kernels compared to LWCW (0.041g) and McWMcW which was significantly lower (0.038 g) compared to other cropping systems (Table 5.10).

Table 5.10: Grain mass (g) as influenced by wheat monoculture (WWWW), wheat after canola in a lupin-wheat-canola-wheat rotation (LWCW) and wheat after medics in rotation (McWMcW) and tillage namely: conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) for the 2011 growing season at Langgewens Research Farm

Tillage practice	Crop rotation			Mean (Tillage)
	WWWW	McWMcW	LWCW	
Conventional-till (CT)	0.038	0.038	0.039	**0.039 c**
Minimum-till (MT)	0.043	0.037	0.040	**0.040 b**
No-till (NT)	0.042	0.038	0.040	**0.040 b**
Zero-till (ZT)	0.043	0.041	0.042	**0.042 a**
Mean (System)	**0.042 a**	**0.038 c**	**0.040 b**	

Values followed by the same letter in rows and columns are not significantly different at 0.05 probability level

In 2011, ZT (0.042 g) produced significantly larger kernels compared to NT (0.04 g) and MT (0.04 g), which were significantly larger than that of CT treatment (0.039 g).

These results are in agreement with that of Satorre and Slafer (1999) who reported an inverse (negative) relationship between the number of ears m^{-2} and the number of kernels per ear. Lopez-Bellido et al. (2000) also found that grain weight decreased with an increase in the number of ears $m^{-2.}$ The below-average rainfall recorded during the last three months of the growing season could be the cause for the smaller kernels produced in the McWMcW system in 2011. McWMcW produced the highest number of ears m^{-2} as well as the highest number of kernels per ear in 2011 which is an indication of good photosynthetic capability. This improved growth in crop canopy will result in an increased water use and rapid depletion of the soil moisture. Such crops with more tillers m^{-2} and larger ears (more kernels per ear) will also experience more competition for assimilates, causing a decrease in individual grain weight. Low kernel mass with ZT in WWWW 2010 was most probably again the result of the competitive effect of the severe herbicide-resistant ryegrass infestation.

5.3.6. Grain yield

Grain yield was not influenced by crop rotation system in both years the study was conducted (Tables 5.11 and 5.12).

Table 5.11: The grain yield (kg ha^{-1}) as influenced by wheat monoculture (WWWW), wheat after canola in a lupin-wheat-canola-wheat rotation (LWCW) and wheat after medics in rotation (McWMcW) and tillage namely: conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) for the 2010 growing season at Langgewens Research Farm

Tillage practice	Crop rotation			Mean (Tillage)
	WWWW	McWMcW	LWCW	
Conventional-till (CT)	2160	2668	2915	**2581 b**
Minimum-till (MT)	2452	3416	3126	**2998 a**
No-till (NT)	2769	3378	3071	**3073 a**
Zero-till (ZT)	2335	2263	1692	**2097 c**
Mean (System)	**2429**	**2931**	**2701**	

Values followed by the same letter in columns are not significantly different at 0.05 probability level

Table 5.12: The grain yield (kg ha^{-1}) as influenced by wheat monoculture (WWWW), wheat after canola in a lupin-wheat-canola-wheat rotation (LWCW) and wheat after medics in rotation (McWMcW) and tillage namely: conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) for the 2011 growing season at Langgewens Research Farm

Tillage practice	Crop rotation			Mean (Tillage)
	WWWW	McWMcW	LWCW	
Conventional-till (CT)	2557	2877	2808	**2747 b**
Minimum-till (MT)	1905	2869	2779	**2518 b**
No-till (NT)	2663	3536	3076	**3092 a**
Zero-till (ZT)	1178	1670	1290	**1379 c**
Mean (System)	**2076**	**2738**	**2488**	

Values followed by the same letter in columns are not significantly different at 0.05 probability level

This is in contrast with results obtained from earlier studies (Kirkegaard et al.1994, López-Bellido et al. 1998, López-Bellido et al. 2000, López-Bellido and López-Bellido 2001) who reported that the inclusion of a legume in a crop rotation system, increased wheat yields, compared to wheat monoculture.

