

Effect of soil forms on soil moisture and dryland cotton production

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ABSTRACT

Cotton (*Gossypium hirsutum*) production in South Africa relies on rainfed cultivation, and as such the availability of water is a key factor in the production of the crop. Cotton production in South Africa is declining gradual annually. The decline is marked by the competition with traditional crops, high input costs, international market prices and a lack of technical production information. The cotton produced in the 2019/2020 season consisted of 27 850 hectares in total from which 15 966 hectares is produced under dryland conditions, and 11 884 hectares under irrigated conditions. Dryland cotton production has been becoming more prominent, which establishes the need for technical information in the production under these conditions. Technical knowledge regarding soil moisture regimes is unknown in the industry and this uncertainty prevents the continued cultivation of the crop. This study aims to quantify the effect of the different soil forms and their associated water regimes on the rainfed cotton seed yield and quantity.

The effect of the water table was duly visible as bedrock interflow soils exhibited a higher amount of soil water throughout the production season in comparison with sandy clay soils. It was expected that the sandy clay soils would indicate higher soil water contents throughout the production season, but certain interflow soils had a substantial amount of soil water more during the both the productions seasons.

To determine the soil water regime the relationship between the soil water and the soil matric potential was established. The soil matric potential was determined by means of undisturbed core sampling and suction under pressure by using a pressure plate apparatus. By determining the soil water capacity at 33 and 1500 kPa, the drained upper limit (DUL) and lower limit (LL) was established for each of the various soil forms. Through the utilization of these parameters, the amount of planting-available water was determined which is critical in the production of cotton. Considering the DUL and LL the state of the soil water content throughout the production season was assessed for each of the soil forms. It was evident that sandy clay loam soils tend to be above DUL during a high rainfall period, but due to the drainage capacity of the soils, the period above DUL does not occur over a long period. The sandy clay soils indicated the opposite effect by being above DUL during the entire production season.

The cotton quality was assessed with the High-Volume Instrument (HVI) system and the focus was on the main quality parameters such as length, strength and micronaire. It was evident that the sandy clay soils produced the best quality cotton in comparison with the sandy clay loam soils. Even though these soil's soil water content was above DUL it produced thicker and stronger fibres with an optimal spinning consistency in comparison with the sandy clay loam soils.

The cotton yield maps for each of the sites was obtained and the yield per soil form was extracted for the specific sites of measurement. Although no statistical differences occurred between the different soil forms it was evident that sandy clay loam soils produced a higher yield in comparison with the sandy clay soils. The ability of cotton roots to shoot in sandy clay loam soils with a less dense compaction, in association with the ability of soil water to be drained enabled the cotton to produce more cotton bolls, resulting in a higher yield.

It was evident that the amount of soil water did vary between the various soil forms due to the variation in the soil physical properties such as the soil profile depth, clay percentage of the soil horizons, and soil moisture retention capabilities. Sandy clay soils tend to remain above DUL for longer periods than sandy clay loam soils, which causes anoxic conditions within the soil profile. These anoxic conditions result in stress induced effects in the rooting system which causes a lowered yield in comparison with the sandy clay loam soils which provides an oxidised environments for the rooting system, resulting in increased yields. Sandy clay loam soils tend to drain freely due to the large amount of macro pores, which in turn creates an oxidized environment for roots to develop and extract soil water.

It is recommended that the sites for both seasons remains the same to ensure consistent data with less variation. In association with the sites the same cultivar should be produced over two cropping seasons to ensure that all possible variation is excluded from the results. By including a weather system that measures the evaporative demand, the soil water balance can be defined more accurately.

Keywords: Cotton quality, DUL, LL, Neutron probe, Soil form.

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Phillippians 4:13 "I can do all things through Christ who strengthens me."

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LIST OF EQUATIONS

$\theta_g = M_w - M_d M_d \times 100$	Eq. 4-1.....	27
$\theta_v = (\theta_g 100)(\rho_b \rho_w)$	Eq. 4-2.....	27
Count Ratio = Count measured/ Standard count measured	Eq. 4-3.....	27
$Y = mx + c$	Eq. 4-4	28
$\theta_v = \theta_v \times \text{soil horizon depth (mm)}$	Eq. 4-5.....	28
Net weight = $M_w - (FR + CS)$	Eq. 4-6	30
$\rho_b = M_s V_t$	Eq. 4-7	30
$VDUL/LL = V_w \times \text{soil horizon depth (mm)}$	Eq. 4-8.....	31
$V_t = V_{\text{Topsoil}} + V_{\text{Subsoil}}$	Eq. 4-9.....	31
$PAW = VDUL - VLL$	Eq. 4-10.....	31
Rand value per hectare = Yield (ton/ha) $\times$ Value of the cotton (R/ per kg)	Eq. 4-11.....	33

CHAPTER 1 INTRODUCTION

Cotton is one of the world's most important fibre producing plant and such the continued cultivation of the crop is of upmost importance for sustainable fibre production, especially in most developing countries where cotton is considered one of the main fibre crops (Abbas & Ahmad, 2018; Chen *et al.*, 2018; Ennahli & Earl, 2005). According to Matloob *et al.* (2020) cotton is the crop most produced under arid conditions across more than 100 countries. Consideration of available resources, domestic requirements and optimal utilization of available resources are considered some of the key focus areas to ensure optimal yields and quality (Matloob *et al.*, 2020). Resource conservation and management is key in cropping management systems that incorporate rotational or intercrops with the cotton production system.

1.1 Background and Problem Statement

The cotton produced in South Africa constitutes up to 74 % natural fibre and 42 % of all the fibre that are processed in South Africa. Cotton is currently produced in the Mpumalanga, Limpopo, Northern Cape, KwaZulu-Natal, and North West provinces of South Africa. According to Cotton SA (2020), the governing body of cotton production in South Africa, 27 850 hectares land was cultivated for cotton in the 2019/2020 season of which 11 884 hectares was cultivated under irrigation, with the remaining 15 966 hectares being produced under dryland conditions. The Limpopo province is currently the province which cultivates the largest area of, with 8 098 hectares under irrigation and 9 115 hectares under dryland conditions. The North-West province is the province with the second highest area under dryland cotton cultivation in South Africa, cultivating on average 5 000 hectares of dryland cotton per annum (Cotton SA, 2020). According to Bonthuys (2018), irrigated fields only account for 25-40 % of South Africa's produced cotton, which makes optimizing dry land production essential. When considering that South Africa is a water scarce country (Bapwa 2019), which will be exasperated due to climate change, there is a need to develop mechanisms to reduce the effect of some inherent risks such as crop failure and production risks due to a lack of crop knowledge, and environmental risks (de Fraiture *et al.*, 2010). This necessitates the need to shift to a holistic approach in conservation agriculture to ensure sustainable and reliable production in the future (Strauss *et al.*, 2021).

The adoption of cotton by a farmer as a profitable crop is dependent on a list of factors, which include technical considerations, associated risks, profitability, environmental conditions, and social acceptability (Gouse *et al.*, 2004). Due to the lack of technical production knowledge on cotton the risks and uncertainties encountered during cotton production outweigh the benefits, which contributes to the declining cotton production in South Africa. Constraints in the production

of cotton in South Africa include competition from international governments where the agricultural sector is subsidized, market competition from traditional crops such as maize, wheat etc., the high input costs associated with seed, herbicides, fertilizer etc., and low-cost imports of the international market due to illegal importation of textiles and cheaper costs associated with the imports (Malinga, 2019).

The amount of cotton planted annually in South Africa increased and reached a peak during the 2018/2019 season with 38 785 hectares planted of which 22 765 hectares is under irrigated conditions and 16 020 hectares under dryland conditions (Cotton SA, 2021a). Table 1-1 illustrates the total hectares cotton planted from the peak in the 2018/2019 season up to the 2020/2021 season. It is evident that cotton production has declined from the peak in the 2018/2019 season to the 2020/2021 season. The dryland production exceeded the irrigated production and contributes more to the total amount of hectares planting.

Table 1-1: Cotton hectares planting in South Africa (Cotton SA, 2021).

Production year	Irrigation	Dryland	Total
2018/2019	22 765	16 020	38 785
2019/2020	11 543	16 132	27 675
2020/2021	5 802	10 511	16 313

One of the areas where there is uncertainty for producers in the dryland cotton production industry is soil water management. Research indicates that there is a relationship between the amount of soil water and the cotton quality and yield. According to Zhang *et al.* (2016) limited soil water in cotton production can inhibit the planting development through diminished water absorbance by planting roots and increased leaf transpiration. This has shifted the focus to soil water management, specifically the effect of soil type on the amount of soil water. The presence of, and depth of a soil water table has been identified as a major factor influencing the yield and quality of cotton under dryland production (Che *et al.*, 2021; Mohamedin *et al.*, 2010). The effect of different soil forms on a field's water regime has lately risen in importance for cotton production, especially under dryland production areas, thus urging the need to establish the effect of the soil forms with their associated water regimes on the cotton quality and yield under dryland conditions.

1.2 Hypothesis

Different soil forms have different soil water regimes due to the differences in soil properties, and as such this has an inherent effect on the seed cotton yield and quality under dryland conditions.

1.3 Aims and Objectives

This study aims to determine the effect of different soil forms on the amount of plant available water and dryland produced cotton quality and yield in the Schweizer-Reneke area in the North West province of South Africa.

This will be accomplished by meeting the following objectives:

- i. Characterization of the dominant occurring soil forms in the cotton region of Schweizer-Reneke in the allocated site locations.
- ii. Determining the soil water content of each of the dominant soil forms by using the neutron probe.
- iii. Determining the water regimes of the different soil forms and assessing the soil forms drained upper limit and lower limit.
- iv. Determining the cotton yield and quality parameters including length, strength, and micronaire of the cotton produced on each of the dominant soil forms.

CHAPTER 2 LITERATURE REVIEW

2.1 Cotton Production

According to Wegier *et al.* (2016) cotton is one of the top ten most produced crops in the world. It is the only crop in the top ten most grown crops with the main purpose not being for food production. According to Wang *et al.* (2020) cotton still dominates the world fibre production, contributing 71 % to the fibre market even with the increase in synthetic fibres. Cotton is mainly used in the textile industry across the world but has several other uses. Cotton is used in the feed and oil industries as the seed produced in the cotton bolls is processed to form oils. These oils are used in the food industry and the shells of the seed in the feeding industry. The seed is rich in oil with an oil content of 18-24 % and a protein content of between 20-40 % (Cetin & Bilgel, 2002). Cotton can be produced under dryland conditions which offer the possibility of economic stability as the crop requires less water than most of the traditional crops (Howell *et al.*, 2004). South Africa is a water scarce country and as a result, dryland crop production accounts for the biggest contributor to the agricultural sector. In South Africa cotton produced under dryland accounts for up to 70 % of the total cotton produced in comparison with irrigated production. According to Cotton SA (2021b) the average seed cotton yield under dryland conditions in South Africa is 1,2-2 ton/ha. Soil water management is considered a key factor in precision farming techniques proven to ensure higher yields.

2.2 Cotton Morphology

According to Basal & Ünay (2006), the most important morphological process occurs in the plant roots which determines the response of the plant to dryland production. According to Turner *et al.* (1986), it has been established through various studies that the effects of water, and more specifically soil water, has various influences on cotton growth indicators, including photosynthesis, leaf expansion, flowering, and boll formation. Li *et al.* (2020) includes other physiological factors such as the root system which forms a great part of the soil moisture uptake, plant height and stem diameter.

2.2.1 Cotton Root System

Cotton has a taproot system that extends to secondary and tertiary roots (Gaber, 2016; Jabran & Chauban, 2020). The roots can reach a depth of 20-25cm before the emergence of the stem and leaves above ground due to the rapid growth of the rooting system. The secondary roots of the cotton first develop and grow laterally after the emergence and unfolding of the cotyledons of the cotton. The tertiary roots grow lastly which is associated with the taproot developing downwards

(Rehman & Farooq, 2020). Gaber (2016) states that the final root depth is associated with a range of environmental factors including soil water, aeration, and air temperature. The root growth and distribution are associated with the amount of soil water available in the soil profile with the highest volume of roots present in the upper part of the soil profile at depths 0-600 mm. According to Taylor & Klepper (1974), cotton roots keep developing up to when maximum planting height is achieved, usually after peak flowering.

Hu *et al.* (2009a) state that the root growth of cotton is directly correlated to the soil water content. Considering the root growth and soil water it is evident that the root growth will be in the direction of soil horizons with a suitable amount of soil water available. If water stress occurs the root activity of the cotton becomes frail and affects the root distribution, growth of the plant and more importantly, the yield (Hu *et al.*, 2009a). In soils where the soil water content is above Drained Upper Limit (DUL) the amount of oxygen is less and root growth will be hindered and cause a reduction in the yield (Hu *et al.*, 2009a).

2.3 Cotton Growth Stages

The cotton plant growth cycle duration varies between 160-180 days (25 weeks) depending on several factors such as the cultivar planted, area of production and the number of growing day degrees (heat units) available for plant development from seedling (Cotton SA, 2021b).

2.3.1 Emergence

According to Gaber (2016) and Cotton SA (2021a) the seeds germinate and emerge between 2-14 days after planting. The germination period success is dependent on the availability of soil water, temperature, and oxygen. During germination, the soil water present in the topsoil seedbed enters the cotton seed through the chalazal aperture at the seed apex and allows for the seedling to emerge within 5-6 days (Gaber, 2016). According to Hussain *et al.* (2020), a shortage soil water during germination is directly correlated to a lower yield. Thus, it is essential that soil water is available during planting due to the inherent effects on the following growth stages.

2.3.2 Flowering

The first leaves start forming 10-12 days after emergence during which the first squares start forming. The cotton plant develops two different types of branches which forms part of the reproductive growth stages. According to Rehman & Farooq (2020), the two branches formed is monopodial, which is the vegetative branches and, sympodial, which is the fruit bearing or cotton boll bearing branches. As the branches form the flowering process commences at 70 days after planting (Cotton SA, 2021a; Gaber, 2016). The soil water needs between emergence and leaf

formation increases drastically and the taproot system occur throughout the soil profile. The flowering reaches a peak at day 90-105 during which soil water sensitivity peaks (McMichael *et al.*, 2011). Soil water shortages during flowering may cause reduced fruiting sites, shedding of immature cotton bolls, reduced cotton boll size and as a result a lower yield.

2.3.3 Boll Formation and Burst

During the reproductive stage, the cotton bolls start to form on the sympodial branches from day 90 after planting. According to Hussain *et al.* (2020), the crop soil water demand decreases from boll formation to boll burst. Water shortages or excess does not have a big effect during the boll formation stage and might only cause the shedding of some bolls. Most bolls open from 120-160 days after planting from which the cotton matures, and harvest is possible from 160-180 days (Cotton SA, 2021a). The harvest time is dependent on the length of the season, climatic conditions, and the cultivar (Rehman & Farooq, 2020).

2.4 Cotton Quality

According to Üreyen & Kadoğlu (2006) the HVI is used to test the fibre properties from a bundle of strands. The properties tested by the automated system is the fibre length, consistency of the fibre, strength, elongation, micronaire, colour and trash content. From these properties the fibre strength, length and micronaire are used to determine the quality class. Since these are the important quality properties only these properties will be discussed.

2.4.1 Cotton Quality Determination

The cotton quality is determined with a Uster HVI (High Volume Fibre test system) as seen in Figure 2-2. The laboratory conditions are very important and should comply with the ASTM standard conditions throughout the cotton classing procedure to ensure accuracy and consistency (Uster, 2008). The first step is to store the cotton samples in a wire basket on open-wire shelves as seen in Figure 2-1. The cotton used in the calibration procedure must be stored within the same space and under the same conditions. It is vital to ensure that the calibration samples are not mixed or contaminated in any possible way. The calibration samples may only be used for a maximum of three repetitive calibration procedures as the sample becomes clumpy (Uster, 2008).



Figure 2-1: Wire basket used for the storage of cotton samples (Uster, 2008).

Figure 2-2 illustrates the HVI set-up containing all the necessary instrumentation to determine the cotton quality. The legend is discussed on the following page.

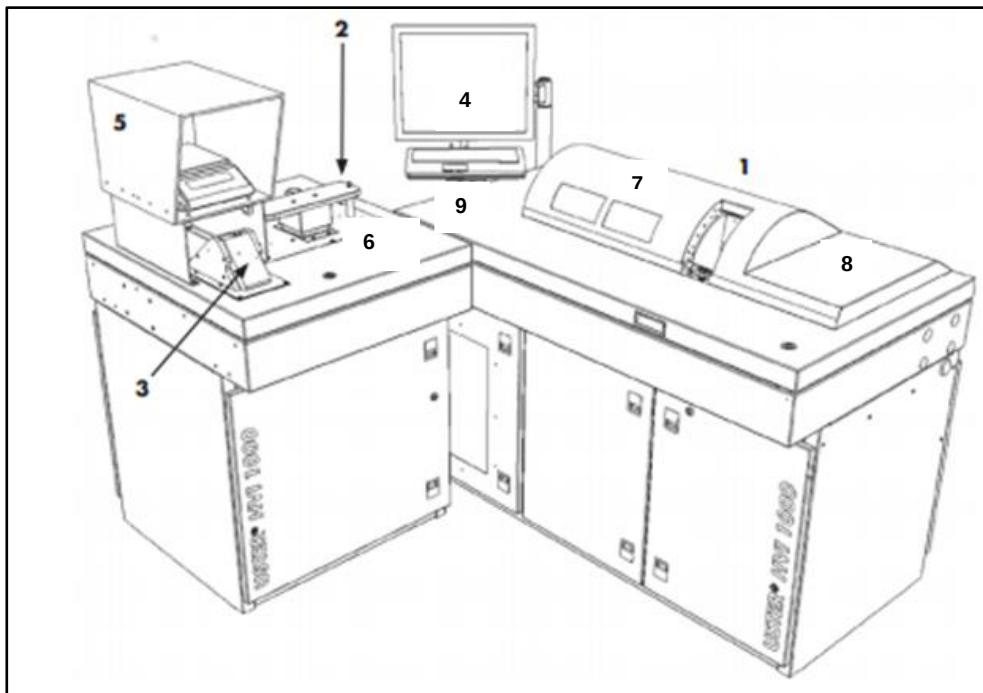


Figure 2-2: Uster HVI System (Uster, 2020).

The legend to the set-up is as follow (Adapted from the Uster 2020):

1. Length/Strength module
2. Colour/Trash module
3. Micronaire module
4. Printer and printer table
5. Micronaire balance
6. Bar code reader
7. Length/Strength cabinet
8. Micronaire, colour and trash cabinet
9. Operating unit

2.4.2 Cotton Quality Properties

The quality of the cotton is a key aspect to consider as it influences the quality of the textile and accordingly the income the farmer receives (Abbas & Ahmad, 2018). It is stated by Bradow & Davidonis (2000) that the management factors during and after harvest influence the fibre properties and in turn determine whether cotton is of high or low quality. The management practices associated include soil moisture management and plant growth. Fang *et al.* (2017) state that the fibre quality is mostly controlled by the genes and environmental conditions. Kannan *et al.* (2019) states that moisture stress may cause adverse effects on the major metabolic processes such as stomatal conductance, chlorophyll stability index, proline content, relative moisture content and most importantly, the photosynthesis process. All the above-mentioned processes influence on the quality of the cotton and as such proper care must be taken regarding the quality of the cotton.

2.4.2.1 Micronaire

Micronaire is defined as a measure of the permeability of air into the compressed fibres of cotton. The micronaire of cotton variants is a key quality assessment property as it impacts the processing and dyeing consistency (Rodgers *et al.*, 2017). According to Montalvo (2005) the micronaire of cotton has been used as a substitute for assessing cotton fineness and maturity. It is considered one of the three most important fibre characteristics influencing the quality of cotton.

A high or low micronaire relates to a coarse or fine fibre which may result in problems during the spinning and for yarn evenness and may result in decreased value for the fibre batch (Montalvo, 2005). The cotton fibres develop in a very precise pattern and according to Hake *et al.* (1990) the final length of the cotton fibre is reached within 16-20 days in the boll formation stage from where the thickening process starts. The thickening process is related to celluloses depositing strands in the cell wall of the cotton boll. Low micronaire values is associated with soil water conditions above the drained upper limit and lower carbohydrate content due to the reduced oxygenated environment (Hake *et al.*, 1990). High micronaire values are associated with water stress causing poor boll formation which may be reduced in size.

2.4.2.2 Strength

Fibre strength is a property that is associated with various other cotton quality properties such as fibre maturity, fineness, and length, and as such, it is an important factor to consider (Fang *et al.*, 2017). Islam *et al.* (2016) state that individual fibre strength is a key attribute that influences the quality and strength of the yarn spun from the cotton fibres. The cotton fibre strength is defined as the amount of force required to rupture the fibres (Haigler, 2010). According to Zhao *et al.* (2020), the cotton strength is considered one of the three most important cotton quality properties. The cotton strength is influenced by the number of cellulose layers much the same as the micronaire. However, the celluloses formation is influenced by environmental conditions such as soil water conditions and amount of heat units (Chen *et al.*, 2017). According to Liu *et al.* (2009) drought induced periods significantly decrease the strength by inhibiting the processes of celluloses production.

2.4.2.3 Length

In cotton spinning the fibre length is an important factor to consider (Morais *et al.*, 2020). The fibre length is essential to the processing sector as it will break if the fibres are not mature or strong enough. Length is also referred to as upper half mean length (UHML). According to Zhao *et al.* (2019) the length of the cotton is mainly influenced by drought stress as it influences the processes related to the cell expansion and as a result shorter fibre is produced. Cotton with short fibres has a lower quality as it influences the spinning consistency of the cotton (Wang *et al.*, 2016).

2.5 Soil Water

According to O'Green *et al.* (2010), the soil directly influences the hydrologic processes in the soil that governs the sustainability of water resources. Shelia *et al.* (2017) states that the process of

determining the amount of soil water is essential to resource management in the agricultural sector which is the biggest consumer of soil water.

2.5.1 Neutron Scattering

Neutron scattering has been proven to be the most accurate method in determining the amount of soil water. According to Kodikara *et al.* (2014), neutron scattering entails the process of neutron thermalization. The hydrogen nuclei in soil water scatter and slow down the emitted neutrons from the neutron probe. The neutron probe emits high-energy neutrons from a radioactive source, radium-beryllium. Water consists of hydrogen nuclei which have almost the same mass as that of the high energy neutrons, but they are almost up to 10 times more effective in slowing down the neutrons in the case of collisions. According to Cooper (2016), most hydrogen in the soil is kept in a weak bond which forms water. In exceptional cases hydrogen was found in organic matter, however, this changes rarely, but it can be followed over a period. The neutrons scattered into the soil react with the hydrogen nuclei, and as a result, the density of the slow neutrons within the area surrounding the neutron probe is nearly proportional to the volumetric soil water content. The neutron probe (503 DR Hydroprobe,) is used to determine the amount of soil water.

2.5.2 Neutron Probe Calibration

The calibration of the neutron probe is considered a key part of the process as the readings tend to drift throughout the measurement period. Many methods exist to measure soil moisture, but the accuracy is determined by way of the calibration procedure used. A standard method is used to calibrate a dataset. This method should be as accurate as possible to prevent any influence of secondary factors or parameters. The standard method for calibration of soil moisture studies is the gravimetric method (Cooper, 2016). The gravimetric method is used to determine the volumetric water content as well as the mass wetness. The top 20 cm of the profile is left out from the equation as the neutron probe is less suitable to localize water discontinuities in this part of the profile due to the soil–air relation.

Soil water is not directly derived from the number of slow neutrons, and as such for reproducibility of a study the soil water content should be derived from the count ratio. Some of the neutrons tend to scatter into the air in this part of the soil profile. One of the most important disadvantages of the gravimetric method as a measurement method is that it is destructive. Observation at the same location is impossible, and as such the long-term monitoring of changes is impossible. The spatial variability increases with the use of this method in continuous soil moisture monitoring. According to Cooper (2016), the changes between the different sites is often much bigger than the actual soil water content changes over a period.

2.6 Soil Water Characteristic Properties

Different states of the soil moisture content occur, saturated, drained upper limit, and lower limit. The soil moisture state is directly influenced by the water potential in the soil and the energy required for water to flow in and out of the soil profile (Brady & Weil, 2017). The water supply to the crops is dependent on the root zone. According to Hensley *et al.* (2011), there are two main parameters influencing the supply of plant available water between the upper and lower limits in the root zone, the drained upper limit, and lower limit. The difference between the two parameters yields the plant available water. The soil water characteristics is an essential part of the assessment of the hydraulic and mechanical behaviour of the different soil forms as it relates to the suction in the soil matrix, total soil capacity and/or both (Wang & Benson, 2004). According to Rehardjo *et al.* (2019) and Brady & Weil (2017), the soil water characteristic properties is determined by means of pressure plate extraction. The basic setup of the pressure plate extractor is illustrated in Figure 2-3. The pressure plate extractor consists of two main components: the porous plate with an air entry that is higher than the maximum matrix suction pressure, and a pressure vessel that is entirely sealed to prevent air-leaks (Wang & Benson, 2004). The pressure of the water in the pores of the undisturbed core sample is maintained at zero to enable the outflow of the water under atmospheric pressure. It is important to note that the texture determines the water holding capacity and drainage of the soils.

2.6.1 Drained Upper Limit

According to Burke & Dalgliesh (2013) the drained upper limit is defined as the amount of soil water that soil retains against gravity, also known as field capacity. According to Brady & Weil (2017) when soil is at field capacity it holds the maximum amount of soil water that is useful for a plant to absorb. Nhalabatsi (2010) states that the drained upper limit of a soil is attained when all the meso-pores are completely drained. The drained upper limit is mainly subjected to gravitational forces but can be determined at a pressure of 33 kPa in the pressure plate extraction system. The water held at field capacity drains freely and as such the soil water at field capacity occupy the macro pores within the soils (Assouline & Or, 2014). It is further stated by Brady & Weil (2017) that though the macro pores are filled with water, sufficient aeration occurs to ensure optimal microbial activity that enhances the growth of the plant. If the amount of soil water increases above the drained upper limit the oxygen supply becomes limited and the root growth is affected by the root zone becoming anoxic. Shelia *et al.* (2017) state that the flow of water takes place when the amount of soil water present in soil is more than the retention capabilities.

2.6.1 Lower Limit

The lower limit is defined as the amount of soil water left in the soil after all the soil water was extracted, also known as the wilting point. During the lower limit, the soil profile appears to be dry, but a small amount of soil water is held in the micropores (Brady & Weil, 2017). The pressure related to the lower limit is at 1500 kPa, and as such the lower limit is determined at this pressure in the pressure plate extraction system (Savage *et al.*, 1996). When a plant reaches the lower limit the water availability decreases as the forces that attract the water to the soil is higher than the extraction ability of the plant roots. The plants close the stomata when the soil is at saturated condition and excess water becomes “free water”. During this state carbon dioxide cannot enter through the stomata and photosynthesis stops. When the process of photosynthesis is slowed or stopped the production of above-ground biomass is decreased. This subsequently reduces the cotton seed yield (Brady & Weil, 2017).

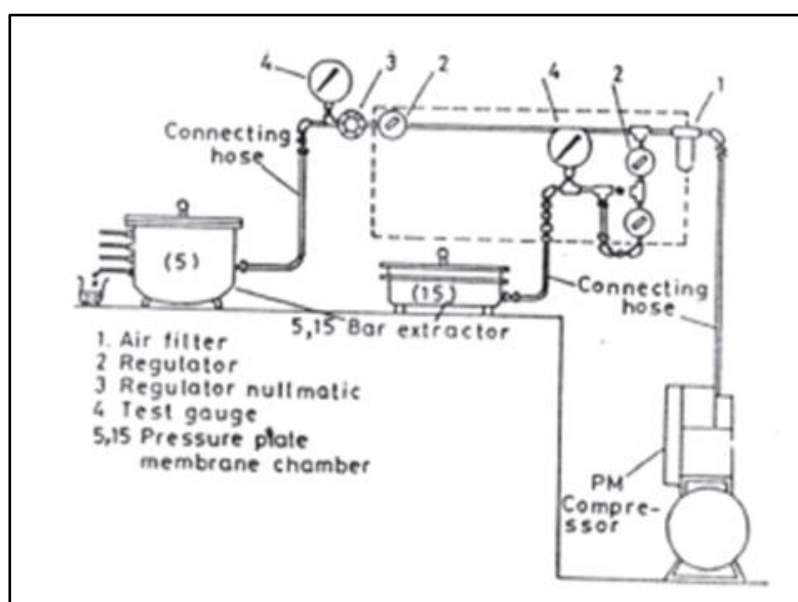


Figure 2-3: Pressure plate extractor setup (Bandyopadhyay & Pradhan, 2012).

2.6.2 Plant Available Water

The plant available water is defined as the amount of water available for planting uptake (Brady & Weil, 2017). Araya *et al.* (2016) state that the plant available water in crop production is the most crucial aspect in agricultural management systems as it is the main cause of crop growth variability. According to Brady & Weil (2017) the amount of plant available water is determined by the soil water potential of the soil horizons, soil texture, soil strength and depth, and the density of the soil horizons.

The effect of the texture on the drained upper limit, and lower limit is illustrated in Figure 2-4. It is evident that the amount of plant available water increases with the clay content from a sandy texture to a clay texture. This is due to the increase in pore spaces from sandy soils to clay soils, however, the lower limit, or wilting point increases with clay content. This increase in lower limit can be quite a risk in crop production as the increased lower limit can cause planting stress in a dry season when the evaporative demand is high (Ninari, *et al.*, 2004).

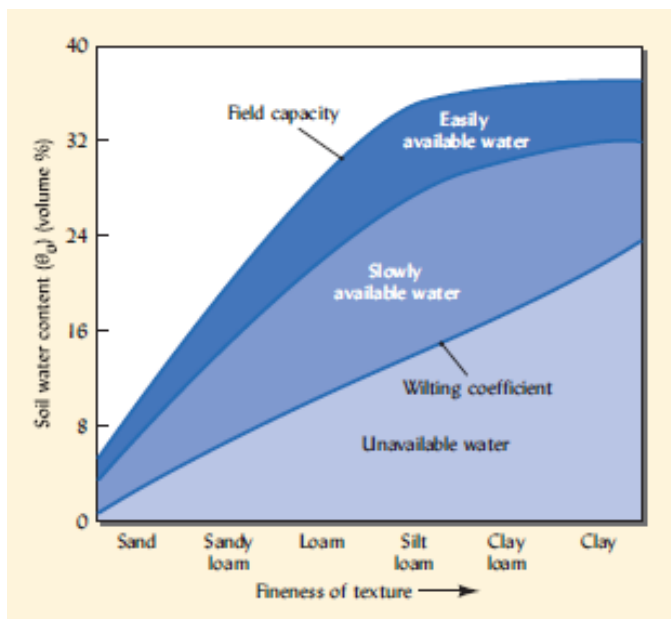


Figure 2-4: Relationship between the soil water characteristics and soil texture (Brady & Weil, 2017).

2.7 Soil Water Studies

Padhi *et al.* (2012) conducted a study of the soil water deficit in an irrigated cotton field over two seasons. Although it was in an irrigated field the concept of soil water measurement remains the same. In the study a neutron probe (503 DR Hydroprobe) was used in determining the amount of soil water. The soil water was measured from the surface to a depth of approximately 1300 mm in 100 mm intervals. Standard reference counts were taken before measurements commenced. After the readings were taken the count measurements were divided with the standard reference count and converted to a volumetric basis using an unknown calibration equation. This leaves some discrepancies on how the calibration was obtained. Lacape *et al.* (1998) conducted a similar study on various cotton varieties, however in the calibration procedure undisturbed core samples were extracted. The soil samples obtained from each of the measuring depths were weighed in the field and noted as the wet weight. The samples were oven-dried in a laboratory to obtain the gravimetric soil water content (Kirda & Reichardt, 1992). In the process of drying the samples the

dry bulk density is obtained and used to convert the gravimetric soil water content to a volumetric soil water content (Hu *et al.*, 2009b). The calibration equation was then obtained by fitting the volumetric water content to the count ratio in a linear regression model to obtain the linear regression equation and regression coefficient (Vera *et al.*, 2009).

According to van Huyssteen *et al.* (2010), a range of environmental conditions influences the variability of soil water. Environmental factors have a tremendous effect on the soil water content, especially the terrain. The slope influences the hydraulic gradient which is the main drive for subsurface and surface flow. The curvature of the landscape influences the lateral flow in soil profiles in terms of convergence or divergence. Upslope areas due to contours can have a critical influence due to the potential to contribute to the flow of soil water laterally (Western *et al.*, 1999).

