Johnston AE. 1986. Soil organic matter, effects on soil and crops. *Soil use management* 2: 97-105.

Kirkegaard JA, Hocking PJ, Angus JF, Howe GN, Gardner PA. 1994. Effect of Brassica break crops on the growth and yield of wheat. *Australian Journal of Agricultural Research* 45: 529-545.

Kumudini S, Grabau L, Van Sanford D, Omielan J. 2008. Analysis of yield-formation processes under no-till and conventional tillage for soft red winter wheat in the South-Central Region. *Agronomy Journal* 100:1026–1032.

Larney FJ, Lindwall CW. 1995. Rotation and tillage effects on available soil water for winter wheat in a semi-arid environment. *Soil and Tillage Research* 36: 111-127.

Liebig MA, Tanaka DL, Wienhold BJ. 2004. Tillage and cropping effects on soil quality indicators in the northern Great Plains. *Soil and Tillage Research* 78: 131-141.

López-Bellido L, Fuentes M, Castillo JE, López-Garrido FJ. 1998. Effects of tillage, crop rotation and nitrogen fertilization on wheat-grain quality grown under rainfed Mediterranean conditions. *Field Crops Research* 57: 265-276.

López-Bellido L, López-Bellido RJ, Castillo JE, López-Garrido FJ. 2000. Effects of tillage, crop rotation and nitrogen fertilization on wheat under rainfed Mediterranean conditions. *Agronomy Journal* 92: 1054-1063.

López-Bellido RJ, López-Bellido L. 2001. Efficiency of nitrogen in wheat under Mediterranean conditions: effect of tillage, crop rotation and N fertilization. *Field Crops Research* 71: 31-46.

Maali SH. 2003. Biomass production, yield and quality of spring wheat to soil tillage, crop rotation and nitrogen fertilization in the Swartland wheat producing area of South Africa. PhD Thesis, Stellenbosch University, South Africa.

Merrill SD, Black AL, Bauer A. 1996. Conservation tillage affects root growth of dryland spring wheat under drought. *Soil Science Society of America Journal* 60: 575–583.

Mrabet R. 2000. Differential response of wheat to tillage management systems in a semiarid area of Morocco. *Field Crops Research* 66: 165–174.

Norwood CA. 2000. Dryland winter wheat as affected by previous crops. *Agronomy Journal* 92: 121–127.

Rasmussen PE, Rickman RW, Klepper BL. 1997. Residue and fertility effects on yield of no-till wheat. *Agronomy Journal* 89: 563–567.

Rieger S, Richner W, Streit B, Frossard E, Liedgens M. 2008. Growth, yield, and yield components of winter wheat and the effects of tillage intensity, preceding crops, and N fertilisation. *European Journal of Agronomy* 28: 405–411.

Satorre EH, Slafer GA. 1999. Wheat: Ecology and physiology of yield determination. Cambridge: Academic Press.

Sinclaire TR. 1998. Historical Changes in Harvest Index and Crop Nitrogen Accumulation. *Crop Science* 38: 638-643

Van Biljon JJ. 1987. Die invloed van verskillende tye van stikstofbemesting op koring. MSc Thesis, Free State University, South Africa.

Weisz R, Bowman DT. 1999. Influence of tillage system on soft red winter wheat cultivar selection. *Journal of Production Agriculture* 12: 415–418.

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.

6.5. References

Anonymous. 2012. Guidelines for the production of small grain in the winter rainfall region, 2012. Compiled by E Burger and W Kilian, ARC-SGI, P/Box X29, Bethlehem, 9700.

Arshad MA, Soon YK, Azooz RH. 2002. Modified no-till and crop sequence effects on spring wheat production in northern Alberta, Canada. *Soil and Tillage Research* 65: 29-36.

Ayoub M, Guertin S, Fregeau-Reid J, Smith L. 1994. Nitrogen fertiliser effect on bread-making quality of hard red spring wheat in Eastern Canada. *Crop Science* 34: 1346-1352.

Blumenthal CS, Batey IL, Bekes F, Wrigley CW, Barlow EW. 1991. Seasonal changes in wheat-grain quality associated with high temperatures during grain filling. *Australian Journal of Agricultural Research* 42: 21-30.

Borghi B. 1996. Nitrogen as determinant of wheat growth and yield. In E.H. Satorre and G.A. Slafer (eds.): Wheat: Ecology and physiology of yield determination. *Food Product Press*. New York.

Borghi B, Corbellini M, Minoia C, Palumbo M, Di Fonzo N, Perezin M. 1997. Effects of Mediterranean climate on wheat bread-making quality. *European Journal of Agronomy* 6: 145-154.

Bundy LG, Andraski TW. 2004. Diagnostic tests for site-specific nitrogen recommendation for winter wheat. *Agronomy Journal* 96: 608-614.

Campbell CA, Read WL. 1968. Influence of air temperature, light intensity and soil moisture on the growth, yield and some growth analysis characteristics of Chinook wheat grown in the growth chamber. *Candian Journal of Plant Science* 48: 299-311.