Tillage treatment resulted in significant differences in grain yield in both 2010 and 2011 growing seasons. In 2010 NT (3073 kg ha^{-1}) and MT (2998 kg ha^{-1}) resulted in higher grain yields compared to the CT (2581 kg ha^{-1}) and ZT which produced the lowest yields (2097 kg ha^{-1}). In 2011, NT (3092 kg ha^{-1}) resulted in significantly higher grain yields compared to CT (2747 kg ha^{-1}) and MT (2518 kg ha^{-1}), while ZT (1379 kg ha^{-1}) once again produced the lowest yields. The higher grain yields recorded for the NT treatments (especially 2011) agree with the results reported by Mrabet (2000) and Izaurralde et al. (1986) who investigated the effect of different methods of tillage in a wheat cropping system and concluded that higher soil moisture availability recorded in the NT to be an important contributing factor. Hemmat and Eskandari (2006), who managed a three year experiment to investigate the effect of tillage on wheat yield and yield components, also reported higher grain yields under NT compared to CT and MT. Contrary to the current study, Rieger et al. (2008) found that grain yield of wheat in NT systems was lower compared to MT and CT, because of fewer ears and a significantly lower thousand-kernel weight.

Although not significant, grain yield tended to be the highest in the McWMcW system in both years of the study period. The positive effect of a legume based cropping system (McWMcW) was also recorded by López-Bellido et al. (2000) who found that during a four year period, wheat-fababean out-yielded wheat-chickpea, wheat-sunflower and continuous wheat systems. In a study by Chan and Heenan (1996), higher yields were recorded for wheat when planted in rotation with lupins and canola compared to wheat monoculture. Higher yields after legume crops such as lupins or legume pastures such as medics may be the result of higher plant available nitrogen content in the soil because of the nitrogen fixing abilities of the legume crop (Carpenter-Boggs et al. 2000, Arshad et al. 2002).

5.3.7. Harvest index (HI)

The Harvest Index (HI) is the ratio of grain mass to total plant mass and an indicator of the crop's efficiency to convert assimilates to grain (Sinclaire, 1998). Mean harvesting index was significantly lower for the WWWW system compared to the McWMcW and LWCW systems in 2010 and 2011 (Tables 5.13 and 5.14).

Table 5.13: Harvest Index (HI) of wheat as influenced by wheat monoculture (WWWW), wheat after canola in a lupin-wheat-canola-wheat rotation (LWCW) and wheat after medics in rotation (McWMcW) and tillage namely: conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) for the 2010 growing season at Langgewens Research Farm

Tillage practice	Crop rotation			Mean (Tillage)
	WWWW	McWMcW	LWCW	
Conventional-till (CT)	0.271	0.351	0.403	**0.342 ab**
Minimum-till (MT)	0.355	0.420	0.383	**0.386 ab**
No-till (NT)	0.455	0.382	0.390	**0.409 a**
Zero-till (ZT)	0.176	0.381	0.477	**0.318 b**
Mean (System)	**0.314 b**	**0.383 a**	**0.404 a**	

Values followed by the same letter in rows and columns are not significantly different at 0.05 probability level

Table 5.14: Harvest Index (HI) of wheat as influenced by wheat monoculture (WWWW), wheat after canola in a lupin-wheat-canola-wheat rotation (LWCW) and wheat after medics in rotation (McWMcW) and tillage namely: conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) for the 2011 growing season at Langgewens Research Farm

Tillage practice	Crop rotation			Mean (Tillage)
	WWWW	McWMcW	LWCW	
Conventional-till (CT)	0.431	0.416	0.437	**0.428**
Minimum-till (MT)	0.411	0.393	0.625	**0.476**
No-till (NT)	0.473	0.468	0.445	**0.462**
Zero-till (ZT)	0.478	0.606	0.391	**0.492**
Mean (System)	**0.448 b**	**0.471 a**	**0.475 a**	

Values followed by the same letter in rows are not significantly different at 0.05 probability level

With the exception of ZT that resulted in significantly (P=0.05) lower mean HI values compared to NT in 2010, no differences due to the tillage treatments applied, were recorded. These results differed from those of Kumudini et al. (2008) who found HI for CT to be higher than that of NT in a wheat crop, but showed that HI could be a sensitive parameter to compare to efficiency of different cropping systems.

5.4. Conclusion

Although 2010 and 2011 represent only the 4th and 5th year after introducing the cropping systems and tillage treatments, significant differences in grain yield as a result of the treatment combinations were recorded.

The legume based cropping system (McWMcW) in combination with reduced soil disturbance (in most cases NT) proved to be superior as number of ear bearing tillers m^{-2} and grain yield were higher compared to the other treatment combinations tested. The tendency of more spikelets per ear in CT over all crop rotations in 2010 and 2011 as well as more kernels per ear in 2010 did not result in higher grain yields compared to ZT, NT and MT. Grain mass of individual kernels did not contribute to any differences in grain yield in 2010 and the significantly lower mean individual grain mass recorded for the McWMcW system could not prevent McWMcW to record the highest grain yields in 2011.