A study was conducted by Hensley *et al.* (2011) during which the soil water was measured daily and compared to the soil types to determine the influence of physical characteristics of the soil. In this study, the soil water content was expressed as the degree of saturation. The degree of saturation is defined as the fraction of the porosity that is utilized by soil water (van Huyssteen *et al.*, 2010). It is stated that by expressing the soil water as a function of saturation that the comparison between the different soils and their pedological interaction is much easier interpreted. A clear example is given by comparing two soils (A & B) with the different bulk densities of 1,3 Mg/m³ and 1,7 Mg/m³, respectively. The volumetric water content for soil A and B at the degree of saturation is 0,7 which corresponds to 36 % and 25 % saturated for soil A and B. When considering the degree of saturation as 1,0 the corresponding values will be 51 % and 36 % respectively for the soil profiles. This might cause misinterpretation that soil A is wetter than soil B, which is irrelevant without the porosity and bulk density as both soil profiles are completely saturated (van Huyssteen *et al.*, 2010). This emphasizes the importance of reporting the bulk density to ensure the correct conclusion is observed.

According to Hensley *et al.* (2011) the fallowing of fields allows for more soil water to be available pre-season in the root zone of the soil profile and prevents crop damage caused by drought. In the study conducted by van Huyssteen *et al.* (2010) the soil water content was measured, and the monthly mean saturation was calculated and is illustrated in Figure 2-5. The soil water content is related to the B horizons. It is evident from Figure 2-5 that the E horizons had the highest mean degree of saturation followed by the G horizon, unspecified material with signs of wetness and soft plinthic horizons. Some discrepancies occurred in the study which illustrates the spatial variability of soils. The E horizon will normally be much drier in comparison to the G horizon due to the texture and structure of the horizon but in this case study the contrary was proved. The E horizon occurred in soils which is highly saturated which was underlain by G horizon soils which is much wetter than the E horizons. This caused the soil water to create a stagnant layer of water

in the E horizon. The G horizon was in much drier soils which may be the reason for being lower than the E horizon (van Huyssteen *et al.*, 2010). The orthic horizon is much wetter than the apedal and neocutanic horizons during the high rainfall months (January to March) from where the plinthic and yellow brown apedal horizons increases above the orthic due to drainage and accumulation in the subsoil horizons. The yellow brown apedal soil is much wetter than the red apedal due to the colour matrix in the horizon indicating reducing states rather than oxidized states.

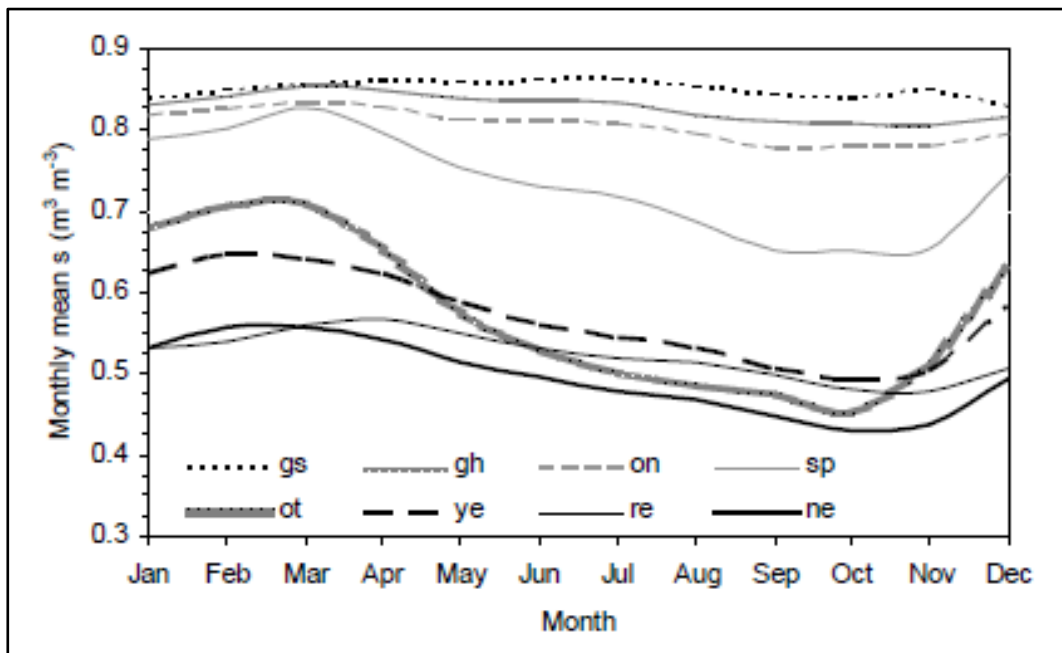


Figure 2-5: The mean monthly soil water in different soil horizons (van Huyssteen *et al.*, 2010).

Where gh = G-horizon, gs = E-horizon, ne = neocutanic, on = unspecified material with signs of wetness, ot = orthic, re = red apedal, sp = soft plinthite, ye = yellow brown apedal.

The area surrounding Schweizer-Reneke is characterized as a semi-arid region, and according to Bennie & Hensley (2001) the soils in the region typically has a clay content lower than 25%. A distinct feature of these soils is a pedogenic horizon below the root zone that may restrict deep drainage of water. In a season that above average rainfall occurs these pedogenic soil horizons may accumulate water and create a shallow perched water table within the root zone. The drainage of deep, well-drained aeolian soils, such as observed in the Schweizer-Reneke area, may be between 0 to 20% of the seasonal rainfall (Bennie, 1994). According to Bennie & Hensley (2004) deep drainage occur when the soil water content in the root zone exceeds the upper limit of the amount of plant available water. It is stated by Mavimbela & van Rensburg (2014) that when

the amount of soil water is above the drained upper limit that most soil water is lost due to deep drainage before evaporation occurs.

2.8 Cotton Growth and Soil Water

Li *et al.*, (2020) conducted a study on the physiological response of cotton to water availability in the soil profile. By monitoring the growth patterns in association with soil moisture parameters such as total water content and evaporation, a correlation between rooting patterns and soil moisture consumption was identified. According to Li *et al.* (2020), soil moisture has both temporal and spatial distribution patterns and as such the soil-water system is complex. In this study's results, it was evident that the soil moisture varied due to factors such as the rooting system, atmospheric evaporation, self-gravity (defined as soil water seepage), and the mulch used. In the study, the soil profile was studied in 10 cm intervals separating each of the soil horizons. It was evident that the soil moisture content increased with an increase in soil depth in the top 30 cm of the soil profile. What is defined as the B horizon in the study indicated an almost constant soil moisture content. In the 80–100 cm part of the soil profile, a higher soil moisture content was observed. The soil moisture content throughout the growth stages had a similar trend in comparison with the study of Chen *et al.*, (2018).

2.8.1 Influence of Water Stress on Seed Cotton Yield and Quality

Cotton quality parameters influenced by low soil water contents is length and micronaire due to the metabolic and photosynthetic processes being inhibited (Hussain *et al.*, 2020). Water stress affects the photosynthetic effect of the leaves by inducing stomatal closure and the inhibition of metabolic processes including ribulose biphosphate and adenosine triphosphate synthesis which in turn influences the yield (Loka *et al.*, 2011).

In a study conducted by Molz & Klepper (1973) it was observed that when the soil is in a moderate drought state (described as 50–60 % of field capacity) that the plant roots were mostly situated in the upper soil profile layer relating to the A and upper B horizon. In the case of sufficient water supply at 80-90 % of field capacity, the roots were more distributed throughout the soil profile.

Ball *et al.* (1994) conducted a study on the growth dynamics of the cotton plant (*Gossypium hirsutum*) during water-deficit stress. The main focus was on the response of the cotton roots to water stress in relation to soil water content (Ball *et al.* 1994). In Ball *et al.* (1994) it was reported that the cotton seems to undergo a stress period between 55 to 65 days after germination. The significance is that the root elongation reported seemed to reduce the water stress by approximately 50 %. The growth was more prominent in the lower soil zone where water was readily available. Ball *et al.* (1994) went on to state that the root size and the position of the roots

within the soil profile are important when investigating the response of root growth to water-deficit stress. In the proposed study area, the roots tend to shoot to a depth of one meter where water is readily available in soils with high clay contents. If this is possible, cotton may overpower crops such as maize, which does not have the ability to shoot roots in soils with a higher clay content as reported by Ackerson and Krieg (1977).

The quality of the cotton is a key aspect to consider as it influences the quality of the textile and accordingly the income the farmer receives (Abbas and Ahmad, 2018). The cotton has the ability to enhance the plant potential of the cotton by undulating the effect of high temperatures and water deficiency during the reproductive stage when sown early, but late sown cotton has the opposite effect and results in later flowering and concluding to a lower cotton quality (Abbas and Ahmad, 2018).

2.9 Hydropedological Classification of South African Soils

The term hydropedology entails a multidisciplinary approach to solve soil water management issues and bridge the gap in the pedological process such as soil genesis and its influence on hydrological processes in soil profiles (Ma *et al.*, 2017). Hydropedology is based on the interaction between soil pedology and soil hydrology. According to Ma *et al.* (2017) it can be divided further into two main research questions: What is the influence of soil pedogenesis on the partitioning of hydrologic fluxes in different landscapes by considering biochemical and ecological functions, and what is the influence of the hydrological landscape on the process of soil genesis, the variability in a landscape and the overall function in spatially distributed areas.

In agricultural areas the process of soil genesis is often different resulting in different hydrological processes. According to Ma *et al.* (2017) hydropedological processes determine the amount of soil water and nutrients as well as the transport thereof and hence the importance in the agricultural sector.

According to Zwart & Bastiaanssen (2004), the biggest challenge in the agricultural sector is the production of a higher quantity of food and fibre in the cotton industry whilst reducing soil water usage. Resource conservation is a key aspect of agriculture and with water being a natural resource it is fundamental to understand the relationship between environmental sustainability and agricultural production. Hydropedology can provide essential information on the relationship between the soil-water interaction in any given landscape (de Mello & Curi, 2012).

2.9.1 Hydropedological Soil Types

Hydrological processes have been conceptualized and quantified in the past decades by focusing on the soil morphology and the soil water regimes of different soil types (van Tol & Le Roux, 2019). The soil water regime is defined as the state and availability of soil water in relation to the growth of plants (van der Watt & van Rooyen, 1995).

Recharge soils are identified as soils which does not indicate any morphological signs such as grey mottles or grey colours in the soil profile which indicates saturation (van Tol & Le Roux, 2019; van Tol, 2020). The soil types associated may be shallow with a rock limiting layer allowing flow into and through the bedrock, or it may be deep well-drained soils as seen in Figure 2-6. These soils predominantly flow to wetland or aquifer areas in valley bottoms (van Tol, 2020).

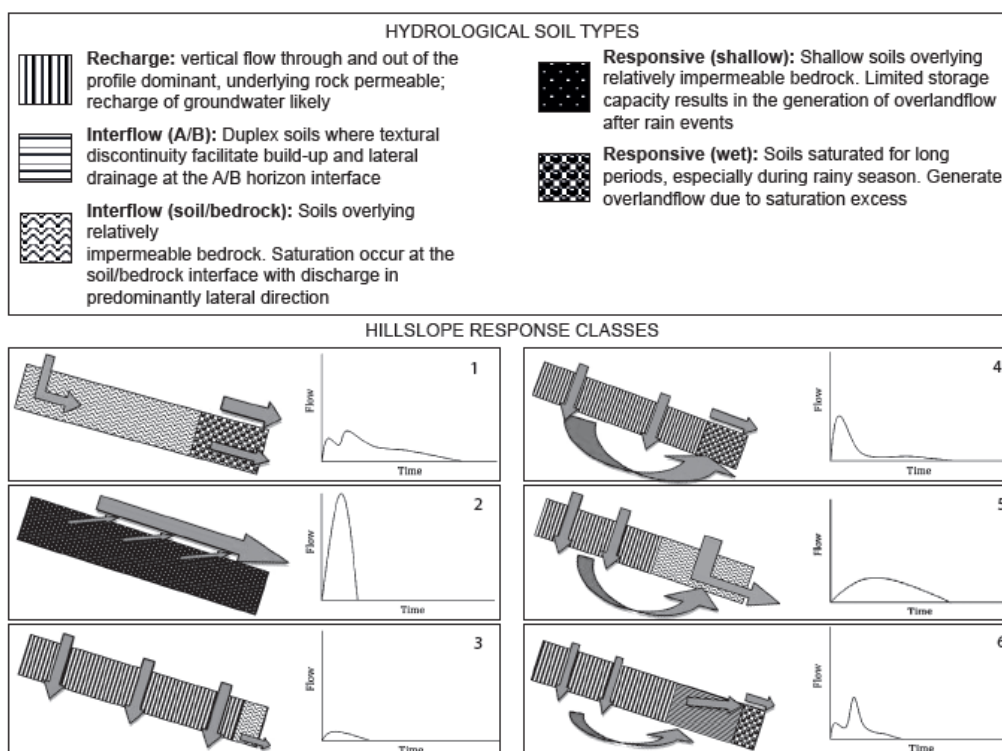


Figure 2-6: Hydropedological response classes of the soil groups (van Tol, 2020).

Interflow soils are separated into two classes: Preferential flow in the A and B horizon interface, and preferential flow in the soil/bedrock interface. A key soil physical property used in the classification of an interflow soil is the texture. An example of A/B horizon interflow soil types is the textural contrasts which allow for soil water build up or accumulation on the interface between these horizons. This feature is common in duplex soils such as the Longlands soil form (Table 2-1) where the textural contrast between the orthic A topsoil horizon and the albic horizon, where

the orthic A horizon allows for water build-up in the albic horizon (van Tol & Le Roux, 2019). The second interflow soil type allows for preferential flow on the soil/bedrock interface. These types of interflow soils are known as water table soils as it is associated with periodic soil water saturation on the bedrock. Water infiltrates the soil profile and flows laterally throughout the soil profile. This lateral flow is dependent on a range of hydrological parameters including the slope of the bedrock, the hillslope position, and the permeability of the overlying soil horizons (van Tol & Le Roux, 2019). Examples of this feature in a South African soil form is the presence of the redox mottles in the interface between the bedrock layer and the soft plinthite horizon where water presence and flow allow for different redox colours.

Responsive soils are unstable in terms of saturation because these soils tend to be rather shallow and has limited soil water storage. These soils that overly impermeable rock layers tend to be oversaturated fast. An example of a shallow responsive soil is the Arcadia soil form (Table 2-1). The Arcadia soil form has a vertic topsoil horizon that cracks during dryer periods. The vertic topsoil horizon overlay a lithic horizon which may be shallow. In heavy rainfall events, these cracks allow for water infiltration but tend to get oversaturated quick due to the slow water infiltration. During periods of soil water conditions above DUL these soils tend to allow overland flow of soil water causing erosion (van Tol, 2020).

Stagnant soils allow water infiltration into the soil profile but tend to inhibit the outflow of water. Morphological indicators such as carbonate accumulations, precipitation of iron and manganese concretions in soil horizons and accumulation of silica are used to determine whether recharge or interflow is possible on these soil types. If any of these morphological indicators occur, recharge or interflow may be restricted or limited (van Tol & Le Roux, 2019). These soils commonly occur in areas where the evaporative demand is higher than the infiltration of water into deeper parts of the soil profile. It is also associated with areas with low rainfall (van Tol, 2020).

2.9.2 Internal Drainage of Soils

According to Mavimbela & van Rensburg (2015) internal drainage is a key process in soil water conservation, especially under dryland conditions. The concept mainly relies on the less permeable soil horizons which act as soil water reservoirs. The drained upper limit is deemed an important factor, as such the quantification of this parameter into the soil water study is important.

The internal drainage of a crop is mainly influenced by the presence of coarse material, texture and density. In a study conducted by Mavimbela & van Rensburg (2015) the internal drainage of the Tukulu, Sepane and Swartland soil forms was evaluated. The focus of the study was to find

the relationship between the hydraulic characteristics, pedological and physical properties of the soil forms to define the internal drainage.

Table 2-1: Examples of hydropedological soils derived from the South African Soil Classification System (van Tol & Le Roux, 2019; Soil Classification Working Group, 2018).

Recharge		Interflow		Responsive		Stagnating
Deep	Shallow	A/B horizon	Soil/bedrock	Shallow	Saturated	Steendal
Kranskop	Nomanci	Kroonstad	Lamotte	Nomanci	Champagne	Immerpan
Magwa	Mayo	Longlands	Fernwood	Arcadia	Rensburg	Dresden
Inanda	Milkwood	Wasbank	Westleigh	Mayo	Willowbrook	Glencoe
Lusiki	Jonkersberg	Klapmuts	Avalon	Milkwood	Katspruit	Molopo
Sweetwater	Glenrosa	Villafontes	Pinedene	Glenrosa		Askham
Bonheim	Mispah	Kinkelbos	Bainsvlei	Mispah		Kimberley
Inhoek	Witbank	Cartref	Bloemdal			Plooysburg
Constantia			Witfontein			Games
Tsitsikamma			Sepane			Etosha
Concordia			Tukulu			Gamoep
Houwhoek			Montagu			Oudtshoorn
Griffin						Addo
Clovelly						Prieska
Hutton						Trawal
Shortlands						Augrabies
Pinegrove						Brandvlei
Groenkop						Coega
Valsrivier						Knersvlakte
Swartland						
Dundee						
Namib						

The internal drainage of these soils was mainly variable due to the layering of the soil horizons, and the presence of coarse material within the soil horizons. The drainage of the soils and their associated horizons was assessed over a period of 30 days. It was found that the drainage had reached a flux of 0.001 mm h^{-1} after 28 days from saturated conditions for all the soil forms. It was found that drainage is enhanced by the presence of the coarse material which increases the pore spaces within the soil profile. The smaller pore spaces were characterized by the silt plus clay content. It was evident that the Sepane and Tukulu soil forms had a silt plus clay content of 36% and 35% respectively. These soils lost a total of 20 to 21 mm soil water due to deep drainage. The Swartland soil form had a silt plus clay percentage of 40% which is slightly higher than that of the Sepane and Tukulu, and this soil form lost a total of 51 mm of soil water. The presence and colour

of mottles was used to prove the drainage capacity of the different soil forms. It is evident that poor drainage is linked to grey, olive and yellow mottles indicating stagnant water.

A study assessing the relationship between soil morphology and the soil water regime was conducted by van Huyssteen *et al.* (2004) in the Whetherley catchment. The focus was on the characterization of the diagnostic soil horizons and their morphology and the relation to the degree of saturation. It is stated by van Huyssteen *et al.* (2004) that most macro pores drain within 48 hours after wetting. This is important to consider as the study of Mavimbela & van Rensburg (2015) did not consider the specific pore drainage. Van Huyssteen *et al.* (2004) further states that 100% saturation will seldomly exist as some pores will still retain some fraction of air. Thus, it then excludes the possibility of using the term oversaturated.

2.10 Statistical Analysis

The analysis of variance (ANOVA) test has been accepted as the most accurate test to determine if significant differences do occur between groups (McHugh, 2011). The (ANOVA) is primarily used in scientific research to test the hypothesis concerning the equality of three or more dataset means. Furthermore, it can be used to determine the significance of multiple factors on the mean and the interactions amongst these individual factors (Santana, 2021). The one-way ANOVA model created from a dataset is dependent on model assumptions that ensure that the error terms must be independent and normally distributed with homogeneous variances (Santana, 2021). The two-hypothesis tested: the errors is normally distributed versus the errors are not normally distributed. A significance level of $p = 0.05$ (95%) is used as the criteria for assumption acceptability.

2.10.1 One-Way ANOVA in R

The semi-parametric one-way ANOVA is used to determine the significance level of the dataset. In this test, the normality and homogeneity test must be accepted for the ANOVA to be accepted as accurate. The one-way ANOVA is based on assumptions that should be checked and tested to ensure that they are valid.

2.10.1.1 Normality Assumption

The first assumption to be tested is the normal distribution. In this assumption, the residuals must be normally distributed, and this can be done graphically or by using formal tests. In graphical tests, the sample quantiles of the residuals of the dataset are plotted against the theoretical normal quantiles. The Shapiro-Wilk test is used as a formal test to determine the normal

distribution of the dataset. The Shapiro-Wilk test is a function that accepts a continuous vector of data as its argument in determining the distribution (Mishra *et al.*, 2019).

2.10.1.2 Homogeneity Assumption

In the test for homogeneity the Bartlett test is used. The Bartlett test is used to test whether three or more factors that are extracted from the normal distribution of the dataset are equal (Li *et al.*, 2020; Odoi *et al.*, 2019; Samad *et al.*, 2017 Santana, 2021).

2.10.1.3 Rejection of Assumptions

In the case where one, or both assumptions are rejected ($p > 0.05$) the Kruscal-Wallis test is used. The Kruscal-Wallis tests the data the same way as a parametric one-way ANOVA, except for the inclusion of non-parametric assumptions to contend to (Emoyan *et al.*, 2018; Santana, 2021; Shar *et al.*, 2018; Tirpáková & Ďuriš, 2020).

2.10.1.4 Groupwise Differences

The ANOVA test is commonly used to determine if at least one group in the dataset differs from the other. This is then followed by the assumptions discussed above. If one or both assumptions is rejected the ANOVA model is not accurate and the Kruscal-Wallis test should be accepted as the most accurate model. The Tukey honestly significant difference test is used as a post-hoc test to determine the group/groups which had an honest difference from the mean (Driscoll, 1996; Santana, 2021). This test is used in the case where a significant value was observed from the assumption tests and there is a need to determine which specific groups was statistically significant. According to (Lee, S., Lee, D.K., 2018) the statistical assumptions should be tested with the Tukey test as well.

CHAPTER 3 STUDY AREA

3.1 Locality of the Study Area

The study area is located in the North-West Province of South Africa in the area surrounding Schweizer-Reneke. Schweizer-Reneke is located on the banks of the Harts River towards the south-west of the North-West Province (Figure 3-1). Schweizer-Reneke is located approximately 200 km west-south-west of Potchefstroom.

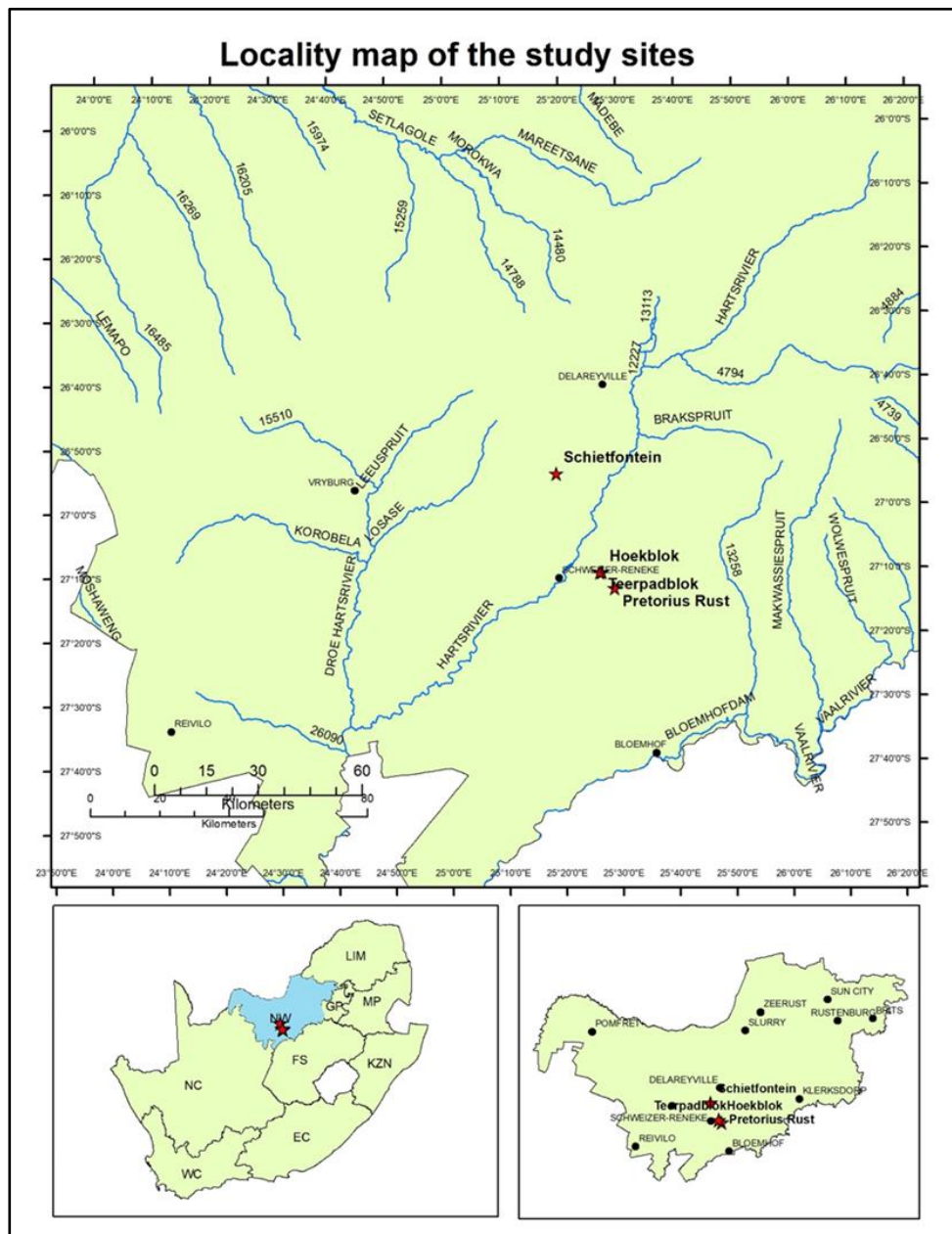


Figure 3-1: Locality map of the study sites

The site locations for both production seasons are marked on Figure 3-1 as red stars. Main towns in the North-West province are marked with a black dot and named. The main flowing streams of the Harts River is illustrated as blue lines throughout the map.

3.2 Agronomic Practices

All the above-mentioned site locations are planting on no-till fields. The crop residue is left post-harvest to enable soil moisture conservation when the field is left to fallow. All the seed cotton cultivars planting in South Africa expresses bollworm resistance due to two stacked *Bt*-genes (Bollgard 2), combined with herbicide tolerance (glyphosate) expressed through the Roundup Ready Flex trait (Cotton SA, 2021b). The planting date, cultivars planted, plant population, row width and harvest dates are included for each of the site locations in Table 3-1.

Table 3-1: Agronomic information of the site location.

Site Location	Plant date	Cultivar	Plant population/ha	Row width	Harvest
Pretorius Rust	04/11/2019	Candia	56 000	75 cm	26/06/2019
Schietfontein	13/11/2019	Candia	55 000	75 cm	29/06/2019
Hoekblok	05/11/2020	DP 1240	45 000	75 cm	15/06/2021
Teerpadblok	02/11/2020	DP 1541	45 000	75 cm	05/06/2021

3.3 Regional Soil Description

According to van Jacobs *et al.* (2018) the soils in the area surrounding Schweizer-Reneke vary considerably within cultivated fields. The dominant soil forms observed in the area are Avalon, Clovelly, Pinedene, Bainsvlei, Hutton and Bloemdal. The soils consist of a sandy texture with a low clay content. The average effective soil depth varies from 950 to 1500 mm. The area is characterised by aeolian sands which is being cultivated (Hurter, 2016). Limiting soil horizons common in the area are plinthic and gleyic soil horizons (Jacobs *et al.*, 2018).

3.4 Geology

The geology of the Teerpadblok, Hoekblok, and Pretorius Rust fields form part of the Karoo Super group (CGS, 2015). The rocks from the Karoo Supergroup consists mostly of sedimentary rocks which were formed by the inland Karoo Sea (McCarthy & Rubidge, 2005). The Karoo Supergroup with its various subgroups covers approximately two-thirds of South Africa's surface. The geology of the subsurface underlying the above-mentioned fields are consistent with that of the Eccia Subgroup. It comprises of the following lithology: Shale, Carbonaceous shale, siltstone, tuff, chert, sandstone which was formed during the Phanerozoic eon and more specifically the Permian area (CGS, 2015).

Schietfontein consists of undifferentiated tonalite, granite and gneiss (CGS, 2015). The lithology of the area is: Potassic gneiss and migmatite which is strongly porphyroblastic and it was formed during the Archaean eon and more specifically the Paleoarchean era (McCarthy & Rubidge, 2005; CGS, 2015)

3.5 Climate

The average rainfall for Schweizer-Reneke is 539 mm per annum (Mapfumo *et al.*, 2020). When considering Schweizer-Reneke the annual rainfall is on average 507 mm (Jacobs *et al.*, 2018). The highest recorded temperatures are recorded in the months of December and January, and the lowest in the months of June and July as the region falls part of the summer rainfall region (Figure 3-2). The region surrounding Schweizer-Reneke is typically free of frost for 240 days per annum (Jacobs *et al.*, 2018).

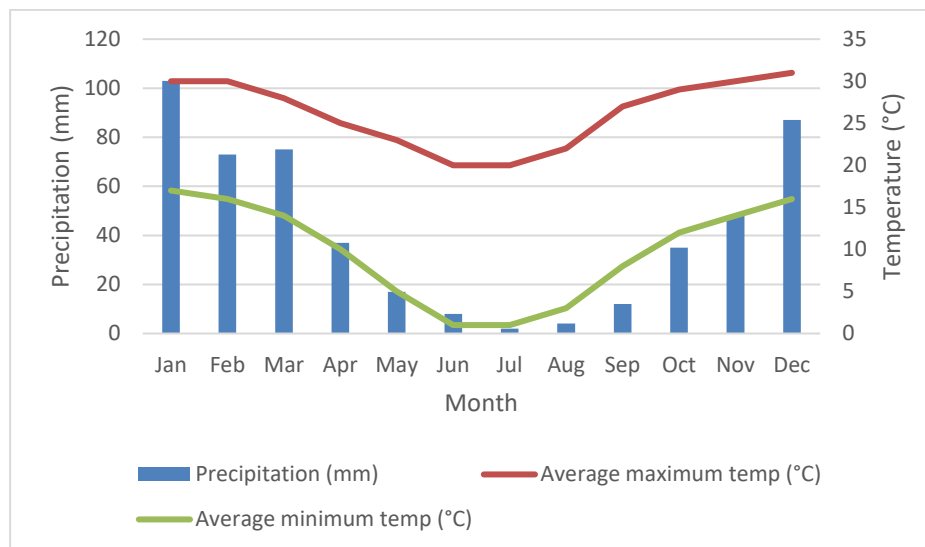


Figure 3-2: Precipitation, maximum- and minimum temperatures for Schweizer-Reneke (Adapted from Jacobs *et al.*, 2018).

CHAPTER 4 MATERIALS AND METHODS

The study was conducted over two cropping seasons, 2019/2020 and 2020/2021 in two cotton fields per season, near Schweizer-Reneke. The farm was chosen by Cotton SA, and the specific fields were based on the crop rotation plan of the farmer. The crop rotation plan followed consists of one season of production of a certain crop, followed by a season of leaving the field fallow. In the following season after fallowing another crop is produced, followed by the fallowing period. Cotton is often incorporated in the rotational plan after the production of maize and one season of fallowing. The maize residue is left on the field during the fallowing period as part of the moisture conservation practices. The selection of which site cotton is planting on is determined on basis of soil moisture content. The fields soil moisture content is monitored on a seasonal basis to determine the soil moisture status. If it is not satisfactory it often happens that a certain field is left to fallow for two consecutive seasons. Selection between fields planted with cotton in the same season was done on recommendation of the farmer to ensure a good variation in the soil type and associated characteristics.

4.1 Determining the Measuring Sites in Each Field

The sites where soil water measurements were taken were determined based on soil survey data provided by the farmer. This soil point dataset comprised of the following: soil form, rooting depth, limiting layer depth and type, percentage clay of each horizon, field capacity and wilting point. These point data were samples on a one-hectare spatial density grid. The depth of sampling is approximately 300 mm, from where composite samples is extracted from the grid sites. By considering the data available, the soil point dataset was spatially analysed, and the four dominant soil forms was identified at each of the site locations. At each site location three repetitions of the four dominant soil forms were selected as soil water measurement sites. The repetitive sites were determined by spatially analysing the data in ArcGIS. The repetitive sites were selected by comparing the above-mentioned soil physical properties and ensuring that the sites are similar in rooting depth, limiting layer depth and type and clay percentage in the soil horizons. In total twelve measurement sites were identified in each of the site locations.

4.2 Installation of the Access Tubes

50 mm PVC pipes were used as the access tubes. Each of the access tubes had a plug at the bottom (not removable) and top (removable to ensure access). At each of the access tube sites a soil auger with the same diameter as the access tube was used to auger a hole down to refusal. Once the hole was augered the access tube was installed while ensuring that no space between the access tube and soil occur as this may cause some inaccuracies in the readings.

4.3 Calibration of the Neutron Probe

The calibration sampling procedure was adapted from Jabro *et al.* (2005). When augering the holes to install the access tubes, samples were taken in 10 cm intervals and placed in airtight bags to ensure that none of the soil moisture escaped. After the samples were taken the bags were labelled with the access site name, number, and the depth of which the sample was taken, for example, PR 10: 10, which relates to the Pretorius Rust field, site number 10 at 10 cm interval. The samples were kept as cool as possible for the remainder of the fieldwork process and weighed in a laboratory within one day to reduce the soil water loss. At each sampling tube, the neutron probe readings were taken at 10 cm increments, corresponding to the sampling depths.

