Evaluating the effect of crop rotations and tillage practices on soil water balances of selected soils and crop performances in the Western Cape.

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Thesis presented in partial fulfilment of the requirements for the degree of Master of Soil Science in the
Faculty of AgriSciences at the Stellenbosch University

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Declaration

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Abstract

The aim of this study was to investigate the influence of crop rotation and soil tillage on the soil water balance and water use efficiency of wheat, canola, lupin and medics in the Swartland sub region of the Western Cape. This trail was conducted as a component study within a long-term crop rotation/tillage trial during 2012 and 2013 at the Langgewens Research Farm ($33^0$16’42.33” S; $18^0$42’11.62” E; 191m) of the Western Cape Department of Agriculture near Moorreesburg.

The experiment was laid out as a randomized complete block, with a split-plot treatment design and replicated four times. Three crop rotation systems, continues wheat (WWWW), wheat/medic/wheat/medic (WMcWMc) and wheat/canola/wheat/lupin (WCWL) were allocated to main plots. . Each main plot was subdivided into four sub-plots allocated to four tillage treatments namely: zero-till (soil left undisturbed and planted with zero-till planter), no-till (soil left undisturbed until planting and then planted with a tined no-till planter), minimum-till (soil scarified March/April and then planted with a no-till planter) and conventional tillage (soil scarified late March/early April, then ploughed and planted with a no-till planter). All straw, chaff and stubble remained on the soil surface and no-grazing was allowed on all tillage treatments. Three replicates were included in this current study. Only the no-till (NT) and conventional till (CT) were included in this current study as main tillage treatments.

The volumetric soil water content was monitored at weekly intervals during the active growing season (May-October) and once a month during the fallow period (November-April) using a Diviner 2000 soil moisture meter. The Diviner 2000 was used to record the soil water content at every 100 mm depth increment up to the maximum depth of the profile. At the end of the growing season the total biomass, grain yield and quality parameters were determined.

The soil water balance data calculated from the 2012 season were found to be inconclusive due to too shallow installation of soil water monitoring tubes and big variations in the depth complicating any attempt in comparing data from treatments and cropping systems. Soil water monitoring tubes was installed to a depth of 900 mm in the 2013 season. Complications during planting in the 2013 season resulted in very poor emergence in the CT sites. Weed counts revealed that only 38 % of CT sites were covered by crop, 31 % with weeds and 31 % were completely bare. The NT sites had 40 % crop coverage, 50.5 % grass weed coverage and only 9.5% bare surface. As a consequences crop rotation had no effect on the soil water balance, while the tillage treatments showed a response. The effect that tillage had on the soil water balance was clearly shown in the 2013 season, in which 79 mm more rainfall occurred than the long-term average. NT retained more soil water in the profile in the drier first half of the season when only 30 % of the total rainfall in the 2013 season

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occurred. There was no real difference in the soil water retention in the second half of the season where 70 % of the total rainfall in the 2013 season occurred.

Crop rotation did have a positive effect on grain yield. Wheat monoculture was out performed by legume based cropping systems. This trend was also observed in the biomass production. No significant difference between tillage treatments were recorded when comparing grain yield data. However wheat mono culture was again out-performed by the McWMcW, CWLW and LWCW systems producing on average significantly higher biomass.

The data from both seasons suggest that in seasons where more rainfall than the long term average occurs, there is no difference in the RUE between cropping systems or tillage practices..

This study highlighted the major effect that the prevailing weather conditions have and that the expected advantages associated with NT most likely only come into play in dry conditions when plant water availability is limited.

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Uittreksel

Die doel van hierdie studie was om die invloed van grondbewerking en gewasproduksiestelsels op die grondwaterbalans en doeltreffendheid van watergebruik te ondersoek in die koringproduserende gebied van Malmesbury. Hierdie eksperiment is uitgevoer as 'n komponentstudie binne 'n langtermyn grondbewerking/gewasrotasieproef gedurende 2012 en 2013 op die Langgewens Navorsingsplaas (33016'42 .33 'S; 18042'11 0,62' E, 191m) van die Wes-Kaapse Departement van Landbou naby Moorreesburg.

Die eksperiment is uitgelê as 'n volledige ewekansige blok, met 'n gesplete perseel behandelingsontwerp met vier herhalings. Drie gewasproduksiestelsels naamlik, koring monokultuur (WWWW), koring/medic/koring/medic (WMcWMc) en koring/canola/ koring/lupiene (WKWL) is elk toegeken aan persele en vier keer herhaal. Elke hoofperseel is onderverdeel in vier subpersele en bewerkingsbehandelings is soos volg toegeken: Konvensionele bewerking (CT) - grond gebreek in Maart/April, en daarna geploeg en geplant met geen bewerkingsplanter. Minimum bewerking (MT) - grond gebreek in Maart/April en daarna geplant met 'n geen bewerkingsplanter. Geen bewerking (NT) - grond is heeltemal onversteur gelaat tot planttyd en daarna geplant met 'n geen bewerkingsplanter. Zero bewerking (ZT) - grond tot planttyd met rus gelaat en dan geplant met 'n sterwielplanter. Alle strooi, kaf en stoppels het op die grondoppervlak gebly en geen beweiding is toegelaat nie. Slegs drie herhalings is ingesluit in die huidige studie en slegs die geen bewerking (NT) en konvensionele bewerking (CT) is in die huidige studie as hoof bewerkingbehandelings ingesluit.

Die volumetriese grondwaterinhoud is weekliks gemonitor tydens die aktiewe groeiseisoen (Mei - Oktober) en een keer 'n maand gedurende die braaktydperk (November - April) met behulp van 'n Diviner 2000 grondvogmeter. Die Diviner 2000 is gebruik om die grondwaterinhoud by elke 100 mm diepte tot die maksimum diepte van die profiel te bepaal. Aan die einde van die seisoen is die totale biomassa, graanopbrengs en kwaliteitparameters bepaal.

Die data vir grondwaterbalans van die 2012-seisoen is buite rekening gelaat weens te vlak installering van moniteringsbuise en groot variasie in die dieptelesings wat enige poging om vergelykende data van rotasie en behandelings te verkry, bemoeilik het. Moniteringsbuise vir grondwater is geïnstalleer tot op 'n diepte van 900 mm in die 2013-seisoen. Komplikasies tydens die plantaksie in die 2013-seisoen het gelei tot 'n baie swak opkoms in die CT-persele. Slegs 38 % van die CT-persele was bedek deur die gewas en 31 % met onkruid, terwyl 31 % van die oppervlak onder CT-behandeling heeltemal kaal was. Die NT-persele het 40 % gewasbedekking, 50.5 %

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grasbedekking en slegs 9.5 % kaal oppervlak gehad. Dit het die poging, om die effek van wisselboustelsels op die grondwaterbalans, in die wiele gery.

Alhoewel wisselbou skynbaar geen effek op die grondwaterbalans gehad het nie, het die tipe bewerking egter wel ‘n effek gehad. Die effek van grondbewerking op die grondwaterbalans het duidelik na vore gekom in die 2013-seisoen. In hierdie seisoen het 79 mm meer reën geval as die langtermyngemiddelde. Geen bewerking het meer grondwater in die droër eerste helfte van die seisoen in die profiel behou, toe slegs 30% van die totale reënval in die 2013 geval het. Daar was geen beduidende verskil in die grondwaterretensie in die tweede helfte van die seisoen toe 70% van die totale reënval in die 2013 geval het nie.

Wisselbou het egter 'n positiewe uitwerking op die graanopbrengs gehad. Koring monokultuur is in opbrengsyfers geklop deur stelsels met peulplante as komponent. Hierdie tendens is ook waargeneem in die biomassaproduksie. Bewerkingsbehandelings het geen beduidende verskil in graanopbrengste tot gevolg gehad nie, hoewel die biomassaproduksie van koring monokultuur weer geklop is deur die McWMcW-, CWLW- en LWCW-stelsels.

Die data van beide seisoene dui daarop dat in seisoene waar meer reën as die langtermyn gemiddelde voorkom, daar geen verskil in die RUE tussen verbouingstelsels of bewerkingspraktykes was nie.

Hierdie studie beklemtoon die groot invloed wat die heersende klimaat speel en dat die verwagte voordele wat verband hou met NT waarskynlik slegs ‘n rol speel in droër jare.

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As a man thinks in his heart so is he

Proverb 23:7

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3D	Three dimensional
^{0}C	Degrees celcius
cm	Centimeter
$cm.s^{-1}$	Centimeter per second
cm^2	Square centimetre
$cm^3.cm^{-3}$	Centimeter cubic per centimeter cubic
CT	Conventional tillage
CWLW	Canola-wheat-lupins-wheat
$ears.m^{-2}$	ears per square meter
EC	Electrical conductivity
FC	Field water capacity
$g.cm^{-3}$	Gram per cubic centimetre
ha	Hectare
kg	Kilogram
$kg.cm^{-2}$	Kilogram per square centimetre
$kg.ha^{-1}$	Kilogram per hectare
$kg.Hl^{-1}$	Kilogram per hector-litre
K_s	Saturated hydraulic conductivity
L	Litre
$L.ha^{-1}$	Litre per hectare
LWCW	Lupins-wheat-canola-wheat
m	Meter
m^{-3}	Meter cube
McWMcW	Medic-wheat-medic-wheat
Mg	Megagram
$mg.m^{-3}$	Milligram per meter cubic
$ml.ha^{-1}$	Millilitre
mm	Millimeter
$mm.h^{-1}$	Milimeter per hour
MT	Minimum tillage
NT	No tillage
OEFA	Organic certification fact sheet
PAW	Plant available water
RUE	Rainwater use efficiency
SWB	Soil water balance
SWC	Soil water content
WCWL	Wheat-canola-wheat-lupin
WLWC	Wheat-lupins-wheat-canola
WMcWMc	Wheat-medic-wheat-medic
WUE	Water use efficiency
WWWW	Wheat-wheat-wheat-wheat
ZT	Zero tillage

Chapter 1: Introduction

1.1 Background

The Western Cape is one of the most important wheat producing areas of South Africa. The fast changing economics of wheat farming puts pressure on dry-land farmers of the Western Cape to produce cash crops sustainably. The Western Cape consists of 13 million ha of which 89.3 % is classified as farmland. Only the Free State has a higher percentage of farmland (Anon 2012 d). There are four main wheat producing provinces in South Africa. The Western Cape (winter rainfall area), the Free State (summer rainfall area), the Northern Cape (irrigated area), and to a lesser extent the North Western Province (irrigated area). In the 2010/2011 season 42 % of the total wheat production in South Africa came from the Western Cape. (Anon 2011). The population of the Western Cape grew from 4 646 000 in 2005 to 5 288 000 people in 2011 (Anon 2012 d). That constitutes to 107 000 more people to feed annually. However, South Africa's wheat production was not increased to the same extent. Large volumes of wheat are imported from other countries, including countries from South America to supply the increases in demand. (Figure 1.1).

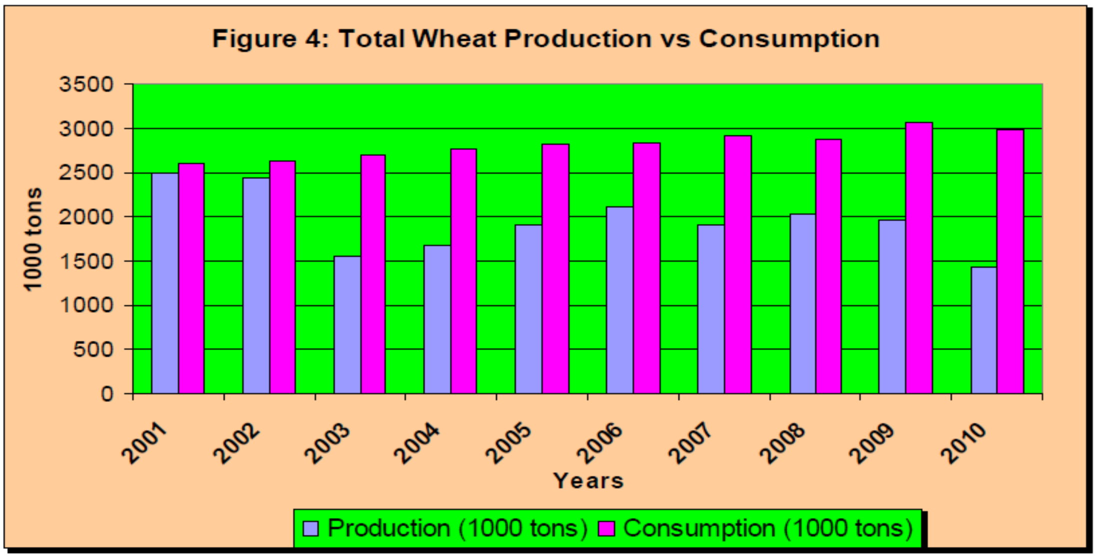


Figure 1.1: Consumption and production of wheat in South Africa (Anon, 2012)

Wheat production in the Western Cape is predominantly under dry-land conditions. South Africa has a mean annual rainfall of 450mm (Palmer and Ainslie, 2006). South Africa is the 30th driest country in the world (Anon, 2012 e).

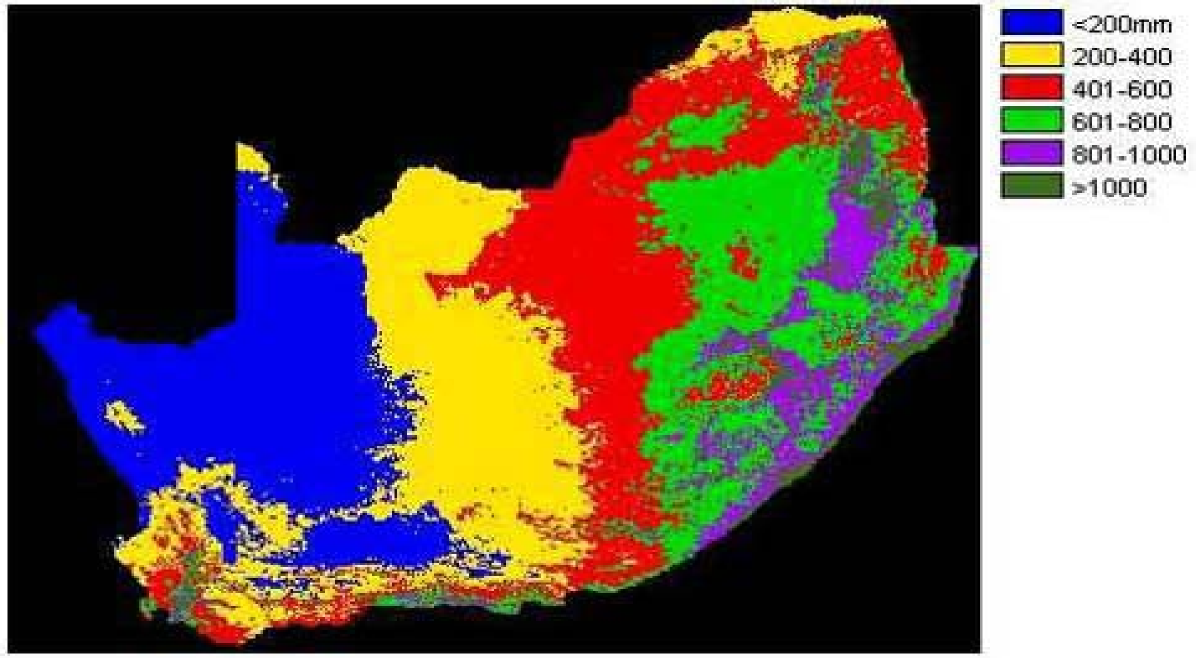


Figure 1.2: Rainfall distribution pattern across South Africa (Palmer and Ainslie, 2006)

The rainfall pattern across the country is very erratic and rainfall generally increases from west to east (Figure 1.2). The wheat producing areas of the Western Cape are classified as semi-arid (Table 1.1 and Figure 1.2).

Table 1.1: Climatic classification according to mean annual rainfall (Palmer and Ainslie, 2006)

Rainfall (mm)	Classification	Percentage of land surface %
< 200	Desert	22.8
201-400	Arid	24.6
401-600	Semi-arid	24.6
601-800	Sub-humid	18.5
801-1000	Humid	6.7
> 1000	Super-humid	2.8

The Western Cape is the second driest province in South Africa (Benhin, 2006). The mean annual rainfall for Malmesbury (in the Western Cape) ranges between 401 and 500 mm (Figure 1.3).

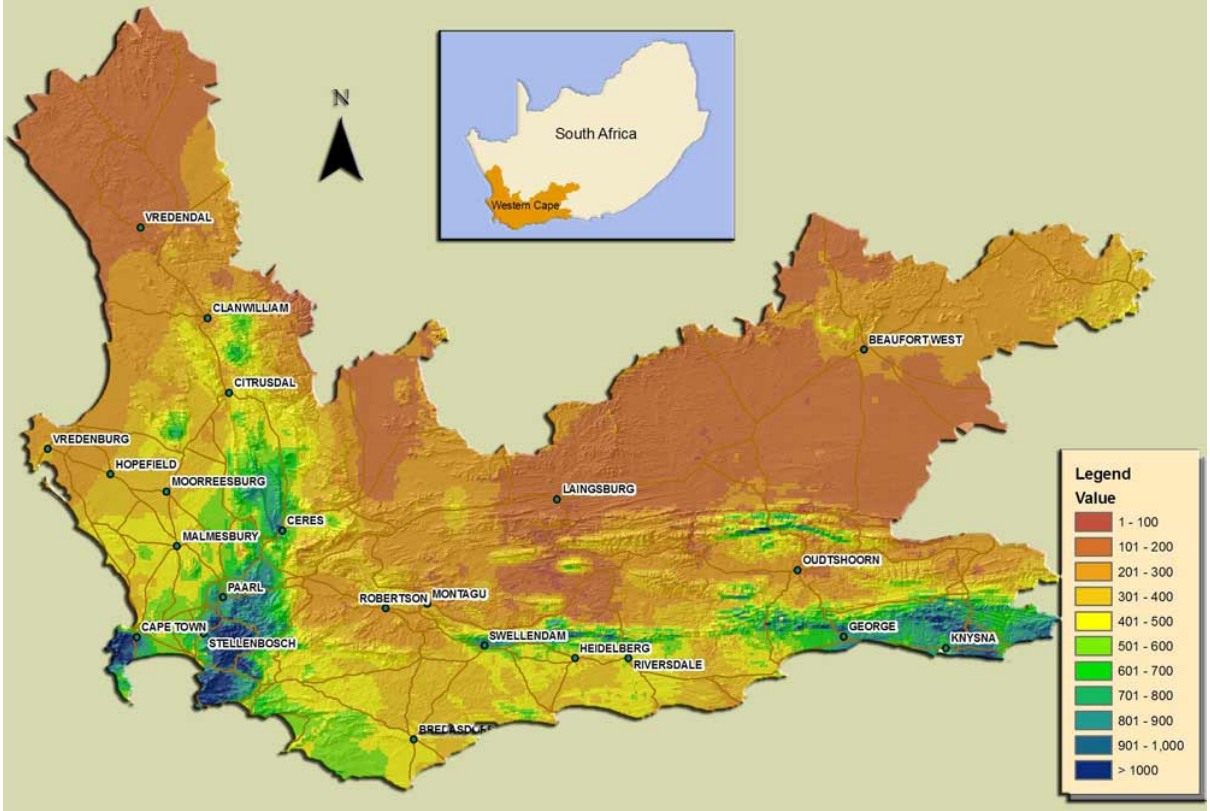


Figure 1.3: Mean annual rainfall distribution of the Western Cape (Anon, 2012 e)

The rainfall in the Western Cape, therefore does, not cater for continuously high yields, and coupled with increasing temperatures and scares water supply, this do not promise a bright future in terms of dry-land crop production in the Western Cape.

The scarcity of water does not only make it difficult for farmers to produce wheat successfully, but the increase in production cost as a result of increased labour cost and higher fuel prices, forces producers to investigate alternative farming systems. The amount and frequency of rainfall, high temperatures late in the season, and prevailing winds, are all environmental factors that are nearly impossible to manipulate, change or control. Research needs to identify management strategies to ensure higher grain yields and optimizing the use of natural resources.

In order to ensure the best possible crop performance in limiting climatic conditions, limited water supply and increasing temperatures, we need to understand the soil-plant-climate interaction. Water is one of the most important limiting climatic factors for crop production in the Western Cape. In dry-land farming systems the total production is completely reliant on rainwater (Hoffman, 1990). This is supported by Bennie et al. (1994) who reported a strong positive correlation between profile available water and the resulting crop yields. The question is how to maximise profile available water for dry-land crop production.

Tillage research in the past 50 years investigated various aspects of the soil water balance. Hoffman (1990) found that rainfall storage efficiency (RSE) is mainly determined by the amount and distribution of rainfall. The RSE is determined by the soil's ability to absorb and store rain water (Hoffman 1990). According to Hoffman (1990) and Bennie (1994) soil preparation, tillage practices and crop rotation are therefore of high importance in maximising the ability of soils to absorb and store rainwater. These aspects can be managed by farmers, and in an effort to address the challenge, an increasing number of producers in the Western Cape adopted conservation agriculture (CA) strategies. It is of critical importance to understand the impact of CA, reduced tillage, maximum stubble retention/cover and crop rotation, on the soil water balance to move forward in environmental sustainable farming systems.

The aim of this study was therefore be to develop a better understanding of the effect of CA, specifically no-till (NT), on soil water relations and to identify/develop management practices and strategies that will ensure maximum RUE by crops.

1.2 The soil water balance

1.2.1 Definition of the soil water balance

In dry-land farming systems, when short periods of drought occur, water stored in the soil profile can buffer the crop through dry spells. Erratic and difficult climatic conditions in the Western Cape necessitate producers to maximise the water infiltration and storage in the soil profile. This can only be achieved if the soil water balance and the different components thereof are well understood.

The soil water balance calculates the change in soil water content by calculating the difference between the water that enters and leaves the soil system (Figure 1.4).

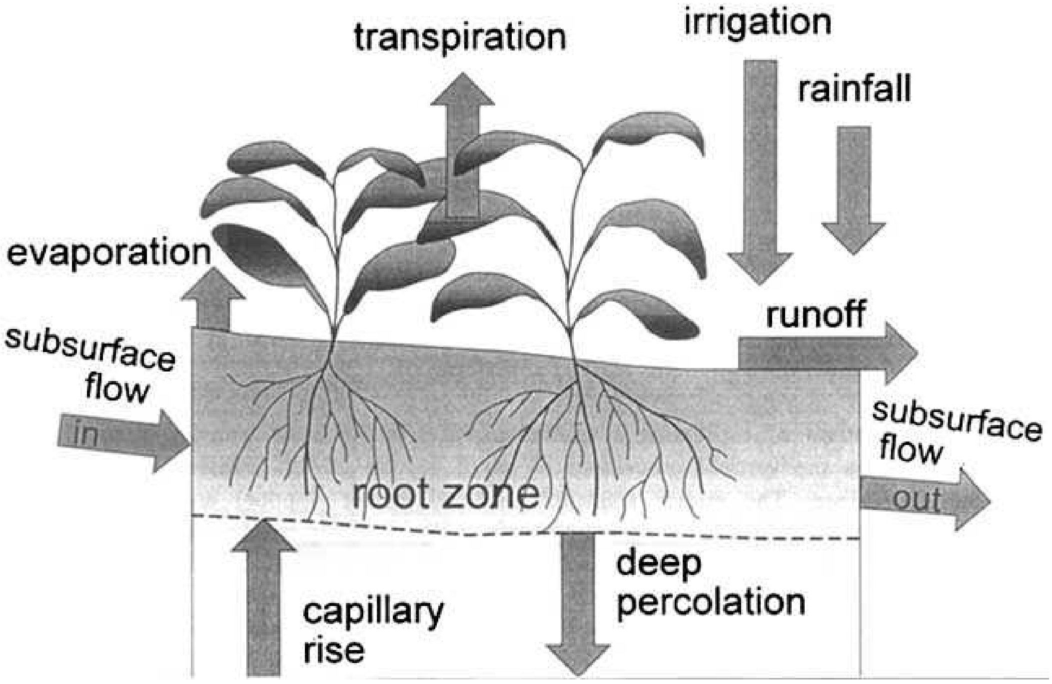


Figure 1.4: Schematic illustration of the soil water balance components (Anon, 2012 a)

Hillel (1998) described the water balance as:

Change in storage = Gains – Losses

$(\Delta S+\Delta V) = (P+I+U) - (R+D+E+T)$

Where

ΔS = the change in soil water
ΔV = the amount of water incorporated in the vegetative biomass
P = Precipitation
I = Irrigation
U = Upwards capillary flow into the root zone from a water table
R = Runoff
D = Drainage or deep percolation
E = Evaporation from the soil surface
T = Transpiration by the plants

Evaporation from the soil surface and transpiration are called evapotranspiration (ET). These processes are interlinked and very difficult to measure separately. The equation can therefore be altered as follows:

$(\Delta S+\Delta V) = (P+I+U) - (R+D+ET)$, where ET refers to evapotranspiration.

1.2.2 Soil water balance and the hydrological balance

The soil water balance forms part of the overall intricate hydrological cycle (Figure1.5). Soil water balances can be computed within defined spatial boundaries whether on field level, farm level or district level (Burt, 1999).

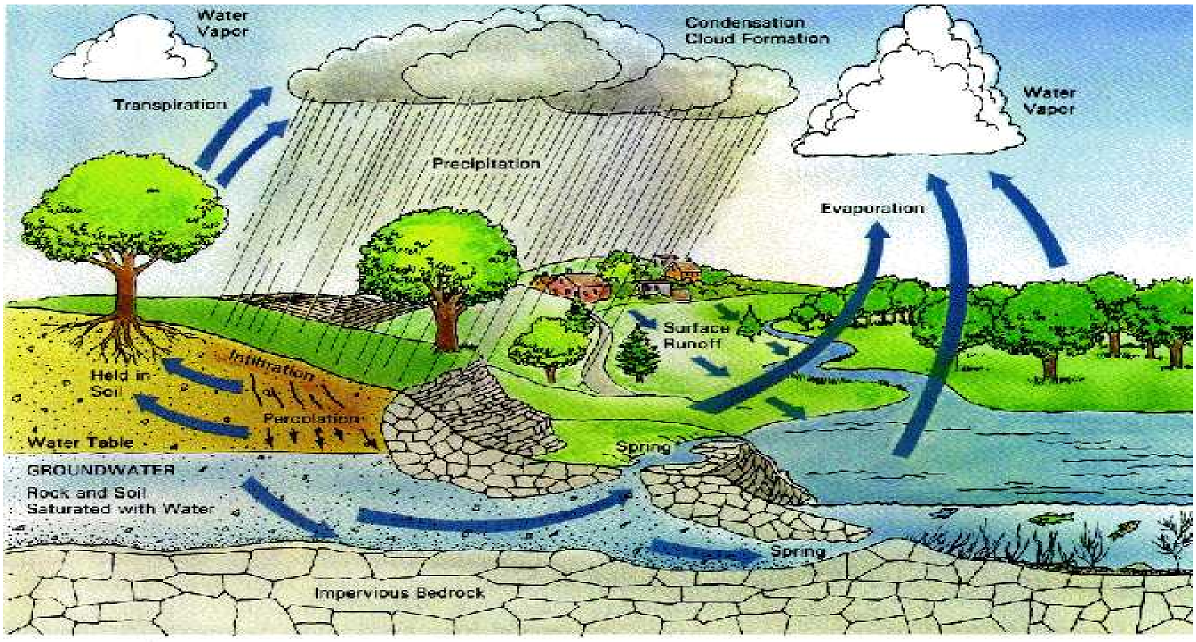


Figure 1.5: The Hydrological cycle (Anon, 2007)

Understanding the hydrological cycle can provide useful information about possible surface runoff and rainfall pattern, which are two key components of the soil water balance.

The soil water balance and the hydrological cycle are intertwined and interact with one another and understanding this will be useful when managing agricultural systems. The current study focused on the effect of crop rotation and tillage on the soil water balance and subsequent availability of soil water for crop development and productivity.

1.2.3 Soil physical characteristics and soil water balance interactions

Soil water content plays a central role in climate and crop production interactions (Fernandez-Illescas et al., 2001) and is affected by the physical properties of soils. Soil texture and structure describe soil physical properties like the textural class of the soil, pore size distribution and bulk density. These in turn determine properties like total porosity, hydraulic conductivity, soil matrix potential and the pore size distribution.

Texture plays an important role in the soil water balance because it affects the partitioning of rainfall into the soil water balance components namely; evapotranspiration, drainage, infiltration and runoff (Fernandez-Illescas et al., 2001). The change in soil water content over time, is strongly affected by the texture of the soil because of the pore size distribution (Figure 1.6).

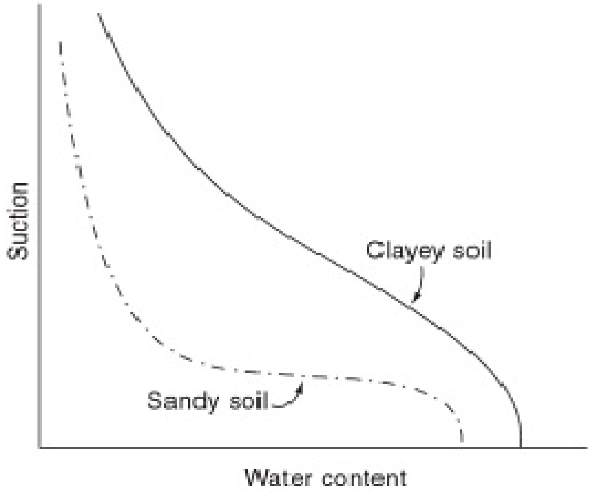


Figure 1.6: Soil water retention curves for different textural classes (Hillel, 1998)

Figure 1.6 illustrates the difference between the soil water retention curves for two textural classes. A clayey has a larger percentage of micro-pores and will result in a higher volumetric water content at a specific matric potential, as appose to a sandy soil. The former soil will retain water more tightly and therefore the change of soil water content over a certain period of time might be longer. The change in soil water content over time in a soil with a high sand fraction will be much faster because of water being more readily available to the plant. Drainage and evaporation will occur more easily in sandy soils because the hydraulic conductivity is much higher in a sandy soil than a clay soil. Plant available water is therefore also a function of soil texture.

Hydraulic conductivity is governed by soil texture due to the impact on pore size, distribution and connectivity (Hillel, 1998, Cresswell, 1992) (Figure 1.7). The hydraulic conductivity in turn governs the process of water infiltration. Water infiltration and runoff are inseparable (Unger and Steward, 1983). Soils with high a clay content have a much lower saturated hydraulic conductivity and infiltration rate and take a longer time to conduct water (Figure 1.8). Loss of water due to runoff is a big threat in clayey soils. Sandy soils may have higher saturated hydraulic conductivities, and conducts the water faster but retain less water than a clay soil.

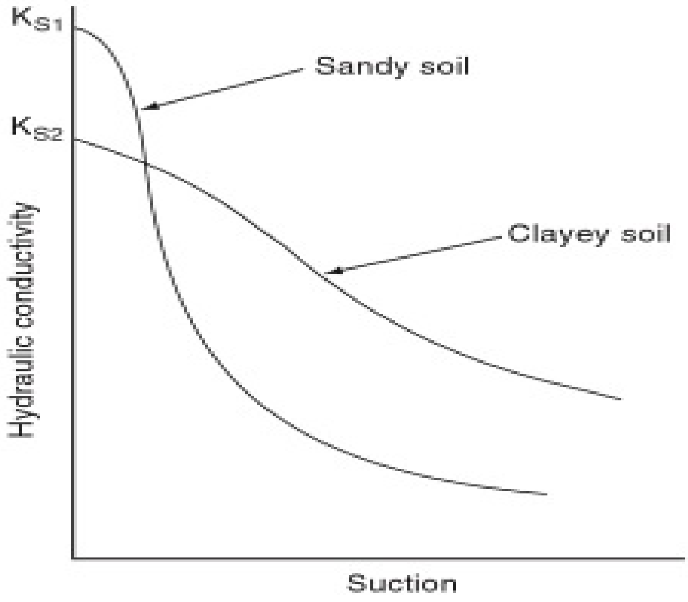


Figure 1.7: Hydraulic conductivity of a clayey soil and sandy soil (Hillel, 1980)

Soil texture also has an important impact on the soil water balance due to the effect it has on the temperature of the soil (Figure 1.8). Temperature is one of three driving forces behind evaporation. An ongoing supply of heat is needed to meet the latent heat requirements for evaporation to take place (Hillel, 1998). This in turn affects one of the largest contributing loss components of the soil water balance, namely evaporation.