It is anticipated that the effects of the treatments will become more apparent over time as this study was done as a component study within a long-term trial planned to continue until 2027.

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Chapter 6

6. The effect of crop rotation and soil tillage on the quality of wheat produced under rain-fed conditions in the Swartland sub-region of the Western Cape

Abstract

In South Africa wheat is primarily produced for bread-baking purposes. The quality of wheat is therefore very important as the price of wheat is linked to quality parameters. Factors influencing grain yields and quality of wheat are amongst others, soil moisture, which depends on rainfall and its distribution during the growing season and plant available N. These factors will influence kernel development and are often a reflection of the allocation and redistribution of assimilates to the grain kernel.

Field research was conducted to investigate the effect of wheat monoculture (WWWW), lupin-wheat-canola-wheat (LWCW) and wheat-medic (McWMcW) crop rotations in combination with conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) on the following grain quality parameters: thousand kernel weight (TKW), hectolitre mass (HLM), falling number and grain protein content.

No clear trends with regards to the effect of crop rotation and soil tillage on the quality parameters studied were found, most probably because rainfall from July to September was below the long-term average for both 2010 and 2011. Thousand kernel weight of ZT in the WWWW crop system was low (P=0.05) compared to other treatments tested. A tendency of lower TKW as soil disturbance decreased within crop rotation systems was found in 2010 but not in 2011. The falling number was only affected significantly in 2010 where the ZT showed lower values compared to MT and NT. Grain protein content was not influenced by the treatments in 2010. However, in 2011 McWMcW and CT resulted in higher (P=0.05) grain protein contents than the other treatments tested.

Keywords: crop rotation, falling number, grain protein, hectolitre mass, soil tillage, thousand kernel weight

6.1. Introduction

The value of wheat grain for baking purposes is determined by various parameters, amongst others protein content, thousand kernel weight (TKW), hectolitre mass and falling number. These quality parameters are influenced by various external factors. Soil moisture which depends on rainfall, including distribution of rain during the growing season, and plant available N will influence grain yield and quality (Cooper et al. 1987). Borghi (1996) identified water as one of the main factors that determined productivity under typical Mediterranean conditions. Other factors and the interaction thereof that play an important role in grain quality include cultivar, soil, climate and cropping practice (Randall and Moss 1990, Blumenthal et al. 1991, Borghi et al. 1997). Mediterranean regions, such as the Western Cape, is characterised by decreasing rainfall during the grain filling phases in spring. This increasing water stress conditions may have an effect on grain yield and quality (Nel et al. 2000a, 2000b, Maali and Agenbag 2006).

Wheat protein content is an important parameter for grain quality. Protein content is negatively correlated with seasonal rainfall (Arshad et al. 2002). Protein content tends to be higher if crop productivity is reduced as a result of moderate conditions of water stress. The protein content of wheat is also dependent on a number of other factors such as temperature, time and rate of nitrogen fertiliser application, crop rotation, method of tillage and also genotype (López-Bellido et al. 2000). When rainfall and N availability are sufficient, the protein content and yield can be influenced positively (Terman et al. 1969).

The primary effect of nitrogen fertiliser is to increase yield if sufficient water to maintain high productivity is available (Terman et al. 1969). López-Bellido et al. (2000) reported higher grain protein content in wheat rotated with fababeans and chickpea. This observation was not recorded in high rainfall years due to the dilution effect of excessive water on mineral nitrogen in the soil. They also found that protein content of wheat after canola was lower than that of wheat after pea and wheat monoculture. In rotational crop production it has been found that higher yields were obtained with wheat when planted in rotation with lupins and canola compared to wheat monoculture (Chan and Heenan 1996). Higher yields after legume crops such as lupins or legume pastures such as medics may be the result of a higher plant available nitrogen content in the soil because of the nitrogen fixing abilities of the legume crop. This higher availability of N throughout the season can positively benefit the quality parameters of wheat.

Under favourable growing conditions, starch and protein build up simultaneously. When water stress and high temperatures prevail during the grain filling stage, it limits the conversion of sucrose into starch (Anonymous 2012). These climatic conditions influence grain filling as Maali and Agenbag (2006) found that rain late in the growing season led to a high hectolitre mass. When N application was delayed to just before the grain filling stages, N availability was higher during grain filling and protein content increased (Ayoub et al. 1994). Low protein concentrations result in poor baking qualities. Protein content of more than 11 % is needed to improve the viscoelastic properties and quality of the dough (López-Bellido et al. 1998).