In the laboratory, the samples were placed in heat resistant containers. The soil samples wet weight was noted, and the container was placed in an oven at 110 °C for 24 hours. After the drying of the soil samples the dry weight was noted with the difference yielding the gravimetric soil water content (Brady & Weil, 2017; Kodikara *et al.*, 2014; Ward & Wittman, 2009). Equation 4-1 illustrates the calculation of the gravimetric soil water content:

$$\theta_g = \frac{M_w - M_d}{M_d} \times 100 \quad \text{Eq. 4-1}$$

Where θ_g is the gravimetric water content (%), M_w is the weight of water contained in the sample (g), and M_d is the dry weight of the sample (g).

The gravimetric soil water content was then converted to a volumetric water content by using the dry bulk density of the sample horizons and the density of water. Equation 4-2 illustrates the calculation of the volumetric soil water content:

$$\theta_v = \frac{\left(\frac{\theta_g}{100}\right)}{\left(\frac{\rho_b}{\rho_w}\right)} \quad \text{Eq. 4-2}$$

Where θ_v is the volumetric water content (cm³/cm³), θ_g is the gravimetric water content (%), ρ_b is the bulk density of the soil (g/cm³) that was obtained from the undisturbed core samples discussed in section 4.5 of this chapter, and ρ_w is the density of water which is equivalent to 1 g/cm³.

During each day of soil water measurements, a standard count was obtained of the neutron probe. By using the counts measured and the standard count the count ratio was calculated through Equation 4-3:

$$\text{Count Ratio} = \text{Count measured} / \text{Standard count measured} \quad \text{Eq. 4-3}$$

The volumetric water content was then plotted against the neutron probe count ratio at each of the sample locations and depths as a scatterplot, with the neutron probe count ratio on the X-Axis, and the corresponding volumetric water content on the Y-axis. A linear regression trend line was plotted, and the regression equation and the R^2 value were noted. Equation 4-4 illustrates the formula obtained from the linear regression.

$$Y = mx + c \quad \text{Eq. 4-4}$$

Where Y is the volumetric water content (cm^3), m is the gradient of the regression line, x is the count ratio calculated from Equation 4-3, and c is the intercept of the regression line.

The process was repeated at each of the access tube sites for the complete soil profile. The equation obtained from Equation 4-4 was used to determine the total soil water content measured monthly.

4.4 Measurement of the Soil Water Content

Soil water measurements with the neutron probe were taken monthly from October until September in the following year, to account for the entire season from before planting (usually at the end of November) until after harvest (usually during July). It was planned to measure the soil water close to the 15th of each month, with some variation due to logistical reasons. During the 2019-2020 season some of the measurements were missed due to the hard Covid 19 lockdown.

Before soil water measurements commenced, a standard count measurement was taken to account for drift in measurements that may occur throughout the day (IAEA, 2008). Thereafter measurements were taken in 10 cm intervals at each sampling site, by lifting the protective sealing cap, and lowering the probe down the access tube to the correct depth and taking a measurement and noting the count. After measuring the soil water at each of the depths up to the limiting layer the probe was removed from the access tube and the protective sealing cap replaced.

The count data noted for each depth at each soil profile was converted to the count ratio value by using Equation 4-3 and then imported into the specific soil water calibration formula for the measurement site obtained from the calibration using Equation 4-4 to obtain the volumetric soil water content. The volumetric water content was then converted from cm^3 to mm per soil horizon to obtain the total amount of soil water per profile per site by using Equation 4-5:

$$\theta_v = \theta_v \times \text{soil horizon depth (mm)} \quad \text{Eq. 4-5}$$

Where θ_v is the total amount of soil water per soil horizon depth (mm), θ_v is the volumetric soil water content per mm of soil in the soil profile (cm^3). Soil horizon depth (mm) is self-explanatory.

4.5 Determination of the Soil Water Regime

4.5.1 Undisturbed Core Sampling

Undisturbed cores were taken in the top and subsoil horizons for a representative soil profile of each soil form within each field. Within the two fields per season undisturbed core samples were taken at each of the four dominant soil forms. The topsoil cores were taken from the soil surface, while a profile pit was dug up to the required depth (halfway into the second horizon) where the core was taken from the bottom of the profile pit.

To take an undisturbed core sample, a plastic core (110 mm in diameter 80 mm high) was pushed into the soil approximately 2 cm deep. At this stage the core was filled with water, to enable easy insertion into the dry soil. After allowing the soil to infiltrate, the core was gently tapped on all sides so that it penetrates the soil with as little disturbance as possible. When the entire core was placed into the soil, it was dug out with a small shovel whilst ensuring that no disturbance occur in the core sample. The top and bottom were scraped off to ensure an exact volume of soil inside the core sample. Both sides were sealed with cardboard pieces and taped together. These cores were then carefully placed in a container in which the samples are tightly placed together to ensure that no disturbance occur during transportation to the laboratory for analysis.

4.5.2 Pressure Plate Extraction

The drained upper limit and lower limit of each of the soil forms was determined through a pressure plate extraction system. The lower limit was determined at a pressure of 33 kPa and the drained upper limit at a pressure of 1500 kPa (Brady & Weil, 2017). By determining these two factors the total amount of plant available water was determined. The first step in the procedure was to clean the core samples from any mud on the outside of the core as it may influence weight. A piece of filter cloth was cut to a size big enough to cover the bottom part of the core sampler. A rubber band was used to keep the filter cloth in place on the core sample to prevent the sample from falling out of the core. The weight of the filter cloth and a rubber band was noted. The next step was to place the filter cloth piece and rubber band on the bottom of the core sampler. This was placed in a container and the container filled with enough water to cover at least three quarters of the height of the core samples to ensure saturation of the sample. In a separate container the ceramic pressure plates were submerged in water. The samples and ceramic pressure plates were left for a minimum of 24 hours prior to the movement to the pressure plate system (Wang & Benson, 2004). After the samples were saturated the weight of the core, which includes the core sampler, soil, filter cloth and rubber band was noted as this is the saturated weight (Rehardjo *et al.*, 2019). After saturating the ceramic plates, it was placed in the pressure

vessel and the air flow pipes were connected. The outflow pipe from the pressure vessel was placed in a graduated cylinder to monitor the outflow which was used to determine when equilibrium is reached in the system. The core samples were placed on the ceramic pressure plate next to each other with spaces between the samples. To keep contact between the saturated sample and the ceramic plates approximately 20 ml of water was added in between the core samples onto the plates (Rehardjo *et al.*, 2019). The next step was to seal the unit by placing the lid onto the pressure vessel and tightening it with the pressure vessel bolts. The lid was sealed properly such that there were no leaks occurring. The airflow was then adjusted to the required pressure for either the drained upper limit or lower limit. When equilibrium was reached on the specific pressure (33/1500 kPa) the air was released from the pressure vessel. The lid was only removed after all the air is removed as a safety precaution. The weight of the core sample was noted on 33 and 1500 kPa when equilibrium was reached at each of the pressures. After completion of all the core samples at both 33- and 1500 kPa pressures the samples were dried in an oven at 60 °C for at least three consecutive days and noted as the dry weight of the core sample. The soil inside the core sampler was then removed and the core cleaned to ensure no soil was left behind and weighed to obtain the soil core sampler weight. After compiling all the data, the drained upper limit, lower limit, and dry bulk density were calculated from the following equations adapted from Bandyopadhyay & Pradhan (2012):

The first step in the calculation procedure was to determine the net weight of the soil sample only at drained upper limit and lower limit. The drained upper limit, lower limit and dry sample net weight were calculated using the following Equation 4-6:

$$\text{Net weight} = M_w - (\text{FR} + \text{CS}) \quad \text{Eq. 4-6}$$

Where net weight is the total weight of the soil sample inside the core only (g), M_w is the weight of the “wet” sample (g) at each soil water state (DUL or LL), and FR is the weight of the filter cloth and rubber band (g), and CS is the weight of the core sampler only (g). The same Equation 4-6 is used to determine the dry sample weight with the only difference being M_w being substituted with M_d which relates to the dry net weight of the soil sample inside the core only.

The bulk density was calculated as it determines the amount of soil water in the soil core at DUL and LL. After determining the net weight, the dry bulk density was calculated by using the volume of the core sample and the net dry weight using Equation 4-7:

$$\rho_b = \frac{M_s}{V_t} \quad \text{Eq. 4-7}$$

Where ρ_b is the bulk density in cm^3 , M_s is the net weight of the dried sample (g), and V_t is the total volume of the core sampler in cm^3 .

After calculating the net weight of the samples at DUL, LL and dried sample the amount of soil water at DUL and LL was calculated by using the same equations used in the calibration of the neutron probe. Equation 4-1 was used to calculate the gravimetric soil water content; Equation 4-2 was used to convert the gravimetric soil water content to a volumetric soil water content by using the dry bulk density of the soil horizon. The volumetric water content was then used to calculate the total soil water content (mm) at DUL and LL by using the following Equation 4-8:

$$V_{DUL/LL} = V_w \times \text{soil horizon depth (mm)} \quad \text{Eq. 4-8}$$

After obtaining the DUL and LL limits of the two core samples at each of the measurement sites the total DUL and LL for the soil profile was calculated by using Equation 4-9:

$$V_t = V_{\text{Topsoil}} + V_{\text{Subsoil}} \quad \text{Eq. 4-9}$$

Where V_t is the total soil water held at DUL or LL throughout the whole soil profile, V_{topsoil} is the total soil water held at DUL or LL in the topsoil horizon, and V_{subsoil} is the total soil water held at DUL or LL in the subsoil horizon.

After determining the DUL and LL for each of the measurement sites the total amount of plant available water was calculated by using Equation 4-10:

$$PAW = V_{DUL} - V_{LL} \quad \text{Eq. 4-10}$$

Where PAW is the total amount of plant available water (mm), V_{DUL} is the total amount of soil water held at DUL of the topsoil and subsoil (mm), and the V_{LL} is the total amount of soil water held at LL of the topsoil and subsoil (mm).

4.6 Cotton Yield and Quality

Cotton yield and quality data were collected after the cotton reached physiological maturity. A week before harvest in each season, the farmer indicated that the cotton was ready for harvest and as such the cotton samples used for laboratory analysis were collected during this week. After the cotton was harvested the yield data was provided.

4.6.1 Seed Cotton Yield

Harvest yield data as measured by the harvester was obtained from the farmer. To get continuous coverage of the entire field the points were interpolated using Inverse Distance Weighing (IDW), and more specifically the nearest neighbour technique. The yield data in a 10-meter radius surrounding the measurement site is used to extrapolate the yield of the site. The harvest yield at each soil profile was then extracted from the interpolated yield map. The average yield on each

of the dominant soil forms was then calculated by averaging the yield data at each of the measurement sites of the same soil form.

4.6.2 Cotton Quality

To determine the cotton quality, ten cotton plants were selected within a five-meter radius of the measuring site randomly. From each of the cotton plants, five cotton bolls were harvested from various sections of the plant and placed in paper bags. This process was repeated at each of the measurement sites. The cotton samples were sent to the laboratory for analysis of the lint strength, length and micronaire according to the method described in Uster (2008). At the laboratory, each sample was split up into two samples and tested separately to obtain an average for each of the quality parameters at each of the measurement sites. After the laboratory analysis, the average of each cotton quality parameter was calculated by averaging the parameters at each measurement site of the same soil form.

4.7 Data Analysis

For the data analysis the soil property and cotton yield and quality data which consists of the rooting depth, limiting layer depth, clay in the topsoil, clay in the subsoil, DUL, LL, PAW, yield, cotton strength, length and micronaire was analysed using the ANOVA test to determine if there are statistical differences between the different soil forms soil properties. After completing the ANOVA test the accuracy of the ANOVA was tested through assumptions including the normality of the data using the Shapiro-Wilk test, as well as the homogeneity of the data using the Bartlett test. If both assumption tests data indicated a p-value $>0,05$ the hypothesis was accepted as accurate. If the hypothesis was accepted, the Tukey post-hoc test was used to determine if statistical differences occur. If one or both assumptions p-value was higher than 0,05 the assumption was rejected, and the ANOVA test is not accurate. In this case the Kruskal-Wallis test was used to determine if statistical differences do occur.

Soil water depth profiles were created to determine where in the soil profile water consumption by the cotton plant is taking place during the various growth stages. The volumetric soil water content was plotted as a line corresponding with the depth of that soil water content for each of the cotton growth stages. By using the depth profiles of the measurement sites over the period the oxidated and unoxidized zones in the soil profile were also identified.

To determine the state of soil water during the production season the total amount of soil water calculated in section 4.4 of the materials and methods was plotted as a line graph over the measurement period, with the DUL and LL limits as straight lines. The growth stages of the cotton were added to the graph to illustrate the soil water state at the specific soil water stage.

The cotton quality and yield were discussed as a result of the state of soil water in the various soil profiles by means of visual interpretation of the soil water in relation to the DUL and LL during the cotton growth stages. The influence of the cotton quality and yield on the various soil forms was assessed by converting the yield and quality of the cotton to rand value per hectare. This was done by using the following Equation 4-11:

$$\text{Rand value per hectare} = \text{Yield (ton/ha)} \times \text{Value of the cotton (R/per kg)} \quad \text{Eq. 4-11}$$

The value of the cotton is calculated from the cotton quality class assigned to the batch and the associated basis price in Rand value.

CHAPTER 5 RESULTS AND DISCUSSION

5.1 Season 1 Results and Discussion

5.1.1 Pretorius Rust Measurement Sites

The soil map with the measurement sites for Pretorius Rust is given in Figure 5-1. Pretorius Rust is approximately 380 hectares large and the dominant soil forms were Avalon, Bainsvlei, Westleigh, and Tukulu, and Table 5-1 gives their horizon sequence. This is substantiated by the dominant soil forms described by (Jacobs *et al.*, 2018) and Hurter (2016).

Pretorius Rust consists mainly of sandy clay loam soils (~30 % clay) with some sections yielding sandy clay soils (~37 % clay). All the mentioned soil forms are known as characteristic water table soils due to the limiting layer prohibiting fast drainage of soil water, as expressed by the signs of wetness observed in the second or third horizon. In each of the above four abundant soil forms three repetitive sites were identified.

Table 5-1: Dominant soil forms of Pretorius Rust and their soil horizon sequence.

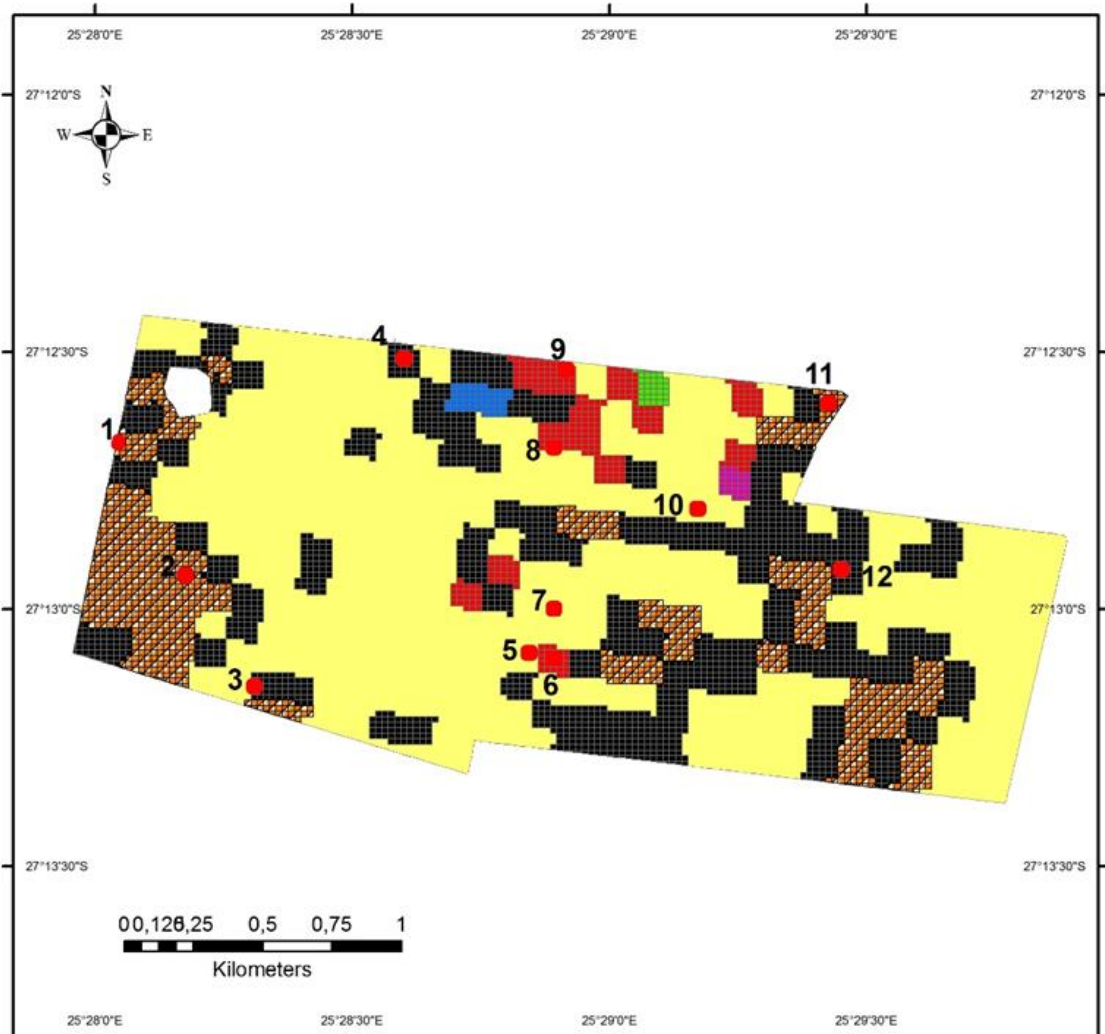
Soil form	Topsoil Horizon	Subsoil Horizon 1	Subsoil Horizon 2
Avalon	Orthic	Yellow-Brown Apedal	Soft Plinthic
Bainsvlei	Orthic	Red Apedal	Soft Plinthic
Tukulu	Orthic	Neocutanic	Gleyic
Westleigh	Orthic	Soft Plinthic	Gleyic

5.1.2 Diagnostic Soil Horizon Descriptions of Pretorius Rust

5.1.2.1 Orthic Topsoil horizon

All the above soil forms have an orthic topsoil horizon. Orthic topsoil horizons occur over a wide range of parent materials and climatic conditions which results in a range of soil forming processes that give rise to certain soil properties. The orthic topsoil is mainly influenced by pedogenic processes, especially the active processes of the underlying subsoil horizons (Fey, 2010). The orthic horizon may occur over a range of colour, texture, base status, organic material content and degree of saturation. Bleached colours are associated with periodic reducing soil water conditions on the sand particles whilst darkened chromic colour is associated with higher organic material contents and mottling associated with the subsoil horizon (Soil Classification Working Group, 2018).

Pretorius Rust soilform distribution map and probe measurement points



Legend

- PRust Probe points
- PRust_Westleigh
- PRust_Tukulu
- PRust_Oakleaf
- PRust_Hutton
- PRust_Clovelly
- PRust_Bainsvlei
- PRust_Avalon

Figure 5-1: Pretorius Rust soil form distribution map and sampling points

5.1.2.2 Yellow-Brown Apedal Subsoil Horizon

The yellow-brown apedal subsoil horizons are formed by excessive weathering in well-drained oxidized environments. The main iron component in yellow-brown apedal soil horizons is goethite. Iron oxides form on soil particles leading to the formation of the yellow-brown colours (Soil Classification Working Group, 2018). These soils have a structure that is weaker than moderate when in a moist state. These horizons tend to form in environments where rainfall is high, and the evaporative demand is low (Fey, 2010). The topographic position in the landscape in association with the soil profile depth gives rise to the yellow-red transition due to the fluctuating soil water content and the amount of organic matter (Soil Classification Working Group, 2018). These horizons do not have a structure in the moist state and are porous even when the texture is clayey. The yellow-brown apedal horizon tends to be wetter than red apedal horizons due to the occurrence of grey and yellow colours indicating periodic water occurrence.

5.1.2.3 Red Apedal Subsoil Horizon

The red apedal subsoil horizon is similar to the yellow-brown apedal horizon in terms of physical properties with the one key difference being the colour difference due to the dominant presence of hematite in red apedal soils instead of goethite (Fey, 2010). The red apedal soil horizons tend to have a weak structure in the moist state due to low activity, non-swelling clay minerals, or the soil moisture regime lacking severe desiccation (Soil Classification Working Group, 2018). The red apedal horizon is known to have a short period of water saturation, but an increased period of water saturation may occur at greater depths in a soil profile.

5.1.2.4 Neocutanic Subsoil Horizon

The neocutanic soil horizon has a weak structure with associated variation in colour throughout the non-uniform soil horizon profile. The horizon is often associated with hard fragments such as stones and gravel which results in horizontal flow of soil water (Fey, 2010). A key feature of the soil horizon is the hard setting nature of the soil which may inhibit the lateral flow of soil water (Soil Classification Working Group, 2018). This soil horizon lacks macrostructure, which is associated with periodic saturation of soil water. An important consideration is the lack of localized iron and manganese mottling which is considered indicators of soil water fluctuation.

5.1.2.5 Soft Plinthic Subsoil Horizon

The soft plinthic horizon is identified as an apedal structured soil with prominent redox morphology characteristics evident as vesicular randomly distributed iron and manganese accumulations (Soil Classification Working Group, 2018). This subsoil horizon is associated with sandy soils and

correlates with the hillslope hydrology. Periods of water saturation allows the localization of high chroma mottles (grey to light yellow) and concretions due to the accumulation and precipitation of oxides and hydroxides.

5.1.2.6 Gleyic Subsoil Horizon

The gleyic subsoil horizon consists of low chroma grey and light-yellow colours on weathered material. High chroma colours such as red and yellow and are associated with the remaining lithic and soil material which indicates fewer reduction reactions in the soil due to shorter periods of water saturation in comparison with a gley horizon. The gleyic soil horizon limits water flow to an extent due to the lithic material and strong structure.

5.1.3 Pretorius Rust Soil Properties Description

From Table 5-2 it is evident that the soil form had a significant effect on the clay percentage of the A and B horizons. Both the A and B horizon p-value was <0.05 which indicates statistical differences. The soil form did not have a statistical influence on the rooting depth, and this is substantiated by the p-value being >0.05 . When considering the post-hoc analysis it is evident that for the A horizon clay percentage the most significant difference occurs between the Westleigh and Avalon soil forms with the p-value <0.05 . Concluding this the Bainsvlei, Tukulu and Westleigh soil forms have an A horizon clay content that is statistically similar, but statistically different to that of the Avalon soil form. The analysis of the B horizon analysis revealed that statistical difference occurs between the Westleigh and Avalon, Westleigh and Bainsvlei, and Westleigh and Tukulu. In this horizon the Westleigh soil form is statistically different to that of the Avalon, Bainsvlei and Tukulu soil forms which in the contrary are all statistically similar.

Table 5-2: ANOVA between the soil forms and their soil properties in Pretorius Rust.

Comparison	Sum Sq.	Mean Sq.	F-value	P-value
Root depth (mm)	15833	5278	0,91	0,5349
Clay A (%)	12,63	4,21	5,58	0,03746 *
Clay B (%)	129,41	43,14	43,28	0,04677 *

By considering Table 5-3 it is evident that the root depth decreases in the following sequence: Bainsvlei, Westleigh, Avalon and Tukulu, while for the topsoil (A horizon) the clay percentages are similar, only ranging between 13,9–16,7 %. Statistical difference occurs in the clay percentage of the subsoil (B horizon) and yields differences with the clay percentage varying from 28,7–36,9% and increases in the following sequence: Avalon, Bainsvlei, Tukulu and Westleigh. This

corresponds with studies conducted by Mavimbela & van Rensburg (2014) and Jacobs *et al.* (2018).

Table 5-3: Pretorius Rust soil properties and averages per soil form.

Site point	Soil form	Root depth (mm)	Clay A (%)	Clay B (%)
PR 1	Westleigh	1200	16,4	37,0
PR 2	Westleigh	1100	18,3	37,1
PR 3	Tukulu	1200	14,5	29,8
PR 4	Tukulu	1000	15,8	31,7
PR 5	Avalon	1200	14,3	27,6
PR 6	Bainsvlei	1200	15,0	28,3
PR 7	Avalon	1100	13,9	28,1
PR 8	Bainsvlei	1200	14,5	29,4
PR 9	Bainsvlei	1100	15,5	30,2
PR 10	Avalon	1100	13,4	30,3
PR 11	Westleigh	1100	15,5	36,7
PR 12	Tukulu	1000	14,6	30,3
Averages	Westleigh		16,7 b	36,9 a
	Tukulu		14,9 b	30,6 b
	Avalon		13,9 a	28,7 b
	Bainsvlei		15,0 b	29,3 b

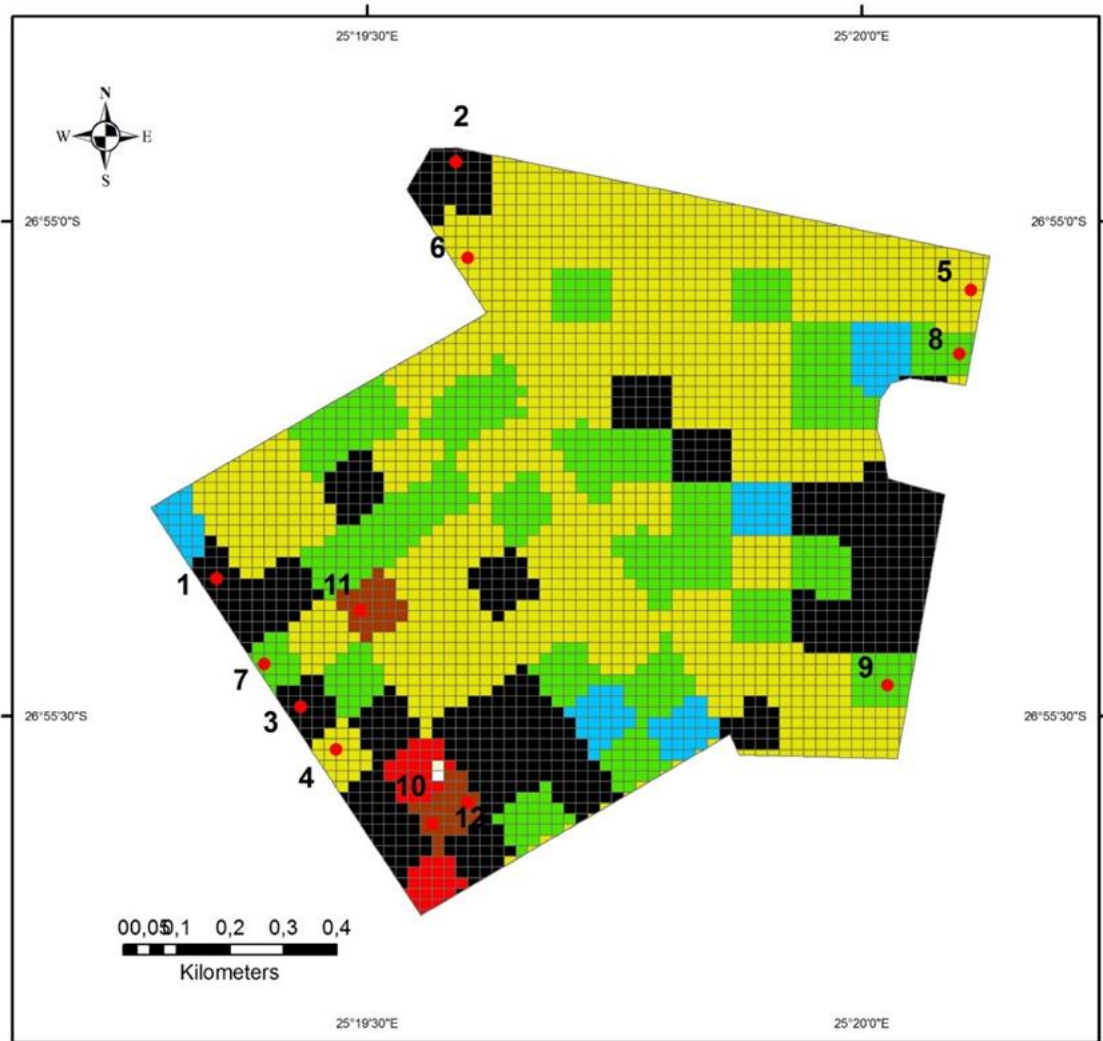
5.1.4 Schietfontein Measurement Sites

The soil map with the measurement sites for Schietfontein is given in Figure 5-2. Schietfontein is approximately 115 hectares large and the dominant soil forms are Tukulu, Avalon, Glencoe, and Oakleaf (Table 5-4). This corresponds to the dominant soil forms described by Jacobs *et al.* (2018) and Hurter (2016). Schietfontein consists mainly of sandy clay loam soils, but some variances occur between the different soil forms. The average clay percentage in the subsoil horizon varies between 24,95-30,34 %. The Tukulu, Avalon and Glencoe soil forms are considered water table soils due to their physical ability to limit the fast drainage of soil water. This is substantiated with the findings in Mavimbela & van Rensburg (2014).

Table 5-4: Dominant soil forms of Schietfontein and their soil horizon sequence.

Soil form	Topsoil Horizon	Subsoil Horizon 1	Subsoil Horizon 2
Tukulu	Orthic	Neocutanic	Gleyic
Avalon	Orthic	Yellow-Brown Apedal	Soft Plinthic
Glencoe	Orthic	Yellow-Brown Apedal	Hard Plinthic
Oakleaf	Orthic	Neocutanic (Thick)	-

Schietfontein soilform distribution map and probe measurement points



Legend

- Schietfontein Probe points
- Schietfontein Avalon
- Schietfontein Dresden
- Schietfontein Glencoe
- Schietfontein Oakleaf
- Schietfontein Pinedene
- Schietfontein Tukulu

Figure 5-2: Schietfontein soil form distribution map and sampling points.

5.1.5 Diagnostic Soil Horizons Description of Schietfontein

Refer to section 5.1.2.1 to 5.1.2.6 for the description of the Orthic, Yellow-Brown Apedal, Neocutanic, Soft Plinthic and Gleyic horizons.

5.1.5.1 Hard Plinthic Subsoil Horizon

The hard plinthic horizon is a hardened continuous sheet of iron and manganese oxides. The hardened sheet may have some sections which is not continuous, but these sections that is not continuous may be filled by a grey-coloured matrix which indicate water saturation. The porosity can either be high for thin near-continuous sheets, or low for thick continuous sheets (Soil Classification Working Group, 2018). These hardened sheets contain red, brown, yellow, black, and/or grey colours which is signs of the horizon accumulating water which could prove valuable for annual crop production (Soil Classification Working Group, 2018). These horizons form by flow of iron rich water that flows impervious subsoil horizons and precipitates.

5.1.6 Schietfontein Soil Properties Description

From Table 5-5 it is evident that the soil form did not have a significant effect on the clay percentage of the A and B horizons as well as the rooting depth. Both the A and B horizon p-value was >0.05 which indicates no statistical difference. The soil form did not have a statistical influence on the rooting depth, and this is substantiated by the p-value being >0.05 .

Table 5-5: ANOVA between the soil forms and their soil properties in Schietfontein

Comparison	Sum Sq.	Mean Sq.	F-value	P-value
Root depth (mm)	20000	6667	0,615	0,4414
Clay A (%)	5,173	1,724	0,719	0,3916
Clay B (%)	55,10	18,366	2,391	0,2479

By considering Table 5-6 it is evident that the root depth decreases in the following sequence: Glencoe, Tukulu, Avalon and Oakleaf, while for the topsoil (A horizon) the clay percentages are similar, only ranging between 13,3–15,1. The clay percentage in the subsoil (B horizon) yields relatively small differences with the clay percentage varying from 25,0–30,3 % increasing in the following sequence: Avalon, Glencoe, Tukulu and Oakleaf.

Table 5-6: Schietfontein soil properties and averages per soil form.

Site point	Soil form	Root depth (mm)	Clay A (%)	Clay B (%)
SC 1	Tukulu	1200	13,2	27,4
SC 2	Tukulu	900	13,5	26,8
SC 3	Tukulu	1200	17,0	29,2
SC 4	Avalon	1200	15,2	27,1
SC 5	Avalon	1100	12,9	25,7
SC 6	Avalon	1100	11,9	22,1
SC 7	Glencoe	1200	14,9	29,3
SC 8	Glencoe	1200	14,1	23,2
SC 9	Glencoe	1200	13,0	23,7
SC 10	Oakleaf	1000	16,0	33,4
SC 11	Oakleaf	1200	13,8	26,8
SC 12	Oakleaf	1100	15,5	30,8
Averages	Tukulu		14,6	27,8
	Avalon		13,3	25,0
	Glencoe		14,0	25,4
	Oakleaf		15,1	30,3

5.1.7 Calibration of the Neutron Probe

5.1.7.1 Pretorius Rust

Table 5-7 indicates the coefficient of determination (R^2) and calibration formula that was used to calculate the volumetric water content measured monthly for the Pretorius Rust cotton field. By considering Table 5-7 containing the calibration data of the Pretorius Rust cotton field, it is evident that there is a highly significant correlation between the volumetric soil water content and the neutron probe count with the average R^2 value of 0,88. The R^2 values ranged from 0,82–0,94 which is comparable to that of Evett *et al.* (2019), which ranged between 0,81 and 0,84, while being slightly less than the values obtained by Jabro *et al.* (2005), which was above 0,9. However, R^2 values above 0,8 can be considered accurate due to spatial variation present in the soil (Evett *et al.*, 2019).