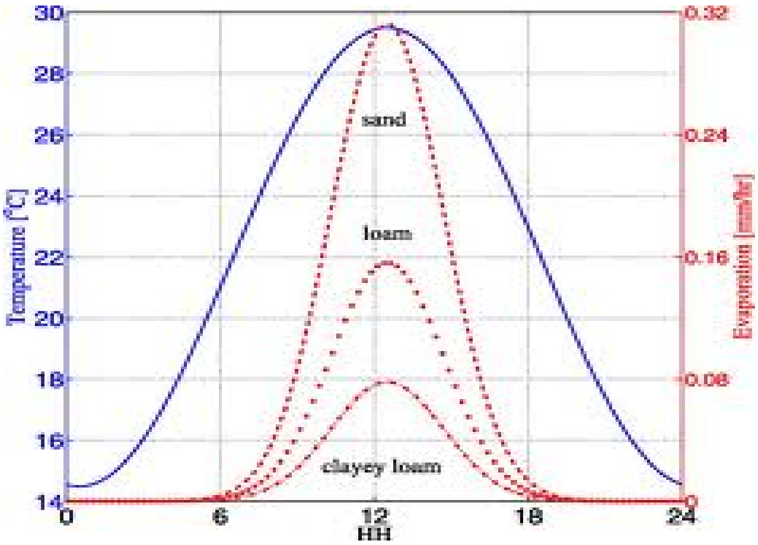


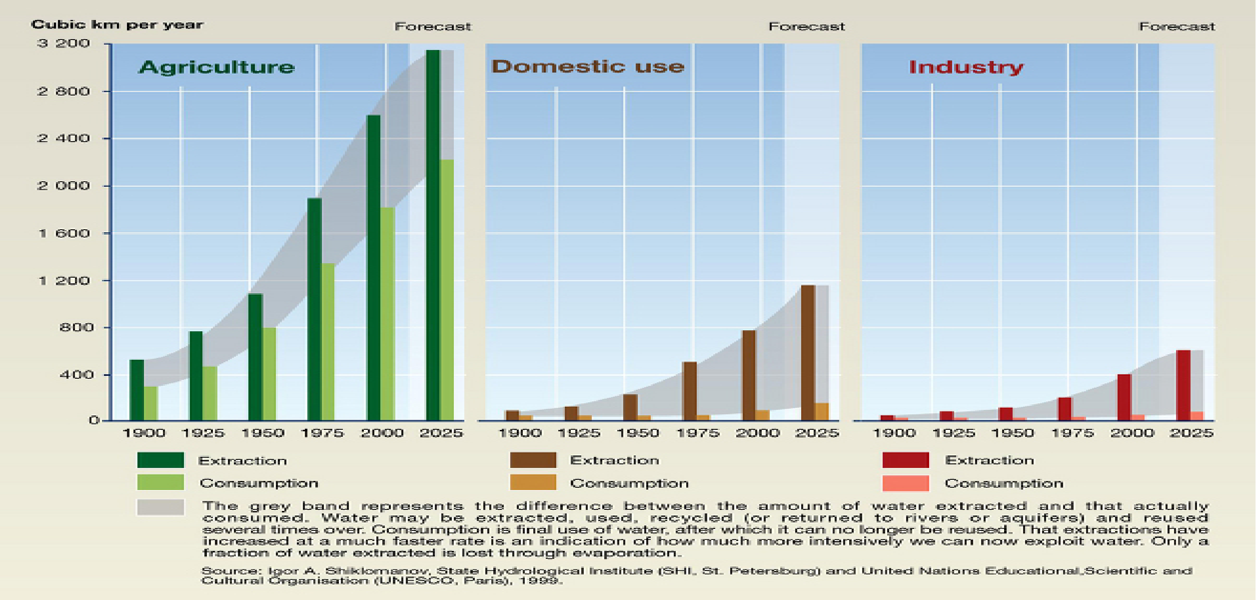
Figure 1.8: Interaction between soil texture, soil temperature and evaporation from the soil surface (Lunati et al., 2012)

Soils with a high sand fraction tend to warm faster than clayey soils. The fraction of soil water loss due to evaporation from a sandy soil is higher, because the higher surface temperature leads to more energy being available for vaporisation and thus higher evaporation and water loss from the soil surface. The physical surface roughness and colour of a soil will also impact the soil water balance through the effect on evaporation of soil water because of the alteration of the soil's albedo. Albedo is the reflectivity coefficient of the soil (Hillel, 1998) which gives an indication of the amount of short wave radiation that is reflected away from the soil surface. A soil's albedo can range between values of 0.1 to 0.4 depending on the soil colour, roughness and inclination (Hillel, 1998). The rougher the soil surface, the lower the albedo which means less reflectance of short wave radiation. More energy in the form of heat increases the potential in evaporation. Soil colour is indicative of the albedo, darker soils have a lower albedo than light coloured soils.

Surface roughness not only impacts the albedo of the soil surface, but also the potential amount of surface runoff of water that can occur. Rougher soil surfaces will lower the potential surface runoff loss, by capturing the water in micro surface depressions and thus allowing more time for infiltration (Guzha, 2004). It is therefore expected that the degree of soil disturbance (through different tillage management strategies and type of crop residues) might influence water balances in differently managed systems.

1.2.4 Soil water balance and agricultural systems

Agricultural systems, or the agricultural sector, is the biggest consumer of water (Figure 1.9)



The grey band represents the difference between the amount of water extracted and that actually consumed. Water may be extracted, used, recycled (or returned to rivers or aquifers) and reused several times over. Consumption is final use of water, after which it can no longer be reused. That extractions have increased at a much faster rate is an indication of how much more intensively we can now exploit water. Only a fraction of water extracted is lost through evaporation.

Source: Igor A. Shiklomanov, State Hydrological Institute (SHI, St. Petersburg) and United Nations Educational,Scientific and Cultural Organisation (UNESCO, Paris), 1999.

Figure 1.9: Consumption of water per industry (Unep, 2008)

In modern agricultural systems the easiest and most effective way to manage water efficiently is through understanding the soil water balance. It is important to understand the complete balance and the individual components in order to maximise efficiency of water resource management in agricultural systems.

1.3 Tillage practices

1.3.1 Conventional tillage

Tillage is the manipulation of the soil by means of implements so that the structural relationship may be improved for crop growth (Leppan and Bosman, 1923). The two objectives of tillage are to pulverise the soil and to put surface manure, stubble, stalks and other organic matter beneath the surface. The pulverising of the soil is threatening the sustainability of crop production under conventional tillage systems. The physical manipulation of the soil can also alter the soil fertility. This can affect crop development and growth (FAO, 1993).

The benefits of conventional tillage are that it aims to remove weeds and prepare a suitable seedbed and incorporate fertiliser and herbicides for the cultivation of crops. This is achieved firstly by working crop residues into the soil using mouldboard or disc ploughs. Thereafter the seedbed is prepared by multiple passes with secondary implements. Post emergence weed control is usually by means of chemical wheat control (once again, this means multiple passes with a tractor over the land). Conventional tillage leaves the surface of the soil bare and unprotected against erosion in the period between cultivation and initial crop growth. Multiple passes of the cultivator has a number of detrimental effects on the soil’s physical environment and pushes up the energy consumption. These factors have forced the farming sector to investigate alternative ways of cultivating soil. Conservation tillage is one such alternative.

1.3.2 Conservation agriculture

Conservation agriculture (CA) can be defined as a more sustainable cultivation system through minimum soil disturbance (Hobbs et al., 2008). CA holds many benefits. And these benefits are locked up in the crop residues left on the soil surface. Per definition, and according to the guidelines set by the FAO for CA a minimum surface cover of 30% crop residue on the soil after planting/seeding is needed. The key principles of CA include, continuous minimum mechanical disturbance, permanent organic soil cover and diversification of crop species in sequence (Derpsch, 2009). Savings in time, labour and fuel, reduced soil erosion, better water use efficiency and nutrient efficiency which leads to great profitability and sustainability can be some of the added benefits (Derpsch, 2009). No-till is one of four main conservation tillage techniques including zero tillage, minimum tillage and reduced tillage. No-till is a widely practiced system and is gaining more popularity across the globe (Gattinger et al., 2011). South Africa in particular has shown very modest growth (Figure 1.10) in the area under NT despite many long term research findings highlighting the benefits. Barriers to the adoption of CA in South Africa include lack of knowledge, fixed mind-sets, inadequate policies such as commodity based subsidies, unavailability of adequate machines, as well as suitable herbicides as part of the management plan (Derpsch, 2009). In the Western Cape however the adoption rate of CA increased drastically from the mid-nineties.

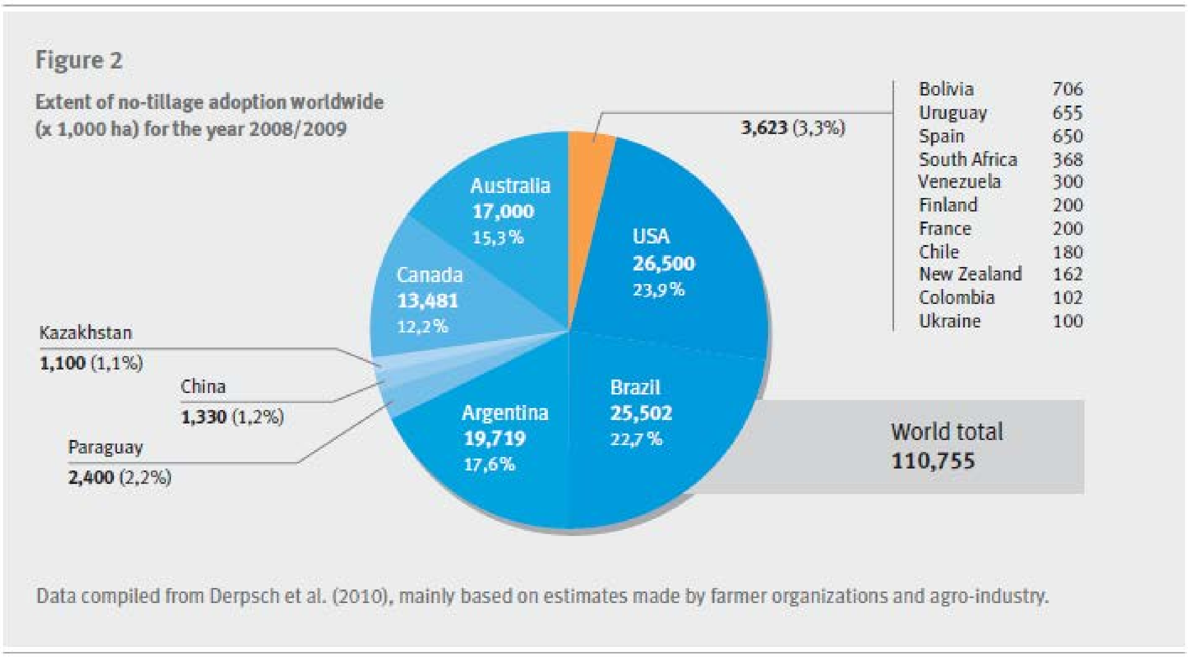


Figure 1.10: Adoption of NT worldwide (Gattinger et al., 2011)

Active participation of farmers in local research and effective communication of information can help to increase the adoption of CA in South Africa. The wide-spread adoption and success of NT systems emphasise the fact that NT can no longer be considered as temporary fashion but is an established practice (Derpsch, 2009).

1.4 Impact of tillage on the soil water balance

One of the major challenges in dry-land farming systems is to maximise water infiltration and minimise runoff (Kovac et al, 2005). Tillage practices cause changes to the physical properties of the soil. This alteration can influence the soil surface-, physical- and hydro-physical properties (Kovac et al, 2005). Tillage practices impact the soil water balance by altering the physical soil properties that govern or influence the individual components of the soil water balance.

1.5 Soil physical properties that influence the soil water balance

1.5.1 Bulk density

Bulk density is an important soil physical properties because of the wide impact that bulk density have on numerous soil processes. Bulk density affects hydraulic conductivity which in turn influences water infiltration and distribution throughout the soil profile. Bulk density in the upper soil surface layers under NT systems, compared to other tillage systems, are higher (Table 1.2).

Fabrizzi et al (2005) firstly reported that the bulk density under NT was higher than under minimum tillage. Results from Mielke et al (1986) reported the same trend, bulk density of the surface layer was higher in NT than in ploughed systems.

Table 1.2: Bulk density difference between minimum tillage and NT systems (Fabrizzi et al., 2005)

	Bulk density (g.cm^{-3}) **Soil depth**	
Treatments	**3-8 cm**	**13-18 cm**
MT	1.19	1.28
NT	1.26	1.32

Hargrove and Hardcastle (1984) also found bulk densities under NT to be greater in the upper 50 cm of the soil profile when compared to a mouldboard plough system. Hoffman (1990) reported lower bulk density values in the upper 0 -150 mm under the conventional tilled sites due of the loosening effect of tillage. Hoffman (1990) further reported a bigger increase in bulk density with soil depth under the conventional tillage system compared to no-till. Ferreras et al. (2000) in Argentina, found no significant difference in bulk density values between the conventional tillage treatment and NT in both the 3-8 cm and 15-20 cm soil layers. They reported an increase in the bulk density values for both treatments from sowing to harvest. This experiment was laid out on soil that was cultivated for 25 years and, at the time that bulk density measurements were made, it was only in its second year of applied tillage treatments. In an attempt to quantify the effect of tillage practices on soil physical properties, Fernandez-Ugalde et al. (2009) measured bulk density at three different depths. Their study was conducted on farm sites in the Ebro Valley in Spain that was under conventional and no-till treatments for seven years before the study was conducted. Results from that study showed a significant higher bulk density value under no-tillage in the upper 0-5 cm soil layer compared to the conventional tillage treatment. Furthermore, the data showed that there was no significant difference in the bulk density values between tillage treatments for the 5-15 and 15-30 cm soil layers.

Blevins et al. (1983) found that after 10 years of continues NT corn production, there was no deterioration of soil physical propertie including bulk density.

1.5.2 Porosity

Porosity is the volume of soil made up by pores and pore space (Van der Watt and Van Rooyen, 1995). Both express denseness and compactness to a certain degree and they are connected to each other. In tilled soils the total porosity of the tilled area increase because of the loosening effect of the tillage practices. Ferreras et al. (2000) reported greater volume of pores with a diameter larger than 20 µm under conventional tillage than NT while Fabrizzi et al. (2005) reported a lower total porosity under a NT system. Higher bulk densities under NT systems corresponded to lower porosity values (Table 1.3) (Osunbitan, 2005). Bulk density explains the degree of the packing density of individual particles, this means that a lower porosity would be the result of a high degree of particle packing.

Table 1.3: Total porosity and bulk density differences between tillage systems adapted (Osunbitan, 2005)

Tillage system	**Bulk density (g.cm^{-3})**	**Saturated Hydraulic Conductivity (x10^{-3}cm s^{-1})**	**Porosity**
NT	1.28	7.2	0.52
MT	1.17	6.9	0.56
PP	1.12	6.8	0.58
PH	1.10	6.1	0.58

NT = no till; MT = minimum tillage; PP = plough-plough tillage; PH = plough harrow tillage

The bulk density affects the total porosity and pore size distribution. Rasmussen (1999) discovered that with an increase in the bulk density, as is the general trend under NT, the volume of macro and meso pore reduces, but the volume of micro pore stays virtually unaffected. This change will certainly affect the water movement and water storage capacity of the soil. Kay and Van den Bygaart (2002) also commented that the soil pores and organic matter cannot be considered to be separate entities. They explained that the different forms of organic matter stabilise pores of different sizes, and therefore increase their stability when exposed to degradation stresses. Pore characteristics influence the organic matter dynamics through their impact on the habitat of the organisms that is responsible for the decomposition of the organic matter (Kay and Van den Bygaart, 2002). These authors also reported that total porosity under NT systems practiced for less than ten years were often reduced. The differences in total porosity between tillage for more than 15 years were more consistent and showed a different picture, contradicting the shorter study.

1.5.3 Hydraulic conductivity

Saturated hydraulic conductivity K_s is governed by the pore size which in turn is affected by the bulk density. Bulk density and porosity will therefore have a prominent impact on hydraulic conductivity, and changes in bulk density and porosity will influence and change the K_s of soils (Tables 1.4 and 1.5). An increase in bulk density corresponds with a decrease in porosity and a decrease in the K_s.

Table 1.4: Bulk density, K_s and total porosity between different tillage practices (Osunbitan, 2005)

Tillage system	Bulk density (g.cm^{-3})	K_s (x10^{-3}cm s^{-1})	Porosity
NT	1.28	7.2	0.52
MT	1.17	6.9	0.56
PP	1.12	6.8	0.58
PH	1.10	6.1	0.58

NT = no till; MT = minimum tillage; PP = plough-plough tillage; PH = plough harrow tillage

Table 1.5: Bulk density and K_s between different tillage systems (Pelegrin et al., 1990)

Treatment	November 1986			June 1987		
	Φ (cm3.cm^{-3})	D_b (g.cm^{-3})	K_s (mm.h^{-1})	Φ (cm3.cm^{-3})	D_b (g.cm^{-3})	K_s (mm.h^{-1})
Disc plough	0.151	1.22a	91.5	0.075	1.36b	64.1
Mouldboard plough	0.136	1.25a	45.5	0.065	1.33a	27.3
Cultivator	0.145	1.24a	43.5	0.075	1.43b	23.9
Disc harrow	0.158	1.34a	50.3	0.095	1.40a	10.0
No-tillage	0.172	1.51a	11.0	0.075	1.64b	3.3

Φ (cm^3.cm^{-3}) = volumetric water content; D_b (g.cm^{-3}) = bulk density; K_s (mm.h^{-1}) = saturated hydraulic conductivity

Saturated hydraulic conductivity can be used to predict the final infiltration rate. It is therefore clear that tillage practices that result in a lower K_s will also cause lower infiltration rates, which in turn will result in lower water use efficiency.

Figure 1.11 confirms the work done by Hoffman (1990). It illustrates the decrease in the hydraulic conductivity in time after tillage and planting which correlates with the re-compaction of the soil. The re-compaction, as well as the decrease in K_s, are most pronounced in tilled soil.

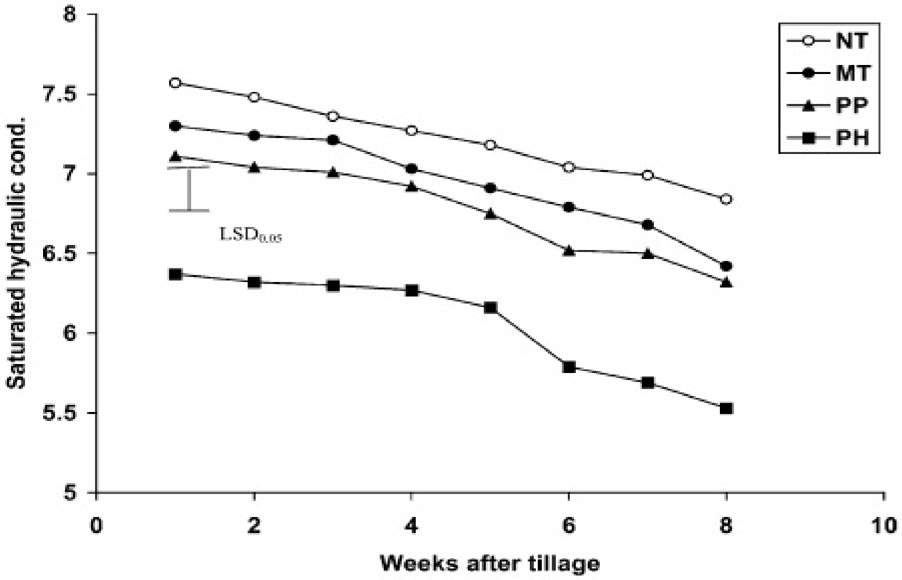


Figure 1.11: Hydraulic conductivity decrease over time of no till (NT) and plough harrow tillage (PH) (Osunbitan , 2005)

Azooz and Arshad (1996), however reported quite the opposite results in a long term study conducted in Canada which was in the 14th and 15th year of implementation. The study showed that long term NT systems reduced the disturbance of soil and kept soil micro and macro pore continuity undisturbed. This resulted in higher infiltration rates, higher hydraulic conductivities and higher water storage capacities under NT. This study highlights a very important fact when considering NT as management option. Soil infiltration is directly related soil structure, bulk density and pore structure (Azooz and Arshad, 1996). It seems the benefits of NT, or stabilisation of the soil's physical conditions, happen over time and it is suggested that these benefits can only be reaped after practicing NT for more than five seasons.

Pelegrin et al. (1990) measured the K_s before and after wheat was planted. The mouldboard plough treatment resulted in four times higher K_s values compared to no-till treatments in the upper 0-20 cm soil layer at the start of the season. At the end of the season mouldboard ploughing resulted in a nine times higher K_s compared to NT. It correlated well with the lower bulk density values reported for the mouldboard plough treatment. Determining saturated hydraulic conductivity by constant head, Ferreras et al. (2000) also reported significantly higher saturated hydraulic conductivity values under the CT treatment compared to the values obtained under NT. Botha (2012) showed a significantly higher K_s under no-tillage compared to conventional tillage. Again contradicting results were found in these studies which suggest that one of the most important factors to consider when evaluating data in tillage studies is time. In the study conducted by Pelegrin et al. (1990) and Ferreras et al. (2000) the time at which the treatments were applied were two and three years respectively. In the case of Botha (2012), the study has been part of an ongoing long-term study of more than 15 years.

1.5.4 Aggregate Stability

Aggregate stability is directly related to the soil organic matter content (Hernanz et al., 2001). As the intensity of soil cultivation decreases, the stability of aggregates increases. Intensive cultivation (ploughing) of the soil leads to massive soil degradation and the destruction of aggregates (Cunha, 1997). This causes a decrease in infiltration rate; an increase in runoff, leading to soil erosion and losses of organic matter, clay and nutrients from the surface layers. Converting management practices from conventional tillage to no-till counter acts the above mentioned destruction of soils. Cunha (1997) found that conservation tillage systems even favoured the restoration of soil degradation caused by the conventional tillage systems. Aggregate stability also play a role in the soil water balance but was not evaluated in this study.

1.5.5 Compaction

Soil compaction is defined as the reduction in soil bulk volume as a result of applied external force. The reduction in bulk volume correlates with an increase in bulk density and a reduction in porosity (Van der Watt & Van Rooyen, 1995). Soil compaction follows the same trend as the bulk density. As bulk density increases, the void ration decrease, causing compaction to increase under no-tillage practices (Pelegrin et al., 1990). Fabrizzi et al. (2005) confirmed the same trend for compaction, reporting significant higher bulk density and lower total porosity values for NT systems that produce an increase in soil compaction. A long term study reported (Blevins et al., 1983) that soil compaction under no-tillage systems is not a problem, even though many studies reported that the bulk density under NT systems is higher than conventional tillage. These results emphasises the fact that NT systems are not a quick fix, but rather a long-term management strategy. Conservation tillage system rehabilitates the soil over time.

1.6 Crop Rotation

1.6.1 Crop rotation systems and functions

According to the OEFA, crop rotation can be defined as the practice of growing a series of different crops sequentially in the same location to achieve various benefits (Anon, 2010 a). There are four functions of crop rotations and have been divided according to the benefits that they obtain, namely:

1. The improvement of soil structure (Anon, 1998).
2. Weed and pest control. (Anon, 1998).
3. Improvements in water managements (Anon, 1998).
4. The enhancement of soil fertility. (Anon, 2010 a).

Cash crops tend to reduce the soil fertility but this loss of nutrients can be counter-acted and regained by crops within the rotation system (Anon, 2010). Soil fertility is enhanced through better nutrient management obtained by rotation systems that include legume crops which retain and fix nitrogen in the soil. Crop rotations that include crops such as legumes are therefore a key component of a successful crop rotation system and also play a role in breaking disease and pest cycles (Anon, 1998).

The organic crop residue contribution from the cover crop should also be considered (Anon, 2010). Soil structure is improved by the increase in the organic matter, as well as the structural improvement contributed by legume based rotations. This leads to better water management because of increased water holding capacity and better infiltration and drought resistance (Anon, 1998). Crop rotation systems together with tillage practices form part of a management strategy aimed at farming environmental sustainability.

1.6.2 Crop rotation and soil water balance interaction

Reduced, minimum or no-tillage and crop rotations are two proven methods in CA. Crop residues left on the surface influence various parameters related to the soil water balance. Depending on reduced tillage practice more than 30 % of the soil surface can be covered with plant residues (Kovac et al., 2005).

The presence of crop residues on the soil surface influences the rate of energy exchange between the soil surface and the atmosphere due to the effects on soil albedo, aerodynamic coefficients and water vapour exchange rates (Hatfield et al., 2001). Important objectives of soil water management strategies, especially in dry land farming, are to encourage water infiltration rather than runoff (Kovac et al., 2005). Reduced, minimum or no-tillage also reduces evaporation through the different crop rotation residues. The interaction between crops grown in rotation and tillage treatments also revealed a significant difference in soil water content between conventional and NT in a study done on the effects of tillage on soil water dynamics (Kovac et al., 2005). This physical characteristics of the residue, for example the height of the stubble, influences soil surface temperature, the aerodynamics just above the soil surface as well as, the colour and the surface roughness of the soil surface. Soils with surface residue management are cooler than tilled soils (Hatfield et al., 2001). The lower temperatures can reduce evaporation, but can also reduce the crop growth rate (Hatfield et al., 2001). Residues and mulches reduce water evaporation because of the reduction in soil temperatures, impeding vapour diffusion, absorbing vapour into the mulch tissue and reducing the wind speed gradient (Hatfield et al., 2001). Residue cover influenced by crops in the rotation are summarised in Table 1.6, confirming that available soil water increased as residue cover percentage was increased.

Table 1.6: Effects of crop cover rate on available soil water in mm (Power et al., 1986)

Crop/Year	**Residue cover (%)**			
	0	**50**	**100**	**150**
Maize				
1980	110	172	226	223
1981	195	168	180	208
1982	204	226	230	244
1983	203	226	257	252
Average	178	198	223	232
Soya bean				
1980	156	208	250	243
1981	119	124	166	188
1982	206	228	251	244
1983	206	254	260	220
Average	172	204	232	224

Power et al. (1986) also reported that it was not the type of residue that influenced water conservation, but rather the percentage cover. The crop cover rate has the same effect on the soil surface temperature than on plant available water (Figure 1.12).

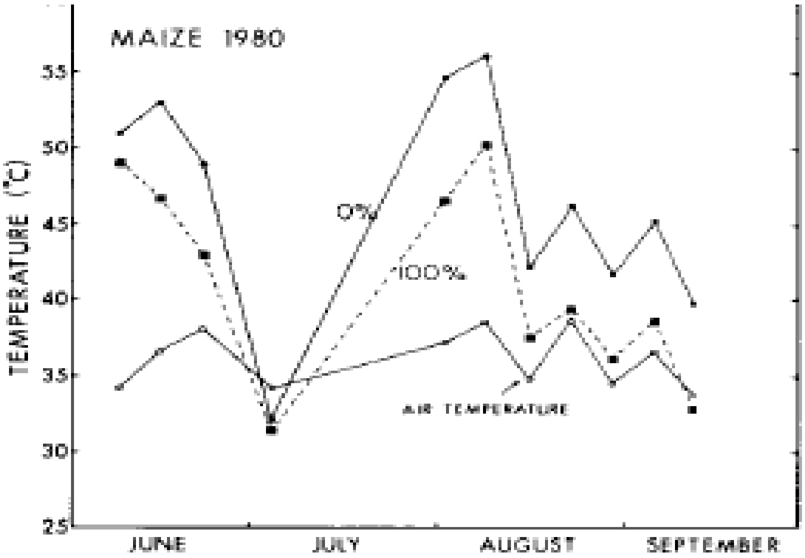


Figure 1.12: Effect of 0 % and 100 % crop residue cover on soil surface temperature (Power et al., 1986)

The type of coverage and the height of the crop residue left on the soil surface impact the SWB, as do the roots below the soil. The root system of the crop can create preferential flow paths that increase the infiltration capacity of the soil. This can also increases the soil water storage. The increased infiltration and a bigger capacity to store the captured water leads to more available soil water.

1.7 The effect of tillage on biomass production

Wiese (2013) reported that tillage did not affect total biomass production but that the cropping system did. Results from that study indicated that the biomass production in medic-wheat-medic-wheat and lupin-wheat-canola-wheat was higher compared to wheat mono culture.

Hemmat and Eskandari (2006) found that no-tillage treatments tended to produce more biomass particularly in the drier seasons. The five year study done by Rieger et al., (2008) reported 2 % higher biomass for no-tillage than conventional tillage.

According to Cooper et al. (1987) factors that influence crop yield, especially grain yield, include soil water content and soil nitrogen.

1.8 Effect of crop rotation and tillage on grain yield

As a result of the influence of crop rotation and tillage on the soil properties that influence the water balance, it is expected that grain/seed yield and quality may also be affected. The soil water content is dependent on the rainfall and its distribution in the growing season (De Vita et al., 2007). These authors did a comparison study between conventional tillage and no-tillage on a wheat mono culture, in two different locations in Southern Italy over a three year period. No-tillage resulted in significantly higher wheat yield for the first two years in the Foggia location, but no difference in wheat yield was reported between tillage methods in the Vasto location in the first two years.

Wiese (2013) concluded that tillage influenced soil water content at Langgewens (same location as the current study), resulting in differences in wheat yield and quality. Even though the data from that study was not significantly different, it was reported that crop rotations had a positive effect on wheat yield. Wheat produced after medic and/or canola resulted in higher yields than the wheat monoculture system. However, it was concluded that only tillage effected wheat yield, with NT resulting in significantly higher wheat yields compared to CT. Hoffman (1990) found that CT resulted in higher grain yield compared to NT.

Crop rotation systems and tillage had no effect on winter wheat yield in the Central Great Plain of America where the effect of crop rotation and soil disturbance on crop yield and soil carbon was studied (Halvorson et al., 2002).

Pala et al. (2007) reported that the greatest limitation to wheat growth and subsequently, yield, was not the soil water potential, but the supply of water. The soil water supply, according to these authors, was largely influenced by the drying out effect which the alternative crop had on the soil profile. This is especially important during relatively dry seasons.

1.9 The effect of tillage and crop rotation on WUE

Pala et al. (2007) reported on the influence that the preceding crop had on the WUE. Some rotation systems yielded higher WUE values, due to the magnitude of the drying out of the soil profile that the preceding crop established. Tillage treatments also had an influence on the WUE in the study done by Hoffman (1990), who concluded that the WUE increased when the amount of soil disturbance increased. Bennie & Botha (1986) reported significant increases in WUE and yield for both maize and wheat when soils were ripped, which coincided with increased rooting depth and density. Similar results concluded that tilled treatments resulted in better yield and WUE under arid conditions (Lopez and Arrue, 1997).

1.10 Conclusion

The threats of economic pressure and global warming on food production and security necessitate studies to understand how this problem can be solved in a sustainable way. The Western Cape is the most important wheat producing region in South Africa, but also the second driest with the most varied rainfall patterns. In order to farm financially and environmentally sustainable, the farmer needs to use all the available resources effectively. The majority of the wheat farmers in the Western Cape are dry-land farmers and 100 % reliant on rainwater for production success. Crop rotation systems and NT are two strategies that can be used to maximise the rainwater storage efficiency as well as the rainwater usage efficiency in an effort to utilise the captured water better and conserve more water. Understanding the principles behind these strategies, and their interaction is crucial if they are to be used effectively to obtain success.