Another quality parameter influenced by locality, cultivar and grain moisture content is the thousand kernel weight (Hook 1984). Flour yield, gluten content and dough development are indicators of grain quality (Khathar et al. 1994) which are strongly influenced by N fertilisation (Maali and Agenbag 2006), water stress (Neales et al. 1963) and high temperatures (Campbell and Read, 1968) during the grain filling stage. The thousand kernel weight (TKW) is a parameter that measures the mass of the wheat kernel and is used as a complement to hectolitre mass (HLM).

The hectolitre mass (HLM) is influenced by environmental factors such as high temperatures during grain filling, rainfall before harvest and disease (Kleijer et al. 2007). López-Bellido et al. (1998) found that crop rotation system and tillage have a significant influence on hectolitre mass. Bundy and Andraski (2004) found that excessive N lead to lower HLM. The HLM is one of the parameters used to determine price, although it has been found that HLM is not always a reliable predictor of milling quality (Hook 1984) and flour yield (Nyiraneza et al. 2012).

Rainy conditions prior to harvest may cause wheat grain to start germinating before it has been harvested. Germinating wheat will have a higher sugar content which is unacceptable for baking purposes. The enzyme alpha-amylase is responsible for the degradation of wheat starch into simple sugars during germination (Hagberg 1960). The falling number of wheat measures the viscosity of a heated meal or flour slurry and gives an indication of the level of starch degradation. Nel et al. (2000b) found that environment was by far the dominating factor affecting falling number.

It is therefore important to investigate the effects of crop rotation and tillage on the quality of wheat since these parameters determine the compensation received for the wheat produced and ultimately determines profitability. High yields of acceptable quality will furthermore improve food security. The purpose of this study was to investigate the effect of crop rotation and different tillage practices on the quality of the grain produced. Knowledge obtained in this study can be used to develop management strategies that ensure grain of acceptable quality is produced.

6.2. Material and methods

This study was conducted at the Langgewens Research Farm (-33.27665°; 18.70463°; altitude 191 m), in the Western Cape Province of South Africa. This study was done as a component study, within a long-term crop rotation and soil tillage research programme that was initiated in 2007. The experimental design was a randomised complete block design with a split-plot treatment design replicated four times (Snedecor and Cochran 1967). The effect of three crop rotation systems namely: wheat monoculture (WWWW), lupin-wheat-canola-wheat (LWCW) and wheat-medic-wheat-medic (McWMcW) in combination with four tillage treatments: conventional- , minimum- , no- and zero-till on thousend kernel weight (TKW), hectolitre mass (HLM) protein content (%) and falling number (s) of wheat during the wheat phase, were studied. Details of the soil, climatic conditions, agronomic practices and tillage treatments are presented in Chapter 2.

The protein content was determined by Near Infra-Red Spectroscopy (Technikon Infraalyzer 400); HLM using the standard Two Level Funnel Method and thousand kernel weight (TKW) was determined by counting thousand kernels and recording the weight. Hagberg falling numbers were determined on 7 g samples. Details of the methods used are described by Nel et al. (1998, 2000a, 2000b).

6.3. Result and discussion

6.3.1. Thousand kernel weight (TKW)

Kernel weight is the final yield component that contributes to grain yield and quality and is dependent on cultivar and growing conditions during grain filling. High temperatures, drought and diseases are some of the factors that will reduce kernel weight (TKW) and subsequently reduce yield potential (Simane et al. 1993).

Tables 6.1 and 6.2 summarise the effect of crop rotation and tillage practice on thousand kernel weight (TKW) during 2010 and 2011 respectively.

Table 6.1: Thousand kernel weight (TKW) (g) as influenced by wheat monoculture (WWWW), wheat after canola in a lupin-wheat-canola-wheat rotation (LWCW) and wheat after medics in rotation (McWMcW) and tillage namely: conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) for the 2010 growing season at Langgewens Research Farm

Tillage practice	Crop Rotation			Mean (Tillage)
	WWWW	McWMcW	LWCW	
Conventional-till (CT)	42.67 a	42.10 a	43.13 a	**42.63 a**
Minimum-till (MT)	42.38 a	40.86 ab	43.00 a	**42.08 a**
No-till (NT)	41.80 a	40.56 ab	42.81 a	**41.72 a**
Zero-till (ZT)	31.03 c	37.29 b	40.10 ab	**35.78 b**
Mean (System)	**39.47 b**	**40.20 b**	**42.40 a**	

Values followed by the same letter (not bold) are not significantly different at 0.05 probability level