The graphs used to create these coefficients and formulas can be found in Appendix A. By considering the graphs in Appendix A it is evident that the higher number of datapoints used to form the soil water calibration formulas are found at higher counts which accounts for a bigger soil water mass. This was evident for all the different soil forms. The depth is key as most of the samples containing a higher soil water content were obtained from deeper levels in the soil profile. The same trend was observed in a study conducted by Steyn (2019). Figure 5-7 illustrates the

trend by using the graph created for one of the Westleigh calibration curves. This feature is influenced by the period during which the samples are taken.

Table 5-7: Coefficient of determination and calibration formula of the measurement sites in Pretorius Rust.

Probe point	Soil form	R ²	Calibration formula
PR 1	Westleigh	0,87	$y = 0,1828x + 0,0815$
PR 2	Westleigh	0,94	$y = 0,2135x + 0,0556$
PR 3	Tukulu	0,84	$y = 0,186x + 0,0597$
PR 4	Tukulu	0,86	$y = 0,1755x + 0,0853$
PR 5	Avalon	0,82	$y = 0,2892x + 0,0028$
PR 6	Bainsvlei	0,87	$y = 0,2861x + 0,0157$
PR 7	Avalon	0,91	$y = 0,2412x + 0,0318$
PR 8	Bainsvlei	0,93	$y = 0,2124x + 0,043$
PR 9	Bainsvlei	0,82	$y = 0,2858x + 0,0182$
PR 10	Avalon	0,86	$y = 0,2154x + 0,0307$
PR 11	Westleigh	0,87	$y = 0,1649x + 0,1098$
PR 12	Tukulu	0,91	$y = 0,2072x + 0,0621$
Average		0,88	

The soil calibration samples were obtained during the dry part of the season during which most soil water would have infiltrated to deeper subsoil levels. As all the cotton fields comprise mostly of water table soils, the stored soil water will accumulate within the water table horizons.

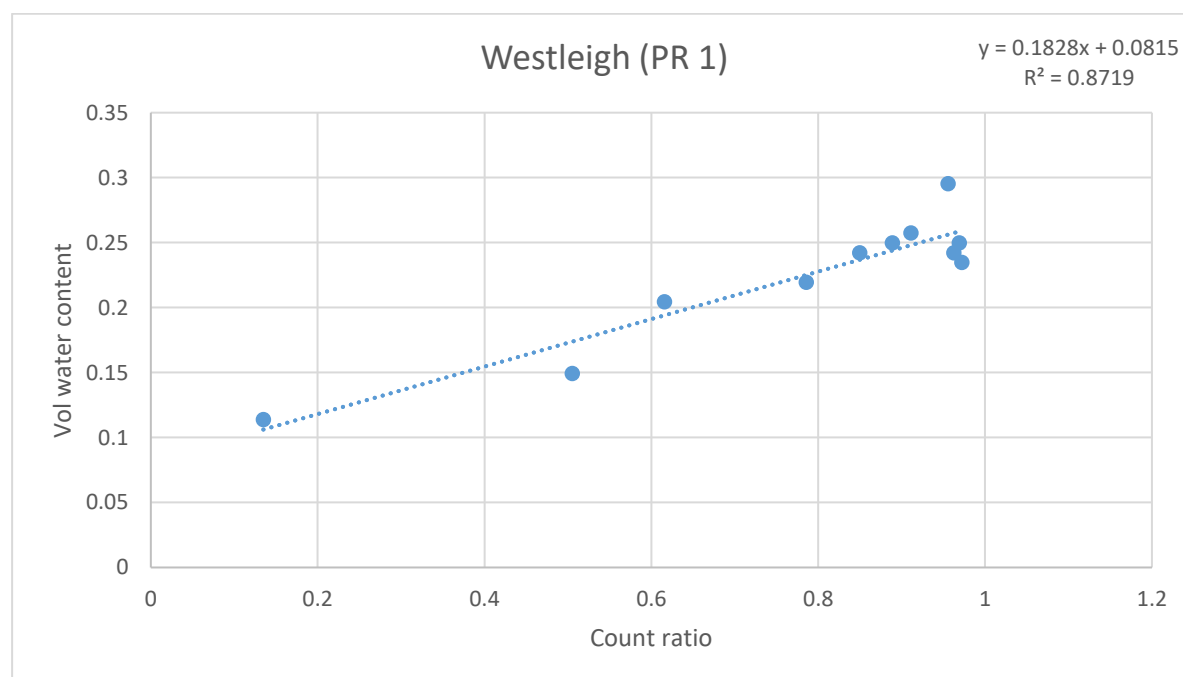


Figure 5-3: The linear regression neutron probe calibration of a Westleigh soil form measurement site in Pretorius Rust.

5.1.7.2 Schietfontein

Table 5-8 indicates the coefficient of determination (R^2) and calibration formula that was used to calculate the volumetric water content measured monthly for the Schietfontein cotton field. By considering Table 5-8 containing the calibration data of the Schietfontein cotton field, it is evident that there is a highly significant correlation between the volumetric soil water content and the neutron probe count with the average coefficient of determination value of $R^2 = 0,91$. The correlation of this field is slightly higher than Pretorius Rust, this is mostly due to the uniform soil form distribution throughout the field. This calibration is deemed accurate based on the studies by Evett *et al.* (2009) and Jabro *et al.* (2005) which regarded R^2 values of above 0,81 accurate.

Table 5-8: Coefficient of determination and calibration formula of the measurement sites in Schietfontein.

Probe point	Soil form	R^2	Calibration formula
SC 1	Tukulu	0,86	$y = 0,3565x + 0,0806$
SC 2	Tukulu	0,96	$y = 0,3475x + 0,0705$
SC 3	Tukulu	0,89	$y = 0,3298x + 0,092$
SC 4	Avalon	0,91	$y = 0,4315x + 0,0482$
SC 5	Avalon	0,89	$y = 0,3229x + 0,0368$
SC 6	Avalon	0,92	$y = 0,3641x + 0,0332$
SC 7	Glencoe	0,87	$y = 0,3842x + 0,0411$
SC 8	Glencoe	0,95	$y = 0,3388x + 0,0536$
SC 9	Glencoe	0,92	$y = 0,3603x + 0,0343$
SC 10	Oakleaf	0,94	$y = 0,4593x + 0,0551$
SC 11	Oakleaf	0,95	$y = 0,4552x + 0,0671$
SC 12	Oakleaf	0,88	$y = 0,4168x + 0,0692$
Average		0,91	

5.1.8 Soil Water

5.1.8.1 Pretorius Rust Total Soil Water

The total soil water per soil form averaged for the Pretorius Rust site is illustrated in Figure 5-4. During October 2019 no rainfall events were noted, and it is only in November 2019 that the first rainfall was noted, 61,6 mm, and as a result, the soil water increased in all the soil profiles. After the rainfall events occurred the cotton was planted in Pretorius Rust on the 4th November 2019. During the period from the start of November 2019 to the end of November 2019 the cotton plants germinated and emerged. December 2019 was recorded as the month with the highest rainfall total in the 2019/2020 season with 124,4 mm. Initially, during the high rainfall period, the Bainsvlei and Tukulu soil forms had the highest soil water content. The Tukulu soil form increased in soil

water content to December 2019 from where a slight decrease is visible after emergence due to the interflow characteristics of the subsoil horizons. As time progressed the Westleigh and Avalon soil form exponentially increased in soil water content. During cotton emergence, the transpiration demand is low as the plant root system is limited to the topsoil and the rainfall high, and as such, no decrease is visible in any of the soil forms.

During January 2020 the flowering growth stage commenced, and the transpiration demand of the cotton plant leaves increased, but the high rainfall events ensured that the transpiration demand had no current effect on the growth stages. During this stage, it is evident that due to the rainfall events that the water had infiltrated and the topsoil and upper part of the subsoil horizon had an abundance of soil water available. During the flowering stage the cotton is most sensitive to soil water and plant stress could occur when the soil water is above DUL or at wilting point. By February 2020 all the soil forms reached a peak in soil water content with the Westleigh soil form having the highest amount of soil water, followed by the Avalon, Bainsvlei and Tukululu soil forms in decreasing soil water content order. This is mainly due to the hydropedological characteristics described in Mavimbela & van Rensburg (2014) with these soils forming a temporary water table.

The boll formation stage commenced from February 2020 up to April 2020 during which rainfall still occurred, but the soil water demand of the cotton plants increased. In the period from boll formation to boll burst, the Westleigh soil form had the second highest amount of soil water in comparison with the Avalon soil form, which means that the cotton extracted more soil water from the Westleigh soil form than from the Avalon soil form. This extraction is also characterised by the internal drainage from the soft plinthic soil horizon. The Bainsvlei soil form had a gradual loss of soil water in this growth period. The Bainsvlei soil form is naturally in a reduced state concluding to the soil water content remaining constant. The Tukululu soil form decreased significantly during the boll formation stage up to boll formation. A significant trend is observed, the two soils with the highest clay content (Westleigh and Tukululu) from the four dominant soil forms in Pretorius Rust had a greater loss of soil water in the boll formation growth stage than the Avalon and Bainsvlei soil forms. This loss was described by Mavimbela & van Rensburg (2014) and Hensley *et al.* (2011) as deep drainage. As the cotton bolls ripen the transpiration demand decreased as the cotton plant was shedding its leaves.

From April 2020 the bolls started to burst and mature. This growth stage is situated in the transition from Fall to Winter and during this period the evaporative demand is low. The soil moisture content still decreases from boll burst and ripening to harvest. The cotton at Pretorius Rust was harvested on the 27th of June 2020. From harvest, there is a gradual increase in soil water up to September 2020 where it becomes constant. The most notable soil water loss from boll formation to post-season is that of the Westleigh and Avalon soil forms. The Bainsvlei and Tukululu soil forms had a

gradual soil water loss throughout the season. An important factor to consider is that more soil water was left in the soil profile post-season than pre-season in all the soil forms.

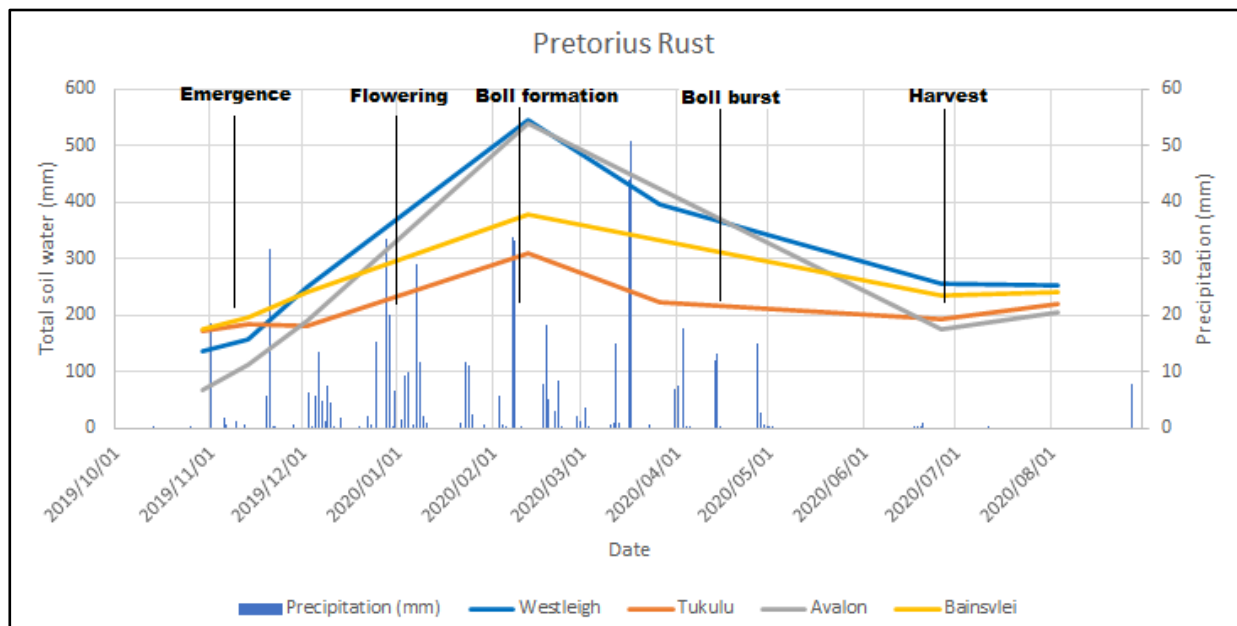


Figure 5-4: Total soil water and precipitation of the Pretorius Rust site.

5.1.8.2 Schietfontein Total Soil Water

The total soil water per soil form averaged for the Schietfontein site is illustrated in Figure 5-5. The cotton on Schietfontein was planted on the 13th of November 2019, but due to unforeseen circumstances, measurements only commenced during December 2019. A key difference between Pretorius Rust and Schietfontein is the average total soil water content of all the soil forms. Schietfontein has a much more uniform soil form distribution and as such a similar trend is observed in all the soil forms. During October 2019 no rainfall events were noted, and it is only until November 2019 that the first rainfall was noted and as a result the soil water increased exponentially in all the soil profiles. During the period from the start of November 2019 to the end of November 2019, 61,6 mm of rainfall was received which allowed the cotton seeds to germinated and emerge.

December 2019 was recorded as the month with the highest rainfall total in the 2019/2020 season with 124,4 mm measured. Initially, during the high rainfall period, the Oakleaf and Tukulu soil forms had the highest soil water content. As time progressed the trend observed between the soil forms remained constant. During the emergence growth stage, the transpiration demand is low as the plant root system is limited to the topsoil and the rainfall high. Although no measurements

were noted in the emergence stage the start of measurements indicates an upwards trend which substantiates this statement.

During January 2020 the flowering growth stage commenced, and the transpiration demand of the cotton plant leaves increased, but the high rainfall events ensured that the transpiration demand had no current effect on the growth stages. During this stage, it is evident that due to the rainfall events that the water had infiltrated and the topsoil and upper part of the subsoil horizon had an abundance of soil water available. During the flowering stage, the cotton is most sensitive to soil water and plant stress could occur when the soil water content is above DUL or at wilting point. By February 2020 all the soil forms reached a peak in soil water content with the Oakleaf soil form having the highest amount of soil water, followed by the Tukulu, Avalon and Glencoe soil forms in decreasing soil water content order. This is explained by the structured neocutanic soil horizon as discussed in Mavimbela & van Rensburg (2014).

The boll formation stage commenced from February 2020 up to April 2020 during which rainfall still occurred, but the soil water demand of the cotton plants increased. In the period from boll formation to boll burst, the Tukulu soil form had the second highest amount of soil water in comparison with the Oakleaf soil form. The Avalon soil form had a slightly bigger loss of soil water in this growth period having approximately the same soil water content as the Glencoe soil form which was previously the soil form having the least amount of soil water. The Oakleaf soil form decreased significantly during the boll formation stage up to boll formation. Towards the end of the boll formation stage, the decrease in soil water became constant with little to no loss of soil water from any of the four dominant soil forms of Schietfontein. As the cotton bolls ripen the transpiration demand decreases as the cotton plants start shedding its leaves.

From April 2020 the bolls started to burst and mature. This growth stage is situated in the transition from Fall to Winter and during this period the evaporative demand is low. The soil moisture content still decreases from boll burst and ripening to harvest. The cotton of Schietfontein was harvested on the 29th of June 2020. From harvest, the soil water content remained constant for the Oakleaf and Tukulu soil forms, but the Avalon and Glencoe soil forms kept on decreasing due to the interflow properties of these soil forms and internal drainage. An important factor to consider is that more soil water was left in the soil profile post-season than pre-season in all the soil forms.

5.1.8.3 Pretorius Rust Soil Water Depth Profiles

All the repetitive sites of the four dominant soil forms volumetric water content were averaged of the growth stages and plotted in the soil water depth profiles. The results correlate with the

hydropedological classification of the soils by van Tol (2020) and their associated responses to the flow of soil water.

5.1.8.3.1 Westleigh

Figure 5-6 illustrates the soil water depth profile of the Westleigh soil form. It is evident that there is an increase in soil water from the pre-season, planting to boll formation, followed by a decrease from boll formation to harvest and post-season. During all these periods a loss of soil water is visible between 1100–1200 mm due to deep drainage. From Figure 5-6 it is evident that there is a slight increase in soil water with depth during the pre-season.

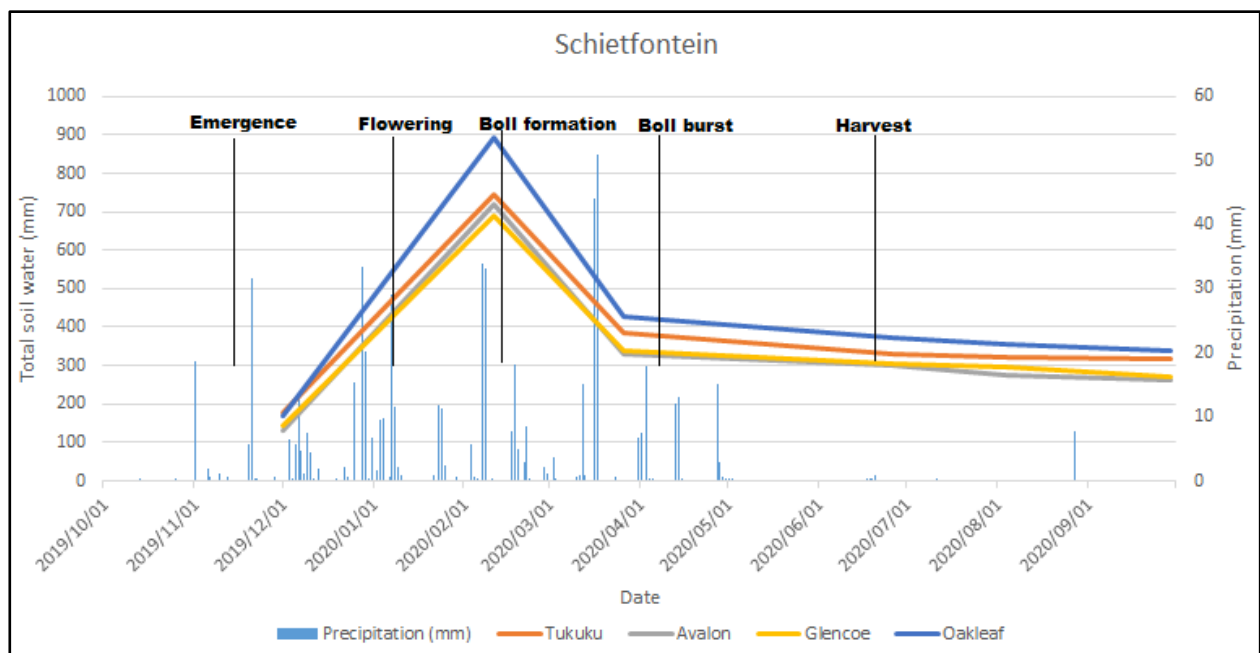


Figure 5-5: Total soil water and precipitation of the Schietfontein site.

When considering the time of harvest the amount of soil water increases with depth throughout the soil profile. This implies that the amount of soil water did indeed increase from the time of planting up until harvest even with the extraction of soil water by the cotton. During this section of the Westleigh soil profile, the soft plinthic horizon becomes more prominent and the effect of the gleyic limiting horizon becomes more inevitable. At the depth between 1100-1200 mm the amount of soil water decreases once more indicating the interflow of soil water on the limiting layer and the extraction of water by the taproot system of the cotton throughout the boll formation growth stage.

5.1.8.3.2 Tukulu

Figure 5-7 illustrates the soil water depth graph of the Tukulu soil form. It is evident that there is an increase in soil water from the pre-season to planting and to boll formation. This is followed by a sharp decrease in soil water up to harvest. During the boll formation there is a significant water loss trend at 1000-1200 mm because of the water consumption of the cotton roots and internal drainage of the soft plinthic horizon. During post season there is a decrease from 300–700 mm in comparison with the harvest period. This is due to the downward flow of the soil water to deeper levels and evaporation of surface water. The post season and harvest soil water content from 800–1100 remained constant. The post-harvest curve corresponds to the harvest curve indicating small soil water loss from harvest to post-harvest. This is mainly due to the neocutanic soil horizon having a structure that allows for water storage. Between 1100–1200 mm a decrease is visible, which is due to the interflow of soil water post-season on the gleyic soil horizon.

5.1.8.3.3 Avalon

Figure 5-8 illustrates the soil water depth graph for the Avalon soil form. When considering the pre-season and planting curves it is evident that the amount of soil water throughout the soil profile is constant up to 1100 mm. From 1100–1200 mm a decrease in soil water is visible which is due to the interflow and internal drainage properties of the Avalon soil form, specifically the soft plinthic soil limiting horizon. In the boll formation curve, it is evident that a significant water loss occurs from boll formation to harvest because of the increased soil water needs of the cotton during this growth stage. In the harvest curve, it is evident that there is an increase of soil water with depth from 300-700 mm, from which there is an abrupt increase in soil water from 700-1200 mm indicating accumulation of water on the limiting layer. No soil water loss occurs post season in the Avalon soil form. When considering the post-harvest curve this curve indicates that more soil water was left post-harvest than there was pre-season.

5.1.8.3.4 Bainsvlei

Figure 5-9 illustrates the soil water depth profile for the Bainsvlei soil form. By considering the pre-season and planting curves it is evident that there is a slight increase in soil water with depth. In the boll formation curve, it is evident that a significant water loss occurs from boll formation to harvest because of the increased soil water needs of the cotton during this growth stage. The harvest curve indicates similar indications of soil water flow as the Avalon soil form but seem to be more constant. No abrupt changes occur in the soil water content between harvest and post season which indicates that the Bainsvlei soil form had less interflow of soil water, thus yielding

the red colour in the subsoil horizons. Similar findings were described by van Huyssteen *et al.* (2010).

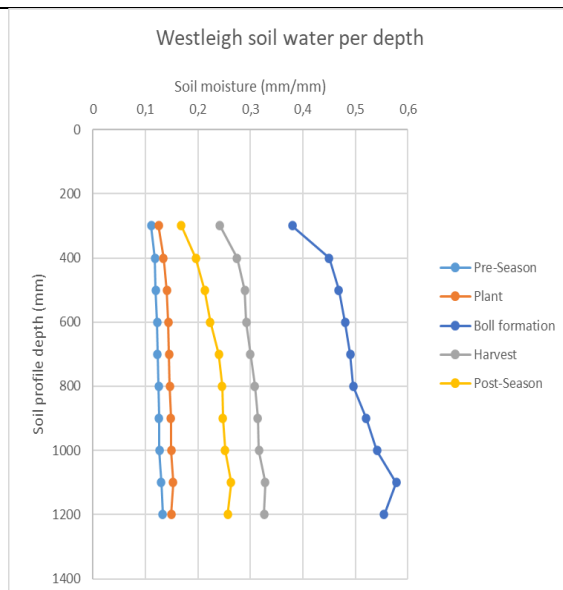


Figure 5-6: Soil water depth profile of the Westleigh soil form in Pretorius Rust.

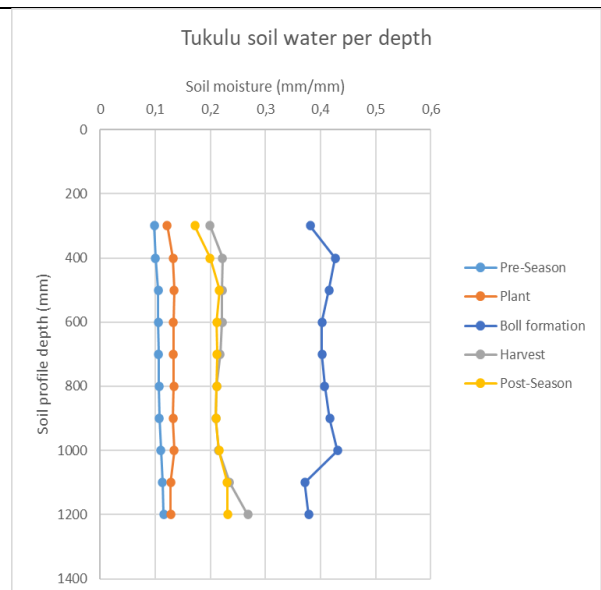


Figure 5-7: Soil water depth profile of the Tukulu soil form in Pretorius Rust.

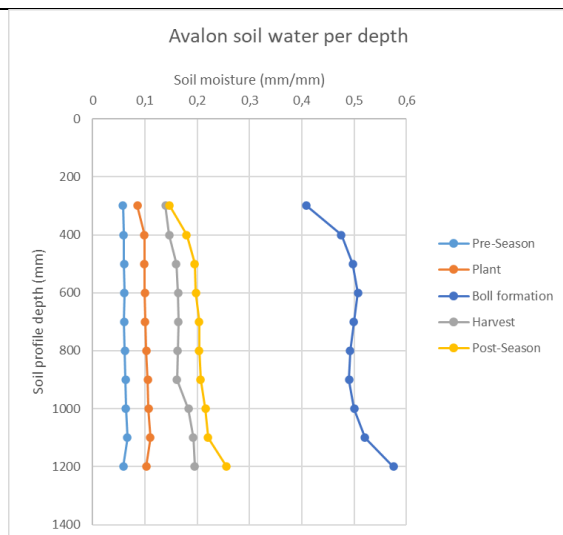


Figure 5-8: Soil water depth profile of the Avalon soil form in Pretorius Rust.

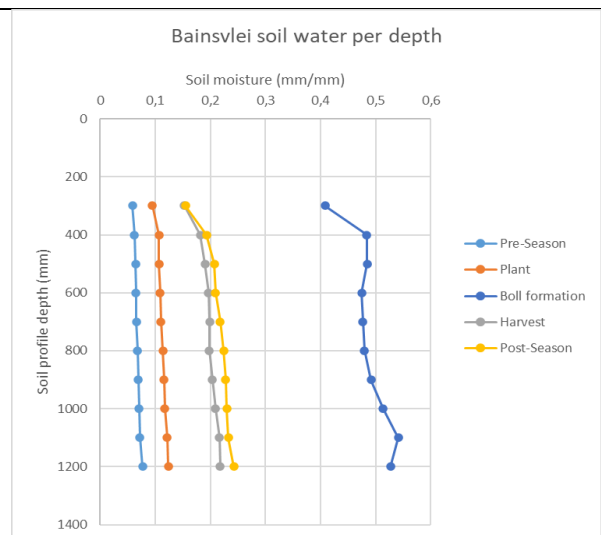


Figure 5-9: Soil water depth profile of the Bainsvlei soil form in Pretorius Rust.

By considering the harvest curve it is evident that from 800-1100 mm the amount of soil water increases but decreases slightly from 1100–1200 indicating interflow. This indicates that a higher level of saturation on the limiting layer is evident. The post-harvest curve has a similar trend to the harvest trend, but with an increased soil water content. Losses in this section of the soil profile tend to be associated with gravel layers which in turn allow flow of water horizontally. The amount of soil water left post-harvest is more than pre-season and planting.

5.1.8.4 Schietfontein Soil Water Depth Profiles

All the repetitive sites of the four dominant soil forms' volumetric water content were averaged of the growth stages and plotted in the soil water depth profiles. The results correlate with the hydropedological classification of the soils by van Tol (2020) and their associated responses to the flow of soil water.

5.1.8.4.1 Tukulu

Figure 5-10 illustrates the soil water depth profile of the Tukulu soil form. It is evident that there is a clear difference in the amount of soil water during planting versus the amount of soil water during harvest and post-season. By considering the planting curve there is a slight increase of soil water with depth. In the period of planting in this cotton field, a few high rainfall events occurred which resulted in the increase of water in the subsoil profile. However, there are no signs of water accumulation on the limiting layer subsoil horizon. In the boll formation curve, it is evident that a significant water loss occurs from boll formation to harvest because of the increased soil water needs of the cotton during this growth stage. When considering the harvest and post-season curves, it is evident that there is a more prominent increase in soil water in the subsoil. At depths 800-1200 mm there is a clear increase in soil water. During this part of the production season the cotton does not extract much soil water and stays constant. Due to the physical nature of the Tukulu soil horizons it tends to retain soil water. By considering the curvature at the bottom of the soil depth profile it is proven that water has accumulated on the limiting layer.

5.1.8.4.2 Avalon

Figure 5-11 illustrates the soil water depth profile for the Avalon soil form. By considering the planting curve it is evident that there is a slight increase from 300-600 mm from where it stays constant deeper in the soil profile. In the boll formation curve, it is evident that a significant water loss occurs from boll formation to harvest because of the increased soil water needs of the cotton during this growth stage. When considering the harvest curve, it is evident that there is an

increase in soil water up to 500 mm followed by a decrease from 500 to 800mm. This is due to the cotton roots extracting soil water from this section in the soil profile throughout the production season. From 900 mm to 1100 mm there is an increase in the soil water content due to water accumulation. There is some soil water loss that occurred from the harvest to post season period due to the interflow of soil water. The post-harvest curve indicates an increase in soil water up to 1100 mm which illustrates the effect of the soft plinthic soil horizon as a limiting layer.

5.1.8.4.3 Glencoe

Figure 5-12 illustrates the soil water depth profile for the Glencoe soil form. By considering the planting curve it is evident that there is a constant increase in the soil water content with depth during planting. In the boll formation curve, it is evident that a significant water loss occurs from boll formation to harvest because of the increased soil water needs of the cotton during this growth stage. When considering the harvest curve, it is evident that there were some soil water losses at depth 600-1000 mm due to interflow in the subsoil horizons. Both the curves indicate a similar trend in the upper section of the soil profile with an increase in soil water from 300-600 mm followed by a constant decrease in soil water content and then a slight increase from 1000-1200 mm due to soil water accumulation on the hard plinthic soil horizon.

5.1.8.4.4 Oakleaf

Figure 5-13 illustrates the soil water depth profile of the Oakleaf soil form. By considering the planting curve it is evident that there is a slight increase in soil water with depth. Some gradual decrease and increase occur between 800 and 1000 mm, which can be associated with gravel layers. In the boll formation curve, it is evident that a significant water loss occurs from boll formation to harvest because of the increased soil water needs of the cotton during this growth stage. When considering the harvest curve, it is evident that there is a substantial increase in soil water from the planting period. There is a constant soil water content throughout the soil profile with an abrupt increase from 900-1100 mm. This is a clear indication of accumulation of water on the limiting horizon. From the time of harvest to post-season some soil water loss is visible due to interflow. As mentioned before the Avalon soil profile is physically able to allow the lateral and horizontal flow of soil water throughout the production season. The amount of variation in the soil water content is also much lower and a constant soil water distribution is evident.

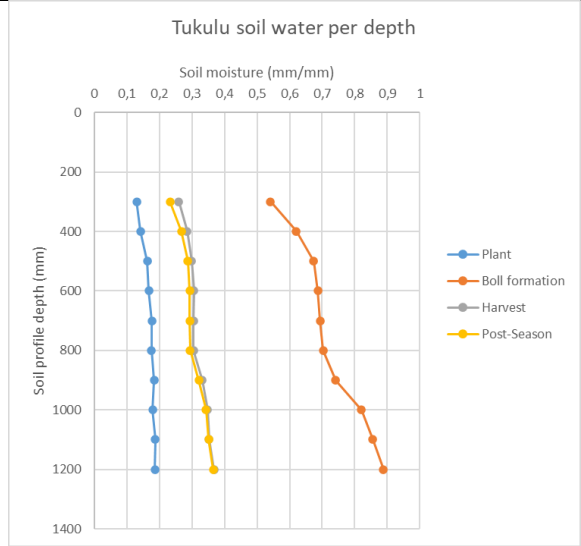


Figure 5-10: Soil water depth profile of the Tukulu soil form in Schietfontein.

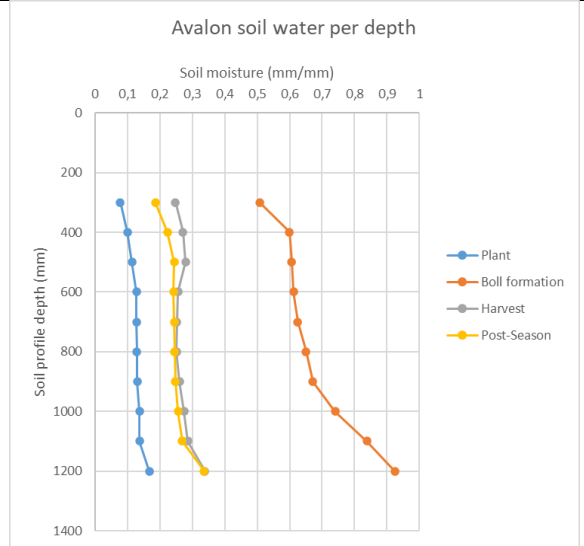


Figure 5-11: Soil water depth profile of the Avalon soil form in Schietfontein.