Two factors should be considered when using or converting to NT systems as part of the total farming strategy. No-till systems are no quick fix, but should form part of a long-term sustainable farming strategy. All decisions involving the implementation of the NT and crop rotation systems and the advantages and disadvantages are all compromises and it is very important that the farmer understands his present situation, what he wants to achieve and the impact that his decision may have.

All farming situations are unique but when the principles crop rotation systems and NT are well understood, it can be applied to custom fit any farmer’s circumstances with a great deal of success.

Chapter 2: Materials and methods

2.1 Experimental site

This trail was conducted as a component study within a long-term crop rotation/soil tillage trial during 2012 and 2013 at the Langgewens Research Farm (33^{0}16’42.33” S; 18^{0}42’11.62” E; 191 m) of the Western Cape Department of Agriculture near Moorreesburg **(**Figure 2.1). Langgewens lies within the boundaries of the high potential grain production area of the Swartland sub-region of the Western Cape. The boundaries of the Langgewens Research Farm are indicated yellow and the experimental site in red.

2.1.1 Soil

Nine soil profile pits were dug and classified according to the binomial soil classification system for South African soils (Soil Classification Working Group, 1991). Soil of the experimental site derived from Malmensbury shales. The dominant soil forms are Glenrosa (GS) and Swartland (SW) (Figure 2.2). Glenrosa and Swartland soil forms constitute 65 % and 35 % of the total experimental area, respectively. The forms however differed in terms of the degree of weathering of the underlying material according to the position in the landscape, which influence their crop production suitability rating. These soils are hard and shallow in the dry state. As a result of high consistency of the subsoil in both the dry and wet state, initial sampling of the B horizon was not possible during the sampling process. However clods and fragments from the B horizon were taken at a later stage. The effective depth of the soil was estimated between 60 and 90 cm. The A horizon varied in depth between 0-30 and 0-40 cm with the shallower A horizons found at the crest. The B horizons varied between 30-90 and 40-100 cm in depth and were characterised by a very hard consistency. In the case of the Glenrosa soil form, the lithocutanic B horizon contained a very large percentage of soft philite (shale) fragments. The A horizon also contained a high percentage of coarse fragments, a characteristic that may negatively influence the water holding capacity of these shallow soils. The clay content of the upper 0-30 cm was between 10-15% resulting in classifying these soils as sandy loam. A thorough description of each of the nine soil profile pits classified can be found in Apendix A

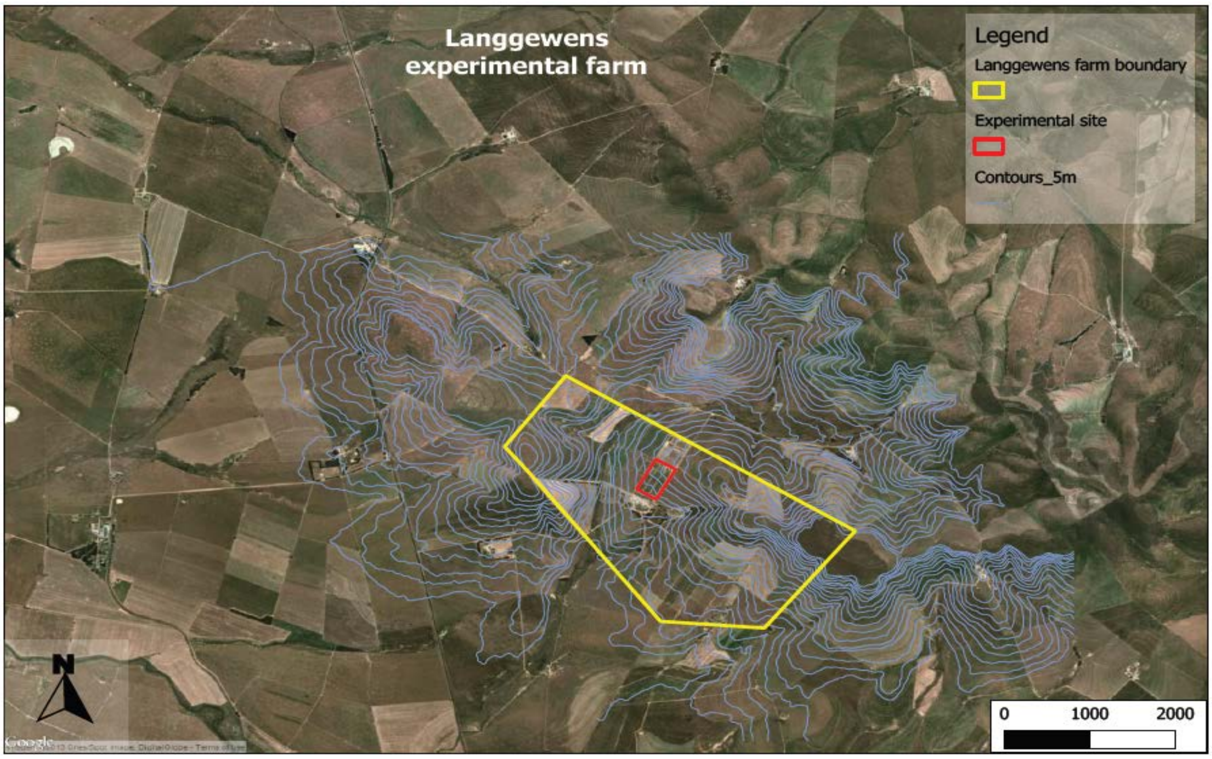


Figure 2.1: Langgewens experimental farm map

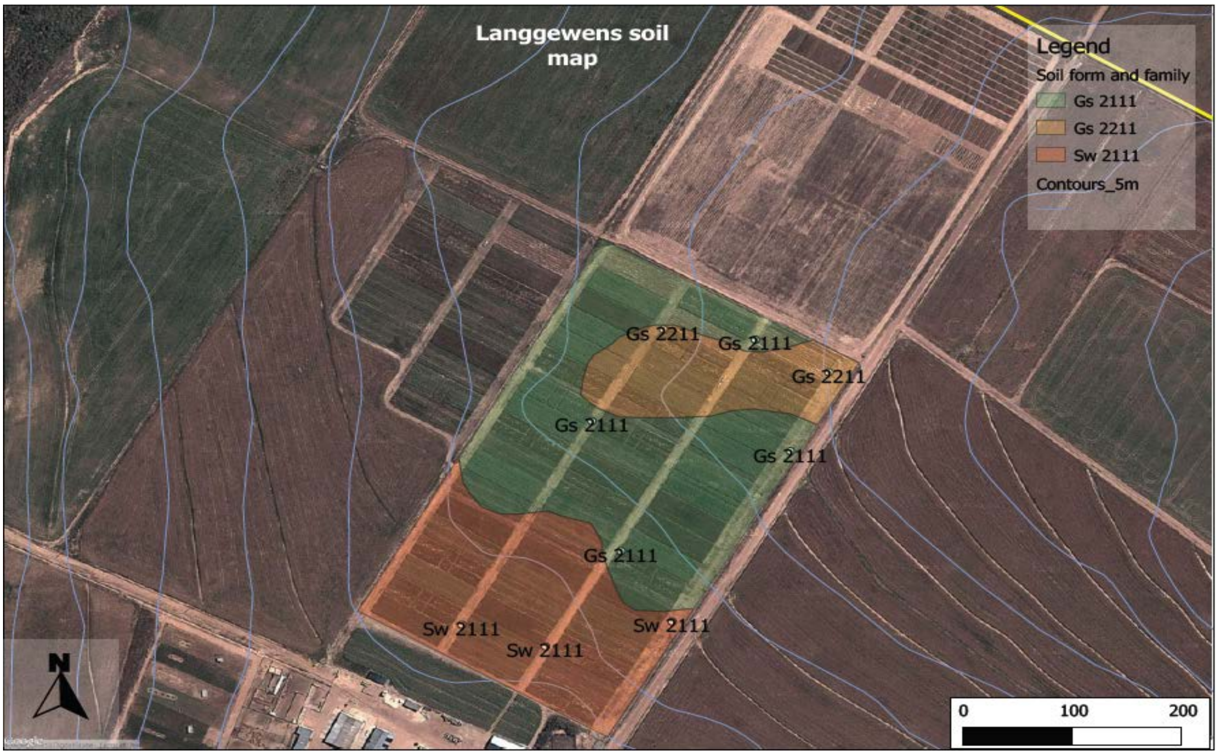


Figure 2.2: Soil map of the experimental site at Langgewens research farm

2.1.2 Climate

The climate is typical Mediterranean characterised by cold, wet winters and hot dry summers. Figure 2.3 shows the rainfall figures for both 2012 and 2103 season in comparison to the long-term average. The long-term mean rainfall is 399 mm of which 335 mm occur between April and October.

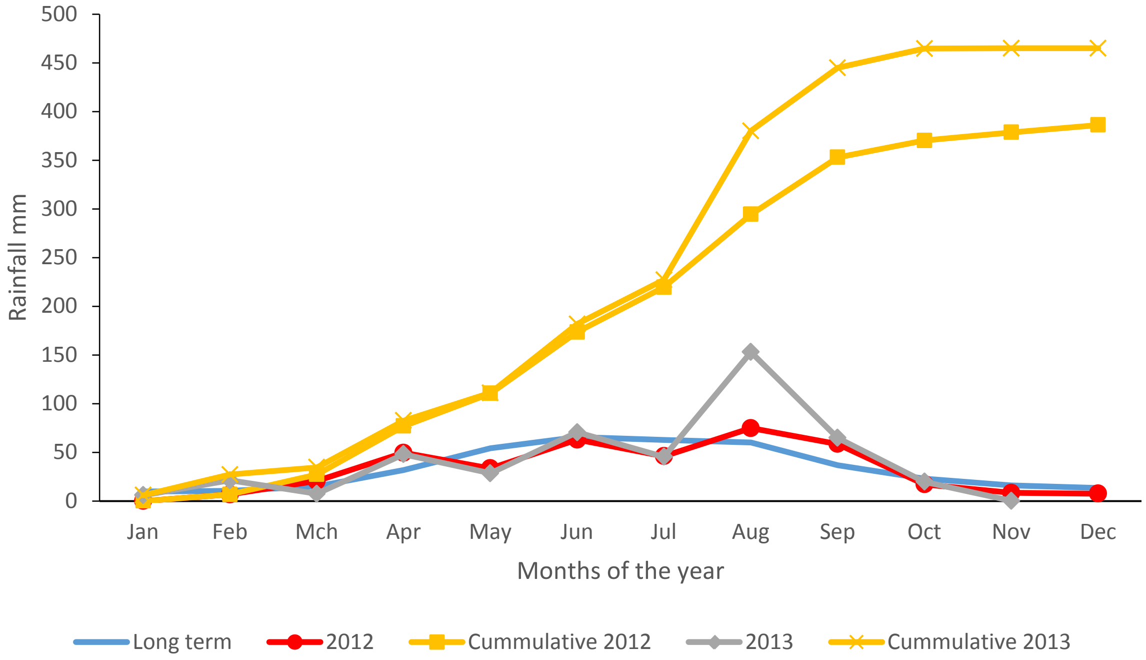


Figure 2.3: The long-term average rainfall (mm) compared to the 2012 and 2013 rainfall (mm) at the Langgewens Reasearch Farm (Data from the ARC-ISCW)

Although the total amount of rainfall in 2012 (391 mm) does not differ much from the long-term average for Langgewens (399 mm), the rainfall distribution during 2012 differed. A considerable amount of rain fell in the beginning of the rainy season (March-May) with the majority of the winter rainfall occurring between August and November.

The high percentage of rainfall in 2012 recorded between August and mid-October coincided with the lowest mean daily temperature (Figure 2.4).

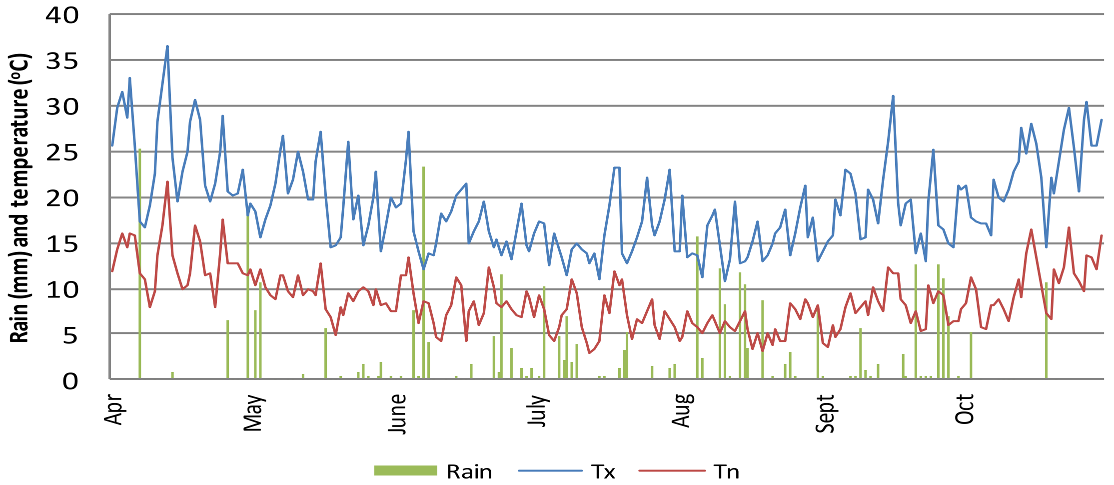


Figure 2.4: Mean daily temperature (^{0} C) and rainfall incidents (mm) at Langgewens (2012) (Tx = Maximum temperature; Tn = Minimum temperature)

It is expected that the temperatures recorded during the 2012 production season were moderate enough not to cause any severe reduction in the yield potential of the crops grown during winter at Langgewens. The daily maximum and minimum temperatures and rainfall for 2013 is shown in Figure 2.5. This figure highlights two important climatic factors that impacted this study during the 2013 season.

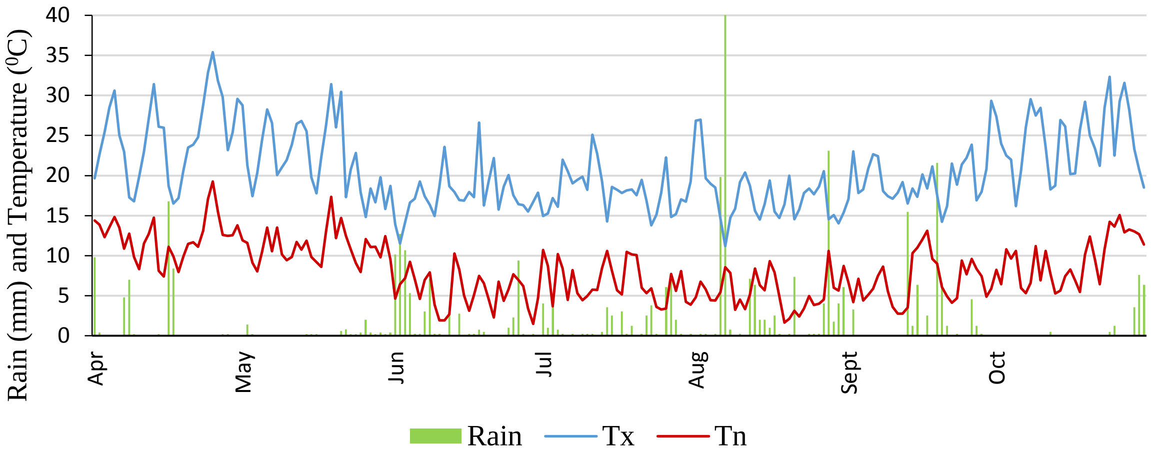


Figure 2.5: Mean daily temperature (^{0} C) and rainfall incidents (mm) at Langgewens (2013) (Tx = Maximum temperature; Tn = Minimum temperature)

Firstly, that the total amount of rainfall in 2013 far exceeded the long-term total and the total rainfall of 2012 by 65.67 mm and 78.72 mm respectively (Figures 2.4 and 2.5). Once again the majority of rainfall occurred between Jun 2013 and Sept 2013 with 72 % of the total rainfall recorded in this period. Secondly, unusually high temperature were recorded at the end of July 2013 and the beginning of August 2013 which impacted both the soil water balance and crop development and growth.

2.2 Experimental design and treatments

The long-term trail was initiated to investigate the interaction of soil tillage and crop rotation on soil quality, crop productivity and -quality. The experimental design was a randomised complete block with a split-plot treatment design. Refer to Appendix B for the illustrations of the layout of the trail treatments and crop rotations systems.

Three crop rotation systems, wheat after wheat continuously (WWWW), wheat/medic/wheat/medic (WMcWMc) and wheat/canola/wheat/lupin (WCWL) were allocated to main plots replicated four times. The last letter in the sequence represents the crop on the field at the time of data collection. The experimental layout was designed to accommodate all seven different cropping sequences and four tillage treatments during any given growing season. Each main plot was subdivided into four sub-plots allocated to four tillage treatments namely: zero-till (soil left undisturbed and planted with zero-till planter), no-till (soil left undisturbed until planting and then planted with a tined no-till planter), minimum-till (soil scarified March/April and then planted with a no-till planter) and conventional tillage (soil scarified late March/early April, then ploughed and planted with a no-till planter). All straw, chaff and stubble remained on the soil surface and no-grazing was allowed on all tillage treatments. Only three replicates were included in this current study. Only the no-till (NT) and conventional till (CT) were included in this current study as main tillage treatments. The seven crop rotations selected and included in the study were:

WWWW: Wheat monoculture

WMcWMc: Medic followed after wheat

McWMcW: Wheat after medics

CWLW: Wheat after lupins

LWCW: Wheat after canola

WCWL: Lupins after wheat

WLWC: Canola after wheat

Yield data collected and shown were only applicable to the crop rotations systems when wheat were in phase.

2.3 Agronomic practices

Best agronomic practices were performed based on recommendations and advice by the Langgewens Technical Committee that included experts of all crop related fields. The experimental sites were 60m x 20m, subdivided into four sub site of 20m x 10m. The tine treatments on the conventional tillage plots were done on April 10th 2012 and April 9th 2013, respectively followed by a mouldboard treatment on the 2nd and May 2012 and 2013, respectively. Only the wheat, canola and lupin plots were subjected to tine and plough treatments. No soil tillage were done during the medic phase. At the beginning of May (7th and 8th) a 2 L.ha^{-1} Glyphosphate application was made as a pre-emergence herbicide before planting commenced for all crops, except in the medic phase. Wheat (cv SST 027) was sown at a rate of 100 kg.ha^{-1} on 24th and 26th of May in 2012 and 2013 respectively, lupin (cv Mandelup) at 110 kg.ha^{-1} on 25th and 27th May 2012 and 2013 respectively and canola (cv Jardee in 2012 and Hyola 555 in 2013) at a rate of 5 kg.ha^{-1} on May 26th and 28th 2012 and 2013 respectively.

Wheat and canola rotation-treatments received top-dressing application in Mid-July (13 July 2012, 148 kg.ha^{-1} and 8 July 2013, 145 kg.ha^{-1}) which consisted of 27 % nitrogen and 3 % sulphur. Weed, insect and disease control for all experimental units included in this study was done in an accordance with best practices for crops in this study area.

All crops were harvested in the second week of November 2012 and 2013, using a small plot harvester specifically designed for small scale research plots.

2.4 Data collection

2.4.1 Soil sampling

Soil was sampled and physical soil parameters determined. A total of 5kg soil per depth were sampled and analysed for particle size distribution.

2.5 Soil Physical Properties

2.5.1 Particle-Size Analysis

Particle size was determined for the 0-100 and 100-200 mm depth for both CT and NT treatments on all crop rotations system. The pipet-method was used as described by Glendon, 2002. In pre-treating the sample prior to dispersion only the organic matter was removed. Results obtained from the particle size analysis were used to group each sample into the textural class using the textural triangle (Van der Watt and Van Rooyen 1995).

2.5.2 Bulk density

Bulk density was determined using the clod method as described by (Grossman and Reinsch 2002). Clods for the determination of the bulk density were excavated at 10 cm depth increments from the profile pits used for soil classification. Clods were excavated up to the depth permitted by the profile and in triplicate.

2.5.3 Coarse fragment percentage and water storage potential

The presence of coarse fragments can decrease the soil water holding capacity due to the dilution effect, but can also contribute to the plant available water that by storing water (Poesen and Lavee 1994). After a profile inspection in April 2013 that revealed the presence of crop roots in the sub-soil layer and a large amount of rock fragments present (mostly shale), it was decided to determine both coarse fragment percentage and water storage potential of the shale fragments. Fragment samples were taken to determine the water holding capacity of these shale fragments and if this water could contribute to the plant available water (PAW). The coarse fragments were sampled from the six Glenrosa soil profiles. The volumetric water content of the water saturated fragments was determined following the same procedure as Botha (2012).

First the gravimetric water content at saturation of the fragments were determined. The fragments were saturated in water. After 48 hour the fragments were taken out of the water and the access water was allowed to drain then the fragments were weighed to determine the wet mass. The fragments were then dried overnight at 104^0 C in the oven. The fragments were taken out, allowed to cool in a desiccator and weighed to obtain the dry mass.

The gravimetric water content at saturation was calculated using the following formula:

$$\Phi_w = \frac{Wett\ mass - dry\ mass}{Dry\ mass} \ldots\ldots 1$$

Φ_w = Gravimetric water content g.g^{-1}

Then the bulk density of the shale fragments was determined using the clod method as described in the previous section.

Finally the gravimetric water content was converted into volumetric values using the bulk density in the following formula:

$$\Phi_v = \Phi_w \times \frac{\rho d}{\rho w} \ldots\ldots 2$$

Φ_v = Volumetric water content cm^3.cm^{-3}

Φ_w = Gravimetric water content g.g^{-1}

ρ_b = Bulk density kg.m^{-3}

ρ_w = Density of water kg.m^{-3}

2.5.4 Saturated Hydraulic Conductivity

The saturated hydraulic conductivity (K_s) was determined in the laboratory using undisturbed soil cores. The constant head method was used (Reynolds and Elrick 2002). Undisturbed cores of 110 mm in diameter and 280 mm deep were collected from each treatment combination using 110 mm steel pipes.

Many external factors can influence the results obtained using this method. One of these is air entrapment within the soil core. When air entrapment occurs it can influence results so that the K_s values are lower than when the soil core is completely saturated. Air entrapment can occur when water is added at a high speed. In an attempt to minimise the problem of air entrapment, all soil cores ends were completely sealed off prior to the start of measurements. The soil columns were saturated, sealed and allowed to stabilise over a period of two hours. The K_s measurements of three replicates per treatment-rotation combination were taken over a period of 3 hours, and the averages calculated. Measurements were taken every 10 minutes whilst keeping a constant hydraulic head on all soil cores.

2.5.5 Overland flow

Overland flow is the preferred term to describe the occurrence of surface runoff. Due to the low intensity of rainfall and relative even slope, occurrences of overland flow were visually evaluated after each rainfall incidence. No overland flow was expected and observed when the sites were visited for both 2012 and 2013.

2.5.6 Drainage

Drainage was determined by monitoring the volumetric water content of the deepest soil layer at the occurrence of a rain shower using the data obtained by the Diviner 2000. Drainage could therefore be evaluated and monitored for all treatments combinations. No deep drainage was observed.

2.5.7 Evapotranspiration

Evapotranspiration was calculated for all treatments-combinations using the soil water balance equation (Hillel 1998).

ΔSoil water = (P+I+C) – (RO+D+ET) ………………………………………………… 3

$\Delta\Phi$= Change in volumetric soil water content of the soil profile between two readings

P= Precipitation

I= Irrigation

C= Contribution to the soil water content of the water table

RO= Runoff / Overland flow

D = Drainage

ET= Evapotranspiration

The Evapotranspiration was calculated weekly during the growing seasons of (May – November) 2012 and 2013 using equation 4.

ET= (P+Δ Φ) – (RO+D)………………………………………………………………… 4

ET= Weekly evapotranspiration (mm.week^{-1})

P = Precipitation between two weekly readings

Δ Φ = Volumetric change in water of the soil profile content between two weekly readings (mm.week^{-1})

RO = No runoff / overland flow was observed in both seasons

D = No deep drainage occurred in both seasons

The monthly evapotranspiration for the fallow period (December 2012 – May 2013) was determined using equation 5

ET= (P+Δ Φ) – (RO+D)………………………………………………………………… 5

ET= Monthly fallow period evapotranspiration (mm.month^{-1})

P = Precipitation between two monthly readings

Δ Φ = Volumetric change in water content between two monthly readings (mm.month^{-1})

RO = No runoff / overland flow occurred in the fallow period

D = No deep drainage occurred in the fallow period

The cumulative evapotranspiration for both seasons 2012 and 2013 were also calculated by adding the weekly evapotranspiration figures recorded during the season.

2.5.8 Soil water content (mm)

The soil water content was measured using the Diviner 2000 device. At the start of the trail the Diviner 2000 were calibrated against volumetric soil water content of soil samples taken at each relevant depth (10 cm increment) of the different experimental sites. Soil water measurements were taken weekly during the growing season (May-November) and monthly during the fallow period (November-April). The volumetric soil water measurements were taken at 10cm depth increments as the Diviner probe were lowered into a PVC access tube (55mm inside diameter) that was installed into the soil at each experimental site. These access tubes were installed up to a depth of 200mm in the 2012 season and 1000mm in the 2013 season. Raw data were captured for each 10 cm depth on the logger of the Diviner 2000 and were then downloaded onto a PC in a csv file format. The raw data of each soil depth were then used to calculate the total soil water content of the soil and the soil water balance of each treatment by using Microsoft excel.

2.6 Crop yield parameters

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

The biomass was expressed as the total above ground plant matter produced per hectare. After the ear bearing tillers were counted, the sampled plant material was oven dried and then the biomass was determined.

2.6.2 Weed count (%)

The relative percentage of weed coverage in selected experimental plots were determined using the line-intersect method as described by Newman (1966).

2.6.3 Grain Yield (kg.ha^{-1})

An area of 37.03 m^2 was harvested with a small plot harvester to determine grain yields.

2.6.4 Rain Water Usage Efficiency (kg.mm^{-1})

The rainwater use efficiency was determined and expressed as the amount of marketable grain yield per unit of rainfall, using the following formula:

$$\text{RUE}=\frac{Grain\ Yield\ kg}{Rainfall}\text{... } 6$$

2.7.8 Statistical Analysis

An appropriate analysis of variance (ANOVA) was performed, using SAS/STAT software, Version 9.2 (SAS, 2008). The Shapiro-Wilk test was performed to test normality of residuals and Student’s t-LSD (least significant difference) was calculated at a 5% significance level to compare means.

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Chapter 3: Soil physical results

3.1 Introduction

The results from selected soil physicals properties determined will be shown and discussed in this chapter. The physical properties of the soil expected to influence the soil water balance included in the study were: coarse fragment percentage, soil texture, bulk density, volumetric water content of saturated shale fragments and saturated hydraulic conductivity. Understanding how crop rotation systems and tillage influence these properties will explain soil water dynamics. The physical properties included in the study were not influenced by crop rotation. Discussion of results will therefore be restricted to the tillage main effects studied.

3.1.1 Coarse fragment percentage

The coarse fragment percentage were determined within the 0-100, 100-200 and 150-300 mm depths. The soil tillage effectively reached a depth of 200 mm and Figure 3.1 illustrates clearly what happens in these soils where high coarse fragments are abundant. The figure shows that the coarse fragment concentration decreased with soil depth. Through the mechanical sieving action of soil tillage, especially in the CT, coarse fragments were concentrated in the upper 0 -100 mm. The mean coarse fragment concentration under CT was significantly higher at 62.5 % than the 56.8 % recorded under no-tillage in the same layer. Coarse fragment percentage under CT and NT for the 100-200 mm soil layer were 50.3 % and 49.1 %, respectively. Although significantly lower than that of the 0-100 mm layer, no significant difference between these treatments for the 100-200 mm soil layer was reported. The same trend was observed for the 150-300 mm soil layer with no significant differences recorded between CT (44.2 %) and NT (44.0 %) treatments.

The results from this study correlated well with those reported by both Oostwoud and Poessen and Lavee (1994) and Botha (2012). Oostwoud and Poessen (1999) found that tillage led to the segregation of rock fragments in the upper soil layer regardless of moisture status of the soil. The extent of the process of kinetic sieving, as this process was named, was more pronounced in the dry state (Oostwoud and Poesen, 1999).

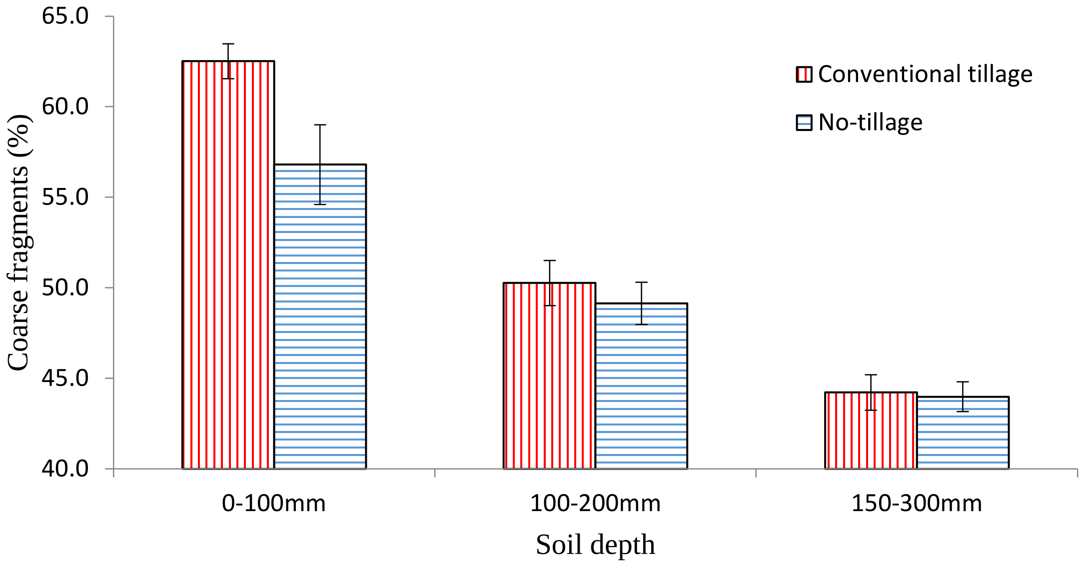

Figure 3.1: Depth distribution of coarse fragments (%) as influenced by tillage treatments at Langgewens (2012)

Botha (2012) also found that the coarse fragment percentage was significantly higher in the CT upper 0-100 mm soil layer compared to NT. Furthermore Botha (2012) found no significant difference in coarse fragment percentage between the soil depths of 0-100 mm and 100-200 mm. The study did however report a significant difference between CT and NT at both depths when comparing coarse fragment percentage. It would appear that these studies all confirm the kinetic sieving phenomena whether it be to a lesser or larger extent may depend on the time that the soil has been subjected to the tillage treatments.

The coarse fragment percentage in the soil profile influences the soil water balance which subsequently influences crop performance, through the effect it has on the soil water storage capacity (Poesen and Lavee, 1994). A higher percentage of coarse fragments leads to less actual soil volume and thus lowering the soil water storage capacity.

3.1.2 Soil Texture:

Soil texture is defined as the relative ratio of sand: silt: clay (van der Watt and van Rooyen, 1995). Twelve different soil textural classes are defined according to their ratios of sand, silt and clay (Van der Watt and Van Rooyen, 1995). Tables 3.1 and 3.2 summarise the particle size composition of the treatment combinations included in this study. Particle size composition in the 0-100 mm soil layer was not enough influenced by the treatment combinations enough to have an effect on the textural class. (Table 3.1).