Values followed by the same letter (bold) in rows and columns are not significantly different at 0.05 probability level

Table 6.2: Thousand kernel weight (TKW) (g) as influenced by wheat monoculture (WWWW), wheat after canola in a lupin-wheat-canola-wheat rotation (LWCW) and wheat after medics in rotation (McWMcW) and tillage namely: conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) for the 2011 growing season at Langgewens Research Farm

Tillage practice	Crop Rotation			Mean (Tillage)
	WWWW	McWMcW	LWCW	
Conventional-till (CT)	38.81	35.91	39.36	**38.03 b**
Minimum-till (MT)	41.77	35.92	39.08	**38.92 ab**
No-till (NT)	40.14	34.97	40.44	**38.50 b**
Zero-till (ZT)	41.51	38.31	40.36	**40.06 a**
Mean (System)	**40.56 a**	**36.28 b**	**39.80 a**	

Values followed by the same letter in rows and columns are not significantly different at 0.05 probability level

Mean TKW as a result of tillage tended to increase as degree of soil disturbance increased in 2010, but responses differed for different crop rotation systems. The interaction (P=0.0153) between crop rotation and soil tillage in 2010 showed lower values with ZT compared to NT, MT and CT in the WWWW and lower than CT in the McWMcW crop ration system, but no differences due to tillage treatments were recorded in LWCW.

In 2011 (Table 6.2), McWMcW produced grain with lower TKW values compared to WWWW and LWCW, while ZT resulted in higher (P=0.05) TKW values compared to CT and NT. Contrasting results for 2010 and 2011 are difficult to explain, but may be due to the dominant effect of environmental conditions during grain filling on grain development and yield (Nel et al. 1998).

6.3.2. *Hectolitre Mass (HLM)*

Hectolitre mass (kg grain hl^{-1}) represents the bulk density of the grain and provides an indication of the expected flour yield. Hectolitre mass is strongly influenced by environmental conditions during grain filling (Nel et al. 2000). Maali and Agenbag (2006) reported that HLM was favoured by rain which fell during September (grain filling period) even under conditions of moderate early season drought conditions. In South Africa a minimum HLM value of 72 kg hl^{-1} is required for bread-baking purposes (Table 6.3).

Table 6.3: The bread-wheat grading regulations for wheat produced in South Africa (Anonymous 2012)

Grading system for bread wheat - Class B			
Grade	**Minimum protein (12% moisture basis)**	**Minimum Hectolitre mass ($kg.ha^{-1}$)**	**Minimum falling number (seconds)**
B1	12	77	220
B2	11	76	220
B3	10	74	220
B4	9	72	200
Utility	8	70	150
Other class	**Does not meet any of the above requirements**		

Hectolitre Mass (HLM) recorded for 2010 and 2011 is presented in tables 6.4 and 6.5.

Table 6.4: The hectolitre mass (HLM) (kg hl^{-1}) as influenced by wheat monoculture (WWWW), wheat after canola in a lupin-wheat-canola-wheat rotation (LWCW) and wheat after medics in rotation (McWMcW) and tillage namely: conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) for the 2010 growing season at Langgewens Research Farm

Tillage practice	Crop Rotation			Mean (Tillage)
	WWWW	McWMcW	LWCW	
Conventional-till (CT)	84.00 a	80.55 ab	81.40 ab	**81.98 a**
Minimum-till (MT)	81.50 ab	80.70 ab	82.05 ab	**81.42 a**
No-till (NT)	81.80 ab	81.20 ab	82.00 ab	**81.67 a**
Zero-till (ZT)	70.75 c	77.80 b	79.20 b	**75.62 b**
Mean (System)	**79.51**	**80.06**	**81.29**	

Values followed by the same letter (not bold) are not significantly different at 0.05 probability level

Values followed by the same letter (bold) in columns are not significantly different at 0.05 probability level

Table 6.5: The hectolitre mass (HLM) (kg hl^{-1}) as influenced by wheat monoculture (WWWW), wheat after canola in a lupin-wheat-canola-wheat rotation (LWCW) and wheat after medics in rotation (McWMcW) and tillage namely: conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) for the 2011 growing season at Langgewens Research Farm

Tillage practice	Crop Rotation			Mean (Tillage)
	WWWW	McWMcW	LWCW	
Conventional-till (CT)	80.95	79.60	80.90	**80.48**
Minimum-till (MT)	81.90	79.60	80.85	**80.78**
No-till (NT)	81.90	79.05	81.45	**80.80**
Zero-till (ZT)	82.30	76.70	82.50	**80.50**
Mean (System)	**81.76 a**	**78.74 b**	**81.43 a**	

Values followed by the same letter in rows are not significantly different at 0.05 probability level

On average high (>78 kg hl^{-1}) HLM values were recorded in both 2010 and 2011, but values for different tillage treatments differed within different crop rotation systems in 2010 (Table 6.4). The interaction (P=0.035) between crop rotation and soil tillage in 2010 showed that HLM recorded for ZT was lower (P=0.05) than the NT, MT and CT in the WWWW system, but not so in McWMcW and LWCW.