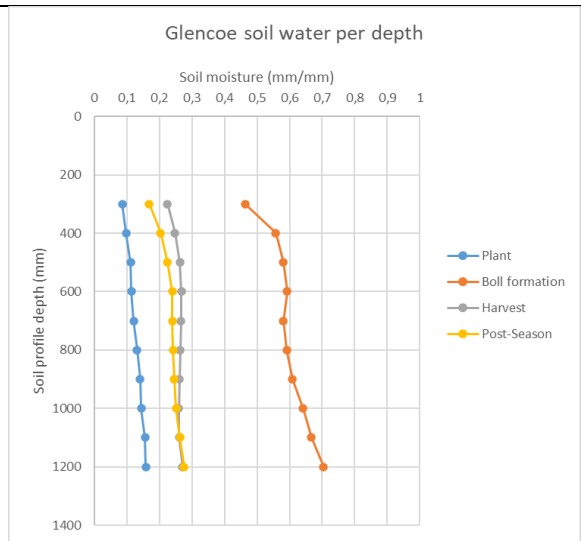


Figure 5-12: Soil water depth profile of the Glencoe soil form in Schietfontein.

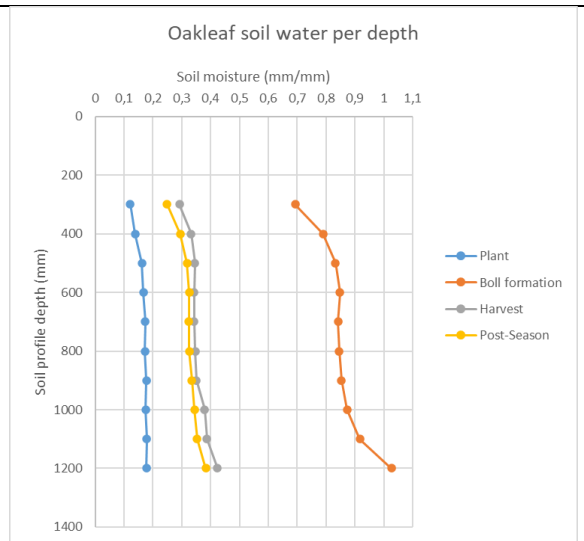


Figure 5-13: Soil water depth profile of the Oakleaf soil form in Schietfontein.

5.1.8.5 Season 1 Soil Water Characteristics

5.1.8.5.1 Pretorius Rust Soil Water Retention Characteristics

Table 5-9 illustrates the soil water retention characteristics of the four dominant soil forms in Pretorius Rust. The dry bulk density varies between 1,40 and 1,55 for the A horizon, and between 1,38 and 1,45 for the B horizon. The statistical analysis indicated that there is statistical significance between all the soil forms in terms of both the A and B horizon dry bulk density with the p-value <0,05. This statistical difference is due to differences in the texture of the various soil horizons. The A horizon dry bulk density is higher than the B horizon dry bulk density and due to this the infiltration of water is affected due to the higher density. The increase in the A horizon density is mainly due to the machinery used to work the soil and plant (Bennie & Hensley, 2001). The difference between the A horizons is not much due to the similar diagnostic topsoil horizon. The Tukulu soil form has the highest B horizon dry bulk density, and this is due to the structure of the neocutanic horizon which is prone to compaction and results in a higher dry bulk density. The Bainsvlei soil form has the second highest B horizon dry bulk density, and this is due to structure forming when the soil is dried out. The Avalon soil form B horizon is the counterpart of the Bainsvlei B horizon, with the only difference being the Avalon soil form being saturated for longer than the Bainsvlei soil form. This influences the density of the soil as it consists of more air and water which results in a lower density. The Westleigh soil form has the lowest dry bulk density in the B horizon which is quite significant considering it has the highest clay content. This is due to the B horizon being the most porous, resulting in more air-filled pockets.

Table 5-9: Drained upper limit, lower limit, and dry bulk density of the soil forms.

Soil form	Horizon	Dry Bulk Density (g/cm ³)	DUL (mm)	LL (mm)	PAW (mm)
Westleigh	A	1,40	61,05	38,95	22,10
Westleigh	B	1,36	166,64	78,25	88,39
Tukulu	A	1,52	57,82	39,28	18,55
Tukulu	B	1,45	236,10	94,31	141,79
Avalon	A	1,55	61,28	37,21	24,07
Avalon	B	1,38	249,09	78,62	170,47
Bainsvlei	A	1,53	61,47	37,40	24,07
Bainsvlei	B	1,42	291,93	94,10	197,82

When considering the Drained upper limit (DUL) in Table 5-9 it is evident that the Bainsvlei has the highest DUL in the A horizon followed by the Avalon, Westleigh and Tukulu soil forms in decreasing order. The DUL values of the A horizon does not differ much from one another since it is classified as the same diagnostic topsoil horizon. When considering the Lower limit (LL) of

the A horizon the Tukulu has the highest LL followed by the Westleigh, Bainsvlei and Avalon in decreasing order. The soil forms with a higher clay content are prone to have a low DUL and higher LL which may cause crop stress easily after high rainfall periods.

The DUL of the B horizon varies much more because the different soils have different subsoil horizons with different water retention capabilities. The LL of the B horizon does not vary much between the different soil forms, and no statistical significance is evident between the different soil forms. The post-hoc statistical analysis indicated that all the soil forms' DUL differ from one another statistically. Due to the statistical difference between the different soil forms DUL the plant available water (PAW) varies between the different soil forms as well because the PAW is derived from the DUL and LL. Table 5-10 indicates the most significant differences in DUL and PAW between the different soil forms in the B horizon. The biggest statistical difference occurs between the Westleigh and Bainsvlei soil forms followed by the following comparisons in decreasing order: Westleigh-Avalon, Tukulu-Bainsvlei, Westleigh-Tukulu, Tukulu-Avalon, and Bainsvlei-Avalon. All the comparisons have p-values < 0,05 which indicates that they are all statistically different from one another.

Table 5-10: Tukey post-hoc comparison test of the DUL, LL and PAW of the B horizon of the soil forms.

Comparison	P-value (DUL)	P-Value (LL)	P-value (PAW)
Westleigh-Bainsvlei	0,0000032 (1)	0,1411698	0,0000032 (1)
Westleigh-Avalon	0,0000267 (2)	0,9939721	0,0000267 (2)
Tukulu-Bainsvlei	0,0001712 (3)	0,9732088	0,0001712 (3)
Westleigh-Tukulu	0,0018994 (4)	0,0781262	0,0018994 (4)
Tukulu-Avalon	0,0060613 (5)	0,11135	0,0060613 (5)
Bainsvlei-Avalon	0,0377738 (6)	0,199188	0,0377738 (6)

* All the values with numbers indicate the rank of most significant comparison

5.1.8.5.2 Schietfontein Soil Water Retention Characteristics

Table 5-11 illustrates the soil water retention characteristics of the four dominant soil forms in Schietfontein. The dry bulk density varies between 1,50 and 1,64 for the A horizon, and between 1,44 and 1,52 in the B horizon. The statistical analysis indicated that there is statistical significance between all the soil forms in terms of both the A and B horizon dry bulk density with the p-value < 0,05. The A horizon dry bulk density is higher than the B horizon dry bulk density and due to this, the infiltration of water is affected due to the higher density. The increase in the A horizon density is mainly due to the machinery used to work the soil and plant. The difference between the A horizons is not much due to the similar diagnostic topsoil horizon. The Avalon soil form has the highest B horizon dry bulk density. The Tukulu soil form has the second highest B

horizon dry bulk density, and this is due to structure of the neocutanic horizon which is prone to compaction and results in a higher dry bulk density.

The Avalon soil form B horizon is the counterpart of the Glencoe B horizon, with the only difference being the plinthic horizon being soft plinthite in the Avalon soil form and hard plinthite in the Glencoe soil form. This influences the density of the soil as it consists of more air and water which results in a lower density.

Table 5-11: Drained upper limit, lower limit, and dry bulk density of the soil forms.

Soil form	Horizon	Dry Bulk Density (g/cm ³)	DUL (mm)	LL (mm)	PAW (mm)
Tukulu	A	1,50	82,60	36,83	45,77
Tukulu	B	1,46	243,08	79,72	163,36
Avalon	A	1,64	75,19	39,68	35,51
Avalon	B	1,52	308,77	122,52	186,25
Glencoe	A	1,53	66,20	33,06	33,15
Glencoe	B	1,44	197,83	67,62	130,22
Oakleaf	A	1,61	62,33	19,71	42,62
Oakleaf	B	1,44	222,12	71,65	150,47

When considering the drained upper limit (DUL) in Table 5-11 it is evident that the Tukulu soil form has the highest DUL in the A horizon followed by the Avalon, Glencoe and Oakleaf soil forms in decreasing order. The DUL values of the A horizon does not differ much from one another since it is classified as the same diagnostic topsoil horizon. When considering the lower limit (LL) of the A horizon the Avalon has the highest LL followed by the Tukulu, Glencoe and Oakleaf soil forms in decreasing order. The soil forms that have a low DUL and higher LL which may cause crop stress easily after high rainfall periods.

The DUL of the B horizon varies much more because the different soils have different subsoil horizons with different water retention capabilities. In the Schietfontein field uniform soils in terms of the B horizon exist, but still yet variance exists. Considering Table 5-11 it is evident that the Avalon soil form has the highest DUL followed by the Tukulu, Oakleaf and Glencoe soil forms. Considering Table 5-11 the Avalon soil form has the highest LL followed by the Tukulu, Oakleaf, and Glencoe. The difference between the LL of the other soil forms except the Avalon LL does not vary much from one another. The post-hoc statistical analysis indicated that all the soil forms' DUL and LL differ from one another statistically. Due to the statistical difference between the different soil forms DUL and LL the PAW varies only between the Glencoe and Avalon soil forms. Table 5-12 indicates the most significant differences in DUL, LL and PAW between the different soil forms. The biggest statistical difference occurs between the Glencoe and Avalon soil forms

followed by the following comparisons in decreasing order: Oakleaf-Avalon, and Tukulu-Avalon. Concluding this significant difference, the main difference is between the Avalon soil form and the other soil forms. Only the values with ranking numbers yielded statistically significant values.

Table 5-12: Tukey post-hoc comparison test of the DUL, LL and PAW of the B horizon of the soil forms.

Comparison	P-value (DUL)	P-Value (LL)	P-value (PAW)
Glencoe-Avalon	0.0024578 (1)	0.0001649 (1)	0.0135857 (1)
Oakleaf-Avalon	0.0068521 (2)	0.0000637 (2)	0.1802760
Tukulu-Avalon	0.0147699 (3)	0.0003630 (3)	0.1503898
Oakleaf-Glencoe	0.8294128	0.6717053	0.3131373
Tukulu-Glencoe	0.5097131	0.8219014	0.3679890
Tukulu-Oakleaf	0.9314531	0.2586072	0.9991052

* All the values with numbers indicate the rank of most significant comparison

5.1.8.6 Pretorius Rust Soil Water Regime

5.1.8.6.1 Avalon

Figure 5-14 illustrates the soil water fluctuation throughout the cotton production season of the Avalon soil form created from the averages of the repetitive site measurements. In October 2019 the total amount of soil water was below the lower limit. During the beginning of November 2019, the first rain was observed which assured that planting can commence. The cotton was planting on the 4th of November 2019 during which the soil form was slightly above the lower limit. Frequent rainfall events followed the planting which ensured that soil water was available for uptake during the emergence of the cotton.

Between the emergence and flowering growth stages the soil water was readily available for plant uptake and soil water conditions above DUL is observed towards the end of January 2020. The amount of soil water kept increasing above the drained upper limit which raises the possibility of plant stress. During the period from November 2019 to February 2020 the evapotranspiration demand increased as the growth stages progress towards the flowering stage, but due to the frequent high rainfall events to the sum of 124,4 mm in total rainfall, this increase had no real effect as the cotton water needs are rather low. During February 2020 a peak in soil water content is observed. The soil water content decreased drastically from February 2020 to June 2020 as the soil water needs of the cotton increased as the growth progressed to the boll formation and boll burst growth stages. The period above DUL lasted from the time just before flowering (January 2020) to boll burst (April 2020) before reaching a point of water becoming freely available for plant uptake without the risk of plant stress. In the period from boll burst commencement to harvest the soil water content kept decreasing, but after harvest increased for a short period

before remaining constant. The soil profile was above DUL during most of the growth stages, especially during the flowering and boll formation stage when the cotton is most susceptible to stress.

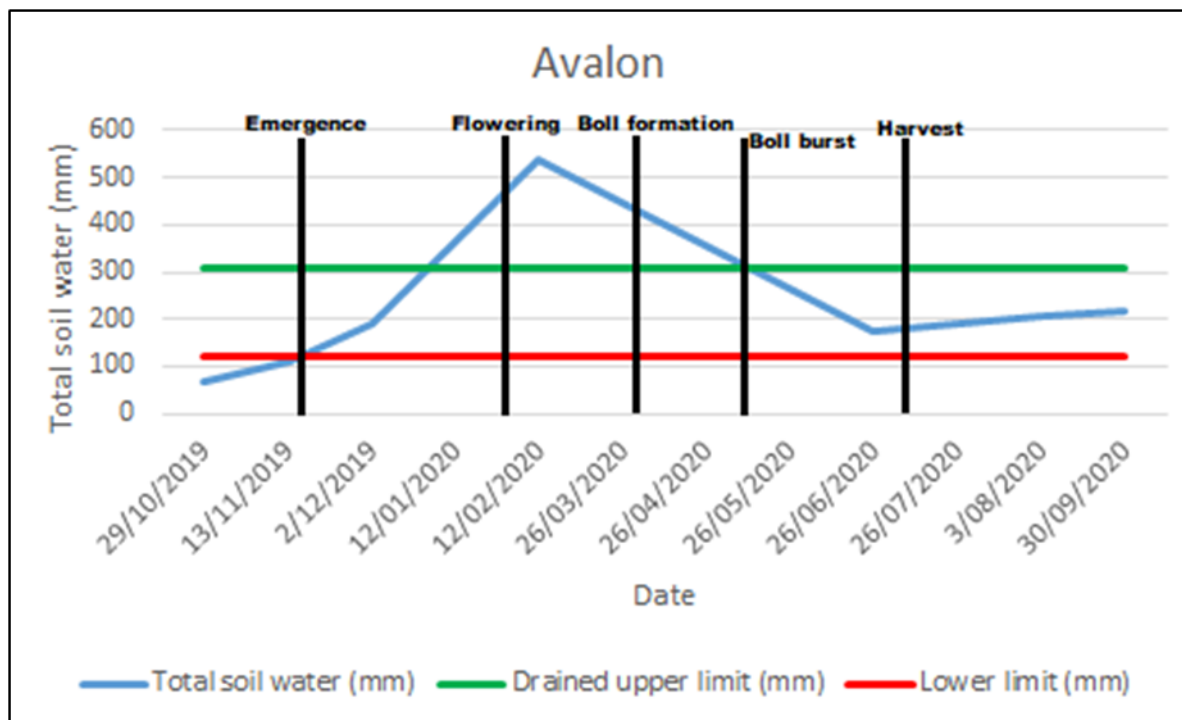


Figure 5-14: Soil water regime on the Avalon soil form in Pretorius Rust.

5.1.8.6.2 Bainsvlei

Figure 5-15 illustrates the soil water fluctuation throughout the cotton production season of the Bainsvlei soil form created from the averages of the repetitive site measurements. During October 2019 the total amount of soil water was slightly above the lower limit. During the beginning of November 2019, the first rain was observed which assured that planting can commence. The cotton was planted on the 4th of November 2019 during which the soil form was well above lower limit. Frequent rainfall events followed the planting which ensured that soil water was available for uptake during the emergence of the cotton. Between the emergence and flowering growth stages the soil water was readily available for plant uptake and soil water conditions above DUL is observed towards the middle of January 2020. The amount of soil water kept increasing above the drained upper limit which raises the possibility of plant stress. During the period from November 2019 to February 2020 the evapotranspiration demand increased as the growth stages progress towards the flowering stage, but due to the frequent high rainfall events this increase had no real effect as the cotton water needs are rather low. During February 2020 a peak in soil water content is observed. The soil water content decreased drastically from February 2020 to

June 2020 as the soil water needs of the cotton increased as the growth progressed to the boll formation and boll burst growth stages.

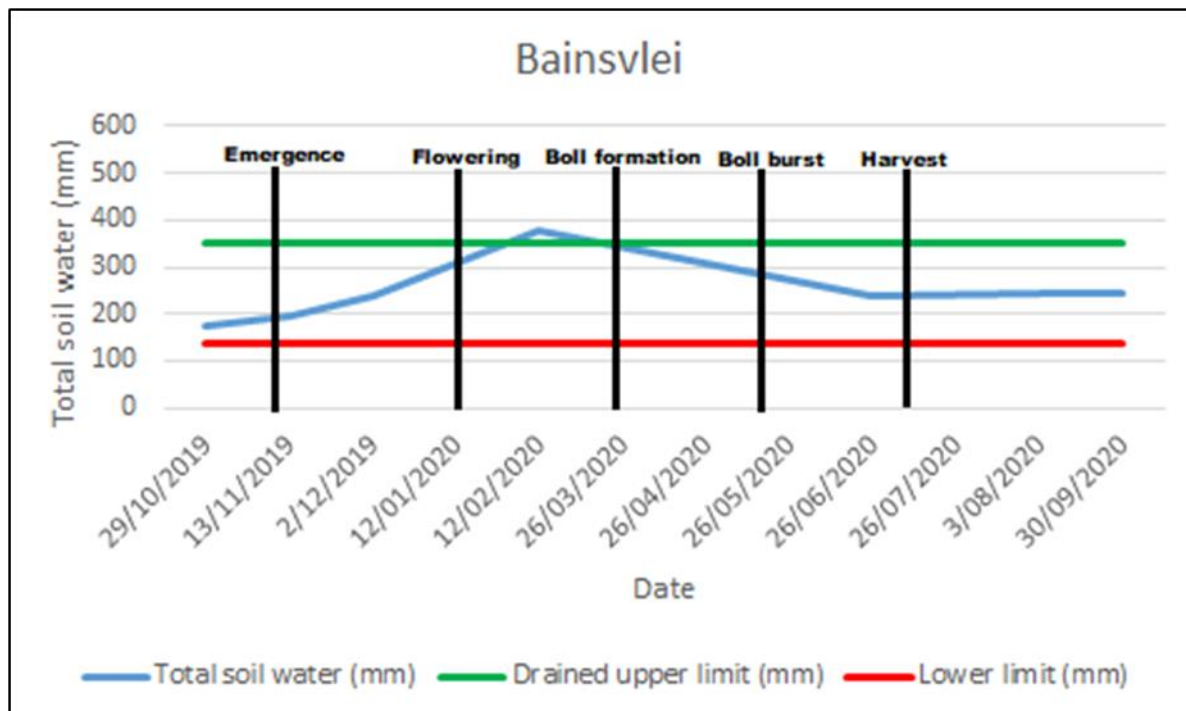


Figure 5-15: Soil water regime on the Bainsvlei soil form in Pretorius Rust.

The period above DUL lasted from the time just after flowering (January 2020) to just before boll burst commenced in April 2020 before reaching a point of water becoming freely available for plant uptake without the risk of planting stress. In the period from boll burst commencement to harvest the soil water content kept decreasing, but after harvest increased for a short period before remaining constant. The soil profile was above DUL only for a short period in between flowering and boll formation but only slightly which might not have a significant effect in terms of planting stress.

5.1.8.6.3 Westleigh

Figure 5-16 illustrates the soil water fluctuation throughout the cotton production season of the Westleigh soil form created from the averages of the repetitive site measurements. During October 2019 the total amount of soil water was slightly above the lower limit. During the beginning of November 2019, the first rain was observed which assured that planting can commence. The cotton was planted on the 4th of November 2019 during which the soil form was still slightly above lower limit. Frequent rainfall events followed the planting which ensured that soil water was available for uptake during the emergence of the cotton. Between the emergence

and flowering growth stages, the soil water was readily available for plant uptake and soil water conditions above DUL is observed during the beginning of December 2019. Soil water contents above DUL is observed very early in the growth process of the cotton. The amount of soil water kept increasing above the drained upper limit which raises the possibility of plant stress. During the period from November 2019 to February 2020 the evapotranspiration demand increased as the growth stages progress towards the flowering stage, but due to the frequent high rainfall events and waterlogged conditions this increase had no real effect as the cotton water needs are rather low. During February 2020 a peak in soil water content was observed and the total amount of soil water is approximately three times the DUL of the soil form. The soil water content decreased drastically from February 2020 to June 2020 as the soil water needs of the cotton increased as the growth progressed to the boll formation and boll burst growth stages. The soil water content above DUL lasted from the time just after emergence in early December 2019 until after harvest where it remained constant. The soil water content was above DUL during all the growth stages except emergence. The soil profile, being highly above DUL throughout the season, should have led to plant stress due to waterlogged conditions that indicates signs of plant stress.

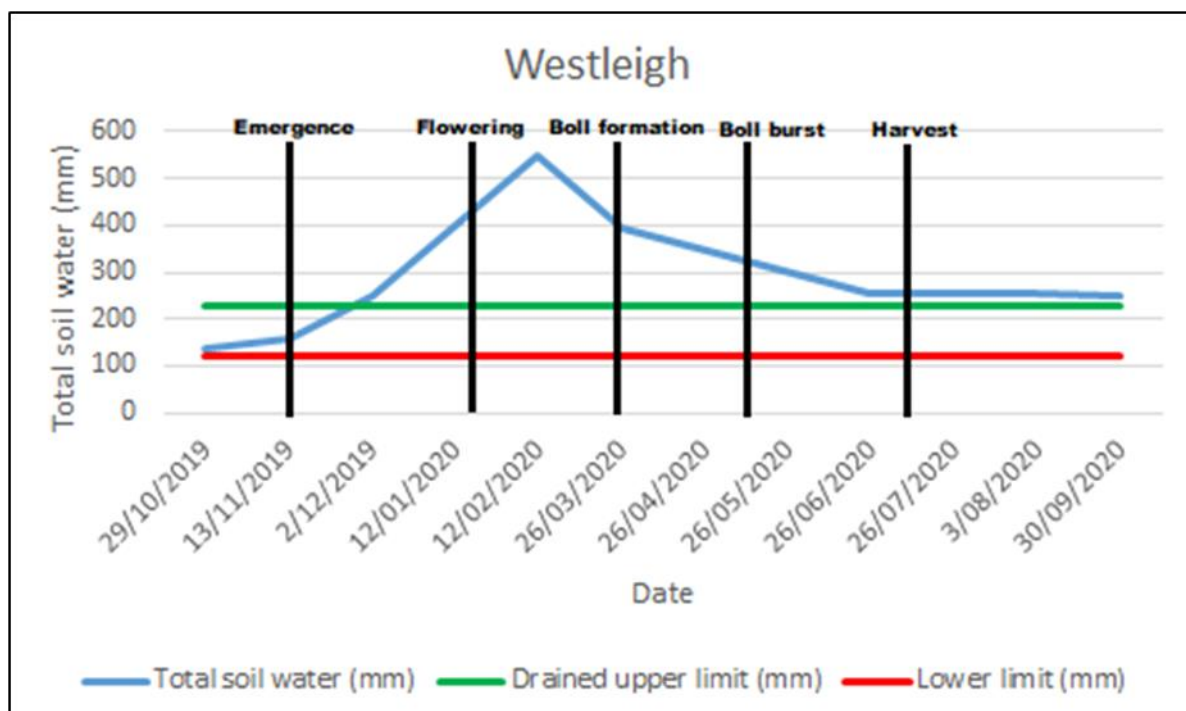


Figure 5-16: Soil water regime on the Westleigh soil form in Pretorius Rust.

5.1.8.6.4 Tukulu

Figure 5-17 illustrates the soil water fluctuation throughout the cotton production season of the Tukulu soil form created from the averages of the repetitive site measurements. During October 2019 the total amount of soil water was slightly above the lower limit. During the beginning of November 2019, the first rain was observed which assured that planting can commence. The cotton was planted on the 4th of November 2019 during which the soil form was well above lower limit. Frequent rainfall events followed the planting which ensured that soil water was available for uptake during the emergence of the cotton. Between the emergence and flowering growth stages the soil water was readily available for plant uptake and no waterlogged conditions were observed. The amount of soil water kept increasing above the drained upper limit, but only for a short period during February 2020. During the period from November 2019 to February 2020 the evapotranspiration demand increased as the growth stages progress towards the flowering stage, but due to the frequent high rainfall events this increase had no real effect as the cotton water needs are rather low. During February 2020 a peak in soil water content is observed. The soil water content decreased drastically from February 2020 to March 2020 as the soil water needs of the cotton increased as the growth progressed to the boll formation growth stage. A gradual decrease in soil water is visible from March 2020 to harvest. In the period from boll burst commencement to harvest the soil water content kept decreasing, but after harvest increased for a short period before remaining constant. The soil water content was above DUL only for a short period in between flowering and boll formation but only slightly which might not have a significant effect in terms of plant stress.

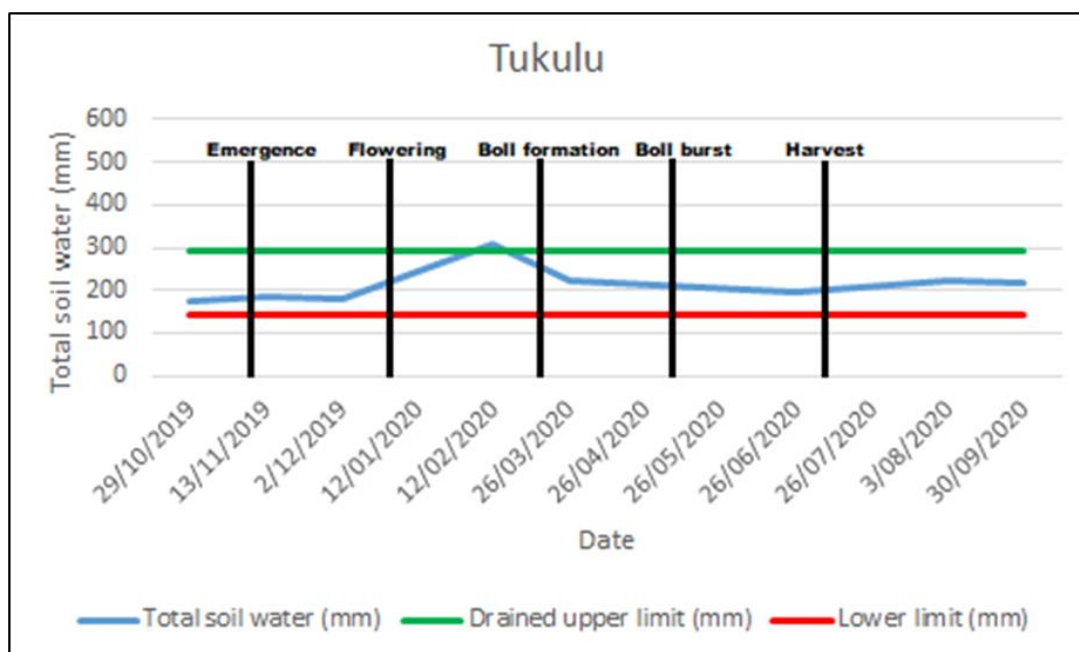


Figure 5-17: Soil water regime on the Tukulu soil form in Pretorius Rust.

5.1.8.7 Schietfontein Soil Water Regime

5.1.8.7.1 Tukulu

Figure 5-18 illustrates the soil water fluctuation throughout the cotton production season of the Tukulu soil form created from the averages of the repetitive site measurements. In November 2019 the total amount of soil water was well above the lower limit. During the beginning of November 2019, the first rain was observed which assured that planting can commence. The cotton was planted on the 13th of November 2019, but the soil water measurements had not yet commenced in Schietfontein. Frequent rainfall events followed the planting which ensured that soil water was available for uptake during the emergence of the cotton. Between the emergence and flowering growth stages the soil water was readily available for plant uptake and soil water contents above DUL is observed during the end of January 2020. Soil water contents above DUL are reached very early in the growth process of the cotton. The amount of soil water kept increasing above the drained upper limit which raises the possibility of planting stress. During the period from November 2019 to February 2020 the evapotranspiration demand increased as the growth stages progress towards the flowering stage, but due to the frequent high rainfall events and soil water conditions above DUL, this increase had no real effect as the cotton water needs are rather low.

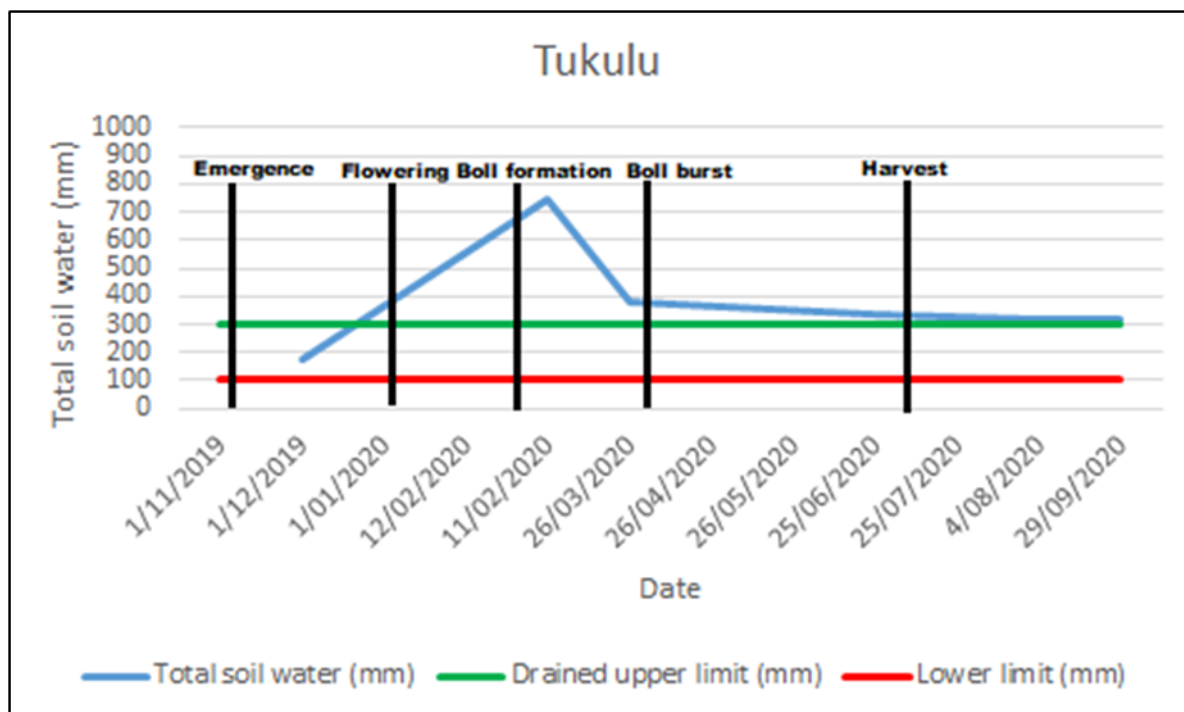


Figure 5-18: Soil water regime on the Tukulu soil form in Schietfontein.

During February 2020 a peak in soil water content is observed and the total amount of soil water is approximately two times the DUL of the soil form. The soil water content decreased drastically from February 2020 to March 2020 as the soil water needs of the cotton increased as the growth progressed to the boll burst growth stages. The soil water conditions above DUL period lasted from the period just after emergence around the end of January 2020 until after harvest where it remained constantly oversaturated. This extensive above DUL soil water conditions creates water stress in the plant and results in lower yield.

5.1.8.7.2 Avalon

Figure 5-19 illustrates the soil water fluctuation throughout the cotton production season of the Avalon soil form created from the averages of the repetitive site measurements. In November 2019 the total amount of soil water was slightly below the lower limit. During the beginning of November 2019, the first rain was observed which assured that planting can commence. The cotton was planted on the 13th of November 2019, but the soil water measurements had not yet commenced in Schietfontein. Frequent rainfall events followed the planting which ensured that soil water was available for uptake during the emergence of the cotton. Between the emergence and flowering growth stages the soil water was readily available for plant uptake and waterlogged conditions is observed towards the end of January 2020 just before flowering commenced. The amount of soil water kept increasing above the drained upper limit which raises the possibility of plant stress. During the period from November 2019 to February 2020 the evapotranspiration demand increased as the growth stages progress towards the flowering stage, but due to the frequent high rainfall events this increase had no real effect as the cotton water needs are rather low. During February 2020 a peak in soil water content is observed. The soil water content decreased drastically from February 2020 to March 2020 as the soil water needs of the cotton increased as the growth progressed to the boll formation growth stage. The soil water conditions above DUL lasted from the period just before flowering (January 2020) to just after boll formation (March 2020) before reaching a point of water becoming freely available for plant uptake without the risk of plant stress. In the period from boll burst commencement to harvest the soil water content kept decreasing until after harvest. The soil profile was above DUL only during the flowering and boll formation growth stages, especially during the flowering and initial boll formation stage when the cotton is most susceptible to plant stress.