Table 3.1: The influence of tillage and crop rotation on particle size composition in the 0-100 mm soil layer at Langgewens (2012)

		Particle size (%) for the 0-100mm soil depth						
Crop rotation	**Tillage treatment**	**Coarse sand**	**Medium sand**	**Fine sand**	**Very fine sand**	**Coarse silt**	**Fine silt**	**Clay**
		2-0.5mm	**0.5-0.25mm**	**0.25-0.106mm**	**0.106-0.05mm**	**0.05-0.02mm**	**0.02-0.002mm**	**<0.002mm**
WWW**W**	No-tillage	18.2	7.0	13.5	14.1	21.5	14.3	10.3
	Conventional	15.2	5.9	14.1	14.8	29.2	10.6	10.3
McWMc**W**	No-tillage	16.2	6.6	15.9	15.6	21.4	13.3	9.7
	Conventional	18.1	6.4	15.1	16.5	22.6	11.2	8.8
W**L**WC	No-tillage	16.2	5.8	16.4	14.6	23.9	11.1	9.3
	Conventional	17.1	7.9	16.4	23.6	22.6	8.0	14.6
WCW**L**	No-tillage	16.9	7.0	17.6	19.3	24.4	11.9	8.5
	Conventional	15.3	6.5	17.7	17.2	21.8	12.1	9.2
WLW**C**	No-tillage	18.1	6.9	16.4	17.3	20.6	12.5	8.2
	Conventional	17.5	6.3	16.0	15.4	20.0	14.1	10.1
LWC**W**	No-tillage	18.5	7.0	15.1	17.1	21.3	13.1	7.8
	Conventional	18.7	6.4	12.5	17.7	25.1	10.4	9.2
WMcW**Mc**	No-tillage	17.5	6.3	15.1	15.9	22.8	12.8	9.7
	Conventional	14.7	6.8	15.9	18.0	22.6	10.8	8.9

WWWW: Wheat monoculture, WMcWMc: Medic followed after wheat, McWMcW: Wheat after medics, CWLW: Wheat after lupins, LWCW: Wheat after canola, WCWL: Lupins after wheat, WLWC: Canola after wheat

Similarly to the 0-100 mm layer, no difference in particle size composition due to treatment combinations was recorded in the 100-200 mm layer (Table 3.2). No differences in particle size composition between the two sampling depths were recorded either.

Table 3.2: The influence of tillage and crop rotation on particle size composition in the 100-200 mm layer at Langgewens (2012)

		Particle size class for the 100-200mm soil depth						
Crop rotation	**Tillage treatment**	**Coarse sand**	**Medium sand**	**Fine sand**	**Very fine sand**	**Coarse silt**	**Fine silt**	**Clay**
		2-0.5mm	**0.5-0.25mm**	**0.25-0.106mm**	**0.106-0.05mm**	**0.05-0.02mm**	**0.02-0.002mm**	**<0.002mm**
WWW**W**	No-tillage	20.2	5.9	13.4	19.4	16.6	12.4	12.0
	Conventional	20.2	5.9	13.2	20.7	14.5	12.6	13.0
McWMc**W**	No-tillage	18.7	6.1	14.8	17.7	15.5	15.0	12.1
	Conventional	18.7	6.1	14.6	18.0	19.2	12.8	10.5
WCW**L**	No-tillage	19.8	5.5	13.2	17.9	18.5	13.0	12.3
	Conventional	20.2	5.8	14.5	16.8	18.8	10.3	13.5
CWL**W**	No-tillage	18.8	6.4	16.6	19.9	18.0	11.1	9.9
	Conventional	19.4	5.5	14.2	18.5	17.7	12.6	12.0
WLW**C**	No-tillage	20.8	6.1	14.9	17.8	19.0	11.5	9.9
	Conventional	19.5	6.5	15.3	18.5	19.6	12.3	9.5
LWC**W**	No-tillage	20.5	5.7	14.2	16.4	19.1	13.7	10.4
	Conventional	23.1	5.9	14.8	16.4	18.9	10.9	10.0
WMcW**Mc**	No-tillage	21.5	6.3	13.8	17.2	19.4	12.4	10.7
	Conventional	20.9	6.3	13.4	17.2	20.0	11.5	9.4

WWWW: Wheat monoculture, WMcWMc: Medic followed after wheat, McWMcW: Wheat after medics, CWLW: Wheat after lupins, LWCW: Wheat after canola, WCWL: Lupins after wheat, WLWC: Canola after wheat

The soil in both layers were classified as sandy loam soils. Both layers contained between 15-20 % clay and 50-70 % sand. This data correlate with data reported by Botha (2012) on research done on the same research farm.

The results shown in Table 3.1 and Table 3.2 therefore, correlate with what was expected, namely that tillage practices cannot change the texture of the soil. Tillage will however influence soil structure due to the negative effect on aggregate stability. Botha (2012) reported a higher aggregate stability under NT compared to minimum tillage (MT), CT and tine tillage (TT) for two sampling depths 0-100 mm and 100 – 200 mm.

Contrary to the current study, a long-term study in Nigeria Lal (1997) did prove that tillage practices could result in changes soil texture. Results from the study showed that after eight years the sand content was significantly lower and the clay content significantly higher in the upper 0-100 mm soil layer of no-till mulched plots compared to plough-based un-mulched plots. The study was done on soils in an area that was prone to soil erosion through water and wind, and the study had a strong focus on mulches. A possible reason for the “change” in texture could therefore be attributed to erosion prevention. The ratio of sand, silt and clay will be affected because the top soil layer will not be lost and could result in a different ratio comparing the top soil layer to soil that has been subjected to erosion.

3.1.3 Bulk density:

Bulk density (g.cm^{-3}) was recorded within the 0-100 and 100-200 mm soil layers, B horizon and shale parent material and results summarised in Figure 3.2. From Figure 3.2 it is clear that the bulk density tended to increase with depth within tillage treatments (P = 0.04 and 0.0012 for CT and NT respectively). CT resulted in higher (P = 0.0023) bulk density values compared to NT in both the 0-100 mm (P = 0.0023) and 100-200 mm (P = 0.004) soil layers.

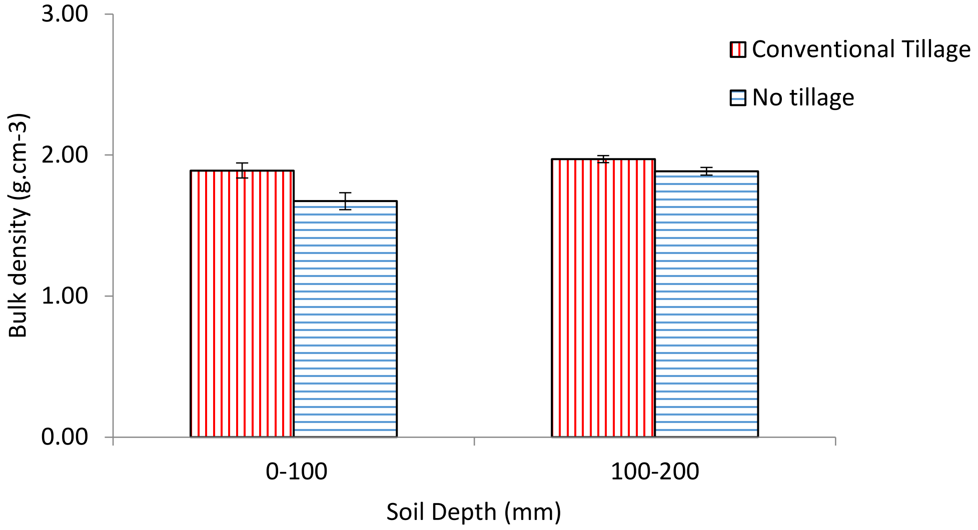

Figure 3.2: Bulk density as influenced by tillage treatment in the 0-200 mm soil layers at Langgewens (2012)

The bulk density increased from 1.67 g.cm^{-3} in the 0-100 mm to 1.88 g.cm^{-3} in the 100 – 200 mm soil layer under NT. The highest bulk density value was recorded in the 100-200 mm layer of the CT treatment (1.95 g.cm^{-3}) which is the layer just above the expected plough pan (a highly compacted layer developed over time at the depth that the plough implement reaches). The lowest bulk density value was recorded in the 0-100 mm layer of the no-tillage (1.67 g.cm^{-3}) treatment.

These results correlate with Botha (2012) who also found that bulk density values under NT was significantly lower compared to CT in the 0-100 mm soil layer. Contrary to the results in the current study, Blevins et al. (1983) reported no difference in the bulk density values between CT and NT in the upper 0-150 mm soil layer in a 10 year tillage corn trail. A similar study done in South Western Spain between 1986 and 1987 also reported no significant difference in bulk density values between mouldboard plough and no-till treatments in the 0-20 cm soil layer at the beginning of the season (Pelegrin et al., 1990).

The depth occurrence of the pedocutanic B horizon varied between 600 - 1000 mm. The bulk density of the pedocutanic B horizon is important and will influence deep storage of water or reduce deep drainage in the profile. The mean bulk density values of the pedocutanic B horizon and shale parent material are shown in Table 3.3. The clods that were taken for the determination of bulk density of the pedocutanic B horizon were taken at a depth of between 600 – 1000 mm. Thus the effect of tillage on these values is not applicable as the soil disturbance would reach a maximum depth of 200 mm. The results in Table 3.3 correlate well with the work done by Botha (2012) at Langgewens.

Table 3.3 Mean bulk density (g.cm^{-3}) of the pedocutanic B horizon and the shale parent material

Material	**Number of replicates**	**Standard deviation**	**Standard error**	**Mean (g.cm^{-3})**
Pedocutanic B horizon	7	0.06	0.03	1.71
Shale parent material	7	0.32	0.19	2.20

3.2 Soil water

3.2.1 Shale water storage potential:

Calculating the gravimetric water content at saturation point and using the bulk density values to covert these values into the volumetric water content, the water storage capacity of the shale fragment was determined and shown in Table 3.4. The potential water storage of the shale fragments were determined in an effort to establish if the shale fragments could store water that would be available for crop use.

Table 3.4: The mean volumetric water content of shale fragments at Langgewens (2012)

Number of replicates	**Standard deviation**	**Standard error**	**Average volumetric water content (mm.mm^{-1})**
6	0.08	0.04	0.17

The mean volumetric water content of the shale rock fragments were 0.17 mm.mm^{-1}. This value correlates with values reported by Botha (2012). The mean volumetric were low. These fragments in the Langgewens area are very brittle. This can become an important source of crop available water deeper down in the profile, if soil preparation is done correctly and crop roots growth is not restricted.

3.3 Saturated hydraulic conductivity (K_s)

The saturated hydraulic conductivity was determined in an attempt to quantify potential flow of water throughout the soil profile.

The K_s of soils is an important physical property in the winter rainfall crop producing area of the Western Cape where soils may reach saturation point several times during one season.

The effect of the treatment combinations on saturated hydraulic conductivity are shown in Figure 3.3. Although differences in K_s were recorded, no trend could be found. The saturated hydraulic conductivity varied between 7.2 mm.h^{-1} for the WWWW and 56 mm.h^{-1} for the WMcWMcW rotation under CT. Values for the NT treatment ranged between 9.9 mm.h^{-1} for the WWWW and 51.3 mm.h^{-1} for the McWMcW rotation. Although no significant differences or definite trend in terms of crop rotation and tillage could be identified, the results suggest that crop rotation does benefit saturated hydraulic conductivity with the lowest in the wheat mono culture.

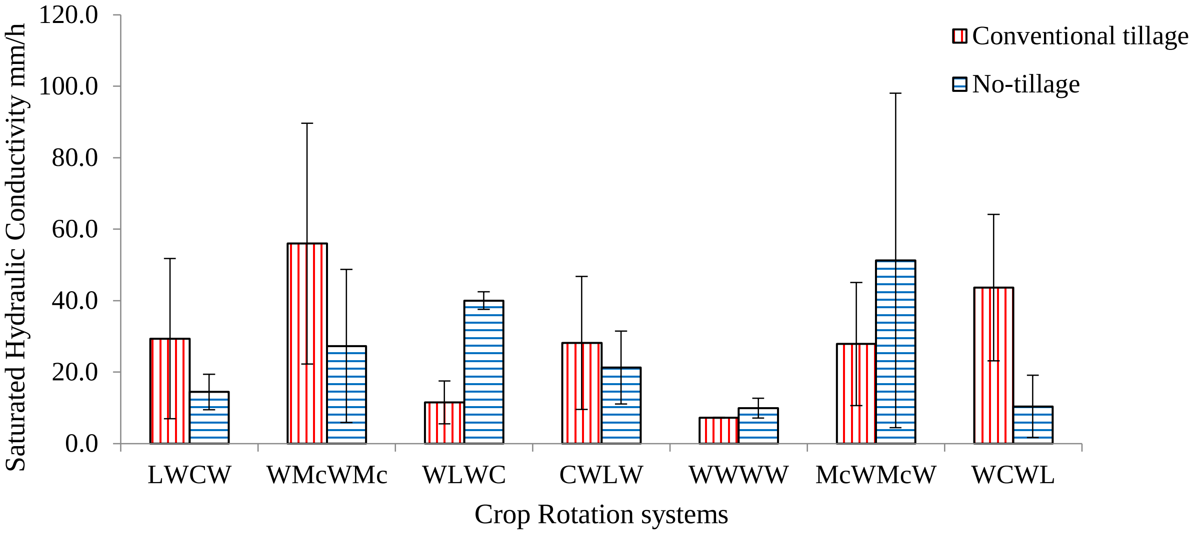

Figure 3.3: The influence of tillage and crop rotation on the saturated hydraulic conductivity at Langgewens (2012).

No significant differences between CT and NT for saturated hydraulic conductivity (K_s) were recorded.

The K_s results is found to be inconclusive, because of the high percentage coarse fragments and stones in the undisturbed cores. This is believed to have a biased influence on the data. The large amount of stones and coarse fragments in the undisturbed cores created large preferential flow paths that lead to unrealistically high K_s values. It is recommended that in such cases where the soil profile is dominated with large percentages of coarse fragments K_s and infiltration studies should rather be determined in-situ.

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Chapter 4: Soil water balances during 2012 and 2013

4.1 Introduction:

Soil water balances during the 2012/13 growing seasons (May-November) were calculated for all treatment combinations, as well as the 2012/13 summer fallow period. The soil water balances were calculated as described by Hillel (1998).

4.2 Results:

The first soil water content (SWC) recording was done on May 24th 2012 (nine days after planting) and June 12th 2013 (two weeks after planting), using the Diviner 2000 apparatus. The SWC of each profile was calculated as the sum of the SWC per 100 mm depth increment. Due to installation difficulties in 2012 the access tubes of the entire experiment could only be installed to a depth of between 200 and 400 mm. Therefore the average soil depth monitored was restricted to 200 mm throughout the 2012 season. Improved installation apparatus and methods used in 2013 increased installation depth of access tubes to 900 mm. After re-evaluating the soil water data recorded in 2012 it was decided to include the 2012 data. However, more emphasis will be placed on the results of the 2013 data.

4.2.1 Soil water balance of the 2012 growing season

Wheat after canola in a wheat-canola-wheat-lupin system

The soil water balance over the average depth of 200 mm for wheat after canola in the CT and NT treatments are shown in Table 4.1. The initial total SWC in NT (13.1 mm) was 2.8 mm higher than in CT (12.3 mm). The SWC of both tillage treatments reached a maximum on July 11th 2012, 61 days after planting. The SWC on July 11th for the CT treatment was 21.7 mm and for the no-tillage treatment 37.6 mm. During this period (24 May 2012 to 11 July 2012) 99.8 mm of rain was recorded. The SWC in the NT treatment compared to the CT, remained higher throughout the growing season until harvesting. The SWC at harvest was 2.5 mm higher in NT than in CT.

After the 11th May 2012 the soil water depletion started to increase. The total water consumption (ΣET, Table 4.1) at the end of the season did not differ significantly ($P > 0.05$) between NT (280.3 mm) and CT (280.0 mm). However, for the first 119 days after planting the cumulative ET under NT was 10.5 mm lower than recorded for CT.

Wheat after lupin in a wheat-canola-wheat-lupin system

The CT (48.2 mm) resulted in 28.2 mm more water in the top 200 mm of the soil profile compared to NT (20.0 mm) in the wheat planted after lupin rotation (Table 4.2). This could be attributed to the fact the SWC for replicate one of the CT was measured up to a depth of 700 mm. This reflected a higher total SWC for the average of three replicates and posed obvious difficulties when comparing results between rotation systems. The SWC in both NT and CT soil profiles reached a maximum 61 days after planting. The soil water retained in the soil profile of both treatments in this cropping system were higher compared to the cropping system discussed in the section to follow. The results in Table 4.2 are in accordance with results reported by Ward et al. (2002) who found 20 mm more water retained when wheat is planted after lupins compared to wheat planted after medic.

Statistical analysis showed no difference ($P > 0.05$) between tillage treatments in the total seasonal water consumption. The cumulative ET for CT (291.4 mm) was however 7.5 mm higher than the NT treatment (283.9 mm). This is in contrast with the study done by Wiese (2013) reporting although that the soil profile under CT treatment did retained less water than NT.

Wheat after medic in a wheat-medic-wheat-medic system

Results of the soil water balance for the wheat after medic in the wheat-medic-wheat-medic system for CT and NT treatments are shown in Table 4.3. At the start of the study on May 24th, the mean SWC of the NT plots (41 mm) were higher compared to the mean SWC of the CT plots (14.7 mm). This difference could be attributed to a deeper soil profile monitored in the third replicate of the NT treatment. The maximum SWC was reached on July 11th 2012 at 62.7 mm and 40.2 mm for NT and CT respectively.

The initial cumulative ET rate was lower under NT than under CT. The average cumulative ET for the first 43 days after planting was 16.1 mm lower under NT compared to CT. A plausible explanation would be the residue cover that restricted evaporation, the dominant component of soil water loss during this early stage of crop development when foliar coverage does not play a role. This observation is substantiated by results from Blevins et al. (1971) reporting that the decrease in evaporation and an improved ability to store water under NT led to a higher SWC under NT. From the 11th of July (day 61 after planting) little difference in the consumptive water use between the two treatments recorded. The total seasonal cumulative ET was 13.9 mm higher under NT but not statistically significant.

Table 4.1 The influence of crop rotation and tillage on the soil water balance for wheat planted after canola in a wheat-canola-wheat-lupin rotation per treatment at Langgewens (2012).

			Date																		
Rotation	Treatment		24-05-12	30-05-12	11-06-12	21-06-12	27-07-12	04-07-12	11-07-12	19-07-12	25-07-12	02-08-12	24-08-12	30-08-12	06-09-12	20-09-12	25-09-12	02-10-12	18-10-12	30-10-12	09-11-12
LWCW	CT	W	10.3	13.6	16.5	14.7	21.2	23.7	21.7	18.3	15.9	14.0	18.7	13.4	8.6	6.4	8.8	7.3	4.4	4.9	4.1
		Δ W		-3.3	-2.9	1.8	-6.5	-2.5	2.0	3.4	2.4	2.0	-4.7	5.2	4.9	2.1	-2.3	1.4	2.9	-0.4	0.8
		P		5.4	36.8	3.2	20.8	13.6	20.0	1.0	9.6	4.6	74.6	3.6	8.4	13.0	13.8	31.4	5.2	10.8	0.0
		ΣET		2.1	36.0	41.0	55.3	66.4	88.3	92.8	104.7	111.3	181.2	190	203.3	218.4	229.9	262.7	270.8	281.2	282.0
LWCW	NT	W	13.1	15.7	26.2	18.3	32.3	35.7	37.6	28.0	30.2	20.7	30.0	26.5	21.9	10.9	13.9	19.5	7.8	8.0	6.6
		Δ W		-2.6	-10.5	7.8	-13.9	-3.4	-1.9	9.6	-2.1	9.5	-9.3	3.5	4.7	11.0	-3.1	-5.6	11.8	-0.2	1.4
		P		5.4	36.8	3.2	20.8	13.6	20.0	1.0	9.6	4.6	74.6	3.6	8.4	13.0	13.8	31.4	5.2	10.8	0.0
		ET		2.8	26.3	11.0	6.9	10.2	18.1	10.6	7.5	14.1	65.3	7.1	13.1	24.0	10.7	25.8	17.0	10.6	1.4
		ΣET		2.8	29.1	40.2	47.0	57.2	75.3	85.9	93.3	107.4	172.7	179.8	192.8	216.8	227.6	253.4	270.3	280.9	282.3

CT = CT; NT = NT; W= Water content (mm); ΔW= change in water content (mm); P= precipitation (mm); ET= ET (mm); ΣET= Cumulative ET (mm), negative ΔW values indicating increase in the SWC

Table 4.2: The influence of crop rotation and tillage on the soil water balance for wheat planted after lupins in a wheat-canola wheat-lupin rotation system at Langgewens (2012).

			Date																		
Crop Rotation	Treatment		24-05-12	30-05-12	11-06-12	21-06-12	27-06-12	04-07-12	11-07-12	19-07-12	25-07-12	02-08-12	24-08-12	30-08-12	06-09-12	20-09-12	25-09-12	02-10-12	18-10-12	30-10-12	09-11-12
CWLW	CT	W	48.2	47.1	54.8	49.7	56.5	58.3	59.0	53.2	49.0	51.3	57.5	51.8	43.0	36.8	39.3	39.8	33.9	33.0	32.6
		Δ W		1.1	-7.7	5.1	-6.8	-1.8	-0.7	5.8	4.2	-2.3	-6.2	5.7	8.8	6.2	-2.5	-0.5	5.9	0.9	0.4
		P		5.4	36.8	3.2	20.8	13.6	20.0	1.0	9.6	4.6	74.6	3.6	8.4	13.0	13.8	31.4	5.2	10.8	0.0
		ET		6.5	29.1	8.3	14.0	11.8	19.3	6.8	13.8	2.3	68.4	9.3	17.2	19.2	11.3	30.9	11.1	11.7	0.4
		Σ ET		6.5	35.6	43.9	57.9	69.7	89.0	95.8	109.6	111.9	180.3	189.6	206.8	226.0	237.3	268.2	279.3	291.0	291.4
CWLW	NT	W	20.0	20.5	37.4	25.8	40.4	45.8	46.0	35.6	33.3	25.1	42.1	35.8	28.1	16.0	17.7	25.5	13.2	13.0	11.9
		Δ W		-0.5	-16.9	11.6	-14.6	-5.4	-0.2	10.4	2.4	8.1	-16.9	6.2	7.8	12.1	-1.8	-7.7	12.3	0.2	1.1
		P		5.4	36.8	3.2	20.8	13.6	20.0	1.0	9.6	4.6	74.6	3.6	8.4	13.0	13.8	31.4	5.2	10.8	0.0
		ET		4.9	19.9	14.8	6.2	8.2	19.8	11.4	12.0	12.7	57.7	9.8	16.2	25.1	12.0	23.7	17.5	11.0	1.1
		Σ ET		4.9	24.7	39.6	45.8	54.0	73.7	85.1	97.1	109.8	167.5	177.3	193.5	218.6	230.6	254.3	271.8	282.8	283.9

CT = CT; NT = NT; W= Water content (mm); ΔW= change in water content (mm); ET= ET (mm) ; ΣET= Cumulative ET (mm), negative ΔW values indicating increase in the SWC

Table 4.3: The influence of crop rotation and tillage on the soil water balance for wheat planted after medic in a wheat-medic-wheat-medic system at Langgewens (2012).

			Date																		
Crop Rotation	Treatment		24-05-12	30-05-12	11-06-12	21-06-12	27-06-12	04-07-12	11-07-12	19-07-12	25-07-12	02-08-12	24-08-12	30-08-12	06-09-12	20-09-12	25-09-12	02-10-12	18-10-12	30-10-12	09-11-12
McWMcW	CT	W	14.7	14.8	20.5	15.7	23.4	25.5	40.2	21.2	21.8	15.4	63.0	27.4	20.5	10.1	12.8	23.7	9.1	8.9	8.5
		Δ W		-0.1	-5.7	4.8	-7.7	-2.1	-14.7	19.0	-0.6	6.4	-47.6	35.6	6.9	10.4	-2.8	-10.8	14.6	0.1	0.4
		P		5.4	36.8	3.2	20.8	13.6	20.0	1.0	9.6	4.6	74.6	3.6	8.4	13.0	13.8	31.4	5.2	10.8	0.0
		ET		5.3	31.1	8.0	13.1	11.5	5.3	20.0	9.0	11.0	27.0	39.2	15.3	23.4	11.0	20.6	19.8	10.9	0.4
		Σ ET		5.3	36.4	44.4	57.5	69.0	74.3	94.3	103.3	114.3	141.3	180.5	195.8	219.2	230.3	250.8	270.6	281.6	282.0
McWMcW	NT	W	41.0	41.6	50.1	46.5	65.8	59.8	62.7	52.0	48.5	43.6	60.1	50.7	39.0	27.6	31.6	32.4	22.4	21.4	20.9
		Δ W		-0.6	-8.4	3.6	-19.3	6.0	-2.9	10.7	3.5	4.9	-16.5	9.4	11.7	11.4	-4.0	-0.8	10.1	1.0	0.5
		P		5.4	36.8	3.2	20.8	13.6	20.0	1.0	9.6	4.6	74.6	3.6	8.4	13.0	13.8	31.4	5.2	10.8	
		ET		4.8	28.4	6.8	1.5	19.6	17.1	11.7	13.1	9.5	58.1	13.0	20.1	24.4	9.8	30.6	15.3	11.8	0.5
		ΣET		4.8	33.2	39.9	41.4	61.1	78.2	89.8	102.9	112.4	170.5	183.5	203.6	228.0	237.8	268.4	283.7	295.4	295.9

CT = CT; NT = NT; W= Water content (mm); ΔW= change in water content (mm); P= precipitation (mm); ET= ET (mm); ΣET= Cumulative ET (mm), negative ΔW values indicating increase in the SWC

Wheat monoculture system

The effect of tillage on soil water balances in wheat monoculture is shown in Table 4.4. The initial SWC under NT (18.0 mm) was marginally higher than in the CT treatment (14.9 mm). However under NT more than twice as much water (70.8 mm) was retained. In the period of planting until the 11th of July 2012, 99.8 mm of rain was recorded. More than twice as much soil water (70.8 mm) was retained in the NT plots compared to the CT plots (29.0 mm) Even though there was a substantial difference in the SWC between treatments initially, the cumulative ET rate for both treatments followed the same trend and did not differ much at any point after the 11th of July 2012. No significant difference in the cumulative ET between NT (278.6 mm) and CT (277.6 mm) were recorded.

Canola after wheat in a wheat-canola-wheat-lupin system

The soil water balance recorded for canola planted after wheat in NT and CT is summarised in Table 4.5. Initial SWC was 6.7 mm higher under NT (22.0 mm) compared to CT (12.3 mm). The NT treatment constantly retained more water than the CT throughout the entire growing season. The NT treatment retained at least 10 mm more soil water in the first 75 days after planting than the CT treatment. After 75 days until the end of the growing season the NT treatment continued to retain more water, however much less compared to within the first 75 days. At the end of the growing season the mean SWC of NT plots and CT plots differed only with 0.8 mm.

The cumulative ET was lower under NT during the initial growth stages until August 2nd 2012 (83 days after planting). These results are once again substantiated by the findings of Blevins et al, (1971). The lower cumulative ET recorded under NT could be the result of residue cover assuming that the residues protected the soil surface and limited soil water loss through evaporation (Power et al., 1986), which is much higher on the bare soil surface of the CT treatment. This could explain the higher SWC under the NT treatment. The latter part of the growing season was characterised by higher cumulative ET values for the NT treatment compared to the CT treatment. This could be explained by the fact that more soil water was available for the crop. That resulted in more above ground biomass and subsequent higher transpiration rates which was the dominant component of cumulative ET at that stage. (Blevins et al., 1971). Although not statistical significant, the NT (291.5 mm) treatment resulted in a 9 mm higher seasonal water consumption than that of the CT treatment (282.5 mm).

Table 4.4: The influence of crop rotation and tillage on the Soil water balance of wheat monoculture at Langgewens (2012).

			Date																		
Crop Rotation	Treatment		24-05-12	30-05-12	11-06-12	21-06-12	27-06-12	04-07-12	11-07-12	19-07-12	25-07-12	02-08-12	24-08-12	30-08-12	06-09-12	20-09-12	25-09-12	02-10-12	18-10-12	30-10-12	09-11-12
WWWW	CT	W	14.9	15.6	22.7	17.3	24.1	25.3	29.0	24.0	23.4	26.5	32.0	28.2	21.1	15.1	23.5	22.3	13.9	13.6	13.2
		Δ W		-0.7	-7.1	5.4	-6.7	-1.3	-3.6	4.9	0.6	-3.1	-5.5	3.9	7.1	6.0	-8.4	1.3	8.4	0.3	0.3
		P		5.4	36.8	3.2	20.8	13.6	20.0	1.0	9.6	4.6	74.6	3.6	8.4	13.0	13.8	31.4	5.2	10.8	0.0
		ET		4.7	29.7	8.6	14.1	12.3	16.4	5.9	10.2	1.5	69.1	7.5	15.5	19.0	5.4	32.7	13.6	11.1	0.3
		Σ ET		4.7	34.4	43.0	57.1	69.4	85.7	91.7	101.9	103.4	172.5	179.9	195.4	214.4	219.8	252.4	266.0	277.2	277.5
WWWW	NT	W	18.0	18.8	36.2	27.9	39.1	46.3	70.8	37.8	37.9	30.6	78.3	41.2	32.9	19.0	20.1	26.1	18.1	16.3	15.1
		Δ W		-0.8	-17.4	8.3	-11.2	-7.2	-24.4	33.0	-0.1	7.4	-47.7	37.1	8.3	13.9	-1.1	-6.0	8.0	1.9	1.1
		P		5.4	36.8	3.2	20.8	13.6	20.0	1.0	9.6	4.6	74.6	3.6	8.4	13.0	13.8	31.4	5.2	10.8	0.0
		ET		4.6	19.4	11.5	9.6	6.4	-4.4	34.0	9.5	12.0	26.9	40.7	16.7	26.9	12.7	25.4	13.2	12.7	1.1
		Σ ET		4.6	24.0	35.5	45.0	51.4	47.0	81.0	90.5	102.4	129.3	170.0	186.7	213.6	226.3	251.7	264.9	277.5	278.6

CT = CT; NT = NT; W= Water content (mm); ΔW= change in water content (mm); P= precipitation (mm); ET= ET (mm); ΣET= Cumulative ET (mm), negative ΔW values indicating increase in the SWC

Table 4.5: The influence of crop rotation and tillage on the soil water balance for canola planted after wheat rotation system at Langgewens (2012).