In 2011, the HLM was only influenced by crop rotation in 2011 with lower (P=0.05) HLM values in the McWMcW system compared to WWWW and LWCW (Table 6.5). Results are in contrast to results reported in earlier studies (Miller and Holmes 2005, De Vita et al. 2007, Carr et al. 2008) who reported significantly higher HLM values with NT compared to CT, while Maali and Agenbag (2006) reported no significant difference in HLM due to crop rotations or tillage practices.

6.3.3. *Falling number*

The falling number, measured in seconds, is an indication of the alpha-amylase enzyme activity in the grain. When the starch molecules in the wheat have been broken down to sugars such as maltose, it will reflect in a low falling number and less than 200 seconds is regarded as unacceptable for commercial milling and baking purposes (Anonymous 2012). The falling numbers for both seasons showed values of more than 300 seconds (Tables 6.6 and 6.7).

Table 6.6: Falling number (s) as influenced by wheat monoculture (WWWW), wheat after canola in a lupin-wheat-canola-wheat rotation (LWCW) and wheat after medics in rotation (McWMcW) and tillage namely: conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) for the 2010 growing season at Langgewens Research Farm

Tillage practice	Cropping rotation			Mean (Tillage)
	WWWW	McWMcW	LWCW	
Conventional-till (CT)	375.8	366.0	382.8	**374.8 ab**
Minimum-till (MT)	370.5	396.3	372.7	**380.5 a**
No-till (NT)	375.5	384.3	382.3	**380.7 a**
Zero-till (ZT)	357.0	365.3	382.0	**368.1 b**
Mean (System)	**369.7**	**377.9**	**380.4**	

Values followed by the same letter in columns are not significantly different at 0.05 probability level

In 2010, crop rotation system did not have any effect on falling number, but ZT resulted in significant lower falling number compared to MT and NT. Values for ZT were however still well above the critical value of 200 seconds so that it would have had no effect on the baking quality of the grain. No differences in falling number due to the crop rotation system or tillage practice used were recorded in 2011 (Table 6.7).

Table 6.7: Falling number (s) as influenced by wheat monoculture (WWWW), wheat after canola in a lupin-wheat-canola-wheat rotation (LWCW) and wheat after medics in rotation (McWMcW) and tillage namely: conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) for the 2011 growing season at Langgewens Research Farm

Tillage practice	Cropping rotation			Mean (Tillage)
	WWWW	McWMcW	LWCW	
Conventional-till (CT)	356.5	369.5	346.5	**357.5**
Minimum-till (MT)	364.5	368.8	340.0	**357.8**
No-till (NT)	359.8	347.8	351.5	**353.0**
Zero-till (ZT)	363.0	358.8	361.5	**361.1**
Mean (System)	**360.9**	**361.2**	**349.9**	

6.3.4. Protein

The dough properties of wheat are primarily due to its protein constituents, especially the gluten protein (Satorre and Slafer 1999). In South Africa protein is one of the most important factors that determine market value and processing quality. High grain protein content ensures that the baker can produce a loaf of bread that will meet consumer requirements (Anon. 2012). López-Bellido and López-Bellido (2001), listed temperature, sunlight and soil moisture during the grain filling stages as the most important environmental factors influencing grain protein content. They also reported that mean protein content tended to decrease as grain yield increased and vice versa, however no negative correlation between yield and grain protein content could be found.

Tables 6.8 and 6.9 summarise the protein content as influenced by tillage crop rotation and tillage practice during 2010 and 2011.