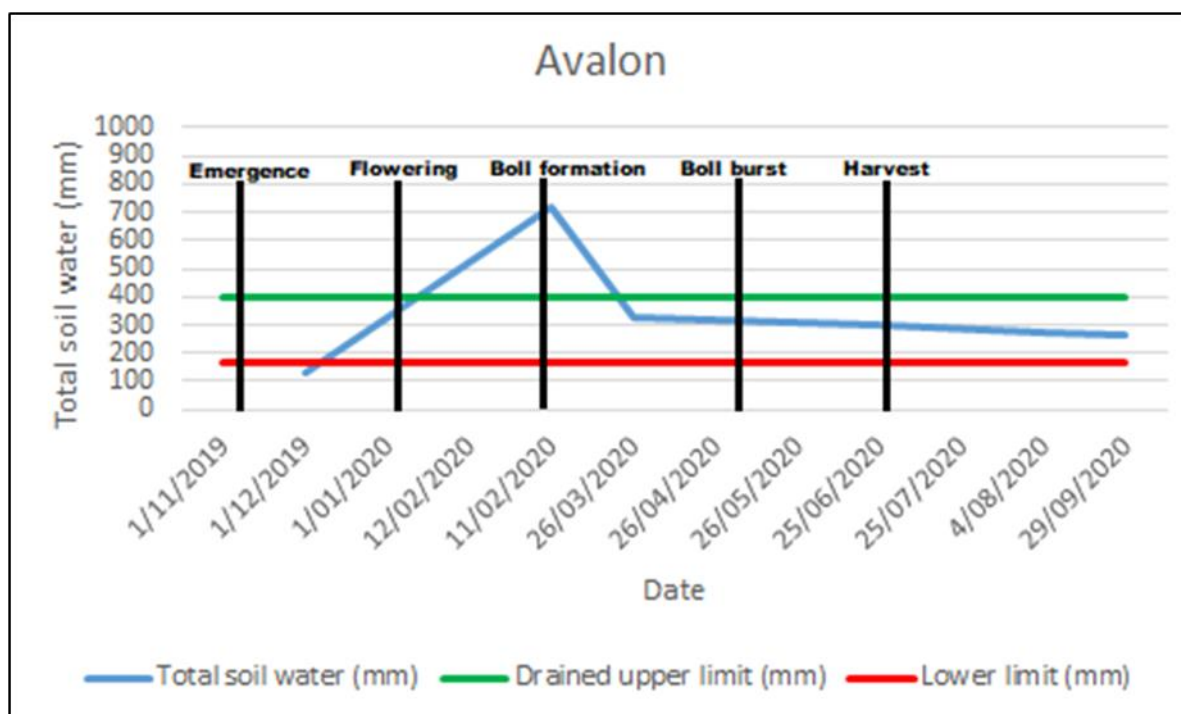


Figure 5-19: Soil water regime on the Avalon soil form in Schietfontein.

5.1.8.7.3 Glencoe

Figure 5-20 illustrates the soil water fluctuation throughout the cotton production season of the Glencoe soil form created from the averages of the repetitive site measurements. During November 2019 the total amount of soil water was slightly above the lower limit. During the beginning of November 2019, the first rain was observed which assured that planting can commence. The cotton was planted on the 13th of November 2019, but the soil water measurements had not yet commenced in Schietfontein. Frequent rainfall events followed the planting which ensured that soil water was available for uptake during the emergence of the cotton. Between the emergence and flowering growth stages the soil water was readily available for plant uptake and soil water conditions above DUL is observed during the end of December 2020. Soil water conditions above DUL are reached very early in the growth process of the cotton. The amount of soil water kept increasing above the drained upper limit which raises the possibility of plant stress. During the period from November 2019 to February 2020 the evapotranspiration demand increased as the growth stages progress towards the flowering stage, but due to the frequent high rainfall events and soil water conditions above DUL, this increase had no real effect as the cotton water needs are rather low.

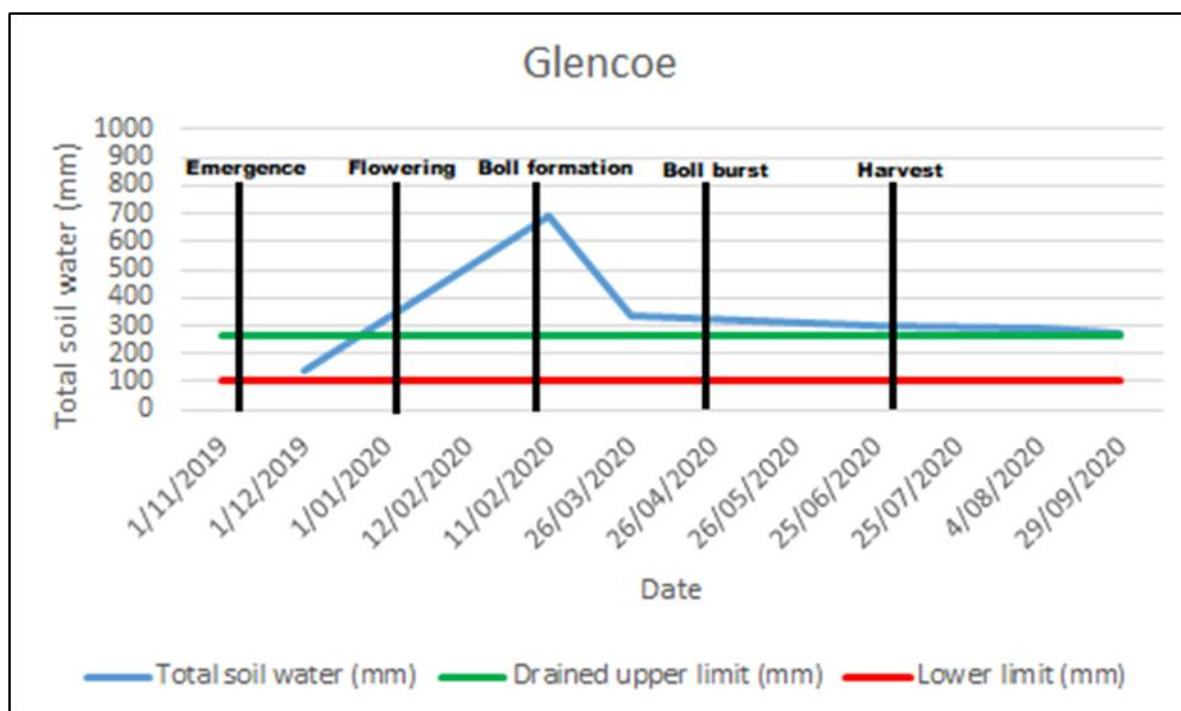


Figure 5-20: Soil water regime on the Glencoe soil form in Schietfontein.

During February 2020 a peak in soil water content is observed and the total amount of soil water is approximately two times the DUL of the soil form. The soil water content decreased drastically from February 2020 to March 2020 as the soil water needs of the cotton increased as the growth progressed to the boll burst growth stages. The soil water conditions above DUL lasted from the period just after emergence around the end of January 2020 until after harvest where it remained constantly above DUL. This extensive soil water conditions above DUL creates water stress in the plants and results in lower yield according to Ninari *et al.* (2004).

5.1.8.7.4 Oakleaf

Figure 5-21 illustrates the soil water fluctuation throughout the cotton production season of the Oakleaf soil form created from the averages of the repetitive site measurements. During the beginning of November 2019, the first rain was observed which assured that planting can commence. The cotton was planted on the 13th of November 2019, but the soil water measurements had not yet commenced in Schietfontein. During the beginning of November 2019, the first rain was observed which assured that planting can commence. Frequent rainfall events followed the planting which ensured that soil water was available for uptake during the emergence of the cotton. Between the emergence and flowering growth stages the soil water was readily available for plant uptake and soil water conditions above DUL is observed during the middle of December 2019. The soil water conditions above DUL are reached very early in the growth

process of the cotton. The amount of soil water kept increasing above the drained upper limit which raises the possibility of plant stress. During the period from November 2019 to February 2020 the evapotranspiration demand increased as the growth stages progress towards the flowering stage, but due to the frequent high rainfall events and soil water conditions above DUL, this increase had no real effect as the cotton water needs are rather low. During February 2020 a peak in soil water content is observed and the total amount of soil water is approximately three times the DUL of the soil form. The soil water content decreased drastically from February 2020 to March 2020 as the soil water needs of the cotton increased as the growth progressed to the boll burst growth stage. The soil water conditions above DUL lasted from the period just after emergence in early December 2019 until after harvest where it remained constantly far above the DUL. The soil water content was above DUL during all the growth stages except emergence. The soil profile being high above DUL throughout the season indicated signs of plant stress.

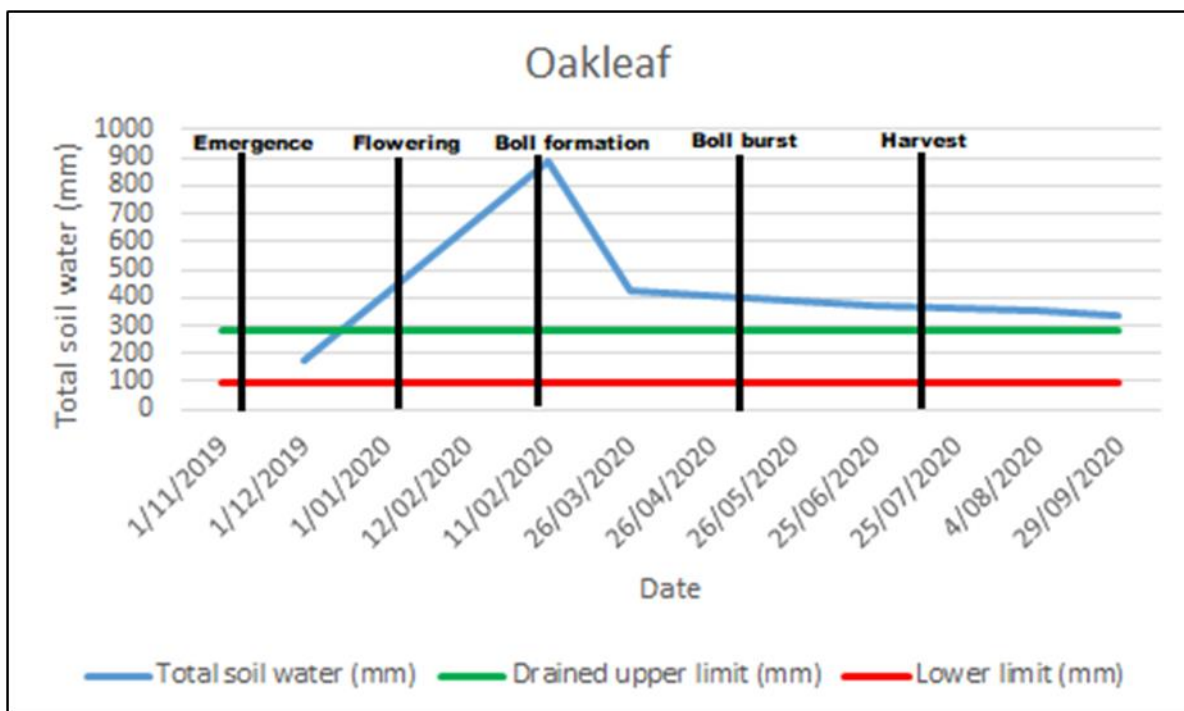


Figure 5-21: Soil water regime on the Oakleaf soil form in Schietfontein.

5.1.9 Cotton Yield and Quality

5.1.9.1 Pretorius Rust Seed Cotton Yield

Figure 5-22 illustrates the cotton yield data per soil form for the Pretorius Rust cotton field for the 2019/2020 production season. From Figure 5-22 it is evident that the Avalon soil form produced the highest cotton yield at 3,96 ton/ha. The Bainsvlei soil form produced the second highest yield

with 3,65 ton/ha. The third highest producing soil form is the Westleigh soil form with 3,25 ton/ha. The lowest yield was measured on the Tukulu soil form with 2,93 ton/ha. The average cotton yield for Pretorius Rust was 3,45 ton/ha.

No statistical differences in yield were observed with the four dominant soil forms of Pretorius Rust. From the results it is evident that the sandy clay loam soils, Avalon and Bainsvlei, produced the highest yield in comparison with the sandy clay soils, Westleigh and Tukulu. The average cotton yield in South Africa under dryland conditions is between 1,2-2 ton per hectare (Cotton SA, 2021b). By considering this the Pretorius Rust cotton field produced an above national average cotton yield in the 2019/2020 cotton season.

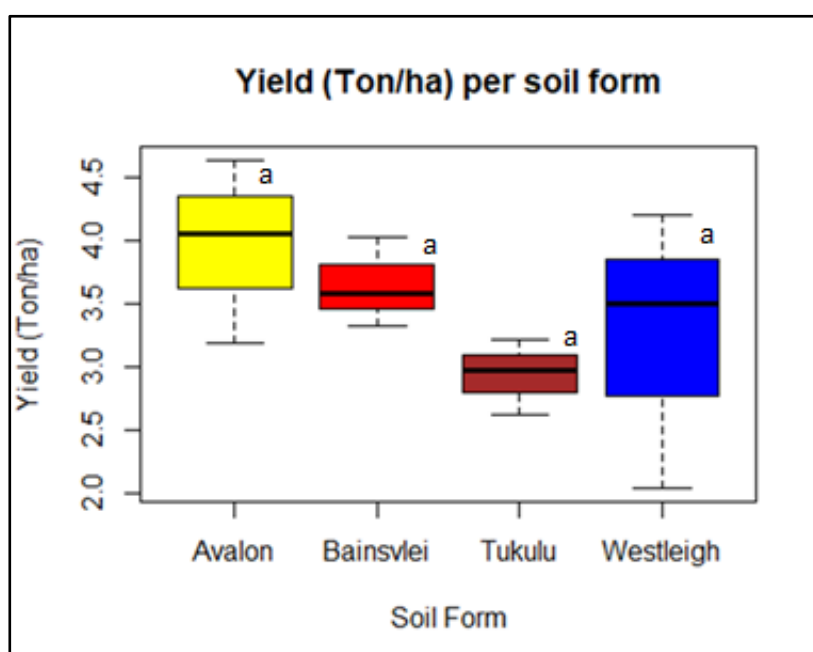


Figure 5-22: Pretorius Rust seed cotton yield (ton/ha) per soil form.

5.1.9.2 Schietfontein Cotton Yield

Figure 5-23 illustrates the cotton yield data per soil form for the Schietfontein cotton field for the 2019/2020 production season. From Figure 5-23 it is evident that the Oakleaf soil form produced the highest cotton yield at 2,61 ton/ha. The Avalon soil form produced the second highest yield with 2,50 ton/ha. The Glencoe soil form produced the third-highest yield with 2,32 ton/ha. The Tukulu soil form produced the lowest yield with 2,04 ton/ha. The average cotton yield from the four dominant occurring soil forms for Schietfontein for the 2019/2020 cotton season was 2,37 ton/ha. This is significantly lower than the average yield of the four dominant soil forms of the Pretorius Rust cotton field.

No statistical differences in yield were observed with the four dominant soil forms of Schietfontein. From the data it is evident that the sandy clay loam soils, Oakleaf, Avalon and Glencoe, produced the highest yield in comparison with the sandy clay soil forms such as the Tukulu. The cotton yield in this cotton field is well above the national average of 1.2-2 ton/ha.

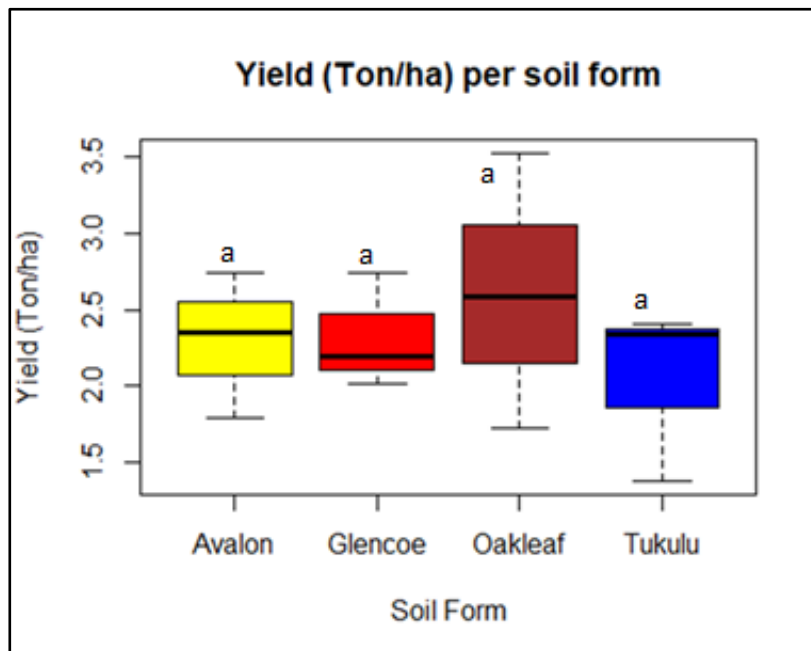


Figure 5-23: Schietfontein cotton yield (ton/ha) per soil form.

5.1.9.3 Pretorius Rust Cotton Quality

Table 5-13 was generated by compiling averages of all the cotton quality parameters from the repetitive sampling points for each soil form. The data is discussed per soil property and assigned to a cotton quality class on basis of a classification scheme considering these quality properties and the current value of the specific cotton class. Statistical analysis revealed that there is no distinct significant difference between the cotton quality parameters of Pretorius Rust, but based on the classifications the small differences account for different quality classes and associated price differentials on the cotton lint.

It is evident that the Tukulu soil form has the highest upper half mean length (UHML) with 1,18 inches. The second highest UHML is that of the Avalon and Westleigh soil forms with 1,16 inches. The cotton fibre with the lowest UHML is that of the Bainsvlei soil form with an average length of 1,15 inches. The higher the UHML, the higher the spinning consistency will be, and a higher price value will be assigned to the cotton fibre batch.

The highest fibre strength is that of the Westleigh soil form with 26,89 g/tex, followed by the Bainsvlei soil form with 26,51 g/tex. The Tukulu soil form has the third strongest fibre strength with 26,44 g/tex. The Avalon soil form has the least strong cotton fibre with a strength of 26,26 g/tex. All the above soil form strength values are categorized as a medium strength. It is evident that the sandy clay soils such as the Westleigh soil forms, produced the higher strength cotton fibres in comparison with the sandy clay loam soils such as the Avalon.

Table 5-13: Pretorius Rust cotton fibre quality per soil form.

Soil form	UHML	Strength	Micronaire	Class	Price (kg)	Price differential (%)
Westleigh	1,16 a	26,89 a	3,73 a	AO+	R22,90	14,5
Tukulu	1,18 b	26,44 a	3,52 a	AX	R23,20	16
Avalon	1,16 a	26,26 a	3,34 a	AOM	R22,20	11
Bainsvlei	1,15 a	26,51 a	3,37 a	AOM	R22,20	11

The soil form producing the highest micronaire value is the Westleigh soil form with 3,73. The second highest micronaire produced is that of the Tukulu soil form with 3,52. The third highest micronaire is that of the Bainsvlei soil form with 3,37. The Avalon soil form produced the lowest micronaire value with 3,34. The Avalon, Bainsvlei and Tukulu soil forms micronaire values are classified as fine. The Westleigh soil form micronaire is classified as medium. It is evident that the sandy clay soils (Westleigh and Tukulu) produced higher micronaire cotton fibre in comparison with the sandy clay loam soils (Avalon and Bainsvlei).

By considering Table 5-13 it is evident that the best cotton quality by class was delivered by the sandy clay soils, Westleigh and Tukulu. All the above soil forms fall in the group O which is the second-best quality group. Within the group classes, AO and AOM exist. The sandy clay loam soil forms, Avalon and Bainsvlei, fibre quality falls within the class AOM which is secondary to the AO class in group O. There is a slight price difference between the two classes but considering the yield, these small differences accounts for a large sum of money.

Table 5-14 illustrates the difference in price based on the yield and quality classes. It is evident that the yield's influence in cotton production considering the rand value of the cotton lint a hectare is highly significant. A higher yield to the cost of slightly lower quality results in a higher rand value than a higher quality to the cost of a lower yield. Both the Westleigh and Avalon soil forms were above DUL during the growth stages where the cotton is most sensitive to soil water stress. The Avalon produced the highest yield, but a lower quality cotton. By considering Table 5-14 the quality of the cotton does not influence the value of the cotton, but the yield. When comparing the Avalon and Westleigh soil forms the limiting layer horizon is different. The yield and quality are

affected by the limiting layer horizon. The Westleigh soil form's gleyic limiting layer horizon tend to create waterlogged conditions that inhibit the formation of bolls and resulting in a lower yield. However, it is more profitable to farm the higher yield soils such as the Avalon and Bainsvlei in comparison with the soils that produce higher quality cotton such as the Westleigh and Tukulu.

Table 5-14: Influence of cotton quality on the rand value of cotton lint (ton/ha) in the Pretorius Rust field.

Soil form	Yield (ton/ha)	Price (R/kg)	Rand value per ton/ha
Westleigh	3,25	22,9	R74 425
Tukulu	2,93	23,2	R67 976
Avalon	3,96	22,2	R90 684
Bainsvlei	3,65	22,2	R84 680

5.1.9.4 Schietfontein Cotton Quality

Table 5-15 was generated by compiling averages of all the cotton quality parameters from the repetitive sampling points for each soil form. The data is discussed per soil property and assigned to a cotton quality class on basis of a classification scheme considering these quality properties. Statistical analysis revealed that there is no distinct significant difference between the cotton quality parameters of Schietfontein, but based on the classifications the small differences account for different quality classes and associated price differentials on the cotton lint.

The UHML varied quite significantly between the different soil forms in the Schietfontein cotton field. The longest UHML was produced by the Glencoe soil form with 30,53 mm, followed by the Avalon soil form with 29,99 mm. The Oakleaf soil form had the third longest UHML with 29,37 mm. The Tukulu soil form produced the shortest UHML with 29,68 mm. A clear trend is observed that the sandy clay loam soils, Glencoe, Avalon and Oakleaf produced the longest fibres in comparison with sandy clay soils such as the Tukulu.

Table 5-15: Schietfontein cotton fibre quality per soil form.

Soil form	UHML	Strength	Micronaire	Class	Price (R/kg)	Price Differential (%)
Tukulu	1,17	27,50	4,32	AO+	R22,90	14,5
Oakleaf	1,16	27,34	4,04	AO+	R22,90	14,5
Glencoe	1,20	27,35	3,78	AX	R23,20	16
Avalon	1,18	28,07	4,02	AX	R23,20	16

The strength varied between the different soil forms. The Avalon soil form produced the strongest cotton fibres with 28,07 g/tex, followed by the Tukululu soil form with 27,50 g/tex. The third strongest cotton fibre was produced by the Glencoe soil form with 27,35 g/tex. The weakest cotton fibre was produced by the Oakleaf soil form with 27,34 g/tex. There is a significant difference between the strongest and weakest cotton fibres, but not enough to be classified in different strength categories. All the soil forms produced medium strength fibres.

The micronaire values varied quite between the different soil forms. The Tukululu soil form produced the highest micronaire with 4,32, followed by the Oakleaf soil form with 4,04. The Avalon soil form produced the third highest micronaire with 4,02. The lowest micronaire value was produced by the Glencoe soil form with 3,78. All the soil form micronaire values is described as medium. A key finding is that one sandy clay soil, Tukululu, produced the highest micronaire value. The micronaire values of the Schietfontein cotton field is higher than that of the Pretorius Rust cotton field due to the influence of the cotton variety planting.

By considering Table 5-15 it is evident that two AX class cotton quality was produced by the Glencoe and Avalon soil forms which is the best quality cotton. The Oakleaf and Tukululu soil forms produced AO class cotton. The AO class is considered the best class of the Group O. There is a very small price difference between the cotton produced in the two classes of cotton quality.

Table 5-16 illustrates the difference in price based off the yield and quality classes. It is evident that the yield's influence in cotton production considering the rand value of the cotton lint a hectare is highly significant. A higher yield to the cost of slightly lower quality results in a bigger rand value than a higher quality to the cost of a lower yield. The Oakleaf, Glencoe and Tukululu soil forms was above DUL during the growth stages where the cotton is most sensitive to soil water stress. The Oakleaf soil form produced the highest yield, but a lower quality cotton. By considering Table 5-16 the quality of the cotton does not influence the value of the cotton, but the yield. When comparing the Oakleaf and Tukululu soil forms the limiting layer horizon is different. The yield and quality are affected by the limiting layer horizon. The Tukululu soil form's gleyic limiting layer horizon tend to create waterlogged conditions that inhibit the formation of bolls and result in a lower yield. However, it is more profitable to farm the higher yield soils such as the Oakleaf and Avalon.

Table 5-16: Influence of cotton quality on the rand value of cotton lint (ton/ha) in the Schietfontein field.

Soil form	Yield (ton/ha)	Price (R/kg)	Rand value per ton/ha
Tukulu	2,04	22,90	R45 891,60
Oakleaf	2,61	22,90	R59 769
Glencoe	2,32	23,20	R53 824
Avalon	2,50	23,20	R58 000

5.2 Season 1 Conclusions

5.2.1 Pretorius Rust

Pretorius Rust dominant soil forms are physically different in terms of texture and as a result, the soil water behaviour is different. Sandy clay loam and sandy clay soils were identified. The Westleigh and Tukulu soil forms had the highest clay percentage in the horizons and as a result, the Westleigh soil form had the highest soil water content throughout the season. The Tukulu soil form on the other hand had the lowest amount of soil water due to seasonal interflow on the gleyic limiting horizon. The Avalon soil form had the lowest clay content in the subsoil horizon but had approximately the same amount of soil water as the Westleigh soil form throughout the season due to the water table characteristics of the soft plinthic soil water limiting layer horizon. Interflow was visible post-season on the limiting layer horizon in the Avalon, Tukulu, and Bainsvlei soil form with accumulation in the bottom 200–300 mm of the soil profiles. Increases in soil water between harvest and post-season is visible in the sandy clay loam soils Avalon and Bainsvlei, but a decrease in soil water was visible in the sandy clay soils Westleigh and Tukulu due to internal drainage. The Avalon and Westleigh soil forms were above DUL during the flowering, boll formation and boll burst stages during which the cotton is most sensitive to soil water stress, and the Bainsvlei and Tukulu only slightly above DUL between the flowering and boll formation growth stages. The sandy clay soils delivered better quality cotton and higher micronaire cotton fibres than the sandy clay loam soils. A higher yield to the cost of lower quality cotton accounts for much more than a better quality to the cost of lower yield. The highest yield was produced by the sandy clay loam soils Avalon and Bainsvlei in comparison with the sandy clay soils Westleigh and Tukulu. Both the Westleigh and Tukulu soil forms has a gleyic limiting horizon which is not favourable for plant roots due to waterlogged or anoxic conditions caused by slow drainage, and the cotton roots is situated in this section of the soil profile during boll formation. During the flowering and boll formation growth stages the Westleigh and Tukulu soil water content was above DUL contributing to the anoxic conditions. This may be the cause of a lower yield in comparison with the plinthic limiting layer horizons of the Avalon and Bainsvlei. The plinthic horizons are also

known to be anoxic, but the waterlogged period is much shorter than that of the gleyic horizon due to the apedal horizon on top of the plinthic horizon which has red and yellow colour indicating the shorter periodical saturated conditions. When comparing the two soils that were above DUL during flowering and boll formation when the cotton is most sensitive to water stress it is inevitable that the cotton prefers the more oxidated environment in the subsoil in the form of apedal horizons on the plinthic horizons. A higher yield to the cost of lower quality cotton accounts for much more than a better quality to the cost of lower yield thus, it is more profitable to manage the land in such a manner to focus on the areas with higher yield potential.

5.2.2 Schietfontein

The Schietfontein soil forms are physically uniform with not much variation in the physical properties of the different soils and their associated horizons. All the soil forms identified in the Schietfontein field are texturally classified as sandy clay loam soils. The Oakleaf and Tukulu soil forms had the highest clay percentage in the topsoil and subsoil horizons. As a result, the Oakleaf and Tukulu soil forms had the highest amount of soil water throughout the season. In all the soil profiles the soil water content decreased from harvest to post-season which is characteristic of interflow soils. All the soil forms in Schietfontein have red colour in the subsoil horizon which indicates water flow from the soil profile with the only exception in the Tukulu soil form. When considering the depth profiles the effect of grey colours in the gleyic horizon is inevitable. Less soil water was lost from harvest to post-season throughout the soil profile. In the bottom section of the soil profile the amount of soil water remained the same. The other soil forms decreased in soil water content throughout the soil profile due to deep internal drainage. The Oakleaf, Glencoe and Tukulu soil forms soil water content was above DUL throughout the entire season from the period just before flowering to post-season. The Avalon soil form was below lower limit by planting time and increased in soil water content being above DUL only during flowering and boll formation. The Oakleaf produced the highest yield of cotton with the Avalon producing the second highest yield. The Tukulu soil form produced the lowest yield which is considerably less than the Oakleaf and Avalon soil forms yield. However, the Glencoe and Avalon soil forms produced the best quality cotton in comparison with the Tukulu and Oakleaf soil forms. The soils with a higher clay content, Oakleaf and Tukulu produced the highest micronaire cotton fibres. A higher yield to the cost of lower quality cotton accounts for much more than a better quality to the cost of lower yield. The Tukulu soil form has a gleyic limiting horizon which is not favorable for plant roots due to waterlogged or anoxic conditions, and the cotton roots is situated in this section of the soil profile during boll formation where the yield is determined. During the flowering and boll formation growth stages the Tukulu was above DUL contributing to the anoxic conditions. This may be the cause of a lower yield in comparison with the plinthic limiting layer horizons of the Avalon and Glencoe.

The plinthic horizons are also known to be anoxic, but the waterlogged period is much shorter than that of the gleyic horizon due to the apedal horizon on top of the plinthic horizon which has red and yellow colours indicating the shorter periodical saturated conditions. When comparing the soils that were above DUL during flowering and boll formation when the cotton is most sensitive to waterlogged conditions it is inevitable that the cotton prefers the more oxidated environment in the subsoil in the form of apedal horizons on the plinthic horizons. A higher yield to the cost of lower quality cotton accounts for much more than a better quality to the cost of lower yield thus, it is more profitable to manage the land in such a manner to focus on the areas with higher yield potential.

5.2.3 Combined Conclusion

In conclusion the soils with a higher clay content results in a higher soil water content throughout the production season. Soils having a gleyic soil horizon with grey colours in the matrix tend to not decrease in soil water content post-season in comparison with plinthic limiting layer horizons. It is evident that in the soils with a soil horizon that is anoxic such as the gleyic soil horizon, that the periods above DUL have an effect on the yield of the cotton of the specific soil form, but crop management factors may be the real cause. No statistical differences occurred in the soil horizons clay percentage. However, variation occurred in the amount of soil water that a soil can hold against gravity (DUL), which then explains the variation in soil water content throughout the production season. The soil water content was observed to be above the drained upper limit during critical growth stages (flowering and boll formation), which may have caused water stress in the cotton through the anoxic conditions. These anoxic conditions suppress the development of the above ground biomass (cotton bolls), resulting in a lowered yield. However, crop management practices such as the application rates of fertilizers might have had an effect. Soil forms with a higher clay content tend to form cotton with a higher micronaire fibre and cotton of a better quality. Although the cotton quality is better the yield remain the deciding factor as a higher yield to the cost of lower quality cotton could prove more valuable than a lower yield to the cost of higher quality cotton.

5.3 Season 2 Results and Discussion

5.3.1 Hoekblok Measurement Sites

The soil map with the measurement sites for the Hoekblok is given in Figure 5-24. The Hoekblok is approximately 90 hectares large and the dominant soil forms are Bainsvlei, Westleigh, Sepane and Bloemdal, and Table 5-17 illustrates the horizon sequence of the soil forms.

The Hoekblok consists mainly of sandy clay soils (~40 % clay) with some areas yielding sandy clay loam soils (~30-40 % clay). This corresponds with the description of soils by Jacobs *et al.* (2018). All the mentioned soil forms are known as characteristic water table soils due to the limiting layer prohibiting fast drainage of soil water, as expressed by the signs of wetness observed in the second or third horizon. In each of the above four abundant soil forms three repetitive sites were identified.

Table 5-17: Dominant soil forms of the Hoekblok and their soil horizon sequence.