			Date																		
Crop Rotation	Treatment		24-05-12	30-05-12	11-06-12	21-06-12	27-06-12	04-07-12	11-07-12	19-07-12	25-07-12	02-08-12	24-08-12	30-08-12	06-09-12	20-09-12	25-09-12	02-10-12	18-10-12	30-10-12	09-11-12
		W	12.3	12.4	14.2	12.6	17.3	20.0	20.4	16.1	15.9	13.3	26.7	21.8	18.3	10.6	14.7	17.3	7.3	6.6	5.6
		Δ W		-0.1	-1.8	1.6	-4.8	-2.7	-0.4	4.2	0.3	2.6	-13.4	4.9	3.5	7.6	-4.1	-2.6	10.0	0.7	1.0
WLWC	CT	P		5.4	36.8	3.2	20.8	13.6	20.0	1.0	9.6	4.6	74.6	3.6	8.4	13.0	13.8	31.4	5.2	10.8	0.0
		ET		5.3	35.0	4.8	16.0	10.9	19.6	5.2	9.9	7.2	61.2	8.5	11.9	20.6	9.7	28.8	15.2	11.5	1.0
		Σ ET		5.3	40.3	45.2	61.2	72.1	91.8	97.0	106.9	114.1	175.3	183.8	195.7	216.3	226.0	254.8	270.0	281.5	282.5
		W	22.0	23.5	28.6	23.5	31.3	34.0	36.1	27.9	28.9	26.0	30.6	28.1	24.9	18.3	21.7	19.2	9.7	7.6	6.4
		Δ W		-1.5	-5.1	5.1	-7.8	-2.7	-2.1	8.2	-1.0	2.9	-4.6	2.5	3.1	6.7	-3.4	2.5	9.5	2.0	1.3
WLWC	NT	P		5.4	36.8	3.2	20.8	13.6	20.0	1.0	9.6	4.6	74.6	3.6	8.4	13.0	13.8	31.4	5.2	10.8	0.0
		ET		3.9	31.7	8.3	13.0	10.9	17.9	9.2	8.6	7.5	70.0	6.1	11.5	19.7	10.4	33.9	14.7	12.8	1.3
		Σ ET		3.9	35.6	43.9	56.9	67.8	85.7	94.9	103.6	111.0	181.1	187.2	198.7	218.4	228.8	262.6	277.4	290.2	291.5

CT = CT; NT = NT; W= Water content (mm); ΔW= change in water content (mm); P= precipitation (mm); ET= ET (mm); ΣET= Cumulative ET (mm), negative ΔW values indicating increase in the SWC

Lupin after wheat in a wheat-canola-wheat-lupin system

The soil profile of the NT treatment retained 10 mm more soil water than the CT treatment at the start of the 2012 season in the WCWL system (Table 4.6**)**. Throughout the initial 61 days after planting, the water content of the CT treatment remained higher than that of the NT. At the end of the season CT (13.4 mm) retained 5 mm more water than NT (8.4 mm). Soil water depletion in the soil profile of the NT was much faster in the last month before harvest compared to the CT soil profile. This could be explained by the deeper soil profile in the CT which potentially retained more water. At this point the inconsistencies in the soil moisture monitoring depth has become a barrier when trying to compare treatments.

The NT treatment resulted in a higher cumulative ET rate throughout the season, despite having lower SWC in the second half of the season. Although not statistically significant ($P > 0.05$), NT (287.5 mm) resulted in 15 mm higher seasonal water consumption than the CT treatment (272.5 mm).

Medic after wheat in a wheat-medic-wheat-medic system

The soil water balance for the medic after wheat rotation system in Table 4.7 showed little difference in the initial SWC with NT resulting in a 2.6 mm lower SWC than the CT treatment. The SWC for both treatments reached a maximum 61 days after planting at 27.6 mm and 25.5 mm for CT and NT treatments respectively. From 61 days after planting NT continued to store more soil water than CT. These results are in accordance with Blevins et al. (1971). At the end of the growing season there was no significant difference in the SWC between the NT and CT treatments.

Cumulative ET between the two tillage treatments throughout the season were very similar and no statistically significant differences ($P > 0.05$) were recorded between the seasonal water consumption for both treatments.

Table 4.6: The influence of crop rotation and tillage on the soil water balance for lupins planted after wheat rotation system at Langgewens (2012).

			Date																		
Crop Rotation	Treatment		24-05-12	30-05-12	11-06-12	21-06-12	27-06-12	04-07-12	11-07-12	19-07-12	25-07-12	02-08-12	24-08-12	30-08-12	06-09-12	20-09-12	25-09-12	02-10-12	18-10-12	30-10-12	09-11-12
WCWL	CT	W	10.0	12.0	27.7	19.8	29.0	24.3	37.5	26.8	26.8	17.6	36.4	29.8	21.1	14.8	18.1	26.1	13.7	14.4	13.4
		Δ W		-2.0	-15.6	7.9	-9.2	4.7	-13.3	10.8	0.0	9.2	-18.9	6.7	8.6	6.4	-3.4	-8.0	12.4	-0.7	1.0
		P		5.4	36.8	3.2	20.8	13.6	20.0	1.0	9.6	4.6	74.6	3.6	8.4	13.0	13.8	31.4	5.2	10.8	0.0
		ET		3.4	21.2	11.1	11.6	18.3	6.7	11.8	9.6	13.8	55.7	10.3	17.0	19.4	10.4	23.4	17.6	10.1	1.0
		Σ ET		3.4	24.6	35.7	47.3	65.6	72.3	84.1	93.6	107.5	163.2	173.5	190.5	209.9	220.3	243.7	261.3	271.4	272.5
WCWL	NT	W	20.0	21.8	24.4	22.9	28.5	35.1	32.1	26.0	25.6	20.5	32.3	26.5	20.6	11.0	14.0	16.4	8.4	9.4	8.4
		Δ W		-1.7	-2.6	1.5	-5.6	-6.6	3.0	6.1	0.4	5.0	-11.7	5.8	5.8	9.7	-3.1	-2.4	8.0	-1.0	1.0
		P		5.4	36.8	3.2	20.8	13.6	20.0	1.0	9.6	4.6	74.6	3.6	8.4	13.0	13.8	31.4	5.2	10.8	0.0
		ET		3.7	34.2	4.7	15.2	7.0	23.0	7.1	10.0	9.6	62.9	9.4	14.2	22.7	10.7	29.0	13.2	9.8	1.0
		Σ ET		3.7	37.9	42.5	57.8	64.7	87.7	94.8	104.9	114.5	177.4	186.8	201.0	223.7	234.4	263.4	276.6	286.5	287.5

CT = CT; NT = NT; W= Water content (mm); ΔW= change in water content (mm); P= precipitation; ET= ET (mm); ΣET= Cumulative ET (mm), negative ΔW values indicating increase in the SWC

Table 4.7: The influence of crop rotation and tillage on the soil water balance for medic planted after wheat rotation system at Langgewens (2012).

			Date																		
Crop Rotation	Treatment		24-05-12	30-05-12	11-06-12	21-06-12	27-06-12	04-07-12	11-07-12	19-07-12	25-07-12	02-08-12	24-08-12	30-08-12	06-09-12	20-09-12	25-09-12	02-10-12	18-10-12	30-10-12	09-11-12
WMcWMc	CT	W	10.6	12.3	20.6	13.0	24.5	26.5	27.6	19.1	21.4	12.8	24.4	22.2	20.0	7.4	10.0	14.3	4.8	4.8	3.9
		Δ W		-1.7	-8.3	7.6	-11.5	-2.1	-1.1	8.6	-2.4	8.6	-11.6	2.3	2.2	12.6	-2.5	-4.3	9.5	0.0	1.0
		P		5.4	36.8	3.2	20.8	13.6	20.0	1.0	9.6	4.6	74.6	3.6	8.4	13.0	13.8	31.4	5.2	10.8	0.0
		ET		3.7	28.5	10.8	9.3	11.5	18.9	9.6	7.2	13.2	63.0	5.9	10.6	25.6	11.3	27.1	14.7	10.8	1.0
		Σ ET		3.7	32.2	43.0	52.3	63.9	82.8	92.3	99.6	112.8	175.8	181.7	192.2	217.8	229.1	256.1	270.8	281.6	282.6
WMcWMc	NT	W	8.5	11.3	19.4	11.7	23.2	23.8	25.5	19.1	22.0	16.0	23.6	21.8	19.7	10.4	12.4	18.0	6.3	5.7	4.0
		Δ W		-2.8	-8.1	7.7	-11.4	-0.7	-1.7	6.4	-2.8	6.0	-7.6	1.8	2.1	9.3	-2.0	-5.5	11.7	0.6	1.6
		P		5.4	36.8	3.2	20.8	13.6	20.0	1.0	9.6	4.6	74.6	3.6	8.4	13.0	13.8	31.4	5.2	10.8	0.0
		ET		2.6	28.7	10.9	9.4	12.9	18.3	7.4	6.8	10.6	67.0	5.4	10.5	22.3	11.8	25.9	16.9	11.4	1.6
		ΣET		2.6	31.3	42.2	51.6	64.5	82.8	90.2	97.0	107.5	174.5	179.9	190.4	212.7	224.5	250.3	267.3	278.6	280.3

CT = CT; NT = NT; W= Water content (mm); ΔW= change in water content (mm); P= precipitation; ET= ET (mm); ΣET= Cumulative ET (mm), negative ΔW values indicating increase in the SWC

4.2.2 Cumulative ET and water consumption for the 2012 season

Water consumption (ET) in the soil profile (0-200mm) of the NT treatment was lower between 27 to 83 days after planting compared to CT (Figure 4.1). In the case of the NT treatment the higher percentage of surface cover due to crop residue seemed to play a prominent role in lowering ET and resulting in a lower water consumption rate and this is substantiated by the work of Power et al. (1986). In the study it was found that with an increase in crop residues the soil temperature decreased and that increased the soil water storage up to 50 mm.

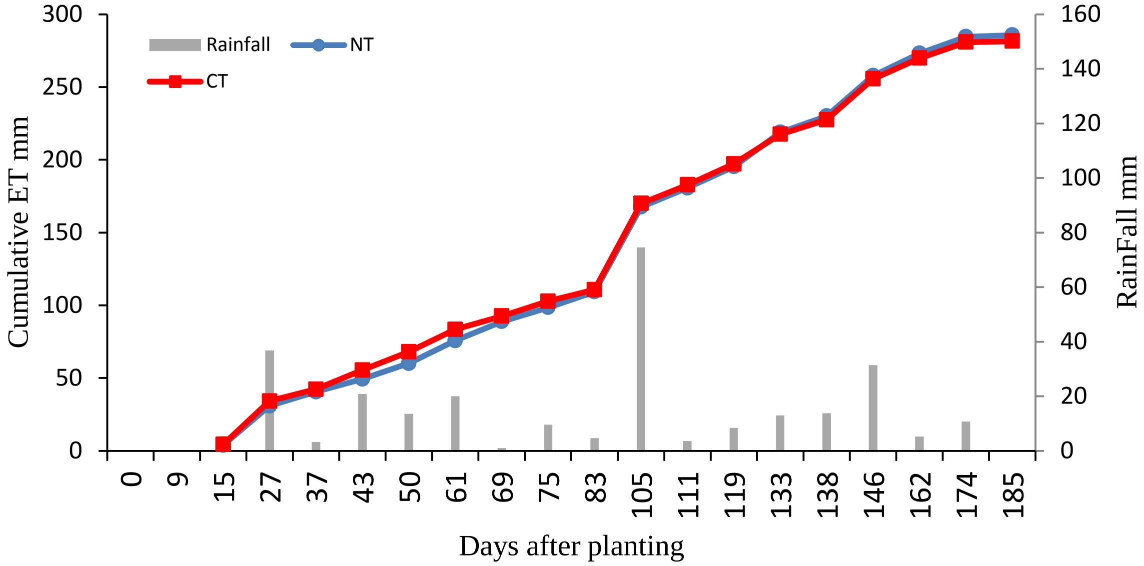

Figure 4.1: The influence of tillage on the cumulative ET (NT= no-tillage, CT= CT) at Langgewens (2012)

The soil water use increased in the period between 83 and 105 days after planting, this correlated with the period of 2 - 24 August 2012, for both treatments which did not differ. In that period 15 days with warmer temperature than the average (15.5 ^{0} C) were recorded with then maximum temperature reaching 22^0 C. The higher temperature combined with good rainfall could be a plausible explanation for the increased ET rate between 83 and 105 days after planting, creating favourable growing condition and subsequently increased ET values.

The seasonal cumulative ET for all treatment combinations tested are illustrated in Figure 4.2. No statistically significant differences in cumulative ET between treatment combinations were recorded.

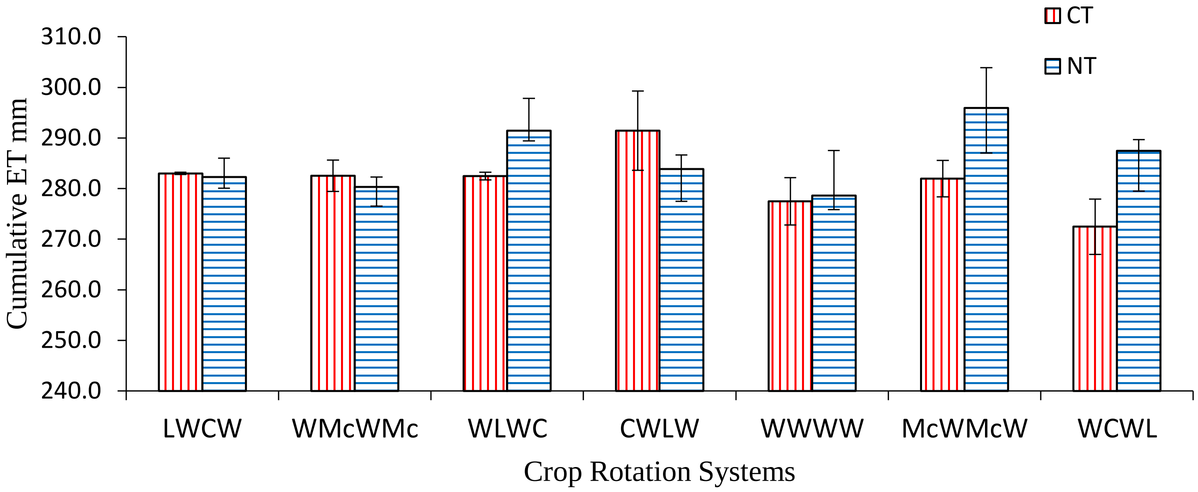

Figure 4.2: The influence of tillage and crop rotation on the cumulative ET (mm) at Langgewens (2012)

4.2.3 Fallow period 2012-2013

4.2.3.1 Percentage post-harvest soil surface coverage

The percentage soil surface coverage determined directly after the harvest season in 2012 is shown in Figure 4.3. A mean soil surface coverage of 62.6 % was recorded for the NT treatments plots as opposed to 4.8 % average in the CT plots. The highest percentage surface cover were recorded in the canola planted after wheat system under the NT treatment. The average surface cover percentages in the NT treatments plots exceeded the prescribed minimum regulations for NT systems by the FAO of only 30 % (Figure 4.3).

The significant higher surface cover of the NT plots compared to the CT plots were expected to have an impact on the soil water dynamics in the fallow period as also reported by Power et al. (1986).

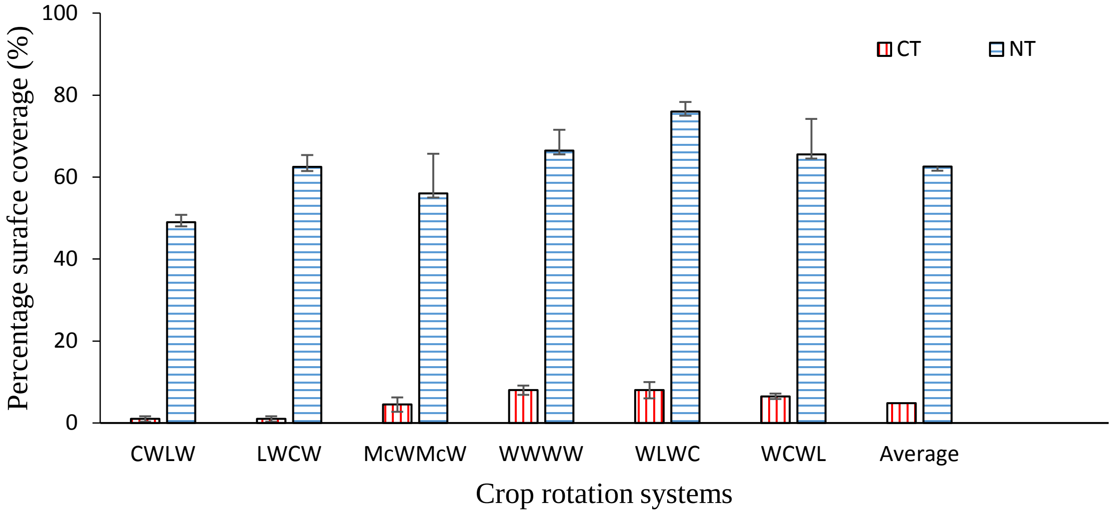

Figure 4.3: The percentage post-harvest soil surface cover at Langgewens (2012)

4.2.3.2 SWC in the fallow period

The SWC during the fallow period of November 2012 - April 2013 was recorded at monthly intervals in the top 0-200mm soil layer. The soil water was monitored during the fallow period to determine the capacity of the treatment combinations to store water between seasons. The SWC did no vary much from harvest (9 November 2012) until 26 March 2012 (Figure 4.4). The increase in the SWC after 26 March 2012 was ascribed to rainfall of 32 mm. The results shows that the soil profile under NT retained slightly more soil water compared to the CT (average difference of only 2 mm). Although a very small amount of soil water, the much higher percentage soil surface coverage under NT proved to be advantage in reducing the soil water loss. The small difference could be attributed to the very shallow soil profiles that were monitored (200 mm deep). This results correspond to results by Power et al. (1986).

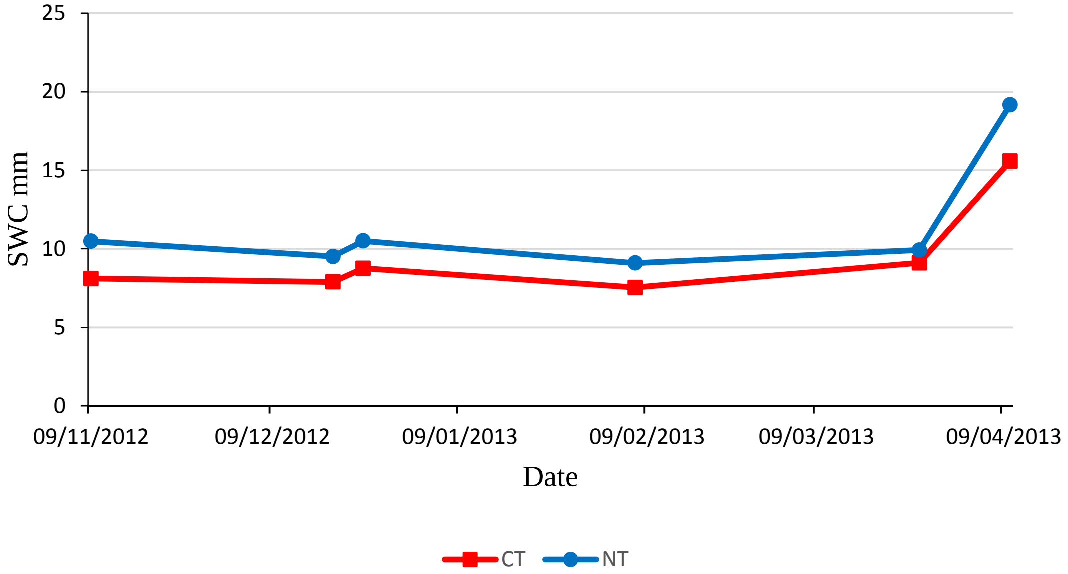

Figure 4.4: The influence of tillage on the SWC of the fallow period at Langgewens (2012)

4.3.2.3 Cumulative evaporation November 2012 – April 2012

There are no statistically significant differences ($P < 0.05$) between NT (64.0 mm) and CT (64.7 mm) for the cumulative evaporation during the fallow period (Figure 4.5)

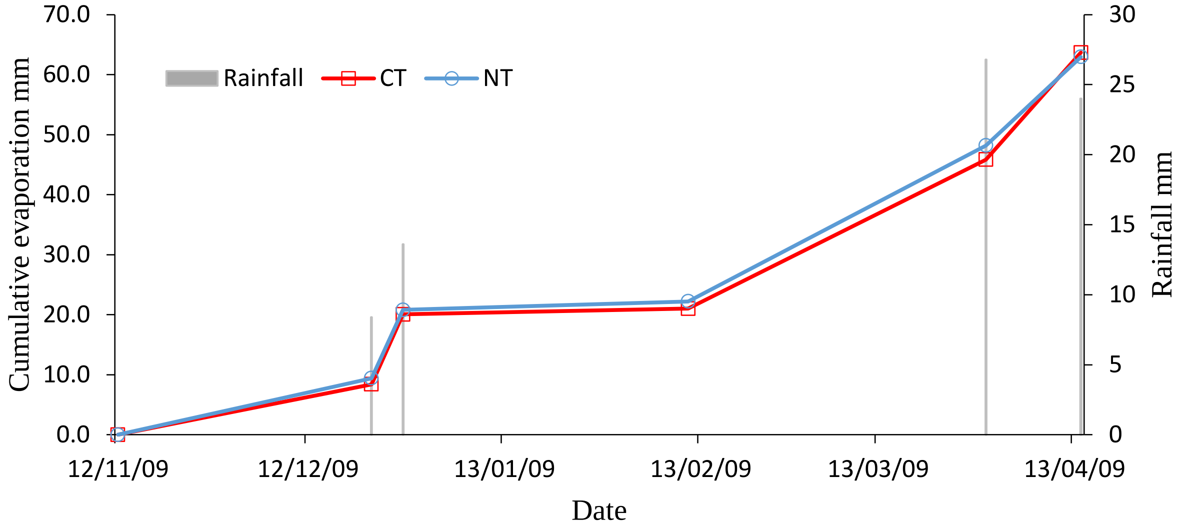

Figure 4.5: The influence of tillage on the evaporation rate (mm) for the fallow period November 2012-April 2013 (CT= Conventional tillage NT= No-tillage) at Langgewens

Initially the rate of evaporation under both the tillage treatments followed the same trend (Figure 4.5). This could be the result of the dry soil profiles under both treatments (NT and CT) with no real differences in SWC at the start of the fallow period in November 2012. However, after 100 days (2 February 2013), the evaporation rate of both treatments increased as a result of late summer, early autumn rainfall. The evaporation rate of the NT treatment soil profile between 100 and 147 days after harvest (9 April 2013), was slightly higher than that of the CT treatment. This could possibly be explained by the higher soil water available in the soil profile under NT.

The results in Figure 4.5 reflected the influence of tillage in the fallow period in a shallow 200 mm deep soil profile. The upper 200mm of the soil profile that is expected to dry out first and not expected to be responsible for storage of water throughout the fallow period. The results are there inconclusive when comparing the effect of tillage treatments on the soil water storage capacity during the fallow period. No differences were recorded in cumulative evaporation during the fallow period as a result of the treatment combinations tested (Figure 4.6). Although not statistically significant, CT resulted in higher cumulative evaporation in all wheat sequences except in the wheat monoculture system.

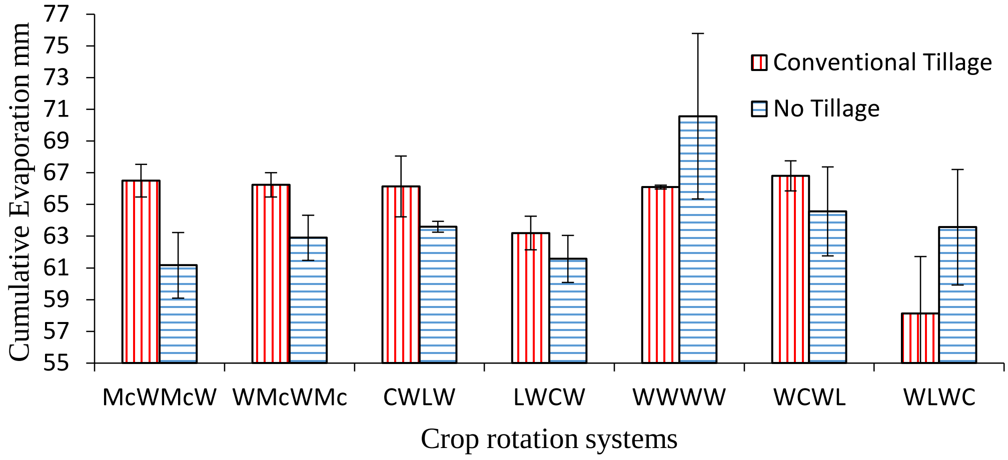

Figure 4.6 The influence of tillage and crop rotation on the cumulative evaporation (mm) for the 2012/13 fallow period at Langgewens

4.3.4 The soil water content of the 2013 season

A total of 251.3 mm of rain was recorded within the 161 days monitored from planting to harvest. As already mentioned in section 2.1.2, the total rainfall in 2013 exceeded the long-term mean average with 79 mm. One of the basic differences between NT and CT was the much higher percentage crop residue cover in the NT plots (Figure 4.7) which far exceeded the FAO prescribed minimum of 30 %.. This is a significant piece of information as it relates to potential evaporation and soil water depletion rates.

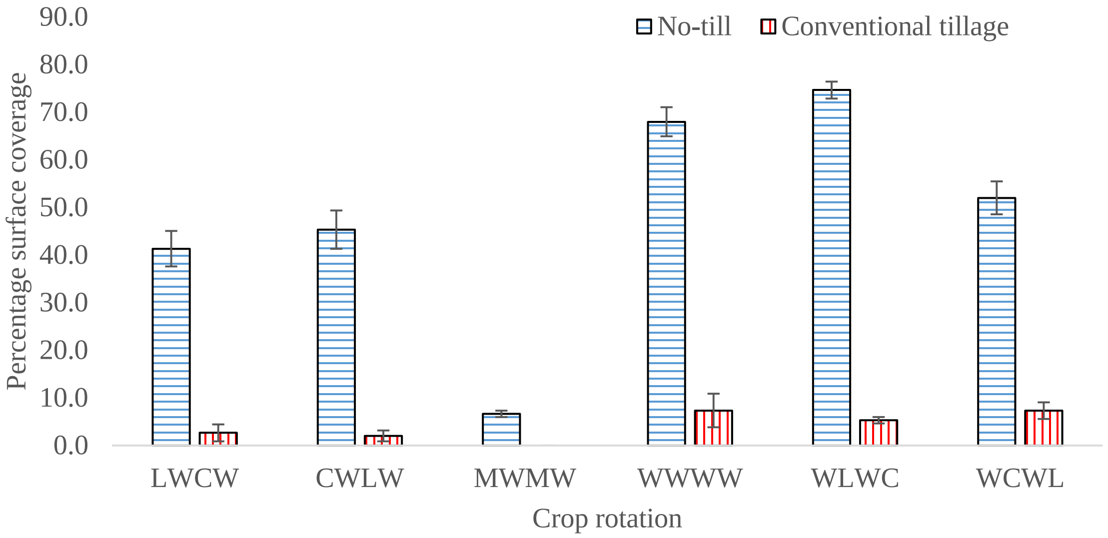

Figure 4.7: Percentage surface coverage after planting at Langgewens (2013) (NT = No tillage; CT = conventional tillage)

As mentioned, the high rainfall and sporadic higher than normal temperature (Figure 2.5) resulted in high weed pressure in the NT sites that was observed early in the season. Weeds counts were performed to quantify the magnitude of this problem (Figure 4.8). The actual crop stance on the CT plots was lower due to practical and technical errors during the planting process. These two factors influenced both the soil water dynamics as well as the yield potential.

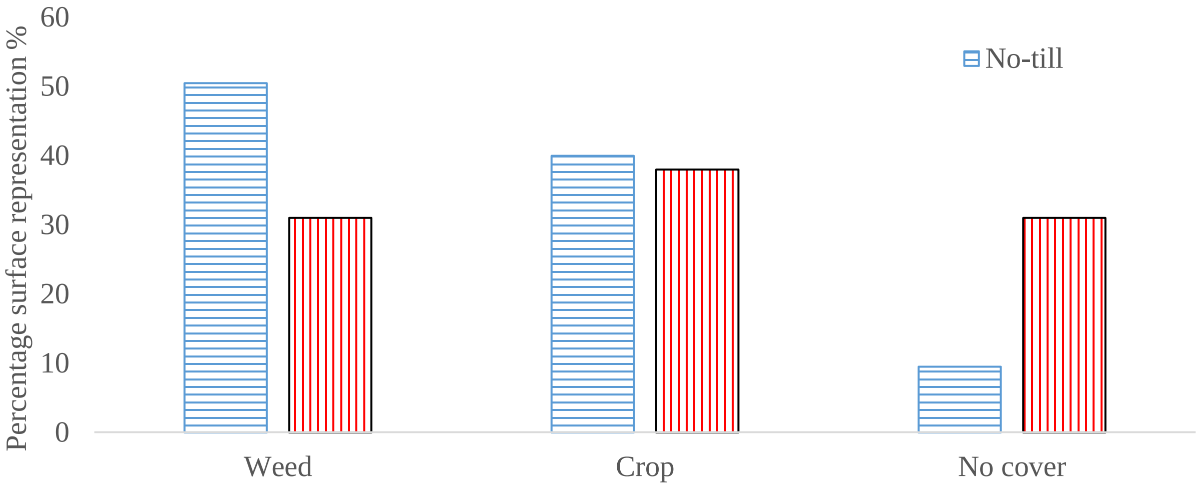

Figure 4.8: Influence of tillage on the percentage surface coverage by weeds and bare soil surface at Langgewens (2013) (NT = No tillage; CT= Conventional tillage)

After intensive investigation of the climate and rainfall data, the season could be divided into two distinct phases. The dry phase from 0 to 69 days after planting and the wet phase during the second half of the season from 69 -161 days after planting. During the first 69 days of the growing season only 30 % of the total rainfall was recorded and 70 % during the second half.

The field water capacity (FC) of the soil profile under CT and NT was determine using the SPAW model (Saxton and Rawls, 2006).The FWC for soil profiles under both treatments were 404 mm. The soil water content monitored in the 2013 were recorded at every 100mm depth increment up to a soil depth of 900mm as opposed 200mm in the 2012 season.

Wheat after canola in a wheat-canola-wheat-lupin system

The initial SWC of both soil profiles of the CT and NT treatments differed only with 4.4 mm Figure 4.9). The SWC in the soil profile of the NT treatments retained on average 28 mm more soil water in that first initial dry phase of the season as previously explained. The maximum soil profile water content of the CT treatments plots (305.2 mm) and NT plots (304.9 mm) were measured 95 days after planting. These values are still approximately 100 mm lower than the FC. In the second wet phase of the season the soil water retention under both treatments were almost identical with NT only retaining 8 mm more water than CT. This suggested that NT could reduce the impact of drought spells during the growing season. At the end of the season NT (104.4 mm) retained only 10.6 mm more soil water than CT (93.8 mm). These results are similar to results reported by Blevins et al. (1971).

The rate at which the SWC increased in the soil profile under NT were much more gradual. A suggested reason for this phenomena could be that the increased surface coverage in NT treatments slowed down the infiltration rate.

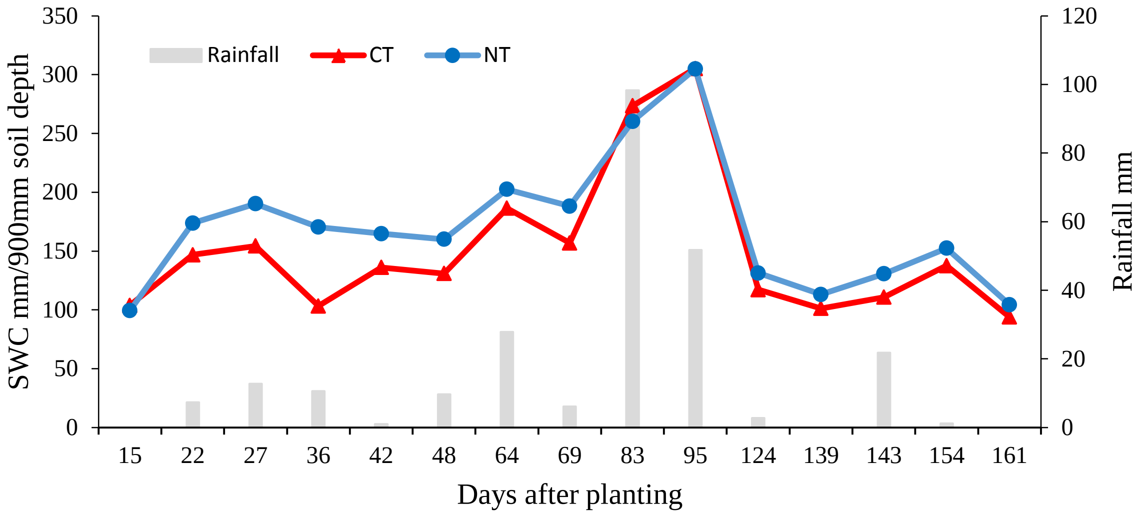

Figure 4.9: The influence of tillage and crop rotation on the SWC for wheat planted after canola in a wheat-canola-wheat-lupin rotation per treatment at Langgewens (2013) (NT = No tillage; CT= Conventional tillage)

Wheat after lupin in a wheat-canola-wheat-lupin system

Figure 4.10 illustrates the influence of tillage and crop rotation on the SWC in the 0- 900 mm soil profile in a wheat after lupin in a CWLW sequence. The same basic trend as discussed previously is observed in Figure 4.10. However the initial SWC in the soil profile under NT retained 48.8 mm more soil water than in the CT treatment. On average the soil profile under NT retained 73.6 mm more water than under the CT in the period from 0 – 83 days after planting. The SWC and rate at which the SWC increased were much higher in the NT treatment for the period of 22 to 36 days after planting. High average temperature (17^{o} C) and a lower percentage of soil surface coverage under the CT treatment could explain the observation because the higher temperature and the soil exposure most probably lead to higher evaporation rates under the CT compared to the NT treatment. This is in accordance with Power et al. (1986) explaining that higher surface coverage leads to lower soil temperature and evaporation rates. The maximum SWC of 296 mm and 290 mm for CT and NT respectively were recorded 95 days after planting. Again these values are far lower than the estimated FC of 404 mm. The rate of soil water depletion were similar under both treatment in the period between 95 and 124 days after planting. From the 3rd of September 2013 the average temperature started to raise rapidly. In the first two weeks of October, there were six days with temperatures above 25^{o} C (Figure 2.5). These prevailing weather condition and the higher available SWC under both soil treatments contributed to a possible crop growth spur and a subsequent higher rates in soil water depletion. At the end of the season the NT plots still retained 39.9 mm more soil water than the CT plots. The soil profile of the NT treatment retained on average in the first half of the season nearly twice the SWC than of the CT soil profile compared to the second wetter half of the season.