Table 6.8: Grain protein content (%) as influenced by wheat monoculture (WWWW), wheat after canola in a lupin-wheat-canola-wheat rotation (LWCW) and wheat after medics in rotation (McWMcW) and tillage namely: conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) for the 2010 growing season at Langgewens Research Farm

Tillage practice	Crop Rotation			Mean (Tillage)
	WWWW	McWMcW	LWCW	
Conventional-till (CT)	10.28	11.15	11.10	**10.84**
Minimum-till (MT)	10.68	11.28	11.10	**11.02**
No-till (NT)	10.50	10.80	11.25	**10.85**
Zero-till (ZT)	11.13	11.25	11.10	**11.16**
Mean (System)	**10.64**	**11.12**	**11.14**	

Table 6.9: Grain protein content (%) as influenced by wheat monoculture (WWWW), wheat after canola in a lupin-wheat-canola-wheat rotation (LWCW) and wheat after medics in rotation (McWMcW) and tillage namely: conventional- (CT), minimum- (MT), no- (NT) and zero-till (ZT) for the 2011 growing season at Langgewens Research Farm

Tillage practice	Crop Rotation			Mean (Tillage)
	WWWW	McWMcW	LWCW	
Conventional-till (CT)	10.90	11.93	10.80	**11.21 a**
Minimum-till (MT)	9.97	11.48	10.85	**10.84 b**
No-till (NT)	10.28	11.83	10.33	**10.81 b**
Zero-till (ZT)	10.08	10.78	10.08	**10.32 c**
Mean (System)	**10.33 b**	**11.50 a**	**10.51 b**	

Values followed by the same letter in rows and columns are not significantly different at 0.05 probability level

Crop rotation and tillage did not influence grain protein content in 2010. In 2011 higher (P=0.05) grain protein content was recorded in the McWMcW (11.50 %) compared to LWCW (10.51 %) and WWWW (10.33 %) crop rotation systems. Maali and Agenbag (2006) also reported higher protein content in wheat after lupins and canola compared to wheat monoculture. Similar results were reported by Miller and Holmes (2005) who ascribed it to the nitrogen fixing abilities of legume crops.

Grain protein content in 2011 tended to increase as degree of soil disturbance increased with the highest protein content recorded in CT and the lowest (P=0.05) at ZT. Lopez-Bellido et al. (1998) reported significantly higher protein content for CT compared to NT. They attributed these results to higher NO_3^--N levels in CT. These results were confirmed by Maali and Agenbag (2006) who found that the wheat protein content was significantly higher under CT compared to NT. Carr et al. (2008) also reported higher protein content in CT compared to NT in wheat monoculture and came to the conclusion that less N was available under NT treatments because of initial N immobilisation due to the decomposition of crop residues. This phenomenon corresponds with results found by Terman et al. (1969) and Halloran (1981) that when the yield was the highest for a treatment, the grain protein content tended to be the lowest.

6.4. Conclusion

In general the quality parameters tested were not influenced by crop rotation or tillage practice to the extent that the flour produced did not qualify for minimum milling and baking criteria. Differences in protein content and HLM may however influence grading and price differences received for grain. The dominant effect of environmental conditions on quality parameters is emphasised by the data recorded. No trends in TKW, HLM and falling numbers were observed. The only trend recorded was for protein content in 2011 where the legume containing McWMcW crop rotation system produced grain of higher protein content compared to WWWW and LWCW. Increased soil disturbance also increased protein content in 2011.

From the results it became clear that although crop rotation and conservation tillage did have a beneficial effect on soil water content and N mineralisation in the Swartland wheat producing area, these advantages resulted in enhanced plant growth and grain yield, but had little effect on grain quality.

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Chapter 7

7. Summary

At present wheat is planted on about 265 000 ha in the Western Cape Province and the production of 710 000 tons in 2011 contributed about 35 % to the total production of South Africa. The Swartland is the most important wheat producing area in the Western Cape. This area is subjected to a Mediterranean-type climate with hot dry summers and wet and mild winters, receiving nearly 80 % of its long-term annual rainfall of 397 mm during the months of April and September. This usually results in very wet conditions during the vegetative growth stages when spring wheat is planted during autumn in May and moisture stress during the grain filling period in September. In the Swartland wheat producing area the predominant soil is a shallow sandy-loam with a clay content of 10 - 15 % and a high stone content in the A horizon. The water-holding capacity of these soils also tends to be low due to restricted depth, high stone and low organic matter content.

In order to improve sustainability of wheat production in the Swartland area, producers are advised to use crop rotation systems and conservation tillage instead of the traditional wheat monoculture and conventional methods of mouldboard tillage.