Soil form	Topsoil Horizon	Subsoil Horizon 1	Subsoil Horizon 2
Bainsvlei	Orthic	Red Apedal	Soft Plinthite
Westleigh	Orthic	Soft Plinthite	Gleyic
Sepane	Orthic	Pedocutanic	Gleyic
Bloemdal	Orthic	Red Apedal	Gleyic

5.3.2 Diagnostic Soil Horizon Description of the Hoekblok

Refer to section 5.1.2.1 to 5.1.2.6 for the description of the Orthic, Red Apedal, Soft Plinthic and Gleyic horizons.

5.3.2.1 Pedocutanic Subsoil Horizon

The pedocutanic soil horizon has a strong structure with distinct cutans on ped surfaces. It is often associated with a clear contrast between the overlying topsoil horizon having a sandy texture and the upper subsurface horizon having a sandy clay loam to clay texture. Brown to dark brown matrix colours exist indicating increased oxygen in the soil profile (Fey, 2010). Brown soil matrix colours in pedocutanic horizons transition to red colours in red structured horizons. This soil horizon is prone to erosion due to the textural contrast between the topsoil and subsoil horizons (Soil Classification Working Group, 2018).

5.3.3 Hoekblok Soil Properties Description

From Table 5-18 it is evident that the soil form had a significant effect on the rooting depth and clay percentage of the A and B horizons. This is substantiated by the p-value being $< 0,05$. The post-hoc analysis revealed that statistical difference occur between the Bainsvlei and all the soil forms in the A horizon, but the most significant difference occur between the Bainsvlei and Sepane soil forms with the P-value = 0,0165. The post-hoc analysis revealed that statistical difference occur between the Bainsvlei and all the other soil forms, but the most significant difference occur between the Sepane and Bainsvlei soil forms with the P-value = 0,0000034. Concluding this it is evident that the Sepane and Westleigh soil forms have a statistically similar clay percentage in the A horizon, but the Bainsvlei and Bloemdal soil forms clay percentage does vary statistically from the Sepane and Westleigh.

Table 5-18: ANOVA between the soil forms and their soil properties in the Hoekblok.

Comparison	Sum Sq.	Mean Sq.	F-value	P-value
Root depth (mm)	5,356	1,7852	571,3	1,14E-09 *
Clay A (%)	124,7	41,56	6,393	0,0161 *
Clay B (%)	697,7	232,56	79,73	2,66E-06 *

From Table 5-19 it is evident that the root depth is the highest for the Bainsvlei soil form with the other soil forms having the same root depth. The topsoil (A horizon) clay percentages vary quite ranging between 12,0–26,0 %. The clay percentage in the subsoil (B horizon) yields larger differences with the clay percentage varying from 19,0–41,0 % and increase in the following sequence: Bainsvlei, Bloemdal, Westleigh and Sepane. The differences are illustrated through the letters in the mean separation columns. The same letters indicate statistical similarity, while different letters suggest statistical difference.

5.3.4 Teerpadblok Measurement Sites

The soil map with the measurement sites for the Teerpadblok is given in Figure 5-25. The Teerpadblok is approximately 160 hectares large and the dominant soil forms are clearly Avalon, Tukulu, Oakleaf and Westleigh, and Table 5-20 illustrates the horizon sequence of the soil forms.

The Teerpadblok consists mainly of sandy clay soils, but some variances occur between the different soil forms. The average clay percentage in the subsoil horizon varies between 37,0-40 % which is not significant. The Avalon, Tukulu and Westleigh soil forms are considered water table soils due to their physical ability to limit fast drainage of soil water.

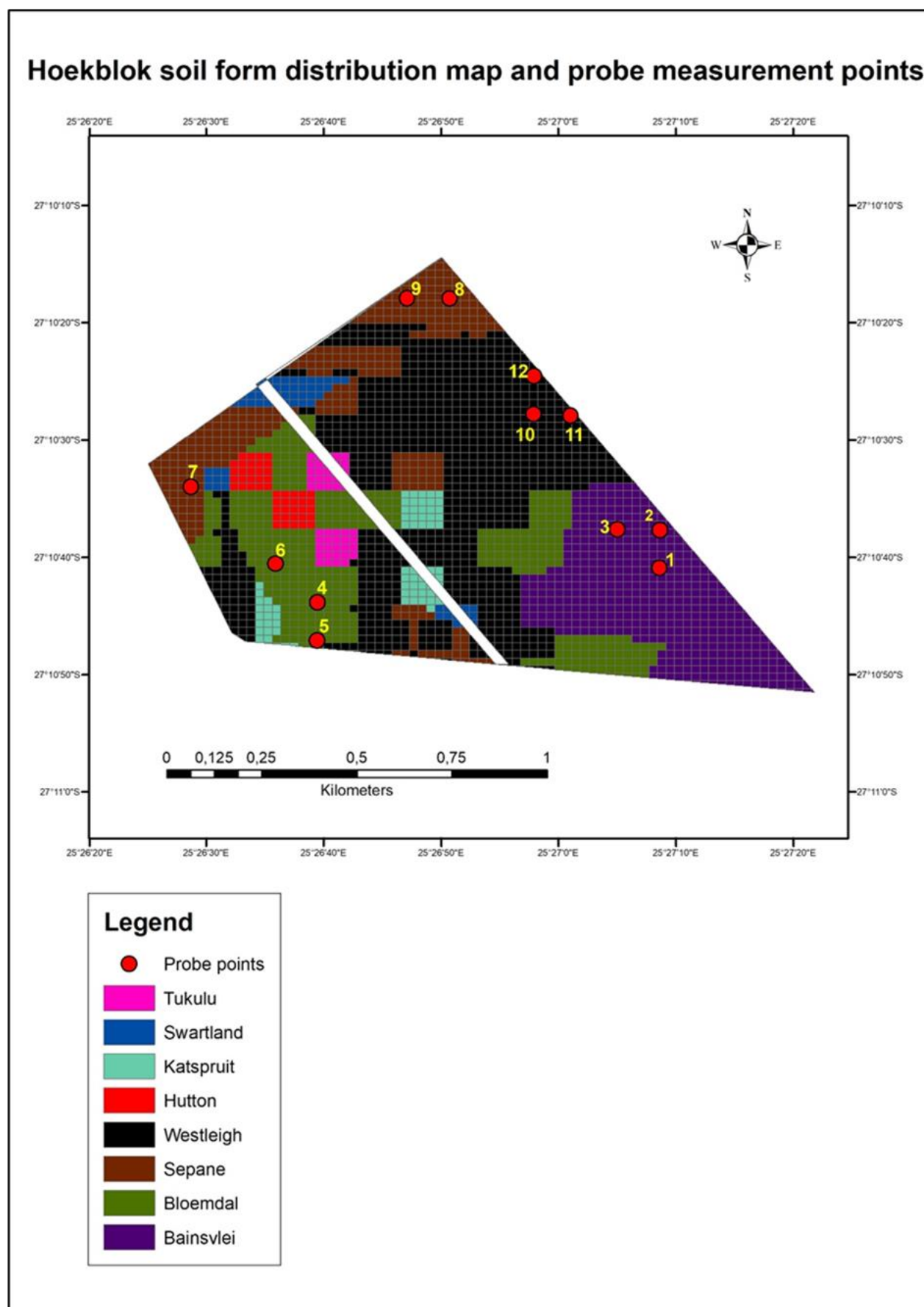


Figure 5-24: Hoekblok soil form distribution map and sampling points.

Table 5-19: Hoekblok soil properties and averages per soil form.

Site point	Soil form	Root depth (mm)	Clay A (%)	Clay B (%)
HB 1	Bainsvlei	2000	12	20
HB 2	Bainsvlei	2000	12	19
HB 3	Bainsvlei	2000	13	23
HB 4	Bloemdal	800	20	36
HB 5	Bloemdal	800	16	33
HB 6	Bloemdal	800	18	36
HB 7	Sepane	800	26	38
HB 8	Sepane	800	18	41
HB 9	Sepane	800	18	41
HB 10	Westleigh	800	20	39
HB 11	Westleigh	800	20	37
HB 12	Westleigh	800	19	39
Averages	Bainsvlei		12,3 b	20,7 c
	Bloemdal		18,0 ab	35,0 b
	Sepane		20,7 a	40,0 a
	Westleigh		19,7 a	38,3 ab

Table 5-20: Dominant soil forms of the Teerpadblok and their soil horizon sequence.

Soil form	Topsoil Horizon	Subsoil Horizon 1	Subsoil Horizon 2
Avalon	Orthic	Yellow-Brown Apedal	Soft Plinthite
Tukulu	Orthic	Neocutanic	Gleyic
Oakleaf	Orthic	Neocutanic (Thick)	-
Westleigh	Orthic	Soft Plinthite	Gleyic

5.3.5 Diagnostic Soil Horizon Description of the Teerpadblok

Refer to section 5.1.2.1 to 5.1.2.6 for the description of the Orthic, Yellow-Brown Apedal, Neocutanic, Soft Plinthic and Gleyic horizons.

5.3.6 Teerpadblok Soil Properties Description

From Table 5-21 it is evident that the soil form had a significant effect on the rooting depth and clay percentage of the A horizon. This is substantiated by the p-value being <0,05 for both the parameters which indicates statistical differences. Statistical similarity in the clay percentage of the A horizon occur between the Oakleaf and Tukulu soil forms, and statistical differences occur between the Avalon and Westleigh soil forms.

Table 5-21: ANOVA between the soil forms and their soil properties in the Teerpadblok.

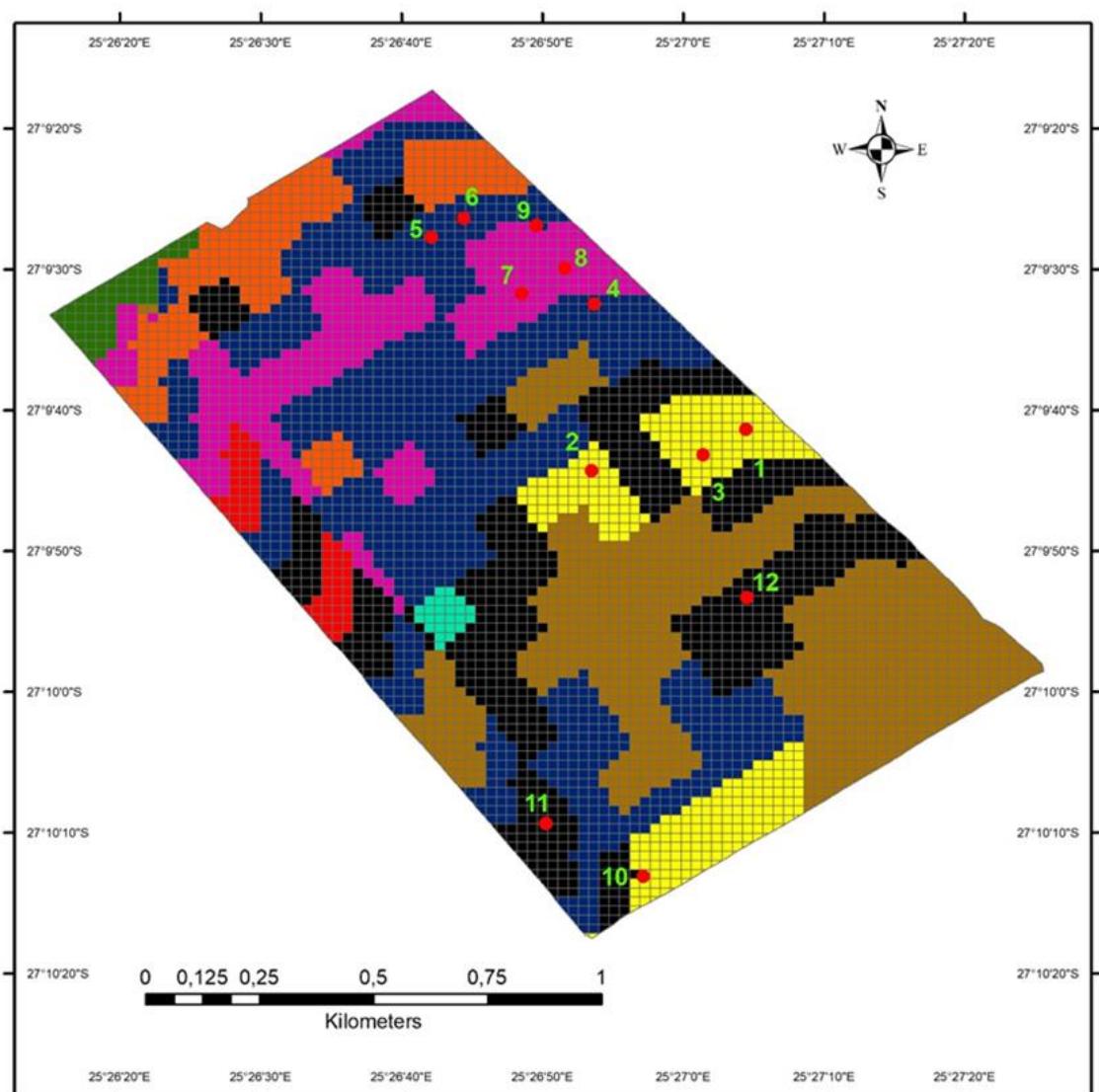
Comparison	Sum Sq.	Mean Sq.	F-value	P-value
Root depth (mm)	129167	43056	25,83	0,00018 *
Clay A (%)	153,67	51,22	9,914	0,00453 *
Clay B (%)	11,667	3,889	3,333	0,077

From Table 5-22 it is evident that the root depth decreases in the following sequence: Westleigh, Tukulu, Avalon and Oakleaf, while for the topsoil (A horizon) the clay percentages vary distinctly and ranges between 10,0–25,0%. The clay percentage in the subsoil (B horizon) yields relatively small differences with the clay percentage varying from 37,0–40,0% increasing in the following sequence: Westleigh, Avalon, Oakleaf and Tukulu.

Table 5-22: Teerpadblok soil properties and averages per soil form.

Site point	Soil form	Root depth (mm)	Clay A (%)	Clay B (%)
TP 1	Avalon	700	18,0	39,0
TP 2	Avalon	800	18,0	37,0
TP 3	Avalon	700	18,0	40,0
TP 4	Tukulu	800	23,0	40,0
TP 5	Tukulu	800	22,0	39,0
TP 6	Tukulu	800	23,0	41,0
TP 7	Oakleaf	800	25,0	37,0
TP 8	Oakleaf	800	23,0	39,0
TP 9	Oakleaf	700	21,0	38,0
TP 10	Westleigh	1000	10,0	37,0
TP 11	Westleigh	1000	18,0	38,0
TP 12	Westleigh	1000	15,0	37,0
Averages	Avalon		18,0 ab	38,7 a
	Tukulu		22,7 a	40,0 a
	Oakleaf		23,0 a	38,0 a
	Westleigh		14,3 b	37,3 a

Teerpadblok soil form distribution map and probe measurement points



Legend

- Probe points
- Westleigh
- Tukulu
- Swartland
- Pinedene
- Oakleaf
- Mispah
- Katspruit
- Clovelly
- Avalon

Figure 5-25: Schietfontein soil form distribution map and sampling points.

5.3.7 Calibration of the Neutron Probe

5.3.7.1 Hoekblok

Table 5-23 indicates the coefficient of determination (R^2) and calibration formula that is used to calculate the total amount of soil water measured monthly for the Hoekblok cotton field. By considering Table 5-23 containing the calibration data of the Hoekblok cotton field, it is evident that there is a highly significant correlated relationship between the volumetric soil water content and the neutron probe count with the average correlation value being: $R^2 = 0,87$. The correlation values range from 0,80–0,97 which is considered accurate in the study of Evett *et al.* (2019) correlation values ranged between 0,81–0,84 and was deemed accurate.

The graphs used to create these coefficients and formulas can be found in appendix B. By considering the graphs in appendix B it is evident that the higher total of plots used to form the soil water calibration formulas are found at higher counts which accounts for a bigger soil water mass. This was evident for all the different types of soils. The depth is key as most of the samples containing a higher soil water content was obtained from deeper levels in the soil profile. The same trend was observed in a study conducted by Steyn (2019).

Table 5-23: Coefficient of determination and calibration formula of the measurement sites in the Hoekblok.

Probe point	Soil form	R^2	Calibration formula
HB 1	Bainsvlei	0,84	$y = 0,1858x - 0,0283$
HB 2	Bainsvlei	0,85	$y = 0,1955x + 0,0351$
HB 3	Bainsvlei	0,80	$y = 0,1451x + 0,0258$
HB 4	Bloemdal	0,97	$y = 0,1355x + 0,0322$
HB 5	Bloemdal	0,84	$y = 0,1034x + 0,1746$
HB 6	Bloemdal	0,95	$y = 0,1538x + 0,0140$
HB 7	Sepane	0,89	$y = 0,1787x - 0,0099$
HB 8	Sepane	0,92	$y = 0,1211x + 0,0067$
HB 9	Sepane	0,80	$y = 0,1076x + 0,1614$
HB 10	Westleigh	0,83	$y = 0,1437x + 0,0190$
HB 11	Westleigh	0,83	$y = 0,1509x + 0,0468$
HB 12	Westleigh	0,94	$y = 0,2012x - 0,0277$
Average		0,87	

Figure 5-26 illustrates the trend by using the graph created for one of the Bloemdal calibration curves. This feature is influenced by the period during which the samples are taken. The soil calibration samples were obtained during the dry part of the season during which most soil water

have infiltrated to deeper subsoil levels. As all the cotton fields comprises mostly of water table soils, the stored soil water will accumulate on the water table horizons.

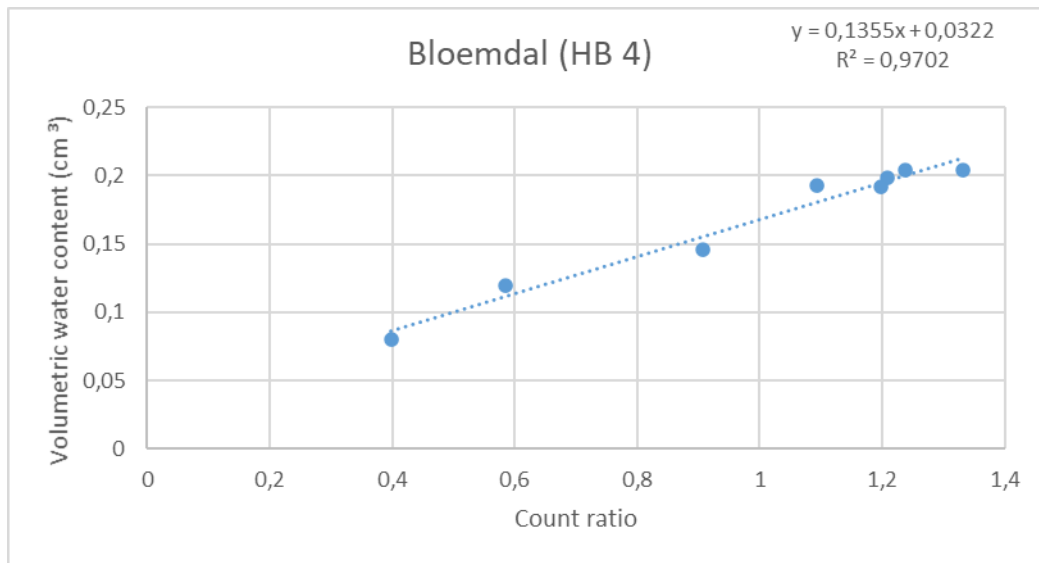


Figure 5-26: The linear regression neutron probe calibration of a Westleigh soil form measurement site in the Hoekblok.

5.3.7.2 Teerpadblok

Table 5-24 containing the calibration data and formulas used to calculate the amount of soil water monthly for the Teerpadblok it is evident that there is a highly significant relationship between the gravimetric soil water content and the neutron probe count with the average value being $R^2 = 0,90$. The correlation of this field is slightly higher than the Hoekblok. This calibration is deemed accurate as the studies of Evett *et al.* (2009) and Jabro *et al.* (2005) states that regression values of above 0,81 was deemed accurate.

5.3.8 Soil water

5.3.8.1 Hoekblok soil water

The total soil water per soil form averaged for the Hoekblok site is illustrated in Figure 5-27. During November 2020 the first rainfall was noted and due to the rainfall events the soil water content of the different soil forms increased. After the rainfall events occurred the cotton was planting in the Hoekblok on the 5th of November 2020. During the period from the start of November 2020 to the end of November 2020 115,6 mm rain was observed during which the cotton seeds germinated and emerged. January 2021 was recorded as the month with the highest rainfall with 143,8 mm in total in the 2020/2021 season. Throughout the production season the Bainsvlei had the highest

amount of soil water because the soil profile is 2000 mm deep in comparison with the 800 mm of the other soil form profiles which accounts for much more soil water throughout the profile.

Table 5-24: Coefficient of determination and calibration formula of the measurement sites in the Teerpadblok.

Probe point	Soil form	R ²	Calibration formula
TP 1	Avalon	0,95	$y = 0,1333x - 0,0243$
TP 2	Avalon	0,89	$y = 0,1832x - 0,0185$
TP 3	Avalon	0,92	$y = 0,1311x + 0,0329$
TP 4	Tukulu	0,85	$y = 0,3628x - 0,0447$
TP 5	Tukulu	0,96	$y = 0,1728x - 0,0014$
TP 6	Tukulu	0,83	$y = 0,0428x + 0,0559$
TP 7	Oakleaf	0,92	$y = 0,1035x + 0,0255$
TP 8	Oakleaf	0,90	$y = 0,1469x + 0,0283$
TP 9	Oakleaf	0,95	$y = 0,0889x + 0,0673$
TP 10	Westleigh	0,85	$y = 0,1486x + 0,0155$
TP 11	Westleigh	0,85	$y = 0,1016x + 0,0932$
TP 12	Westleigh	0,94	$y = 0,0996x + 0,0773$
Average		0,90	

The soil water content of the Bainsvlei can then not be compared to that of the Westleigh, Bloemdal and Sepane soil forms due to this depth difference. The Westleigh soil form increased in soil water content to February 2020 much faster than the Sepane and Bloemdal soil forms with similar soil water because of the situation of the interflow characteristics of the subsoil horizons.

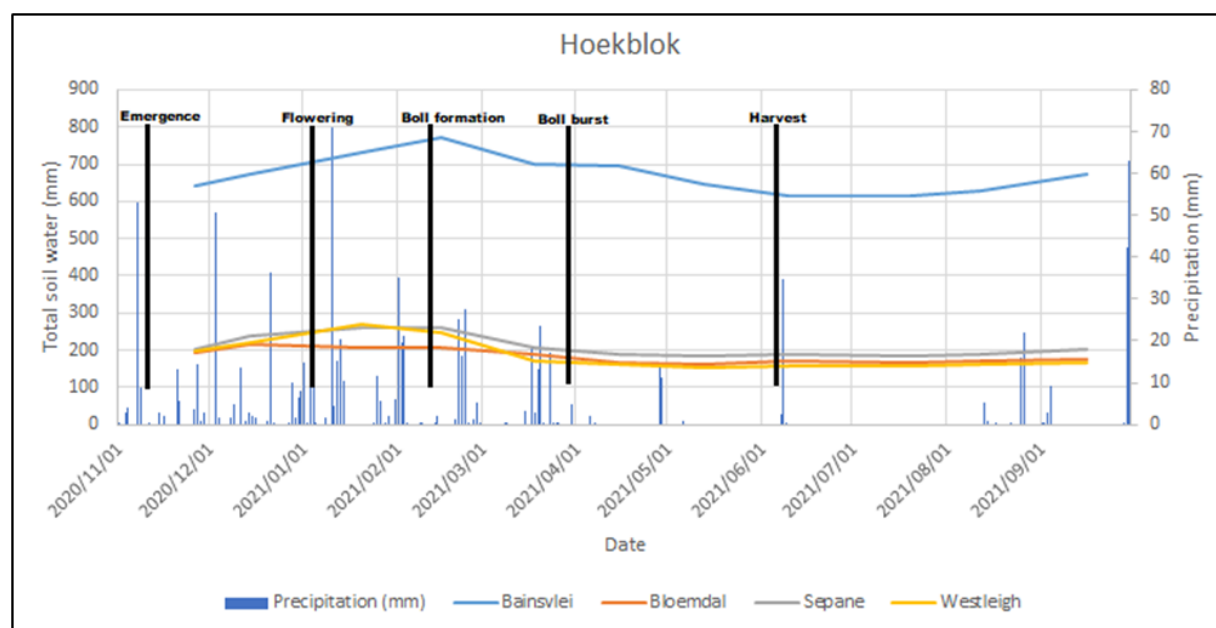


Figure 5-27: Total soil water and precipitation of the Hoekblok site.

As time progressed the Bloemdal soil form decreased only slightly in comparison with the other soil forms soil water loss throughout the cotton growth stages. During the emergence growth stage, the transpiration demand is low as the plant root system is limited to the topsoil and the rainfall high, and as such no decrease is visible in any of the soil forms.

During January 2021 the flowering growth stage commenced, and the transpiration demand of the cotton plant leaves increased, but the high rainfall events being 204,4 mm for this period ensured that the transpiration demand had no current effect on the growth stages. During this stage it is evident that through the rainfall events that the water had infiltrated and the topsoil and upper part of the subsoil horizon had an abundance of soil water available. During the flowering stage the cotton is most sensitive to soil water and plant stress could occur when the soil profile is waterlogged or at wilting point. By February 2021 all the soil forms reached a peak in soil water content.

The boll formation stage commenced during February 2021 up to April 2021 during which rainfall still occurred, but the soil water demand of the cotton plants increased. In the period from boll formation to boll burst the soil forms decreased a lot in the total soil water content with the Bainsvlei and Westleigh having the most notable losses. The Bloemdal and Sepane soil forms had a gradual loss of soil water in this growth period. A significant trend is observed, the two soils with a soft plinthic horizon (Bainsvlei and Westleigh) from the four dominant soil forms in the Hoekblok had a greater loss of soil water in the boll formation growth stage than the Sepane and Bloemdal soil forms. As the cotton bolls ripen the transpiration demand decreases as the cotton plant start shedding its leaves.

From April 2021 the bolls started to burst and mature. This growth stage is situated in the transition from Fall to Winter and during this period the evaporative demand is low. The soil water content still decreases from boll burst and ripening to harvest but remains rather constant. The cotton of the Hoekblok was harvested on the 15th of June 2021. From harvest there is a gradual increase in soil water of the Sepane soil form up to September 2021 where it becomes constant due to interflow characteristics. The Bainsvlei soil form drastically increased after harvesting due to interflow on the soft plinthic limiting layer. An important factor to consider is that more soil water was left in the soil profile post-season than pre-season in the Bainsvlei and Sepane soil forms, but the Westleigh and Bloemdal soil forms were drier post-harvest than the start of the season.

5.3.8.2 Teerpadblok Total Soil Water

The total soil water per soil form averaged for the Teerpadblok site is illustrated in Figure 5-28. During November 2020 the first rainfall was noted and due to the rainfall events, the soil water

content of the different soil forms increased. After the rainfall events occurred the cotton was planted in the Teerpadblok on the 2nd of November 2020. During the period from the start of November 2020 to the end of November 2020 the cotton seeds germinated and emerged. January 2021 was recorded as the month with the highest rainfall total in the 2020/2021 season as mentioned previously. Throughout the production season, the Westleigh soil form had the highest amount of soil water because of the water table characteristics of the soft plinthic horizon. The Westleigh and Avalon soil form increased in soil water content to February 2020 where a peak was reached in comparison with the early peak of the Tukulu and Oakleaf soil forms in middle January 2021 because of the occurrence of the interflow characteristics of the subsoil horizons. During the emergence growth stage, the transpiration demand is low as the plant root system is limited to the topsoil and the rainfall high, and as such, no decrease is visible in any of the soil forms.

During January 2021 the flowering growth stage commenced, and the transpiration demand of the cotton plant leaves increased, but the high rainfall events ensured that the transpiration demand had no current effect on the growth stages. During this stage, it is evident that due to the rainfall events that the water had infiltrated and the topsoil and upper part of the subsoil horizon had an abundance of soil water available. Notable decreases are evident during the flowering stage of the Tukulu and Oakleaf soil forms.

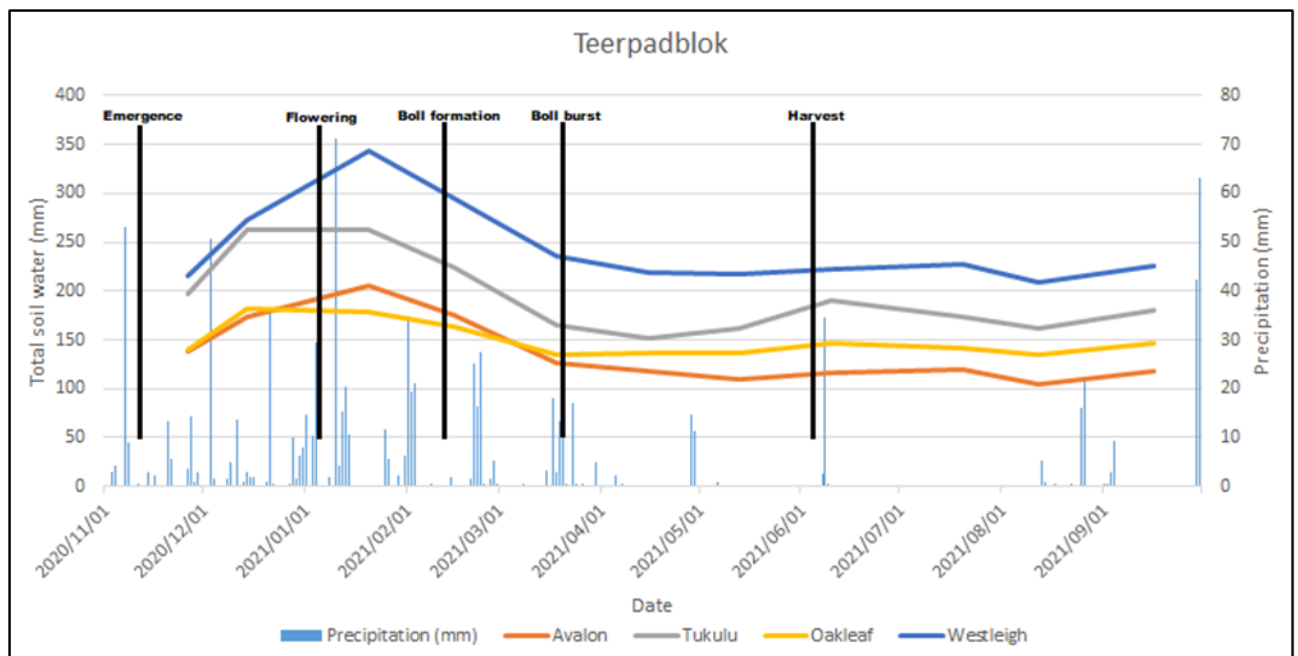


Figure 5-28: Total soil water and precipitation of the Hoekblok site.

As time progressed the Oakleaf soil form soil water content decreased much less drastic in comparison with the other soil forms soil water loss. During the flowering stage the cotton is most sensitive to soil water and planting stress could occur when the soil profile is waterlogged or at wilting point.

The boll formation stage commenced during February 2021 up to April 2021 during which rainfall still occurred, but the soil water demand of the cotton plants increased. In the period from boll formation to boll burst the soil forms decreased a lot in the total soil water content with the Westleigh, Tukulu and Avalon having the most notable losses. The Oakleaf soil forms had a gradual loss of soil water in this growth period. A significant trend is observed, the two soils with a soft plinthic horizon (Westleigh and Avalon) from the four dominant soil forms in the Teerpadblok had a greater loss of soil water in the boll formation growth stage than the soil forms with a neocutanic B horizon. As the cotton bolls ripen the transpiration demand decreases as the cotton plants start shedding its leaves.

From April 2021 the bolls started to burst and mature. This growth stage is situated in the transition from Fall to Winter and during this period the evaporative demand is low. The soil water content still decreases from boll burst and ripening up to middle March when an increase in soil water is visible. The cotton of the Teerpadblok was harvested on the 5th June 2021. From harvest there is a gradual increase in soil water of the Tukulu soil form up to July 2021 where it declines up to August 2021 and becomes constant due to interflow characteristics. An important factor to consider is that more soil water was left in the soil profile post-season than pre-season in the Westleigh soil forms, but the Tukulu, Oakleaf and Avalon soil forms was drier post-harvest than the start of the season.

5.3.8.3 Hoekblok Soil Water Depth Profiles

All the repetitive sites of the four dominant soil forms volumetric water content were averaged of the growth stages and plotted in the soil water depth profiles.

5.3.8.3.1 Bainsvlei

Figure 5-29 illustrates the soil water depth profile of the Bainsvlei soil form. It is evident that there is an increase in soil water from planting to boll formation and a decrease from boll formation to harvest, followed by an increase from harvest to post-season, concluding more soil water is present in the profile post-season than pre-season. A significant increase in soil water in the topsoil is present during boll formation, but it is due to a rainfall event that occurred during this period.