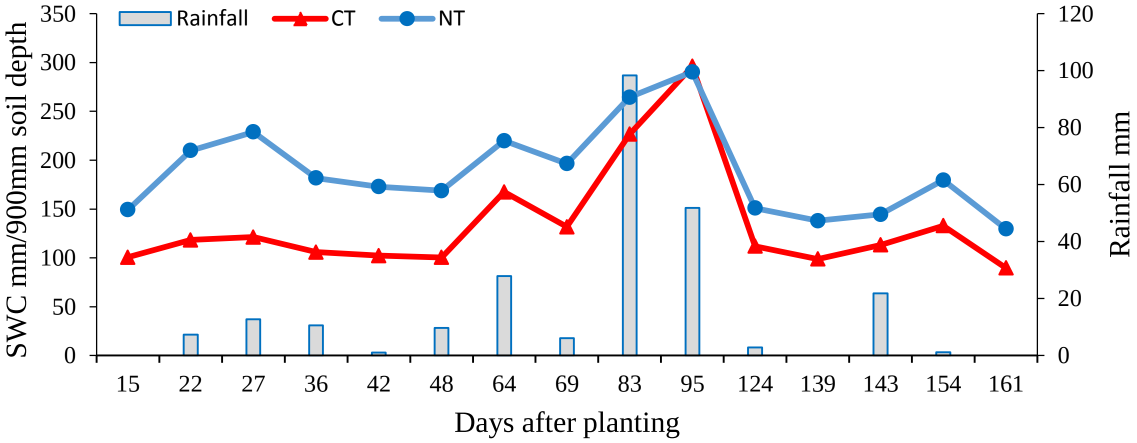

Figure 4.10: The influence of tillage and crop rotation on the SWC for wheat planted after lupins in a wheat-canola wheat-lupin rotation system at Langgewens (2013)

Wheat after medic in a wheat-medic-wheat-medic system

The soil water variation for the McWMcW system throughout the season follow much of the same trend as the other systems (Figure 4.11). At the start of the season 69.9 mm more soil water was retained in the 0 - 900 mm soil profile in the NT treatments compared to CT treatments. In the period 15 – 27 days after planting the increase of the SWC in the CT treatment was much more rapid than in soil profile of the NT treatment. It has to be kept in mind that the soil was tilled in 2011, skipping one year of tillage. A possible explanation for this higher increase in the SWC could be the much looser soil structure in the CT treatment. This idea is in accordance with work done by Guzha (2004). The soil profile of the NT treatments continued to retain on average 25.7 mm more soil water than CT from planting until 83 days after planting. The maximum SWC in the NT treatment (220.6 mm) was reached 83 days after planting. The maximum SWC in the CT treatments (277.3 mm) was reached 95 days after planting. The soil water depletion rate in the period of 95 -124 days after planting was again almost equal due to higher temperatures and good crop growing condition accelerating ET. At harvesting CT retained 9.7 mm more soil water than the NT treatment. However small, this difference is in contrast to the work done by Blevins et al. (1971) who reported on the advantage NT has over CT in terms of soil water retention.

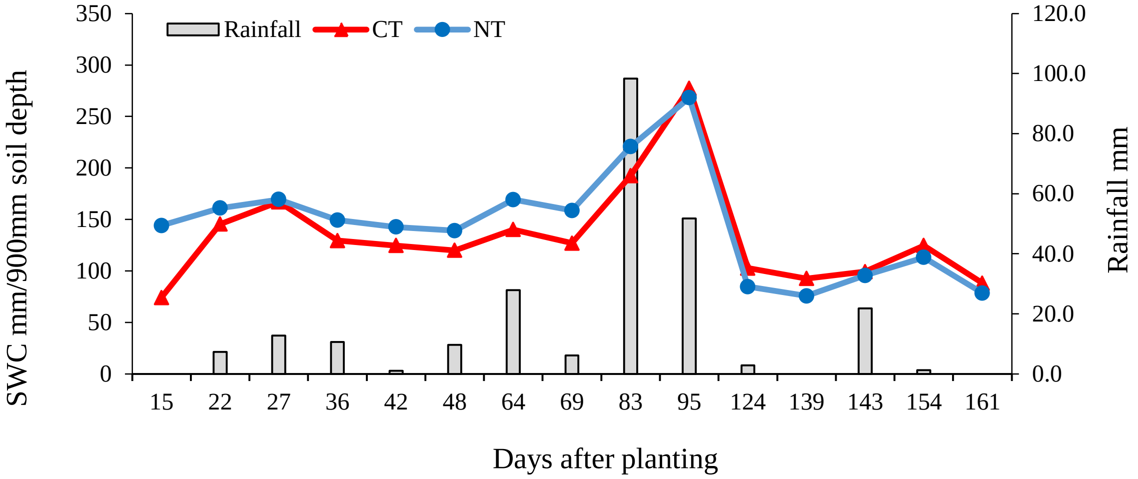

Figure 4.11: The influence of tillage and crop rotation on the SWC for wheat planted after medic in a wheat-medic-wheat-medic system at Langgewens (2013)

Wheat monoculture system

At planting the soils of the NT treatments retained 88 mm more soil water than of the CT treatments (Figure 4.12). The rate and trend in soil water variation as the soil profile between treatments nearly identical. The soil profile under the NT treatment managed to retain on average 75.1 mm more soil water throughout the season than the CT treatment. The maximum SWC for both CT and NT was reached 95 days after planting, with values of 344.1 mm and 241.3 mm for NT and CT respectively. Again both profiles showed an increased soil water depletion rate in the period of 95 - 124 days after planting, as highly favourable climatic conditions could have accelerated the crop growth and ET. Still more soil water was retained under the NT treatment. This could possibly be because of higher percentages of surface coverage under NT and thus a reduction in the evaporation leading to lower soil water depletion rates. This notion was substantiated by Power et al. (1986).

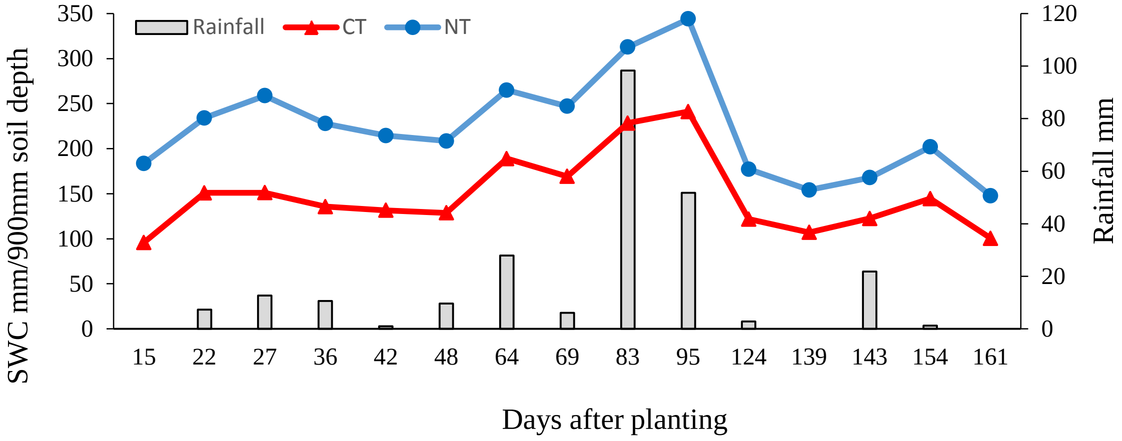

Figure 4.12: The influence of tillage and crop rotation on the SWC of wheat monoculture at Langgewens (2013)

At the end of harvest the soil water profile under NT still retained 47.2 mm more soil water than the CT treatment. The results suggests that the soil profile of the NT treatments does have a higher soil water storage capacity.

Canola after wheat in a wheat-canola-wheat-lupin system

The initial SWC of the NT soils was 27.3 mm higher than those of the CT soils in the canola phase in the WLWC system (Figure 4.13**)**. The SWC remained relatively constant until 48 days after planting. In the period of 48 – 69 days after planting, the soil profile of the NT treatment showed a greater increase in the SWC than that of the CT treatment. From field observations the plant stance in the canola phase was especially poor under the CT treatment site due to technical errors at planting. The lower SWC of the soil profiles of the CT plots could therefore be explained by the bare soil and the high temperatures accelerating evaporation. The maximum SWC was reached 95 days after planting, 315.5 mm in the soil profile of the NT treatment and 335.3 mm in the soil profile of the CT treatment. Throughout the growing season the NT treatment retained on average 33.3 mm more soil water than that of the CT treatment. At harvest 29.9 mm more soil water was recorded under NT than CT.

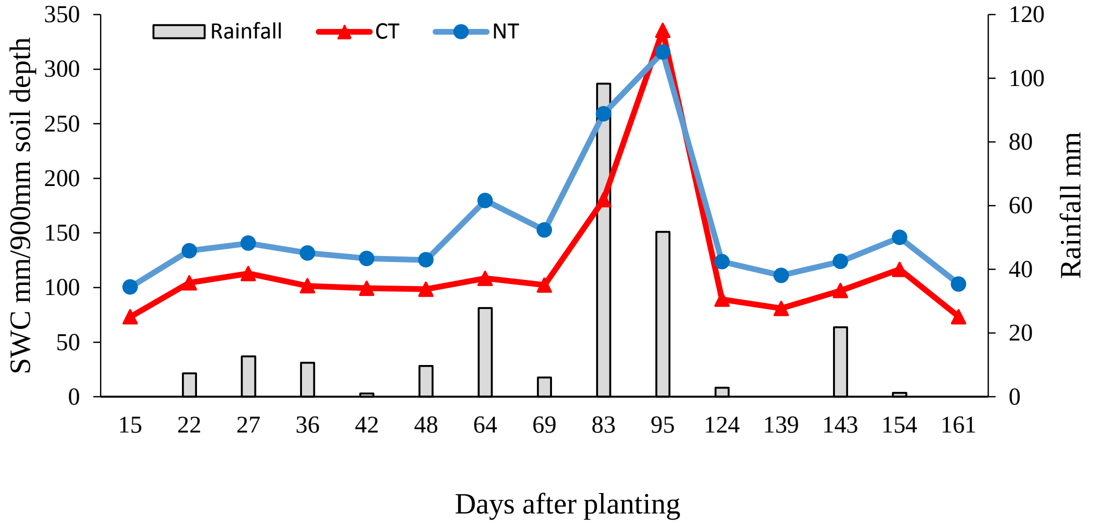

Figure 4-13: The influence of tillage and crop rotation on the SWC for canola planted after wheat rotation system at Langgewens (2013)

Lupin *after wheat in a wheat-canola-wheat-lupin system*

At planting the SWC in the soil profile of the NT treatment retained 26.9 mm more soil water than of the CT treatment (Figure 4.14).

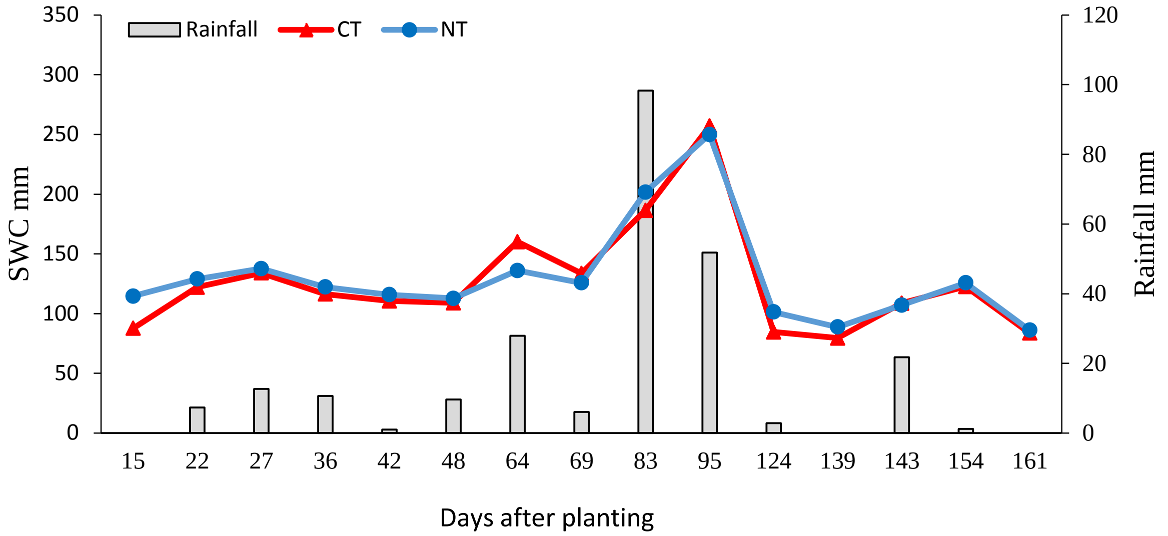

Figure 4-14: The influence of tillage and crop rotation on the SWC for lupins planted after wheat rotation system at Langgewens (2013)

In the first 15 days after planting the SWC increased with 20.1 mm more soil water in the soil profile of the CT than that of the NT treatment. The variation in the SWC in both NT treatments and CT treatment profiles in the period 22 – 48 days after planting was similar. Between 48 – 69 days the SWC in the CT profile increased more than the NT keeping in mind that the same amount of rainfall apply to both profiles. One speculation could once again be the looser soil structure in the tilled soil leading to more rapid infiltration as also reported by Guzha (2004). The maximum SWC in both NT treatment and CT treatment profiles were recorded 95 days after planting, with values of 257.0 mm and 249.9 mm respectively. In the remainder of the growing season the SWC variation followed the same trend as all the other systems with an increased rate of soil water depletion observed from 95-124 days after planting believed to be related to the favourable climatic conditions stimulating crop growth and thus higher ET levels. At the end of harvest there was only a 2.5 mm difference in the SWC between NT and CT.

Medic after wheat in a wheat-medic-wheat-medic system

The SWC variation throughout the season did not follow the same trend as any of the other systems (Figure 4.15). It is important to note at this point that the soil was not tilled in either in the NT or CT sites and the medic crop were simply allowed to grow and was not sown. The initial SWC in the CT soil profile were 21 mm higher than of the NT treatment soil profile. The increase in the SWC between 15 – 22 days after planting (after the initial rainfall) were much higher and the rate of increase was also much more rapid in the CT soil profile compared to the NT soil profile. Within the initial growth period (0-48 days after planting) the soil profile of the CT treatment retained 70 mm more soil water than that of the soil profile of the NT treatment. Both profiles reached a maximum SWC at 95 days after planting. NT retained 14.2 mm more soil water when the SWC reached a maximum in the soil profiles of both treatments. This results again suggests that the soil water holding capacity in the soil profile of NT treatment were higher. Conventional tillage continued to retain more soil water throughout the remainder of the season. The same higher depletion rate in the SWC was observed between 95 – 124 days after planting relating to the suggestion that the prevailing climatic condition played an important mayor role in crop growth stimulus.

Climatic conditions and the soil surface coverage were more or less the same and no soil disturbance occurred after harvest in the CT treatment sites. The technical errors during planting did not happen as medic was just allowed to sow itself. The explanation for the higher SWC in the CT soil profile was that the previous year’s tillage and loosening of the soil increased the soil infiltration. This notion was supported by the work done by Guzha (2004).

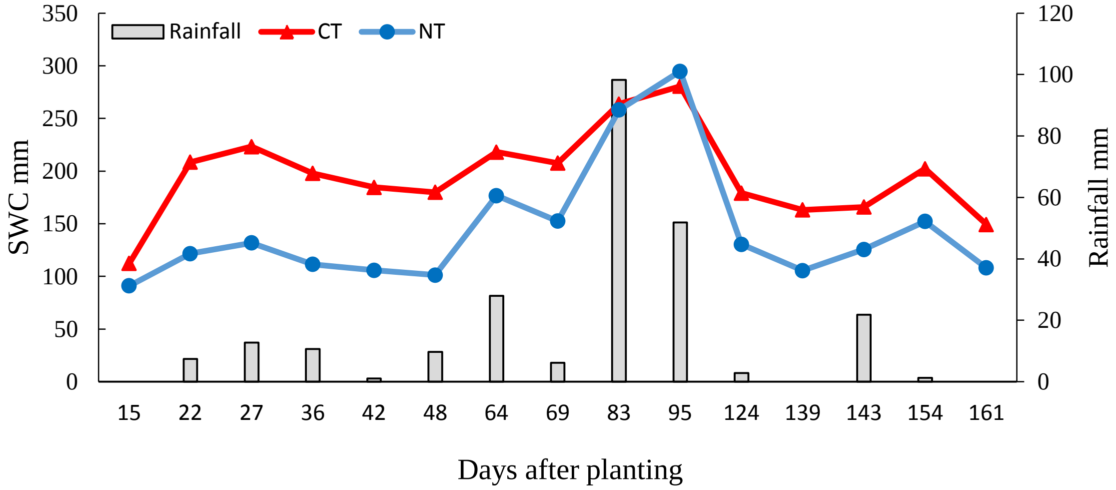

Figure 4-15: The influence of tillage and crop rotation on the SWC for medic planted after wheat rotation system at Langgewens (2013)

4.3.4.1 Tillage as main effect

Data reveal no real trend when comparing the effect of crop rotation on the SWC. When analysing the average SWC as influenced by tillage only the same trend observed in the crop rotation systems appeared (Figure 4.16).

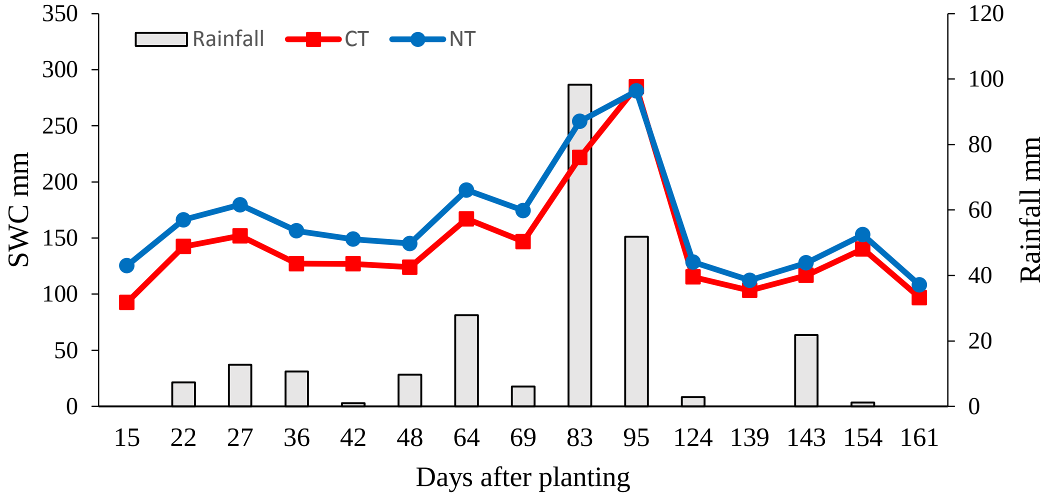

Figure 4-16: The influence of tillage on the SWC at Langgewens (2013)

At the start of the season the soil profile under the NT treatment retained 32 mm more soil water than of the CT treatment profile. Both profiles followed the same trend and the rate at which the soil water increased and depleted in the period of 0 - 95 days after planting. The maximum SWC of 284.7 mm and 280.9 mm in the CT and the NT treatment respectively were reached 95 days after planting.

The influence of soil tillage on the SWC seemed to be more pronounced in the first drier half of the season (0 - 69 days after planting). NT retained on average 26.2 mm more soil water in the mentioned period than CT. The difference in SWC was less during the second wetter half where NT retained only 12.2 mm more soil water than CT treatment to a depth of 900 mm. This observation stressed the advantage of NT under conditions of restricted soil water availability to crops. The higher water content in NT compared to CT will most certainly reduce the risk of reduction in grain, seed or fodder production under temporary drought conditions. These results are in accordance with many authors such as Blevins et al. (1971), Bescansa et al. (2006) and Wiese (2013) all reporting higher soil water retention under NT compared with CT treatments.

4.2.5 Cumulative ET for 2013

Wheat after canola in a wheat-canola-wheat-lupin system

The cumulative ET between systems were nearly identical in the first 15 - 27 days after planting Figure 4.17). From 83 days after planting the average difference between CT and NT were 49.5 mm. An explanation for this trend was strengthened by the high percentage bare soil surface (Figure 4.8) in the CT treatment. At harvest the seasonal water use for wheat after canola were 61.8 mm higher than under NT. Caution should however be used when referring to the seasonal water usage and relating this to the rainfall use efficiency later in chapter 5 due to the high percentage of bare soil surface.

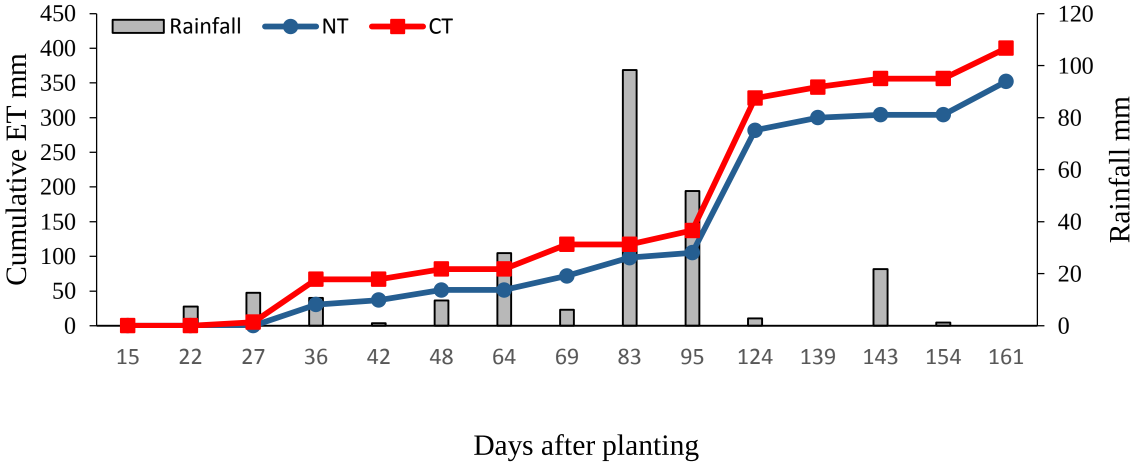

Figure 4-17: The influence of tillage and crop rotation on the cumulative ET for a wheat planted after canola system at Langgewens (2013)

Wheat after lupin in a wheat-canola-wheat-lupin system

A similar trend as in the LWCW was observed in the wheat after lupin (CWLW) system (Figure 4.18).

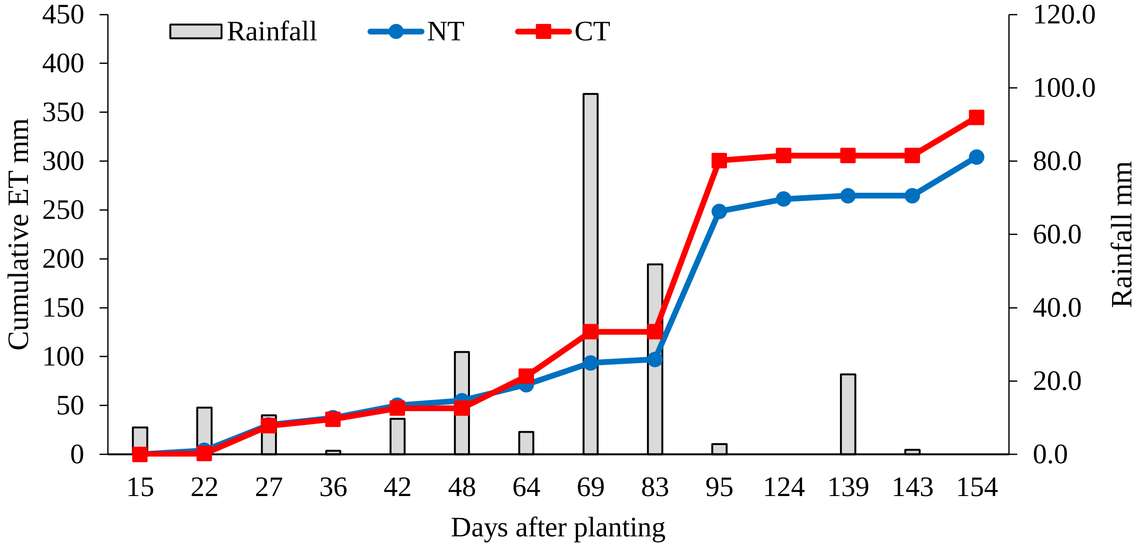

Figure 4-18: The influence of tillage and crop rotation on the cumulative ET for a wheat planted after lupins system at Langgewens (2013). (P= rainfall)

Wheat after medic in a wheat-medic-wheat-medic system

The cumulative ET rate for both treatments were very similar in the first initial 27 days after planting Figure 4.19. From 27 days after planting until harvest CT maintained on average only 13.4 mm more ET than that of the NT treatment. Again this is a similar trend was noticed in other systems and the same explanation of the high bare soil surface exposure is offered. At harvest 22.4 mm more water evapotranspirated by wheat under CT than the NT treatment.

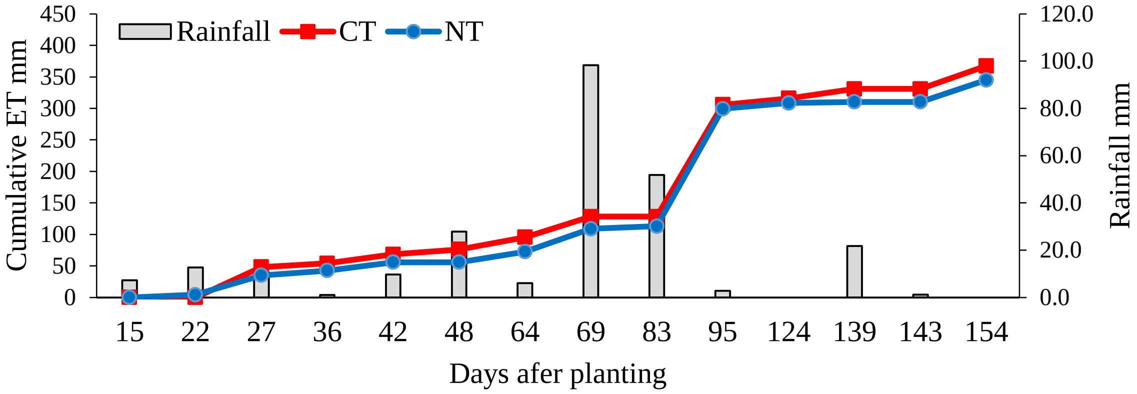

Figure 4-19: The influence of tillage and crop rotation on the cumulative ET for a wheat planted after medic system at Langgewens (2013)

Wheat monoculture system

The cumulative water consumption of wheat grown in monoculture under both CT and NT treatments followed the same trend as the crop rotation system discussed in the previous section, during the 2013 production season (Figure 4.20). Initially in the period between 15 and 27 days after planting, the wheat monoculture in the CT treatment had a higher average ET value than that of the NT treatment. During this period only 30 mm of rainfall occurred and relative high temperatures were recorded as well. This higher ET values of the CT treatment could be explained by the higher crop residues under the NT treatment which reduced the rate of evaporation. From 36 days after planting until harvest higher ET values in the NT treatment was recorded. The difference between the treatments became progressively more pronounced. At harvest the ET values in the NT treatment was 56, 4 mm more than for the CT treatment. A simple possible explanation could may be in the higher percentage of surface cover by weeds and crop, resulting in higher plant water usage even if it included that of weeds and not only reflecting the water usage of wheat.

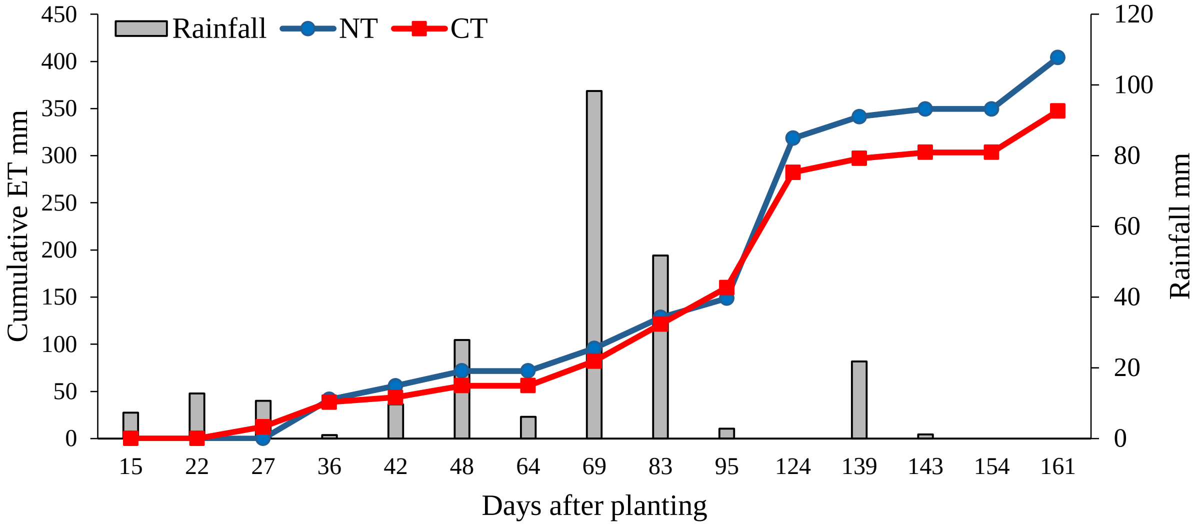

Figure 4-20: The influence of tillage and crop rotation on the cumulative ET for a wheat monoculture system at Langgewens (2013)

Canola after wheat in a wheat-canola-wheat-lupin system

The cumulative ET for WLWC is shown in Figure 4.21. The figure clearly illustrated a difference in the cumulative ET values between treatments. For the first 22 days after planting until harvest the NT treatment maintained a higher ET rate. This difference is especially large in the period of 69 – 95 days after planting and continues that trend until the end of the season. When referring back to the SWC in Figure 4.11 the higher average SWC in the NT treatment may explain the higher ET values. When more soil water is available potentially higher ET values could be reached. The total water consumption of canola recorded at the end of the season under CT (396.3 mm) was 61.7mm higher than under the NT (334.6 mm) treatment, but keeping in mind the high percentage of weeds in the NT treatment caution should be used referring to the seasonal water use of the crop.