Although the beneficial effects of crop rotation and conservation tillage are well known, soil and crop responses differ as a result of soil properties and climatic conditions in different production areas. In order to determine the effect of crop rotation systems and tillage practices on the soil properties and the development, yield and quality of crops in the Swartland a long-term study was started at the Langgewens Research Farm, near Moorreesburg (-33.27665°; 18.70463°; altitude 191 m) in 2007. The present study was done as a component study within the above-mentioned long-term crop rotation/soil tillage trial. The aim was to quantify the effects of conventional-till (CT), minimum-till (MT), no-till (NT) and zero-till (ZT) on soil water and mineral-N content and the subsequent response of a wheat crop grown in a wheat monoculture (WWWW) system, compared to crop rotation systems which included lupins and canola (LWCW) or annual medics (McWMcW). This was done to get a better understanding of soil parameters that will improve sustainability in crop production systems on the shale derived soils of the Western Cape. Data were recorded for the wheat crops during the growing seasons of 2010 and 2011 which were the fourth and fifth year of the long-term study and the end of the first crop rotation cycle. A very severe ryegrass infestation occurred in the ZT plots, because the planting technique (star-wheel planter) made it impossible to efficiently apply herbicides which require mixing with the soil (Trifluralin). Results obtained with this treatment were generally poor and not a realistic indication of the potential of this treatment.

Soil water content is a very important factor determining the crop development and grain filling leading to grain yield and quality. Soil water content was not significantly influenced by the crop rotation systems used in this study. The soil water content was however influenced by tillage practice, with MT and NT showing higher levels compared to CT and ZT at some sampling dates in both years. Zero-till had the lowest soil moisture content due to the high ryegrass infestations.

The soil mineral-N content was influenced by crop rotation system and tillage practice. Although not significant at all sampling dates, mineral-N content tended to be higher during the growing season of the wheat crops in the crop rotation systems which included legumes (lupins and medics) compared to monoculture wheat. During 2010 a higher mineral-N content was reported for CT which is an indication of a higher mineralisation rate due to soil disturbance and aeration. In contrast to this, no specific trends, except for low values with ZT, were evident in 2011 which confirmed the effect of climatic conditions during the growing season on N mineralisation and explain contrasting results reported in literature.

Crop rotation influenced crop growth and development as measured by leaf area index (LAI), light interception, biomass production during the vegetative stages as well as total biomass at harvest. In general, different crop measurements showed the beneficial effects of having a crop rotation system which included legume and/or oilseed crops very clearly. From the results obtained, medic-wheat rotations (McWMcW) seemed to be the most sustainable crop rotation system, most probably due to the higher availability of N fixed during the previous season (medic pasture). The different tillage treatments affected LAI, light interception biomass production and total biomass accumulated. The ZT treatments were again significantly lower than other tillage treatments except for light interception which was increased by the dense weed canopy. Leaf development and chlorophyll content tended to increase as degree of soil disturbance increased and especially in the crop rotation system that included medics, but total biomass production tended to be higher with MT and NT, most probably due to the higher soil water content.

Results of the wheat yield and yield components in this study gave an indication of the advantages of crop rotation systems and implementing conservation tillage practices such as MT and NT. Higher number of ear-bearing tillers and spikelets per ear were obtained with the crop rotation systems compared to wheat monoculture while McWMcW tended to record the highest yields in both 2010 and 2011. With regards to tillage, NT and MT caused the highest number of ear bearing tillers, but CT resulted in a higher number of spikelets per ear and the highest number of kernels per ear because a higher LAI gave this treatment a higher photosynthetic potential. Although ZT resulted in the highest number of plants m^{-2}, this tillage practice cannot be recommended due to the inability to ensure effective weed control until new herbicides become available. The grain yield was, as expected from measurements and prevailing soil conditions, the highest for NT and MT in 2010 and highest for NT in 2011.

Inconclusive results with regard to the quality parameters in both 2010 and 2011 illustrate the important effect of environmental conditions on the quality of wheat grain. Although the protein content, which is one of the most important quality parameters, was higher in the crop rotation systems which included legumes compared to wheat monoculture, no specific trend with regards to tillage practice was found. This was most probably due to below-average rainfall during the grain filling stage in both seasons.

This study indicated that crop rotations which include legume and oilseed crops such as canola are a very important management practice to ensure sustainable wheat production in the Swartland. It also showed the advantages of implementing conservation tillage practices such as MT and NT. It is strongly believed that the trends and tendencies for the particular treatment combinations will become more apparent with time as the reported results were obtained during the fourth and fifth years of the trial and it is well known that changes in soil properties as a result of crop rotations and tillage need several years to develop. With time the interaction between environmental conditions and cropping practices should also become clear for the Swartland crop production area, but even at this early stage, results encourage the use of conservation tillage instead of conventional tillage and even more so the implementation of crop rotation systems which include crops such as lupins, canola and medics.