Carr PM, Martin GB, Horsley RD. 2008. Wheat grain quality response to tillage and rotation with field pea. *Agronomy Journal* 100: 1594-1599.

Chan KY, Heenan DP. 1996. The influence of crop rotation on soil structure and soil physical properties under conventional tillage. *Soil and Tillage Research* 37: 113- 125.

Cooper PJM, Gregory P, Tully D, Harris H. 1987. Improving water-use efficiency in the rainfed farming systems of West Asia and North Africa. *Experimental Agriculture* 23: 113-158.

De Vita P, Di Paolo E, Fecondo G, Di Fonzo N, Pisante M. 2007. No-tillage and conventional tillage effects on durum wheat yield, grain quality and soil moisture content in Southern Italy. *Soil and Tillage Research* 92: 69-78.

Hagberg S. 1960. A rapid method for determining alpha-amylase activity. *Cereal Chemistry* 37: 218-222.

Halloran GM. 1981. Cultivar differences in nitrogen translocation in wheat. *Australian Journal of Agricultural Research* 32: 535-544.

Hook SCW. 1984. Specific weight and wheat quality. *Journal of the Science of Food and Agriculture* 35: 1136-1141.

Khathar BS, Bell AE, Schofield JD. 1994. The dynamic rheological properties of gluten and gluten sub-fractions from wheat of good and poor bread-making quality. *Journal of Cereal Sience* 22: 29-44.

Kleijer G, Levy L, Swaerzei R, Fossat D, Brabant C. 2007. Relationship between test weight and several quality parameters in wheat. *Revue Suisse Agriculture* 39: 305-309.

López-Bellido L, Fuentes M, Castillo JE, López-Garrido FJ. 1998. Effects of tillage, crop rotation and nitrogen fertilizer on wheat-grain quality grown under rainfed Mediterranean conditions. *Field Crops Research* 57: 265-276.

López-Bellido L, López-Bellido RJ, Castillo JE, López-Garrido FJ. 2000. Effects of long-term tillage, crop rotation and nitrogen fertilization on bread-making quality of hard red spring wheat. *Agronomy Journal* 72: 197-210.

López-Bellido RJ, López-Bellido L. 2001. Efficiency of nitrogen in wheat under Mediterranean conditions: effect of tillage, crop rotation and N fertilization. *Field Crops Research* 71: 31-46.

Maali SH, Agenbag GA. 2006. Effect of soil tillage and nitrogen application rates on bread-baking quality of spring wheat (*Triticum aestivum* L.) in the Swartland wheat producing area of South Africa. *South African Journal of Plant and Soil* 23: 163-168.

Miller PR, Holmes JR. 2005. Cropping sequence effects on four broad-leaf crops on four cereal crops in the northern Great Plains. *Agronomy Journal* 94: 261-272.

Neales TF, Anderson MJ, Wardlaw IF. 1963. The role of the leaves in the accumulation of nitrogen by wheat during ear development. *Australian Journal of Agricultural Research* 14:725-736.

Nel MM, Agenbag GA, Purchase JL. 1998**.** Sources of variation for yield, protein content and hectolitre mass of spring wheat (*Triticum aestivum* L.) cultivars of the Western and Southern Cape. *South African Journal of Plant and Soil* 15(2):72-79.

Nel MM, Agenbag GA, Purchase JL. 2000a**.** Sources of variation for milling and mixing characteristics of spring wheat (*Triticum aestivum* L.) cultivars of the Western and Southern Cape. *South African Journal of Plant and Soil* 17(1): 30-39.

Nel MM, Agenbag GA, Purchase JL, 2000b. Sources of variation for baking characteristics of spring wheat (*Triticum aestivum* L.) cultivars of the Western and Southern Cape. *South African Journal of Plant and Soil* 17(1): 40-48.

Nyiraneza J, Cambouris AN, Ziadi N, Tremblay N, Nolin MC. 2012. Spring wheat yield and quality related to soil texture and nitrogen fertilization. *Agronomy Journal* 104: 589-599.

Randall PJ, Moss HJ. 1990. Some effects of temperature regime during grain filling on wheat quality. *Australian Journal of Agricultural Res*earch 41: 603-617.

Satorre EH, Slafer GA. 1999. Wheat: Ecology and physiology of yield determination. Cambridge: Academic Press.

Simane B, Peacock JM, Struik PC. 1993. Differences in developmental plasticity and growth rate among drought-resistant and susceptible cultivars of durum wheat (*Triticum turgidum* L. var. durum). *Plant Soil* 157:155–166.

Snedecor GW, Cochran WG. 1967. Statistical Methods, Sixth Edition, The Iowa State University Press, AMES, IOWA USA. Chapter 4 and 11-12

Terman GL, Raming RE, Dreier AF, Olson RA. 1969. Yield-protein relationships in wheat grain, as affected by N and water. *Agronomy Journal* 61: 755-759.

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.