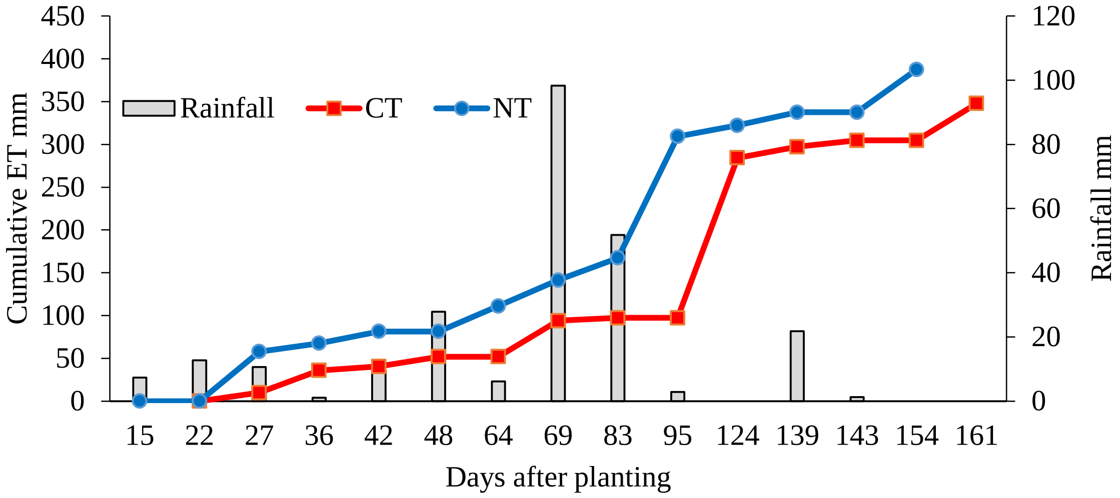

Figure 4-21: The influence of tillage and crop rotation on the cumulative ET for a canola planted after wheat system at Langgewens (2013)

Lupin after wheat in a wheat-canola-wheat-lupin system

The first difference in the ET values was only observed from 69 days after planting until harvest (Figure 4.22). Thereafter the CT treatment recorded higher ET values than that of NT throughout the remainder of the season. However the cumulative ET recorded under CT was only 10.5 mm more than that of the NT treatment. A possible explanation could be locked up in the SWC (Figure 4.10). The NT treatment on average only retained 19 mm more soil water and thus combined with the high percentage of bare soil surface under CT this could explain the higher ET values in the CT treatment.

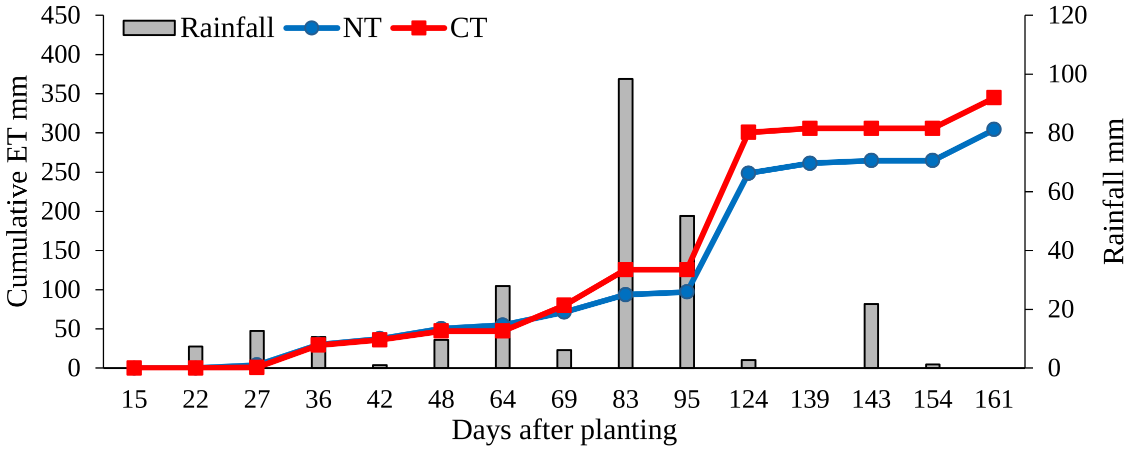

Figure 4-22: The influence of tillage and crop rotation on the cumulative ET for a lupins planted after wheat system at Langgewens (2013)

Medic after wheat in a wheat-medic-wheat-medic system

No statistically significant difference in cumulative ET were recorded up until 60 days after planting in the WMcWMc system (Figure 4.23). In the twelve day period of 83 – 95 days after planting higher cumulative ET values were recorded the CT treatment compared to the NT treatment. Again the high bare soil surface exposure is thought to be the explanation. In the period of 95 to 124 days the rate at which the cumulative ET increased was much more rapid in the NT treatment and corresponded to September 2013 and early October 2013. During the period higher temperatures were recorded, and the growth spur associated with favourable condition may explain a higher water usage rate by both the crop and weeds. At harvest there were no statistically significant differences were recorded between treatments for the cumulative ET

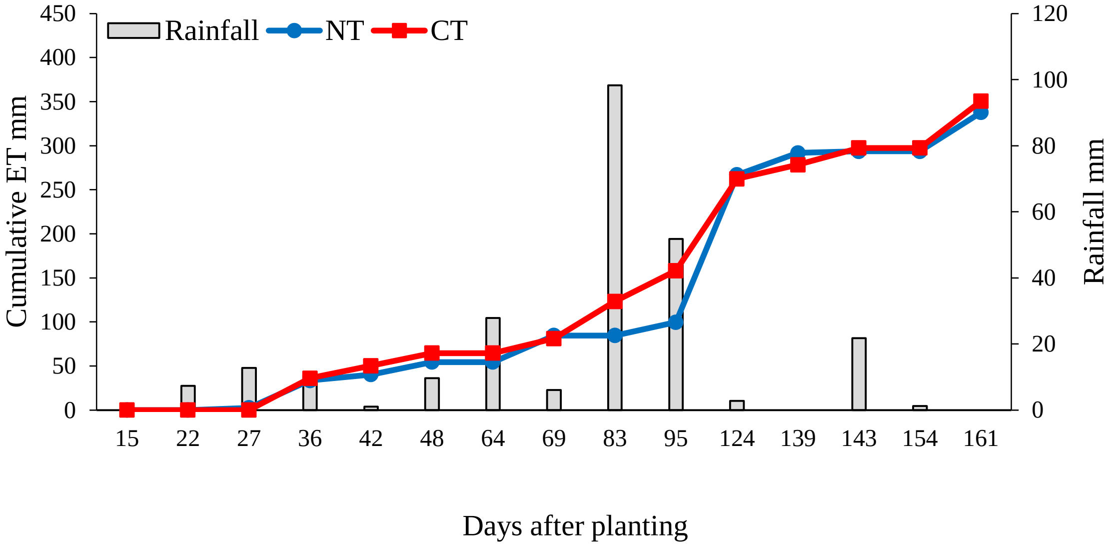

Figure 4-23: The influence of tillage and crop rotation on the cumulative ET for a medic planted after wheat system at Langgewens (2013)

After careful consideration and investigation the results concluded that the main treatment (tillage) did not have an influence on the cumulative ET. The results furthermore seem to suggest that crop rotation also had no effect on the cumulative ET, however this was not statistically verified. No definite trend could be identified in terms of the treatment rotation combinations. This is supported by Figure 4.24 that clearly shows that there is no difference between treatments on the cumulative ET throughout the season, although it seems that the ET recorded was higher under the CT treatment. This higher average cumulative ties in well with the notion that the high bare surface soil exposure had an impact on the cumulative ET and caution should be used when relating these values to the rainfall use efficiency of wheat in rotation under tillage treatments.

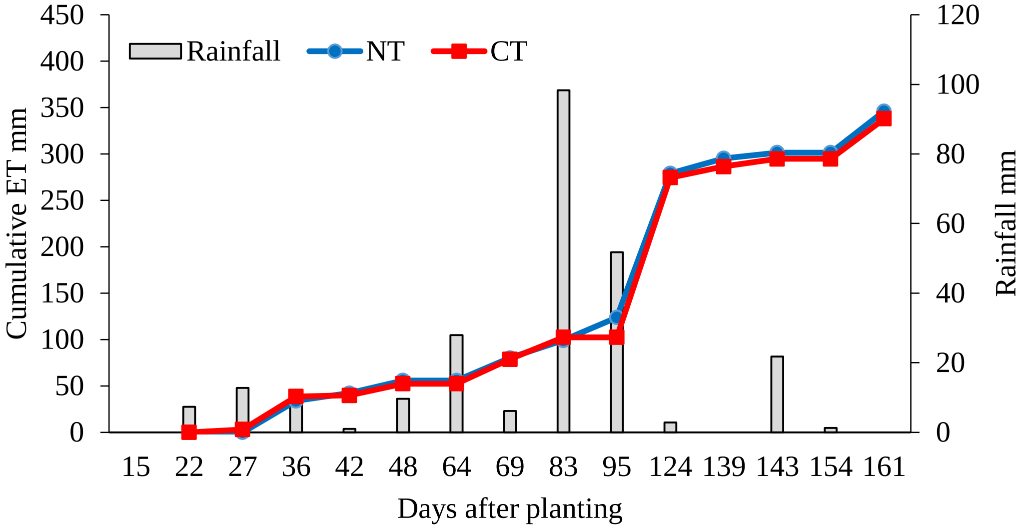

Figure 4-24: The influence of tillage on the cumulative ET at Langgewens (2013)

4.2.6 Conclusions:

The annual rainfall of both 2012 and 2013 season far exceeded the long-term average. The 2013 season were characterized by short sporadic higher than normal temperatures especially in late July and early October. Several factors contributed and challenged the interpretation of the data in both 2012 and 2013. In 2012 the soil water monitoring access tubes could not be installed deeper than 200 mm into the 900 mm deep soil profile. It was concluded that the access tubes were too shallow and data were deemed inconclusive.

Technical difficulties in 2013 during planting, led to seed been sown too deep in the conventional tilled sites, which lead to a very poor crop stand and only a small percentage of the plots actually being covered with the crop. Large bare soil surfaces raised concerns about the accuracy of the data reported. The above average rainfall lead to high weed pressure observed in the NT sites and created obvious concerns when evaluating the crop rainfall use efficiency values as more than 50% of NT site were covered with weeds.

The data collected and reported on of the 2013 season does however lead to the following conclusions. The soil profile under the NT treatment had a higher soil water holding capacity. The soil profile under NT retained more soil water in the profile compared to the CT treatment. The high weed percentage in the NT treatment and the very poor crop stance in the CT treatment site due to technical difficulties during planting, made the seasonal water use per crop difficult to interpret and relate to actual crop water usage. The high percentage of bare soil surface drove the evaporation component of ET under the CT. The high weed pressure under the NT drove the transpiration component of the ET and thus complicating the comparison of ET between treatments. Finally it can be concluded that no clear influence by the crop rotation on the SWC or seasonal water consumptions could be observed.

Chapter 5: The effect of crop rotation and tillage treatments on wheat yield and rainwater use efficiencies

5.1 Introduction:

Various scientists investigated the effect of soil tillage and crop rotation on soil properties and the resultant influence on grain yield and quality. In this chapter yield components and rainfall use efficiency (RUE) of both 2012 and 2013 seasons were determined.

5.2 Biomass production:

Tillage main effect

The mean biomass production with CT (11750 kg.ha^{-1}) did not differ significantly from NT (10247 kg.ha^{-1}) for the 2012 season (Table 5.1). The biomass production for 2013 (Table 5.2) were 861.7 kg ha^{-1} higher in the CT treatment compared to the NT treatment. This difference were similar to the difference in the 2012 season but not significantly different.

Cropping system main effect

In the wheat planted after lupin system (CWLW) produced the highest biomass (11841 kg.ha^{-1}) and wheat monoculture the lowest (9518 kg.ha^{-1}) in the 2012 season (Table 5.1). No significant difference was found between McWMcW and CWLW which produced 11702 kg.ha^{-1} and 11841 kg.ha^{-1} respectively in the 2012 season. The LWCW system produced 10853 kg.ha^{-1} biomass, significantly less than the McWMcW and CWLW systems, but significantly more than the wheat monoculture. The WWWW system produced significantly the lowest biomass of all systems tested.

The highest yield biomass production in the 2013 season was produced by the CWLW rotation system in the conventional tillage treatment (12696 kg.ha^{-1}) and the lowest by the wheat monoculture in the no-tillage treatment (7937 kg.ha^{-1}) in the 2013 season (Table5.2). A statistically significant difference in biomass production between conventional and no-till in the WWWW system were observed in the 2013 season. Furthermore the biomass production of 7937 kg.ha^{-1} in the NT in the WWWW system was not just significantly lower than the CT treatment in the WWWW system but also significantly lower than all the rotation-treatment combinations. Again the wheat monoculture system yielded significantly the lowest biomass in the 2013 season (Table 5.2). The highest biomass production were in the CT treatment in the McWMcW system and the lowest in the wheat monoculture also in the CT treatment.

Table 5.1: The influence of crop rotation and tillage on biomass production (kg.ha^{-1}) at Langgewens (2012)

Tillage treatment	**Cropping system**				
	WWWW	**McWMcW**	**LWCW**	**CWLW**	**Mean**
No-till	7937 c	11139 a	10310 a	11602 a	**10247 a**
Conventional-till	11200 a	11854 a	11250 a	12696 a	**11750 a**
Mean	**9518 c**	**11702 a**	**10853 b**	**11841 a**	

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

Table 5.2: The influence of crop rotation and tillage on biomass production (kg.ha^{-1}) at Langgewens (2013)

Tillage treatment	**Cropping system**				
	WWWW	**McWMcW**	**LWCW**	**CWLW**	**Mean**
No-till	4973.61ab	4973.61 a	8686.50 a	6910.05 a	**6385.95 a**
Conventional-till	4524.07b	9399.80 a	8550.28 a	6516.47 a	**7247.66 a**
Mean	**4748.84 b**	**7186.71 ab**	**8618.39 a**	**6713.26 a**	

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

These results of both 2012 and 2013 were in accordance with work done by Wiese (2013) at the same site. Wiese (2013) also found that tillage did not affect total biomass production but that the cropping system did. Results from that study indicated that the biomass production in McWMcW and LWCW were higher. Hemmat and Eskandari (2006) found that no-tillage treatments tend to produce more biomass. Rieger et al. (2008) reported 2 % higher biomass for NT compared to CT.

5.3 Wheat yield

Tillage main effect

The mean grain yield produced in 2012 was 5233.7 kg.ha^{-1} and 5353.8 kg.ha^{-1} with NT and CT respectively but not significantly different (Table 5.3). No significant difference between the mean values of NT (2158.3 kg.ha$^{-1)}$ and CT (2412.1 kg.ha^{-1}) were reported in the 2013 season either (Table 5.7).

Cropping system main effect

In the 2012 season (Table 5.3) the wheat monoculture (4541.8 kg.ha^{-1}) resulted in significantly lower mean grain yield compared to the other systems tested. With the exception of NT in LWCW that produced significantly lower grain yields than all the other treatments tested. No significant difference in grain yields were recorded between treatment combinations. The highest grain yield was produced in the McWMcW system in the NT treatment (6009.8 kg.ha^{-1}) and the lowest in the WWWW system also under NT (4277.7 kg.ha^{-1}). In the 2013 season (Table 5.4) similarly to the 2012 season the mean grain yield produced in a wheat monoculture system was significantly lower grain per hectare compared to the other systems. Furthermore significant differences in grain yield was report under the CT treatment when comparing cropping systems. The grain yield produced in the wheat monoculture system were significantly lower than grain produced in the McWMcW, LWCW and CWLW systems. No significant differences were reported between the LWCW and CWLW systems under CT. The highest grain yield were recorded in the McWMcW cropping system in the CT treatment. Statistical analysis revealed no difference between cropping systems in NT treatments.

Table 5.3: The influence of crop rotations and tillage on grain yield (kg.ha^{-1}) at Langgewens (2012)

Tillage treatment	Cropping system				Mean
	WWWW	**McWMcW**	**LWCW**	**CWLW**	
No-till	4277.7 a	6009.8 a	4775.3 b	5633.3 a	**5233.7 a**
Conventional-till	5035.3 a	5244.3 a	5557.5 a	5578.0 a	**5353.8 a**
Mean	**4541.8 b**	**5466.5 a**	**5152.0 a**	**5551.3 a**	

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

Table 5.4: The influence of crop rotations and tillage on grain yield (kg.ha^{-1}) at Langgewens (2013)

Tillage treatment	Cropping system				Mean
	WWWW	**McWMcW**	**LWCW**	**CWLW**	
No-till	1048.30 ab	1048.30 ab	3158.57 abc	3377.89 abc	**2158.26 a**
Conventional-till	1563.19 a	4124.41 b	1197.24 c	2763.69 c	**2412.13 a**
Mean	**1305.74 b**	**2586.35 ab**	**2177.90 a**	**3070.79 a**	

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

The results reported for 2012 and 2013 correlated with similar studies done across the world under similar conditions. NT resulted in significantly higher wheat yield for the first two years in a study done by De Vita et al., (2007). The same author reported no statistically significant differences in wheat yield between tillage methods in the Vasto (Spain) location in the first two years but there after CT out-performed NT.

Results in Tables 5.6 and 5.7 disagree with conclusions drawn by Wiese (2013) who concluded that tillage and crop rotation systems effected grain yield and quality. However not significant Wiese (2013) reported positive effects of crop rotation on wheat yield. Wheat produced after medic and or canola resulted in higher yields than the wheat monoculture system. It also contradict results from Mrabet (2002) who reported higher yields under NT. The higher yield was ascribed to the increased residue cover in the NT treatment (Mrabet 2002).

Similar to the work done by Hoffman (1990) CT resulted in higher grain yield compared to NT.

Crop rotation systems or tillage had no effect on winter wheat yield in the Central Great Plain in a study that looked at the effect that different soil disturbances and crop rotation had on crop yield and Soil Carbon (Halvorson A.D et al., 2002).

5.4 Rainwater use efficiency:

The rainwater use efficiency (RUE) for the 2012 season expressed as the total grain yield produced per mm rainfall and is shown in Figure 5.1.

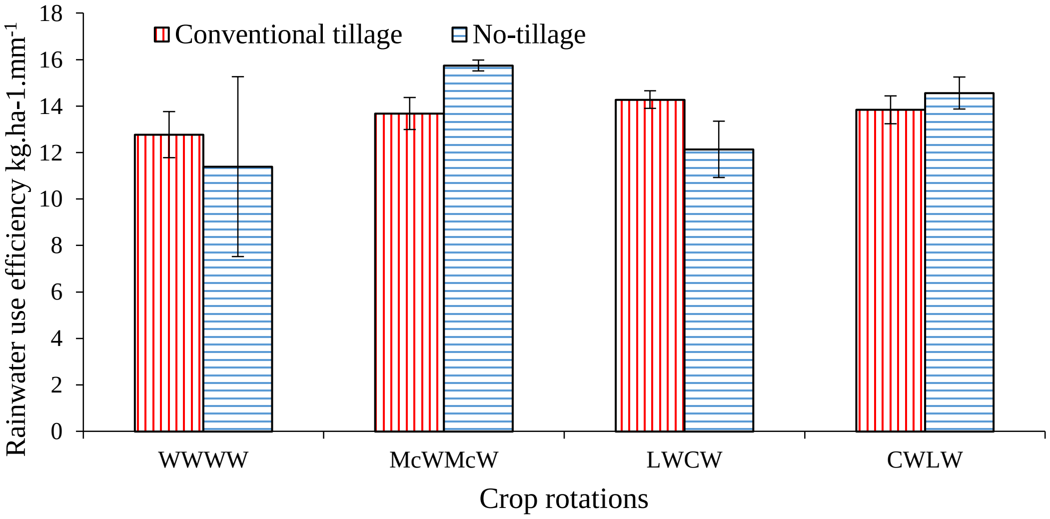

Figure 5.1: The effect of tillage and crop rotation on rainwater use efficiency at Langewens (2012)

The RUE of the conventional tillage (13.7 kg.ha^{-}1.mm^{-1}) in the McWMcW system was significantly ($P < 0.05$) lower than the RUE of no-till (15.8 kg.ha^{-1}.mm^{-1}). No significant differences were reported between the tillage treatments of the WWWW, LWCW and CWLW cropping systems. No significant difference was also not recorded between the average RUE values when comparing CT and NT. The highest RUE (15.8 kg.ha^{-1}.mm^{-1}) was recorded for the no-till treatment in the McWMcW system. The lowest RUE (11.7 kg.mm^{-1}) was recorded for the no-till treatment in the WWWW system. As RUE efficiency is an expression of the ratio of wheat yield to mm rainfall, the lower RUE in the wheat monoculture was explained by the lower yield recorded when compared to McWMcW, CWLW and LWCW (Table 5.4) systems. The average RUE for CT was 13.7 kg.ha^{-1}.mm^{-1} and 13.4 kg.ha^{-1}.mm^{-1} for NT.

The RUE of the 2013 season is presented in Table 5.5**.** The results indicated that tillage had no significant influence on the RUE.

The cropping systems did have an influence (P=0.0053) on the RUE for the 2013 season. The wheat monoculture system had significantly lower RUE than the McWMcW and the CWLW system but not from the LWCW system.

Table 5.5: The effect of tillage and crop rotation on rainwater use efficiency (kg.ha^{-1}.mm^{-1}) at Langewens (2013)

Tillage treatment	**Cropping system**				**Mean**
	WWWW	**McWMcW**	**LWCW**	**CWLW**	
No-till	4.17 ac	4.17 a	12.57 ac	13.44 ab	**8.59 a**
Conventional-till	6.22 c	16.41 a	4.76 c	11.00 b	**9.60 a**
Mean	**5.20 b**	**10.29 a**	**8.67 ab**	**12.22 a**	

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

The results from the 2013 season (Table 5.10) were similar to that found by Hoffman (1990) reporting CT resulted in higher RUE compared to NT. Pala et al. (2007) suggested that legume based crop rotations that fixate more nitrogen results in higher RUE, whilst Turner (2004) argued that a combination of agronomical procedures improved RUE for dryland crops.

5.5 Conclusions

Due to the limitations and challenges that was experienced in terms of the monitoring and interpretation of the soil water and crop water usage results and relating that results to the crop yield, proved to be difficult.

Crop rotation did have and influence on all the parameters investigated. The data concluded that in regards to all the yield components mentioned above, the wheat monoculture consistently resulted in significantly lower values when compared to McWMcW, CWLW and LWCW systems. This confirmed the positive influence of cropping systems on the wheat yield.

Tillage had no statistically significant influence on the seedling survival rate, ears.m^{-2} biomass production, grain yield, thousand kernel mass, hector-litre mass or the RUE. CT did however result in significantly higher protein content values.

Chapter 6: Conclusions and recommendations

6.1 Conclusions

This study aimed to investigate possible strategies to produce wheat, canola, lupin and medics environmentally sustainable because soil and water together with many other natural resources has come under pressure due to the massive increase in the global population.

The study investigated the influence that crop rotation systems have on the soil water balance and crop yield. The influence of no tillage and conventional tillage were also investigated and compared to determine the effect of soil tillage treatments on the soil water balance and wheat production.

The average rainfall in 2013 exceeded that of the long term average. The rainfall was not very evenly distributed over the 2012 season with the majority of the rainfall occurring in the latter part of the season. The same pattern was observed in 2013 and the 2013 season could be divided into two distinctive phases in terms of the rainfall distribution. In the first dry phase only 30 % of the total rainfall occurred. Unusually high temperatures were recorded in May, End of July and early August 2013. The second phase of 2013 were very wet with 70% of the total rainfall occurring in the period between mid-August and end of October 2013

The influence of crop rotation and tillage on the soil water balance was not very clear as several external factors influenced the outcome of the study. Incorrect installation of the soil water access tubes in 2012 led to the fact the probes were not being installed deep enough. The soil water balance equation of Hillel (1980) was therefore only applied to the top 200 mm of an 800 mm - 1000 mm soil profile. This did not give true and accurate account of the influence that rotation and tillage had on the soil water balance. Technical difficulties during sowing of the crop in the 2013 led to seeds sown too deep under the CT treatment and as a result never emerged. Weed counts were done on an arbitrary scale. Although statistically evaluated, the results revealed some answers to the data. Fifty one percent of the NT treatment site’s surface were covered with grass weeds and only 40 % were covered by actual crops. In the CT sites only 38 % of the sites were covered with crops, 31 % coverage were by grass weeds and 31 % of the site had no coverage. The fact that higher percentages of the surface in the NT treatment sites were covered with weeds and that high percentages of the surface in the CT treatment sites were bare, complicated the interpretation of the results obtained in the SWB. In the CT treatment higher ET rates were most probably dominated by the evaporation component with less contribution from the plant transpiration due to the high percentage of bare soil surface. In the NT treatments the seasonal water usage of the very high percentage of weeds could not be ignored and did not give a true account of the cumulative ET of the crop in phase.

In the 2013 season NT retained more soil water than CT in the soil profile in all the systems accept lupins planted after wheat and medic planted after wheat. In the WCWL system the plant population after planting was nearly identical between treatments, as appose to in all the other systems where the plant population under NT was nearly twice of that in the CT treatment. This fact is offered as the possible reason why the soil water variation during the season under NT and CT were the same. In the WMcWMc system the soils have been tilled two years prior to the 2013 season. The notion that the soil structure under CT is looser and therefor has a higher infiltration potential which led to the higher SWC under the CT treatment is substantiated by Guzsha (2004).

The study prove that some key aspects needs to be considered before implementing and evaluating the performance of tillage treatments. These include firstly that the prevailing weathers conditions has the biggest impact and influence on the effect that tillage treatments has and the subsequent production of wheat. The NT treatment retained more soil water than CT but this effect was only prominent in the dry part of the season. This suggest that the possible advantages that is to be gained in terms of the reductions in soil water loss in a NT systems is negated when there is an abundance of water available. Secondly the rainfall distribution during the growing season also influence yield and quality.

The higher soil water retention in the NT treatment confirmed that the presence of a high percentage of coarse fragments has a diluting effect on the soil volume and reduce the soil water holding capacity. This concludes that tillage influence the soil water balance physically because of the effect it has on the coarse fragment percentage and soil water holding capacity. This effect will be important in dry years where the soil water storage potential will determine the success of crop production.

Tillage on average did not have a statistical significant effect on the cumulative ET. However in the 2013 season five of the seven cropping system the CT treatments had a higher seasonal water use. This did not related to higher yields.

Contradictory to many studies done and expectations tillage had no significant effect on the soil texture, saturated hydraulic conductivity or bulk density. This suggest that another very important aspect when implementing tillage is the time factor. Six years after this long-term study on tillage started no significant difference in the soil physical properties could be recorded confirming that tillage is no quick fix and should form part of a long-term strategy in environmental sustainable farming.

The effect of crop rotations on the soil water balance proves to be unclear as the presence of weeds and the poor seedling emergence in CT site clouds and attempt in making conclusions. For this reason it is also difficult to draw conclusions on the effect of cropping systems on yield and yield components. However, both 2012 and 2013 results concluded that wheat mono culture cultivated conventionally performed poorly in every aspect of wheat production and therefore not an option to be considered when producing wheat. Crop rotation does hold yield and quality advantages not to be discarded.

The RUE as determined for the 2013 season were also not a true account of the yield produced per millimetre of ET or rainfall as the high bare soil surface and weed percentage influence both ET and yield in such a manner that the data were inconclusive.

6.2 Recommendations

This study was one of the first projects that specifically looked at the effect that crop rotations and tillage has on the soil water balance and wheat, canola, lupin and medic production in Swartland. Cropping systems does have an effect on crop production but to really understand the effect cropping systems have on the soil water balance, studies should rather be conducted in a more control environments where every component and aspect that has and influence could be properly monitored to eliminate any speculation. For example to explain differences in the SWC due to rotation systems the root system of the crop needs to be study extensively, understand the effect of the preceding and in the crop in phase. No tillage is believed to be a more sustainable practise especially under dry conditions however a more focussed study over a longer period than six years should be done to quantify these advantages. When conducting similar studies, the study sites should be carefully identified, opting to use sites with as homogenous soils as practically possible. Soils with a higher percentages of coarse fragments will be difficult to work with and when studying soil physical properties, they should rather be measured in-situ as laboratory experiments proved to be inconclusive and unsuccessful. Soil in the Western Cape is generally very shallow, which provide many difficulties and obstacles when conducting these studies. Installation of infield equipment should be done correctly and with great effort otherwise results will prove to be not very conclusive as with the soil water data collected in the 2012 season It is furthermore recommended that such a study should rather form part of a elaborated multidisciplinary project that cover all aspects of the soil physical, chemical and biological environment.

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Apendix A: Soil Classification and profile description

Table 1

Profile number:	1	Apect:	North West
Co-ordinates:	$33^0$16’24.2”S/$18^0$42’29.2”E	Terrain unit:	Mid-Slope
Soil form:	Glenrosa	Altitude:	197m
Soil family:	Bisho (2211)	Surface coarse fragments:	30-65%
Underlying parent material:	Shale	Wetness:	None
Slope form:	Convex		
Slope:	5%		

Horizon	**Depth (mm)**	**Description**	**Diagnostic horizon**
A	0-300	Dry colour: Very pale brown 10YR 7/3; Moist colour Dark brown 10YR4/4; Structure: Massive apedal with 10-15% clay; Consistence: hard in wet and dry state; gravel 2-6mm common; few roots visible; transition abrupt and tonguing clear to observe	Orthic
B	300-900	Dry colour: Very pale brown 10YR7/4; Moist colour: Yellowish brown 10YR5/6; Structure weak fine angular blocky with more than 40% clay; Consistence: hard in wet and dry state; many coarse shale fragments 6-25mm and 25-75mm; no roots were observed	Lithocutanic

Table 2

Profile number:	2	Apect:	North West
Co-ordinates:	33^{0}16’26.7”S/18^{0}42’27.2”E	Terrain unit:	Upper mid-slope
Soil form:	Glenrosa	Altitude:	195m
Soil family:	Overberg (2111)	Surface coarse fragments:	30-65%
Underlying parent material:	Shale	Wetness:	None
Slope form:	Convex		
Slope:	3%		

Horizon	Depth (mm)	Description	Diagnostic horizon
A1	0-250	Dry colour: Very pale brown 10YR 7/3; Moist colour Dark brown 10YR4/4; Structure: Massive apedal with 10-15% clay; Consistence: hard in wet and dry state; gravel 2-6mm common; few roots visible; transition gradual and smooth	Orthic
A2	250-400	Dry colour: Very pale brown 10YR 7/3; Moist colour Dark brown 10YR4/4; Structure: Massive apedal with 5-10% clay; coarse gravel 8-25mm very common; few roots visible; transition abrupt and tonguing clear to observe	Orthic/E
B	400-900	Dry colour: Very pale brown 10YR7/4; Moist colour: Yellowish brown 10YR5/6; Structure weak fine angular blocky with more than 40% clay; Consistence: hard in wet and dry state and have some degree of stickiness and plasticity when wet; 25-50% clay cutans visible; distinct black and brown geogenic mottling common many coarse shale fragments 8-25mm; no roots were observed	Lithocutanic

Table 3

Profile number: 3

Apect: North West

Co-ordinates: 33^{0}16’31.5”S/18^{0}42’23.9”E

Terrain unit: Lower mid-slope

Soil form: Swartland

Altitude: 185m

Soil family: Adelaide (2111)

Surface coarse fragments: 30-65%

Underlying parent material: Shale

Wetness: None

Slope form: Convex

Slope: 1-2%

Horizon	**Depth (mm)**	**Description**	**Diagnostic horizon**
A1	0-200	Dry colour: Very pale brown 10YR 7/3; Moist colour Dark brown 10YR4/4; Structure: Massive apedal with 10-15% clay; Consistence: hard in wet and dry state; 15-25% gravel 2-6mm; few roots visible; transition gradual and smooth;	Orthic
A2	200-350	Dry colour: Very pale brown 10YR 7/3; Moist colour Dark brown 10YR4/4; Structure: Massive apedal with 10% clay; few gravel 2-6mm with coarse gravel 8-25mm common; few roots visible; transition abrupt and tonguing clear to observe	Orthic/E
B	350-900	Dry colour: Brownish yellow 10YR6/6; Moist colour: Brownish yellow 10YR6/8; Structure Moderate fine angular blocky with more than 45% clay; Consistence: hard in wet and dry state and have some degree of stickiness and plasticity when wet; 25-50% clay cutans; no roots were observed	Pedocutanic

Table 4

Profile number:	4	Apect:	North West
Co-ordinates:	33^{0}16’33.3”S/18^{0}42’20.4”E	Terrain unit:	Lower mid-slope
Soil form:	Swartland	Altitude:	182m
Soil family:	Adelaide (2111)	Surface coarse fragments:	30-65%
Underlying parent material:	Shale	Wetness:	None
Slope form:	Convex		
Slope:	1%		

Horizon	**Depth (mm)**	**Description**	**Diagnostic horizon**
A	0-300	Dry colour: Very pale brown 10YR 7/3; Moist colour Dark brown 10YR4/4; Structure: Massive apedal with 10-15% clay; Consistence: hard in wet and dry state; 15-25% gravel 2-6mm; few roots visible; transition abrupt and smooth	Orthic
B1	300-600	Dry colour: Brownish yellow 10YR 6/6; Moist colour brownish yellow 10YR6/8; Structure: moderate fine angular blocky; Consistence: hard in wet and dry state and have some degree of stickiness and plasticity; few gravel 2-6mm; few roots visible; transition abrupt and tonguing clear to observe	Pedocutanic
B2	600-900	Dry colour: Brownish yellow 10YR5/6; Moist colour: Brownish yellow 10YR6/8; Structure Moderate fine angular blocky with more than 45% clay; Consistence: hard in wet and dry state; no roots were observed	Lithocutanic

Table 5

Profile number:	5	Apect:	North West
Co-ordinates:	$33^0$16’29.4”S/$18^0$42’22.4”E	Terrain unit:	Upper mid-slope
Soil form:	Glenrosa	Altitude:	186m
Soil family:	Overberg (2111)	Surface coarse fragments:	30-65%
Underlying parent material:	Shale	Wetness:	None
Slope form:	Convex		
Slope:	2-3%		

Horizon	**Depth (mm)**	**Description**	**Diagnostic horizon**
A1	0-300	Dry colour: Very pale brown 10YR 7/3; Moist colour Dark brown 10YR4/4; Structure: Massive apedal with 10-15% clay; Consistence: hard in wet and dry state; 15-25% gravel 2-6mm; few roots visible; transition gradual and smooth	Orthic
A2	300-400	Dry colour: Very pale brown 10YR 7/3; Moist colour Dark brown 10YR4/4; Structure: apedal with 10% clay; Consistence: hard in wet and dry state; 50-90% gravel 2-6mm and coarse gravel 6-25mm ; few roots visible; transition abrupt and smooth	Orthic/E
B1	400-600	Dry colour: Very pale brown 10YR7/4; Moist colour: Yellowish brown 10YR5/6;Structure: moderate fine blocky more than 45% clay; coarse black and brown geogenic mottles common; clay cutans common; transition gradual and smooth	Pedocutanic
B2	600-900	Dry colour: Brownish yellow 10YR5/6; Moist colour: Brownish yellow 10YR6/8; Structure weak fine angular blocky; Consistence: hard in wet and dry state; no roots were observed	Lithocutanic

Table 6

Profile number:	6	Apect:	North West
Co-ordinates:	33^{0}16’23.5”S/18^{0}42’26.3”E	Terrain unit:	Mid-slope
Soil form:	Glenrosa	Altitude:	195m
Soil family:	Overberg (2111)	Surface coarse fragments:	30-65%
Underlying parent material:	Shale	Wetness:	None
Slope form:	Convex		
Slope:	5%		

Horizon	**Depth (mm)**	**Description**	**Diagnostic horizon**
A1	0-300	Dry colour: Very pale brown 10YR 7/3; Moist colour Dark brown 10YR4/4; Structure: Massive apedal with 10-15% clay; Consistence: hard in wet and dry state; 15-25% gravel 2-6mm; few roots visible; transition gradual and smooth	Orthic
A2	300-450	Dry colour: Very pale brown 10YR 7/3; Moist colour Dark brown 10YR4/4; Structure: apedal with 5-10% clay; Consistence: hard in wet and dry state; 50-90% gravel 2-6mm and coarse gravel 6-25mm ; few roots visible; transition abrupt with tonguing	Orthic/E
B	600-900	Dry colour: Brownish yellow 10YR5/6; Moist colour: Brownish yellow 10YR6/8; Structure Moderate fine angular blocky with more than 45% clay; coarse black and brown geogenic mottles common; Consistence: hard in wet and dry state and have some degree of stickiness and plasticity ;clay cutans commonly visible;many shale fragments 6-25mm; no roots were observed	Lithocutanic

Table 7

Profile number:	7	Apect:	North West
Co-ordinates:	33^{0}16’23.2”S/18^{0}42’23.7”E	Terrain unit:	Mid-slope
Soil form:	Glenrosa	Altitude:	192m
Soil family:	Bisho (2211)	Surface coarse fragments:	30-65%
Underlying parent material:	Shale	Wetness:	None
Slope form:	Convex		
Slope:	5%		

Horizon	**Depth (mm)**	**Description**	**Diagnostic horizon**
A	0-300	Dry colour: Very pale brown 10YR 7/3; Moist colour Dark brown 10YR4/4; Structure: Massive apedal with 10-15% clay; Consistence: hard in wet and dry state; coarse gravel 6-25mm common; few roots visible; transition abrupt and tonguing clear to observe	Orthic
B	300-900	Dry colour: Very pale brown 10YR7/4; Moist colour: Yellowish brown 10YR5/6; Structure weak fine angular blocky with more than 40% clay; Consistence: hard in wet and dry state; distinct black and brown geogenic mottling common; many coarse shale fragments 6-25mm and 25-75mm; no roots were observed	Lithocutanic

Table 9

Profile number:	8	Apect:	North West
Co-ordinates:	$33^0$16’25.7”S/$18^0$42’21.7”E	Terrain unit:	Upper mid-slope
Soil form:	Glenrosa	Altitude:	189m
Soil family:	Overberg (2111)	Surface coarse fragments:	30-65%
Underlying parent material:	Shale	Wetness:	None
Slope form:	Convex		
Slope:	2-3%		

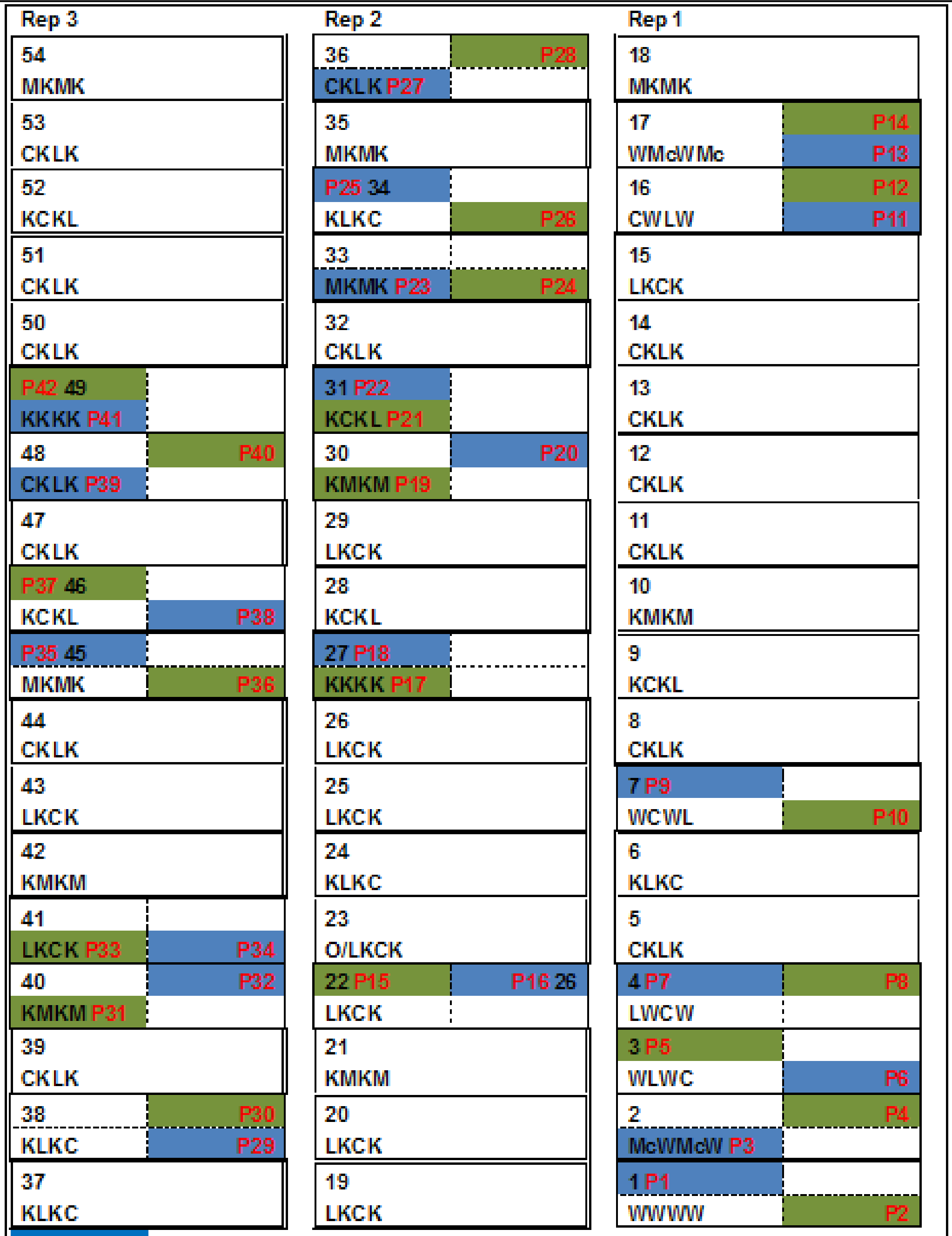
Horizon	**Depth (mm)**	**Description**	**Diagnostic horizon**
A1	0-300	Dry colour: Very pale brown 10YR 7/3; Moist colour Dark brown 10YR4/4; Structure: Massive apedal with 10-15% clay; Consistence: hard in wet and dry state; 15-25% gravel 2-6mm; few roots visible; transition abrupt and show some degree of tonguing	Orthic
B	300-900	Dry colour: Very pale brown 10YR 7/3; Moist colour yellowish brown 10YR5/6; Structure: weak fine angular blocky; Consistence: hard in wet and dry state with some stickiness and plasticity when wet; few black and brown geogenic mottling; few clay cutans visible; 50-90% coarse shale fragments ; few roots visible; transition abrupt with tonguing	Lithocutanic
R	900-1000	Hard Rock	Shale

Table 10

Profile number:	9	Apect:	North West
Co-ordinates:	$33^0$16’31.6”S/$18^0$42’17.6”E	Terrain unit:	Lower mid-slope
Soil form:	Swartland	Altitude:	180m
Soil family:	Adelaide (2111)	Surface coarse fragments:	30-65%
Underlying parent material:	Shale	Wetness:	None
Slope form:	Convex		
Slope:	2%		

Horizon	**Depth (mm)**	**Description**	**Diagnostic horizon**
A	0-300	Dry colour: Very pale brown 10YR 7/3; Moist colour Dark brown 10YR4/4; Structure: Massive apedal with 10-15% clay; Consistence: hard in wet and dry state; 15-25% gravel 2-6mm; few roots visible; transition abrupt and smooth	Orthic
B1	300-800	Dry colour: Brownish yellow 10YR 6/6; Moist colour brownish yellow 10YR6/8; Structure: moderate fine angular blocky with 40-45% clay; Consistence: hard in wet and dry state and have some degree of stickiness and plasticity; black and brown cutans common; common gravel 2-6mm; few roots visible; transition abrupt and tonguing clear to observe	Pedocutanic
B2	800-900	Dry colour: Brownish yellow 10YR5/6; Moist colour: Brownish yellow 10YR6/8; Structure Moderate fine angular blocky; Consistence: hard in wet and dry state; no roots were observed	Lithocutanic

Appendix B: Experimental design



🟦 No Till	No tillage treatment
🟩 Con	Conventional tillage treatment
WWWW	Wheat-wheat-wheat-wheat rotation
McWMcW	Medic-wheat-medic-wheat rotation
WLWC	Wheat-lupin-wheat-canola rotation
LWCW	Lupin-wheat-canola-wheat rotation
WCWL	Wheat-canola-wheat-lupin rotation
CWLW	Canola-wheat-lupin-wheat rotation
WMcWMc	Wheat-medic-wheat-medic rotation

P1,2,3...	Diviner access tube number
Rep 1	Replicate 1
Rep 2	Replicate 2
Rep 3	Replicate 3

Apendix C Soil water balances of the 2013 season

Table 1: The influence of tillage and crop rotation on the soil water balance for wheat mono culture per treatment at Langgewens (2013)

Rotation	Treatment	Date	2013-06-12	2013-06-19	2013-06-26	2013-07-05	2013-07-11	2013-07-17	2013-08-02	2013-08-07	2013-08-22	2013-09-03	2013-10-17	2013-10-21	2013-11-01	2013-11-08	2013-11-14
WWWW	NT	Wl	183,6	234,0	258,8	227,9	214,5	208,4	265,0	247,1	312,8	344,1	177,2	154,2	167,9	202,0	147,7
		Δ W		-50,4	-24,8	30,8	13,5	6,1	-56,6	17,9	-65,6	-31,4	166,9	23,0	-13,7	-34,2	54,4
		P		7,4	12,7	10,7	1,0	9,7	27,9	6,1	98,3	51,8	2,8	0,0	21,8	1,2	0,0
		RO															
		D		-43,0	-12,1	0,0	0,0	0,0	-28,7	0,0	0,0	0,0	0,0	0,0	0,0	-33,0	0,0
		ET		0,0	0,0	41,5	14,5	15,7	0,0	24,0	32,7	20,4	169,7	23,0	8,1	0,0	54,4
		Cum ET		**0,0**	**0,0**	**41,5**	**55,9**	**71,7**	**71,7**	**95,7**	**128,3**	**148,7**	**318,5**	**341,5**	**349,6**	**349,6**	**404,0**
WWWW	CT	W	95,9	150,9	151,1	135,7	131,6	128,8	189,1	169,2	228,4	241,3	121,9	107,1	122,5	144,6	100,5
		Δ W		-55,1	-0,2	15,4	4,2	2,7	-60,2	19,9	-59,2	-12,9	119,4	14,8	-15,4	-22,1	44,1
		P		7,4	12,7	10,7	1,0	9,7	27,9	6,1	98,3	51,8	2,8	0,0	21,8	1,2	0,0
		RO															
		D		-47,7	0,0	0,0	0,0	0,0	-32,3	0,0	0,0	0,0	0,0	0,0	0,0	-20,9	0,0
		ET		0,0	12,5	26,1	5,2	12,4	0,0	26,0	39,1	38,9	122,2	14,8	6,4	0,0	44,1
		Cum ET	**0,0**	**0,0**	**12,5**	**38,6**	**43,7**	**56,1**	**56,1**	**82,1**	**121,2**	**160,1**	**282,3**	**297,0**	**303,5**	**303,5**	**347,5**

CT = conventional tillage; NT = no tillage; W= Water content (mm); ΔW= change in water content (mm); P= precipitation (mm); ET= Evapotranspiration (mm); ΣET= Cumulative Evapotranspiration (mm)

Table 2: The influence of tillage and crop rotation on the soil water balance for wheat planted after canola in a wheat-canola-wheat-lupin rotation per treatment at Langgewens (2013)

Rotation	Treatment	Date	2013-06-12	2013-06-19	2013-06-26	2013-07-05	2013-07-11	2013-07-17	2013-08-02	2013-08-07	2013-08-22	2013-09-03	2013-10-17	2013-10-21	2013-11-01	2013-11-08	2013-11-14
LWCW	NT	W	99,5	173,7	190,2	170,3	164,8	160,0	202,5	188,2	260,2	304,9	131,3	113,0	130,6	152,4	104,4
		Δ Water		-74,2	-16,5	19,9	5,5	4,8	-42,5	14,3	-72,0	-44,7	173,6	18,3	-17,5	-21,8	48,0
		P	86,6	7,4	12,7	10,7	1,0	9,7	27,9	6,1	98,3	51,8	2,8	0,0	21,8	1,2	0,0
		RO															
		D		-66,9	-3,8	0,0	0,0	0,0	-14,6	0,0	0,0	0,0	0,0	0,0	0,0	-20,6	0,0
		ET		0,0	0,0	30,5	6,5	14,5	0,0	20,4	26,3	7,1	176,4	18,3	4,3	0,0	48,0
		Cum ET	**0,0**	**0,0**	**0,0**	**30,5**	**37,1**	**51,5**	**51,5**	**71,9**	**98,2**	**105,3**	**281,7**	**300,0**	**304,3**	**304,3**	**352,2**
LWCW	CT	W	103,8	146,8	154,3	103,2	136,1	130,9	186,4	156,9	273,5	305,2	117,2	101,3	110,7	137,5	93,8
		Δ Water		-43,0	-7,5	51,1	-32,8	5,1	-55,4	29,4	-116,6	-31,7	188,0	15,9	-9,5	-26,8	43,7
		P	86,6	7,4	12,7	10,7	1,0	9,7	27,9	6,1	98,3	51,8	2,8	0,0	21,8	1,2	0,0
		RO															
		D		-35,7	0,0	0,0	-31,8	0,0	-27,5	0,0	-18,3	0,0	0,0	0,0	0,0	-25,6	0,0
		ET		0,0	5,2	61,7	0,0	14,8	0,0	35,5	0,0	20,1	190,8	15,9	12,3	0,0	43,7
		Cum ET	**0,0**	**0,0**	**5,2**	**66,9**	**66,9**	**81,7**	**81,7**	**117,2**	**117,2**	**137,4**	**328,2**	**344,1**	**356,4**	**356,4**	**400,1**

CT = conventional tillage; NT = no tillage; W= Water content (mm); ΔW= change in water content (mm); P= precipitation (mm); ET= Evapotranspiration (mm); ΣET= Cumulative Evapotranspiration (mm)

Table 3: The influence of tillage and crop rotation on the soil water balance for wheat planted after lupins in a wheat-lupin-wheat-canola rotation per treatment at Langgewens (2013)

Rotation	Treatment	Date	2013-06-12	2013-06-19	2013-06-26	2013-07-05	2013-07-11	2013-07-17	2013-08-02	2013-08-07	2013-08-22	2013-09-03	2013-10-17	2013-10-21	2013-11-01	2013-11-08	2013-11-14
CWLW	NT	W	149,4	210,0	228,9	181,7	172,9	168,8	220,0	196,5	264,4	290,3	151,0	138,1	144,6	179,5	129,6
		Δ W		-60,6	-18,9	47,2	8,8	4,1	-51,2	23,5	-68,0	-25,9	139,3	12,9	-6,5	-35,0	50,0
		P	86,6	7,4	12,7	10,7	1,0	9,7	27,9	6,1	98,3	51,8	2,8	0,0	21,8	1,2	0,0
		RO															
		D		-53,3	-6,2	0,0	0,0	0,0	-23,3	0,0	0,0	0,0	0,0	0,0	0,0	-33,8	0,0
		ET		0,0	0,0	57,8	9,8	13,8	0,0	29,6	30,3	25,9	142,1	12,9	15,3	0,0	50,0
		Cum ET	**0,0**	**0,0**	**0,0**	**57,8**	**67,6**	**81,4**	**81,4**	**111,0**	**141,4**	**167,3**	**309,4**	**322,3**	**337,6**	**337,6**	**387,6**
CWLW	CT	W	100,6	118,4	121,3	105,9	102,2	100,5	167,6	131,7	226,6	296,0	111,9	98,9	113,2	133,0	89,7
		Δ W		-17,8	-2,9	15,5	3,7	1,7	-67,0	35,9	-94,9	-69,5	184,2	13,0	-14,3	-19,8	43,3
		P	86,6	7,4	12,7	10,7	1,0	9,7	27,9	6,1	98,3	51,8	2,8	0,0	21,8	1,2	0,0
		RO															
		D		-10,5	0,0	0,0	0,0	0,0	-39,1	0,0	0,0	-17,7	0,0	0,0	0,0	-18,6	0,0
		ET		0,0	9,8	26,1	4,7	11,3	0,0	42,0	3,4	0,0	187,0	13,0	7,5	0,0	43,3
		Cum ET	**0,0**	**0,0**	**9,8**	**35,9**	**40,5**	**51,9**	**51,9**	**93,8**	**97,3**	**97,3**	**284,2**	**297,2**	**304,7**	**304,7**	**347,9**

CT = conventional tillage; NT = no tillage; W= Water content (mm); ΔW= change in water content (mm); P= precipitation (mm); ET= Evapotranspiration (mm); ΣET= Cumulative Evapotranspiration (mm)

Table 4: The influence of tillage and crop rotation on the soil water balance for wheat planted after medic in a wheat-medic-wheat-medic rotation per treatment at Langgewens (2013)

Rotation	Treatment	Date	2013-06-12	2013-06-19	2013-06-26	2013-07-05	2013-07-11	2013-07-17	2013-08-02	2013-08-07	2013-08-22	2013-09-03	2013-10-17	2013-10-21	2013-11-01	2013-11-08	2013-11-14
McWMcW	NT	W	144,0	161,0	169,3	149,3	142,7	139,0	169,2	158,6	220,6	166,8	84,7	75,7	95,6	113,2	78,5
		Δ W		-17,0	-8,3	20,0	6,6	3,7	-30,1	10,5	-62,0	53,8	82,1	9,0	-19,9	-17,5	34,7
		P	86,6	7,4	12,7	10,7	1,0	9,7	27,9	6,1	98,3	51,8	2,8	0,0	21,8	1,2	0,0
		RO															
		D		-9,6	0,0	0,0	0,0	0,0	-2,2	0,0	0,0	0,0	0,0	0,0	0,0	-16,3	0,0
		ET		0,0	4,4	30,7	7,6	13,3	0,0	16,6	36,3	105,6	84,9	9,0	1,9	0,0	34,7
		Cum ET	**0,0**	**0,0**	**4,4**	**35,1**	**42,6**	**56,0**	**56,0**	**72,6**	**108,9**	**214,5**	**299,4**	**308,4**	**310,3**	**310,3**	**345,0**
McWMcW	CT	W	74,1	145,4	167,0	129,4	124,7	120,0	140,2	126,9	192,3	277,3	102,8	92,6	99,3	124,6	88,1
		Δ W		-71,4	-21,6	37,6	4,8	4,7	-20,1	13,3	-65,4	-85,0	174,6	10,2	-6,7	-25,3	36,5
		P	86,6	7,4	12,7	10,7	1,0	9,7	27,9	6,1	98,3	51,8	2,8	0,0	21,8	1,2	0,0
		RO															
		D		-64,0	-8,9	0,0	0,0	0,0	0,0	0,0	0,0	-33,2	0,0	0,0	0,0	-24,1	0,0
		ET		0,0	0,0	48,2	5,8	14,3	7,8	19,4	32,9	0,0	177,4	10,2	15,1	0,0	36,5
		Cum ET	**0,0**	**0,0**	**0,0**	**48,2**	**54,0**	**68,3**	**76,1**	**95,4**	**128,3**	**128,3**	**305,7**	**315,8**	**330,9**	**330,9**	**367,4**

CT = conventional tillage; NT = no tillage; W= Water content (mm); ΔW= change in water content (mm); P= precipitation (mm); ET= Evapotranspiration (mm); ΣET= Cumulative Evapotranspiration (mm)

Table 5: The influence of tillage and crop rotation on the soil water balance for medic planted after wheat in a medic-wheat-medic-wheat rotation per treatment at Langgewens (2013)

Rotation	Treatment	Date	2013-06-12	2013-06-19	2013-06-26	2013-07-05	2013-07-11	2013-07-17	2013-08-02	2013-08-07	2013-08-22	2013-09-03	2013-10-17	2013-10-21	2013-11-01	2013-11-08	2013-11-14
WMcW**Mc**	NT	W	91,1	121,6	131,8	111,5	105,7	101,2	176,7	152,5	258,0	294,8	130,5	105,5	125,6	152,2	108,0
		Δ Water		-30,5	-10,2	20,3	5,7	4,6	-75,5	24,1	-105,5	-36,7	164,3	25,0	-20,1	-26,6	44,2
		P	86,6	7,4	12,7	10,7	1,0	9,7	27,9	6,1	98,3	51,8	2,8	0,0	21,8	1,2	0,0
		D		-23,2	0,0	0,0	0,0	0,0	-47,6	0,0	-7,2	0,0	0,0	0,0	0,0	-25,4	0,0
		ET		0,0	2,6	30,9	6,7	14,2	0,0	30,2	0,0	15,1	167,1	25,0	1,7	0,0	44,2
		Cum ET	**0,0**	**0,0**	**2,6**	**33,5**	**40,2**	**54,5**	**54,5**	**84,7**	**84,7**	**99,8**	**266,9**	**291,8**	**293,6**	**293,6**	**337,7**
WMcW**Mc**	CT	W	112,3	208,5	223,2	197,8	184,6	180,0	218,0	207,5	263,7	280,6	179,2	163,1	165,8	202,3	149,3
		Δ Water		-96,2	-14,7	25,4	13,2	4,7	-38,1	10,5	-56,2	-16,9	101,4	16,0	-2,7	-36,4	53,0
		P	86,6	7,4	12,7	10,7	1,0	9,7	27,9	6,1	98,3	51,8	2,8	0,0	21,8	1,2	0,0
		D		-88,8	-2,0	0,0	0,0	0,0	-10,2	0,0	0,0	0,0	0,0	0,0	0,0	-35,2	0,0
		ET		0,0	0,0	36,0	14,2	14,3	0,0	16,6	42,1	34,9	104,2	16,0	19,1	0,0	53,0
		Cum ET	**0,0**	**0,0**	**0,0**	**36,0**	**50,2**	**64,6**	**64,6**	**81,2**	**123,3**	**158,2**	**262,4**	**278,4**	**297,5**	**297,5**	**350,5**

CT = conventional tillage; NT = no tillage; W= Water content (mm); ΔW= change in water content (mm); P= precipitation (mm); ET= Evapotranspiration (mm); ΣET= Cumulative Evapotranspiration (mm)

Table 6: The influence of tillage and crop rotation on the soil water balance for lupin planted after wheat in a lupin-wheat-canola-wheat- rotation per treatment at Langgewens (2013)

Rotation	Treatment	Date	2013-06-12	2013-06-19	2013-06-26	2013-07-05	2013-07-11	2013-07-17	2013-08-02	2013-08-07	2013-08-22	2013-09-03	2013-10-17	2013-10-21	2013-11-01	2013-11-08	2013-11-14
WCWL	NT	W	114,6	129,0	137,7	122,2	115,8	112,8	136,0	125,7	201,7	249,9	101,3	88,7	107,1	125,8	86,1
		Δ Water		-14,4	-8,7	15,4	6,4	3,1	-23,2	10,3	-76,0	-48,1	148,6	12,5	-18,3	-18,7	39,7
		P	86,6	7,4	12,7	10,7	1,0	9,7	27,9	6,1	98,3	51,8	2,8	0,0	21,8	1,2	0,0
		RO															
		D		-7,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	-17,5	0,0
		ET		0,0	4,0	26,1	7,4	12,7	4,7	16,4	22,3	3,7	151,4	12,5	3,5	0,0	39,7
		Cum ET	**0,0**	**0,0**	**4,0**	**30,1**	**37,5**	**50,2**	**54,9**	**71,3**	**93,5**	**97,2**	**248,6**	**261,1**	**264,6**	**264,6**	**304,3**
WCWL	CT	W	87,7	122,2	134,1	116,4	110,6	108,9	160,2	133,6	186,5	257,0	84,6	79,5	108,7	122,7	83,6
		Δ Water		-34,5	-11,9	17,7	5,8	1,6	-51,3	26,6	-52,8	-70,6	172,4	5,1	-29,2	-14,0	39,0
		P	86,6	7,4	12,7	10,7	1,0	9,7	27,9	6,1	98,3	51,8	2,8	0,0	21,8	1,2	0,0
		RO															
		D		-27,1	0,0	0,0	0,0	0,0	-23,4	0,0	0,0	-18,8	0,0	0,0	-7,4	-12,8	0,0
		ET		0,0	0,8	28,4	6,8	11,3	0,0	32,7	45,5	0,0	175,2	5,1	0,0	0,0	39,0
		Cum ET	**0,0**	**0,0**	**0,8**	**29,2**	**36,0**	**47,3**	**47,3**	**79,9**	**125,4**	**125,4**	**300,6**	**305,7**	**305,7**	**305,7**	**344,8**

CT = conventional tillage; NT = no tillage; W= Water content (mm); ΔW= change in water content (mm); P= precipitation (mm); ET= Evapotranspiration (mm); ΣET= Cumulative Evapotranspiration (mm)

Table 6: The influence of tillage and crop rotation on the soil water balance for canola planted after wheat in a canola-wheat-lupin-wheat- rotation per treatment at Langgewens (2013)

Rotation	Treatment	Date	2013-06-12	2013-06-19	2013-06-26	2013-07-05	2013-07-11	2013-07-17	2013-08-02	2013-08-07	2013-08-22	2013-09-03	2013-10-17	2013-10-21	2013-11-01	2013-11-08	2013-11-14
WLWC	NT	W	94,5	133,6	140,5	131,6	126,6	125,3	179,7	152,5	259,1	315,5	123,7	111,1	123,8	145,8	103,2
		Δ Water		-39,2	-6,9	9,0	5,0	1,3	-54,4	27,2	-106,6	-56,5	191,8	12,6	-12,7	-22,0	42,6
		P	86,6	7,4	12,7	10,7	1,0	9,7	27,9	6,1	98,3	51,8	2,8	0,0	21,8	1,2	0,0
		RO															
		D		-31,8	0,0	0,0	0,0	0,0	-26,5	0,0	-8,3	-4,7	0,0	0,0	0,0	-20,8	0,0
		ET		0,0	5,8	19,6	6,0	10,9	0,0	33,3	0,0	0,0	194,6	12,6	9,1	0,0	42,6
		Cum ET	**0,0**	**0,0**	**5,8**	**25,4**	**31,4**	**42,4**	**42,4**	**75,7**	**75,7**	**75,7**	**270,3**	**282,9**	**292,0**	**292,0**	**334,6**
WLWC	CT	W	73,1	104,3	112,9	101,6	99,4	98,4	108,5	102,3	180,3	335,3	89,2	80,9	97,2	116,6	73,3
		Δ Water		-31,2	-8,6	11,3	2,2	0,9	-10,1	6,2	-78,1	-155,0	246,1	8,3	-16,3	-19,5	43,3
		P	86,6	7,4	12,7	10,7	1,0	9,7	27,9	6,1	98,3	51,8	2,8	0,0	21,8	1,2	0,0
		RO															
		D		-23,8	0,0	0,0	0,0	0,0	0,0	0,0	0,0	-103,2	0,0	0,0	0,0	-18,3	0,0
		ET		0,0	4,1	22,0	3,2	10,6	17,8	12,3	20,2	0,0	248,9	8,3	5,5	0,0	43,3
		Cum ET	**0,0**	**0,0**	**4,1**	**26,1**	**29,3**	**39,9**	**57,7**	**70,0**	**90,2**	**90,2**	**339,2**	**347,5**	**353,0**	**353,0**	**396,3**

CT = conventional tillage; NT = no tillage; W= Water content (mm); ΔW= change in water content (mm); P= precipitation (mm); ET= Evapotranspiration (mm); ΣET= Cumulative Evapotranspiration (mm)