When considering the boll formation stage, it is evident that there is a clear increase in soil water with depth, but the soil water content stays constant from 1500-2000 mm as anoxic conditions occur at this depth and the cotton roots does not thrive in this part of the soil profile. A clear increase in soil water with depth is evident during all these periods, except with planting where a constant soil water content is visible from 1400 – 2000 mm. The most significant soil water loss from boll formation to harvest occur from 500-1500 mm due to the soil water needs of the cotton during the vegetative growth stages as well as deep internal drainage of the soil horizons. There is a slight decrease in the topsoil water content from harvest to post-season due to evaporation. It is evident that from planting the soil water was extracted from the topsoil to approximately 1600 mm where an increase in soil water is observed for the boll formation, harvest, and post-season period. The clear increase in soil water from 1600–2000 mm in both the harvest and post-season periods suggest that soil water accumulated on the soft plinthic horizon which forms a water table. This feature is due to the interflow capabilities of the subsoil horizon. This soil profile had a big amount of soil water throughout the season which illustrates the effect of the yellow and red colours in the yellow-brown apedal horizon.

5.3.8.3.2 Bloemdal

Figure 5-30 illustrates the soil water depth graph of the Bloemdal soil form. It is evident that there is a decrease in soil water from planting to harvest. During post season there is an increase in soil water throughout the soil profile in comparison with the harvest period. This is due to the downward flow of the soil water deeper in the soil profile. There is a slight decrease in the topsoil from harvest to post-season due to evaporation. The harvest soil water line indicates a decrease in soil water with depth from 300–700 mm and then increases slightly from 700–800 mm to a soil water content the same as in the topsoil which illustrates that the cotton extracted most water from 300–700 mm in the soil profile and drainage from the subsoil horizons occurred. From 700–800 mm the gleyic horizon becomes prominent and soil water extraction by the taproot harder. The planting and post-season curve which seems to be similar indicate that approximately the same amount of soil water is present during planting than what were present in the post-season.

5.3.8.3.3 Sepane

Figure 5-31 illustrates the soil water depth graph for the Sepane soil form. The planting soil water line illustrates a clear increase in soil water with depth. When considering planting and post-season curves it is evident that the same trend is followed, except less soil water is left post season than by planting time. In the boll formation curve, it is evident that a significant water loss occurs from boll formation to harvest because of the increased soil water needs of the cotton during this growth stage. In the harvest curve it is evident that there is a decrease of soil water

with depth from 300-700 mm, from which there is a slight increase in soil water from 700-800 mm indicating that soil water was extracted by the cotton from 300–700 mm. In the section from 700–800 mm slight water accumulation occurs. When considering the post-season curve this curve indicates that less soil water was left post-harvest than there was during planting in the Sepane soil form due to interflow, drainage and cotton soil water consumption.

5.3.8.3.4 Westleigh

Figure 5-32 illustrates the soil water depth profile of the Westleigh soil form. It is evident that there is a decrease in soil water from the planting to harvest and post-season. When considering all four the lines it is evident that there is an increase in soil water with depth. This implies that the amount of soil water did indeed increase from the time of planting up until harvest even with the extraction of soil water by the cotton. In the boll formation curve, it is evident that a significant water loss occurs from boll formation to harvest because of the increased soil water needs of the cotton during this growth stage. There is a slight decrease from 300–400 mm in the soil water content due to evaporation. The effect of the soft plinthic and gleyic subsoil horizons is evident, but not clear indication exists of water accumulation on the gleyic limiting horizon. Less soil water is present post-season than by planting time.

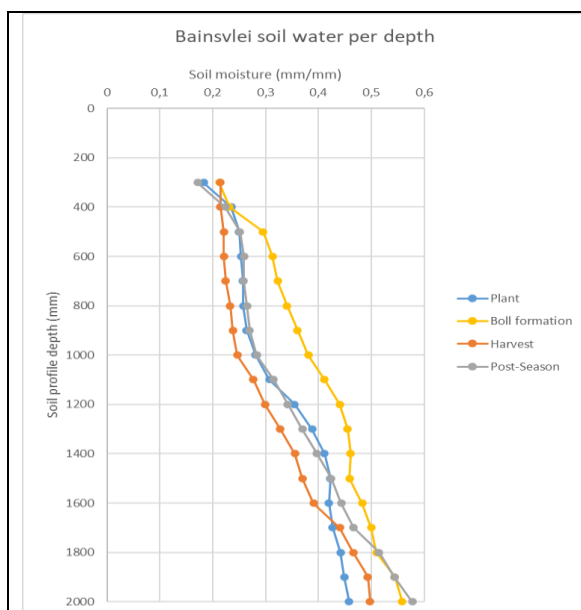


Figure 5-29: Soil water depth profile of the Bainsvlei soil form in the Hoekblok.

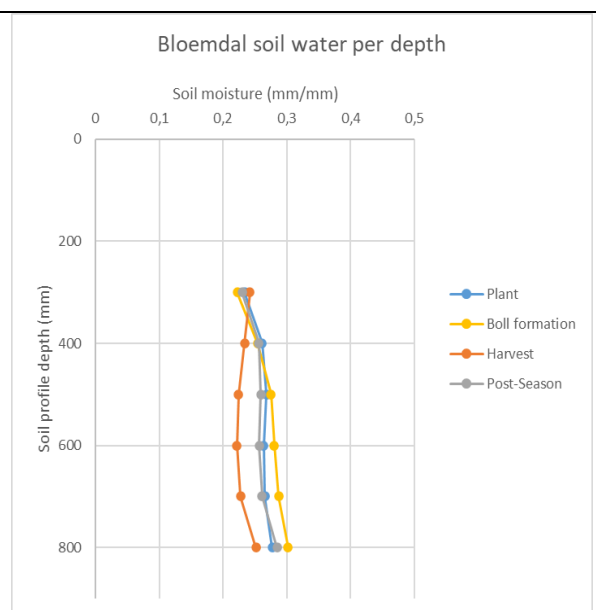
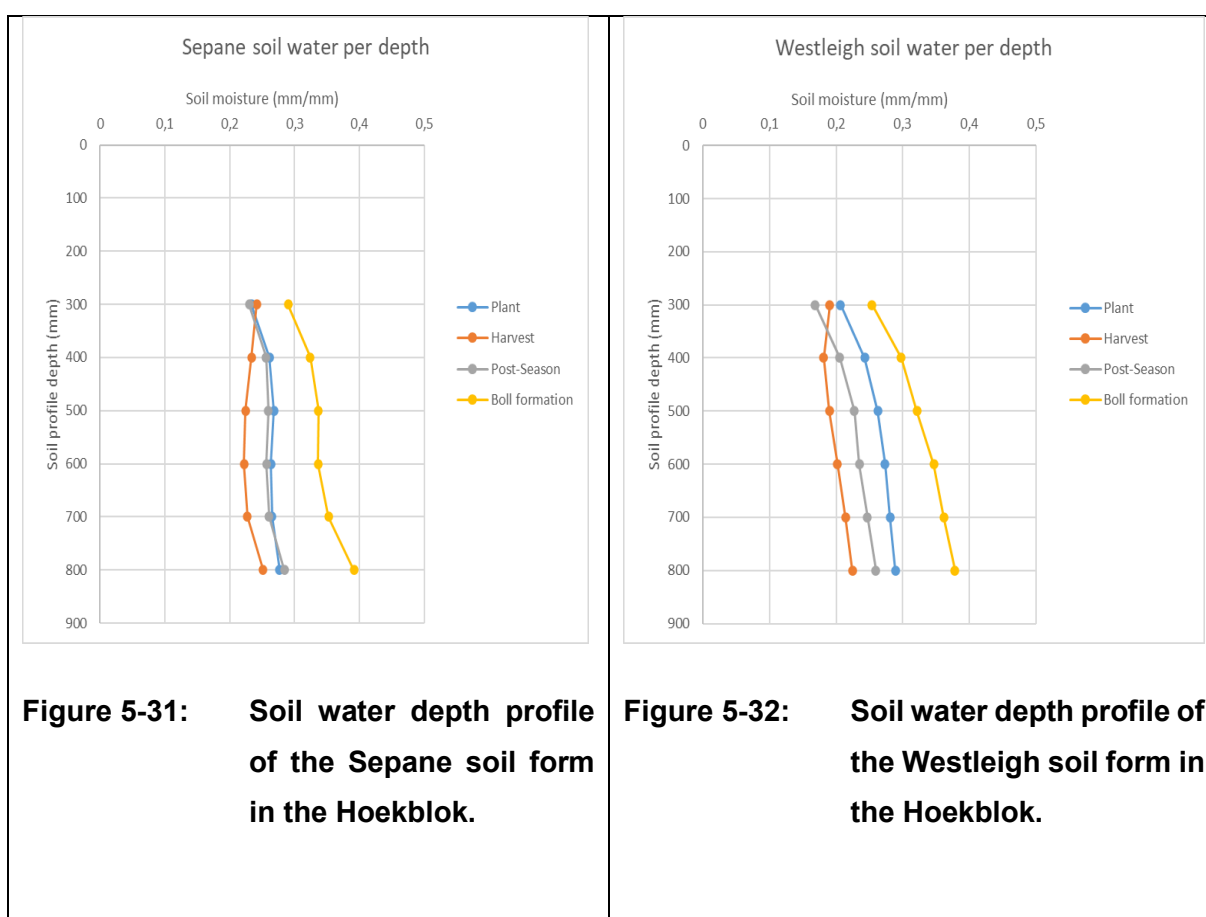


Figure 5-30: Soil water depth profile of the Bloemdal soil form in the Hoekblok.



5.3.8.4 Teerpadblok Soil Water Depth Profiles

5.3.8.4.1 Avalon

Figure 5-33 illustrates the soil water depth profile for the Avalon soil form. By considering the planting curve it is evident that there is an increase from 300-500 mm from where it stays constant up to 600 mm and then increases up to 700 mm indicating a small accumulation of soil water on the limiting layer which is soft plinthite. In the boll formation curve, it is evident that a significant water loss occurs from boll formation to harvest because of the increased soil water needs of the cotton during this growth stage. When considering the harvest curve, it is evident that there is a decrease in soil water up to 600 mm followed by an increase up to 700 mm but the amount of soil water at 700 mm is less than in the topsoil horizon. This indicates that the taproot system of the cotton extracted soil water from the top to the bottom of the soil profile during the season. From the boll formation stage, roots are situated in the limiting layer horizon from where more soil water can be extracted to the needs of the growth stage. In the post-season curve the amount of soil water increased due to interflow, but it is still much less than what was available during planting time.

5.3.8.4.2 Tukulu

Figure 5-34 illustrates the soil water depth profile of the Tukulu soil form. It is evident that there is a clear difference in the amount of soil water during planting versus the amount of soil water during boll formation, harvest and post-season. By considering the planting curve there is an increase of soil water with depth and accumulation of soil water on the limiting layer is visible. In the period of planting in this cotton field, a few high rainfall events occurred which resulted in the increase of water in the subsoil profile. In the boll formation curve, it is evident that a significant water loss occurs from boll formation to harvest because of the increased soil water needs of the cotton during this growth stage at depths 300-700 mm. When considering the harvest and post-season curves, it is evident that there is less soil water present than during planting. The harvest curve has more soil water in the topsoil horizon, but this is due to the rainfall events just before harvest. The amount of soil water of the harvest curve decreases from 300–700 mm and then increases slightly. This indicates that the taproot system of the cotton extracted soil water from the top to the bottom of the soil profile during the season, especially during boll formation. In the post-season curve, the amount of soil water increased due to interflow, but it is still much less than what was available during planting time.

5.3.8.4.3 Oakleaf

Figure 5-35 illustrates the soil water depth profile of the Oakleaf soil form. By considering the planting curve it is evident that there is a slight increase in soil water with depth. In the boll formation curve, it is evident that a significant water loss occurs from boll formation to harvest because of the increased soil water needs of the cotton during this growth stage. When considering the harvest curve, it is evident that there is a slight decrease in soil water from the planting period. There is a constant soil water content throughout the soil profile with an abrupt increase from 700-800 mm. This is a clear indication of accumulation of water on the limiting horizon. The amount of soil water in the Oakleaf soil profile is slightly higher than during planting which is due to the interflow capabilities on the limiting layer horizon and the structure of the neocutanic subsoil horizon.

5.3.8.4.4 Westleigh

Figure 5-36 illustrates the soil water depth profile of the Westleigh soil form. It is evident that there is an increase in soil water from planting to boll formation and a decrease in soil water from boll formation to harvest, followed by an increase from harvest to post-season. In the boll formation curve, it is evident that a significant water loss occurs from boll formation to harvest because of the increased soil water needs of the cotton during this growth stage.

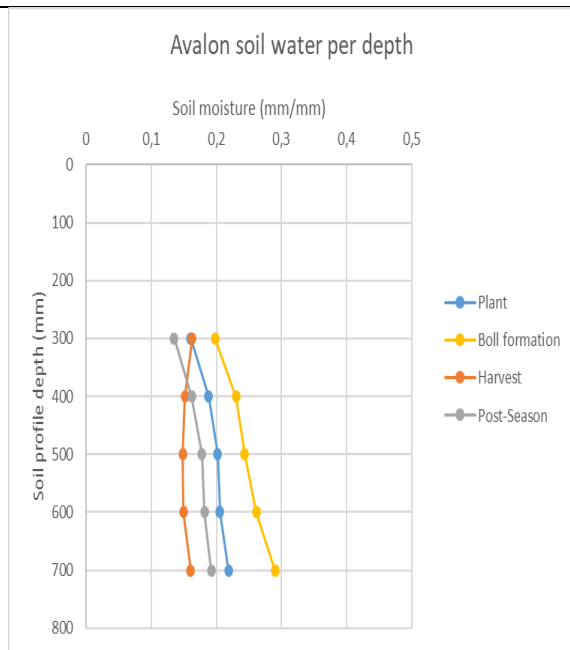


Figure 5-33: Soil water depth profile of the Avalon soil form in the Teerpadblok.

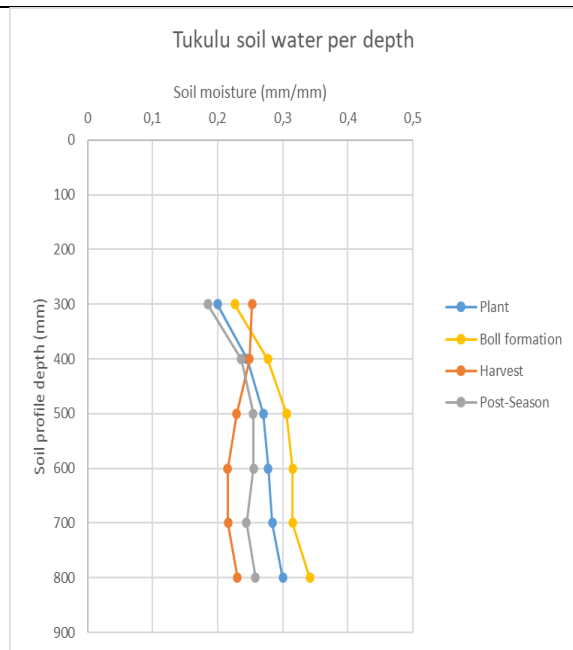


Figure 5-34: Soil water depth profile of the Tukulu soil form in the Teerpadblok.

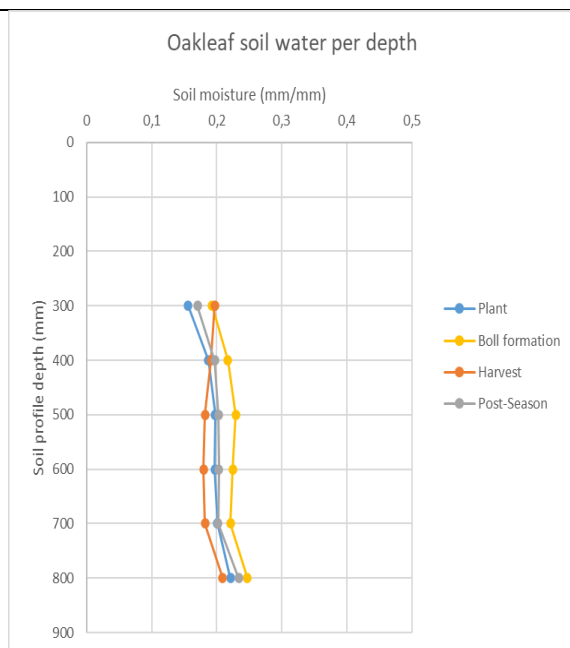


Figure 5-35: Soil water depth profile of the Oakleaf soil form in the Teerpadblok.

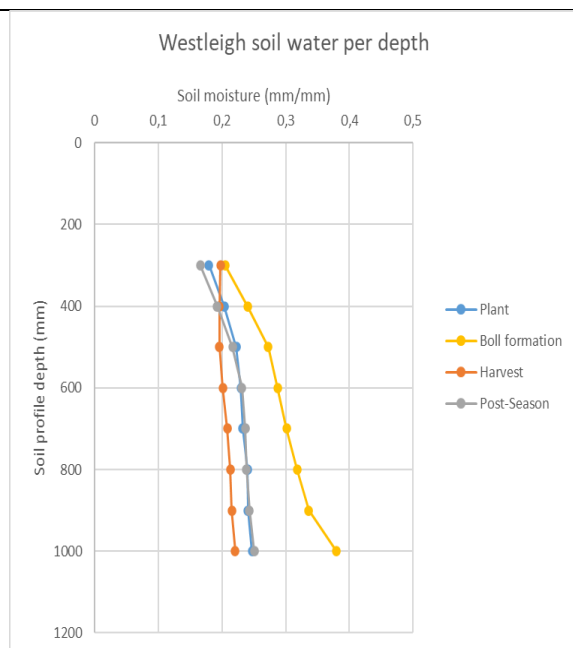


Figure 5-36: Soil water depth profile of the Westleigh soil form in the Teerpadblok.

The most significant soil water loss during boll formation to harvest is from 500-1000 mm. When considering the harvest curve, the amount of soil water remains constant with depth throughout the soil profile. Since the Westleigh soil form has interflow capabilities a constant source of water must be available to keep this trend, meaning a constant flow of soil water is occurring in the soil profile. During this section of the Westleigh soil profile the soft plinthic horizon becomes more prominent and the effect of the gleyic limiting horizon becomes more inevitable. At the depth between 900-1000 mm the amount of soil water increases indicating an accumulation of water, especially during boll formation.

5.3.8.5 Season 2 Soil Water Characteristics

5.3.8.5.1 Hoekblok Soil Water Retention Characteristics

Table 5-25 illustrates the soil water retention characteristics of the four dominant soil forms in the Hoekblok. The dry bulk density varies between 1,44 and 1,52 for the A horizon, and between 1,42 and 1,45 in the B horizon. Statistical analysis yield that there is statistical significance between all the soil forms in terms of both the A and B horizon dry bulk density with the p-value <0,05. The A horizon dry bulk density is higher than the B horizon dry bulk density and due to this the infiltration of water is affected due to the higher density. The increase in the A horizon density is mainly due to the machinery used to work the soil and plant. The difference between the A horizons is not much due to the similar diagnostic topsoil horizon. The Sepane and Westleigh soil forms have the highest B horizon dry bulk density, and this is due to the structure of the pedocutanic horizon in the Sepane which is prone to compaction and resulting in a higher dry bulk density, and they gleyic horizon in the Westleigh, which by nature is much denser. The Bainsvlei soil form has the second highest B horizon dry bulk density, and this is due to structure forming when the soil is dried out. The Bloemdal soil form B horizon is the counterpart of the Bainsvlei B horizon, with the only difference being the Bloemdal soil form having a gleyic limiting layer. This influences the density of the soil as it consists of more air and water which results in a lower density. A trend is observed that the soil forms with a higher clay content and both having a gleyic limiting layer has the highest dry bulk density.

When considering the Drained upper limit (DUL) in Table 5-25 it is evident that the Bloemdal has the highest DUL in the A horizon followed by the Sepane, Westleigh and Bainsvlei soil forms in decreasing order. The DUL values of the A horizon does not differ much from one another since it is classified as the same diagnostic topsoil horizon. When considering the Lower limit (LL) of the A horizon the Sepane has the highest LL followed by the Westleigh, Bloemdal and Bainsvlei in decreasing order. The soil forms with a higher clay content are prone to have a higher DUL and higher LL which may cause crop stress easily after high rainfall periods. The DUL of the B horizon

varies much more because the different soils have different subsoil horizons with different water retention capabilities. Considering Table 5-25 it is evident that the Bainsvlei soil form has the highest DUL followed by the Westleigh, Sepane and Bloemdal soil forms. The LL of the B horizon does vary between the different soil forms, and statistical significance is evident between the different soil forms. The post-hoc statistical analysis indicated that all the soil forms' DUL and LL differ from one another statistically. Due to the statistical difference between the different soil forms DUL and LL the Planting available water (PAW) varies between the different soil forms as well because the PAW is derived from the DUL and LL. The soil forms vary statistically due to the p-value = 0 which indicates that the soil forms are indeed statistically different in DUL, LL and PAW and as such the ANOVA table was included for this field.

Table 5-25: Drained upper limit, lower limit, and dry bulk density of the soil forms.

Soil form	Horizon	Dry Bulk Density (g/cm ³)	DUL (mm)	LL (mm)	PAW (mm)
Bainsvlei	A	1,45	42,76	10,80	31,96
Bainsvlei	B	1,43	296,84	120,19	176,65
Bloemdal	A	1,44	55,81	11,62	44,20
Bloemdal	B	1,42	108,61	39,55	69,05
Sepane	A	1,47	54,11	12,29	41,83
Sepane	B	1,45	134,18	53,28	80,89
Westleigh	A	1,52	44,12	12,15	31,97
Westleigh	B	1,45	146,71	55,30	91,42

5.3.8.5.2 Teerpadblok Soil Water Retention Characteristics

Table 5-26 illustrates the soil water retention characteristics of the four dominant soil forms in the Teerpadblok. The dry bulk density varies between 1,45 and 1,57 for the A horizon, and between 1,34 and 1,46 for the B horizon. Statistical analysis yield that there is an extreme statistical significance between all the soil forms in terms of both the A and B horizon dry bulk density with the p-value <0,05. The A horizon dry bulk density is higher than the B horizon dry bulk density and due to this, the infiltration of water is affected due to the higher density. The increase in the A horizon density is mainly due to the machinery used to work the soil and plant. The difference between the A horizons varies quite with the Oakleaf having the highest A horizon bulk density followed by the Westleigh, Tukulu and Avalon soil forms in decreasing order. The Oakleaf soil form has the highest B horizon dry bulk density. The Tukulu soil form has the second highest B horizon dry bulk density, and this is due to the structure of the neocutanic horizon which is prone to compaction and results in a higher dry bulk density.

When considering the Drained upper limit (DUL) in Table 5-26 it is evident that the Oakleaf soil form has the highest DUL in the A horizon followed by the Tukulu, Westleigh and Avalon soil forms in decreasing order. The DUL values of the A horizon does not differ much from one another since it is classified as the same diagnostic topsoil horizon. When considering the Lower limit (LL) of the A horizon the Westleigh has the highest LL followed by the Tukulu, Avalon and Oakleaf soil forms in decreasing order. The soil forms that have a low DUL and higher LL which may cause crop stress easily after high rainfall periods.

The DUL of the B horizon varies much more because the different soils have different subsoil horizons with different water retention capabilities. In the Teerpadblok field non-uniform soils in terms of the B horizon exist and a high statistical difference is evident. Considering Table 5-26 it is evident that the Avalon soil form has the highest DUL followed by the Oakleaf, Tukulu and Westleigh soil forms. Considering Table 5-26 the Oakleaf soil form has the highest LL followed by the Avalon, Tukulu, and Westleigh soil forms. The difference between the LL of the other soil forms except the Westleigh LL does not vary much from one another. The post-hoc statistical analysis indicated that all the soil forms' DUL, LL, and PAW differ from one another statistically. Due to the statistical difference between the different soil forms DUL and LL the PAW varies between all soil forms. No table is included as all the p-value = 0 which is highly statistically different.

Table 5-26: Drained upper limit, lower limit, and dry bulk density of the soil forms.

Soil form	Horizon	Dry Bulk Density (g/cm ³)	DUL (mm)	LL (mm)	PAW (mm)
Avalon	A	1,45	48,74	15,34	33,39
Avalon	B	1,34	165,17	50,90	114,27
Tukulu	A	1,47	53,27	16,19	37,08
Tukulu	B	1,45	117,85	50,81	67,03
Oakleaf	A	1,57	53,72	13,83	39,90
Oakleaf	B	1,46	127,24	65,30	61,94
Westleigh	A	1,56	51,77	17,74	34,03
Westleigh	B	1,44	95,84	27,99	67,85

5.3.8.6 Hoekblok Soil Water Regime

5.3.8.6.1 Bainsvlei

Figure 5-37 illustrates the soil water fluctuation throughout the cotton production season of the Bainsvlei soil form. Throughout the season the total amount of soil water was extremely high above the DUL. During the beginning of November 2020, the first rain was observed which assured that planting can commence. The cotton was planted on the 5th November 2020 during

which the soil form was well above the drained upper limit. Frequent rainfall events followed the planting which ensured that soil water was waterlogged which makes crop stress a real effect factor. Between the emergence and flowering growth stages the soil water was readily available for plant uptake and above DUL. The amount of soil water kept increasing well above the drained upper limit which raises the possibility of plant stress. During the period from November 2020 to February 2021, the evapotranspiration demand increased as the growth stages progress towards the flowering stage, but due to the frequent high rainfall events this increase had no real effect as the cotton water needs are rather low. During February 2020 a peak in soil water content is observed. The soil water content decreased slightly from February 2021 to March 2021 as the soil water needs of the cotton increased as the growth progressed to the boll formation and boll burst growth stages. In the period between boll formation and boll burst the soil water content became constant and no decrease or increase is evident, but in the period directly before boll burst a decline is visible. In the period from boll burst commencement to harvest the soil water content kept decreasing, but after harvested increased once more.

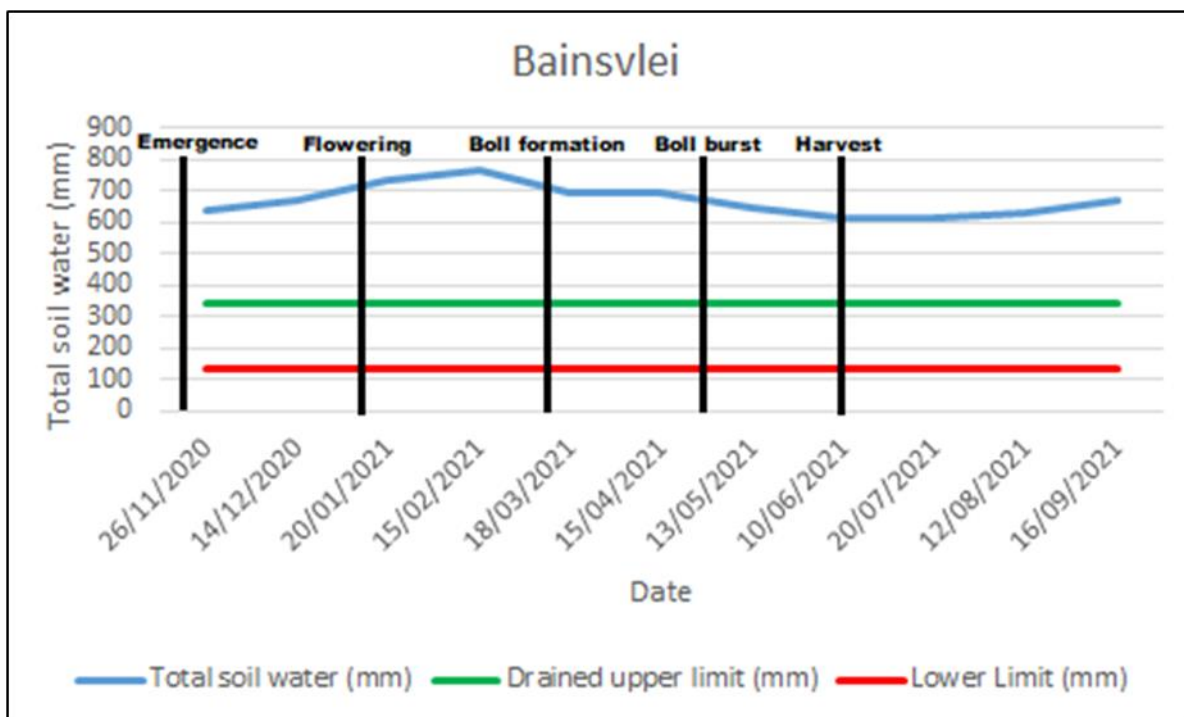


Figure 5-37: Soil water regime on the Bainsvlei soil form in the Hoekblok.

5.3.8.6.2 Bloemdal

Figure 5-38 illustrates the soil water fluctuation throughout the cotton production season of the Bloemdal soil form. Throughout the season the total amount of soil water was slightly above the Drained upper limit. During the beginning of November 2019, the first rain was observed which

assured that planting can commence. The cotton was planted on the 5th November 2020 during which the soil form was well above drained upper limit. Frequent rainfall events followed the planting which ensured that soil water was waterlogged which makes crop stress a real effect factor. Between the emergence and flowering growth stages the soil water was readily available for plant uptake and slightly above DUL. The amount of soil water kept increasing well above the drained upper limit which raises the possibility of planting stress. During the period from November 2020 to February 2021, the evapotranspiration demand increased as the growth stages progress towards the flowering stage, but due to the frequent high rainfall events, this increase had no real effect as the cotton water needs are rather low. During December 2020 a peak in soil water content is observed which is much earlier than the Bainsvlei soil form. The soil water content decreased slightly from February 2021 to March 2021 as the soil water needs of the cotton increased as the growth progressed to the boll formation and boll burst growth stages. In the period between boll formation and boll burst, the soil water content became constant up to harvest. In the period from boll burst commencement to harvest, the soil water content remained constant, but after harvest increased slightly.

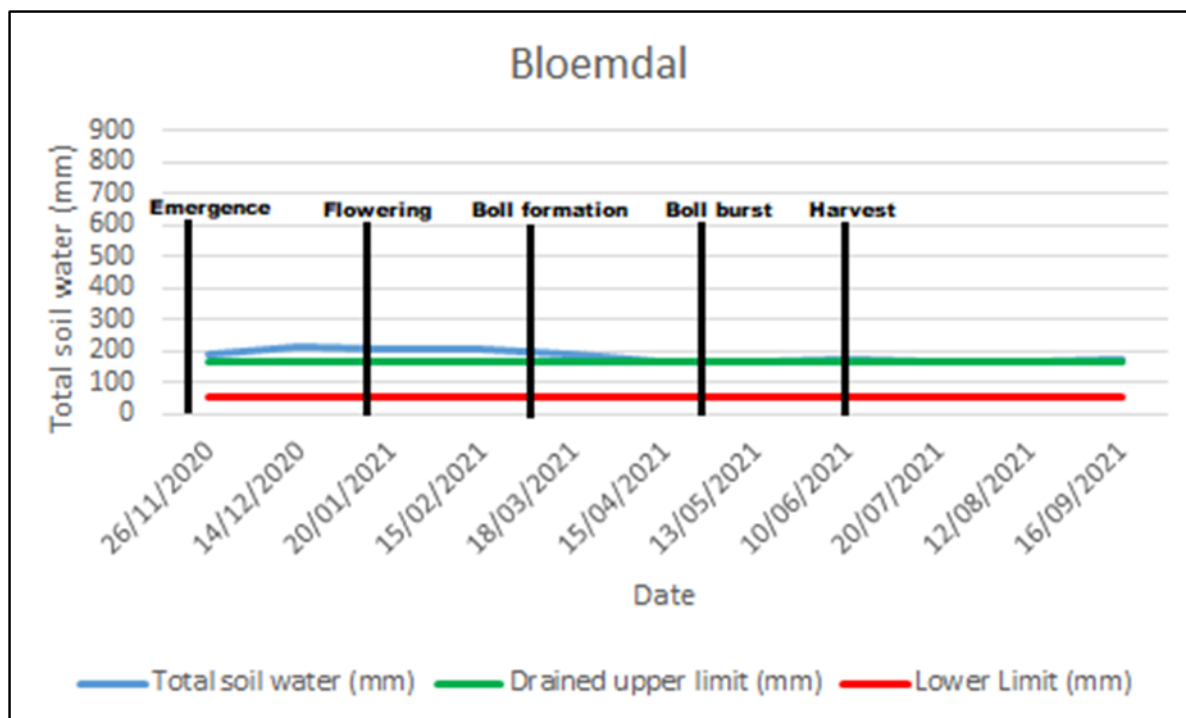


Figure 5-38: Soil water regime on the Bloemdal soil form in the Hoekblok.

5.3.8.6.3 Sepane

Figure 5-39 illustrates the soil water fluctuation throughout the cotton production season of the Sepane soil form. Throughout the season the total amount of soil water was slightly above the

drained upper limit, but higher for the Sepane than Bloemdal. During the beginning of November 2019, the first rain was observed which assured that planting can commence. The cotton was planted on the 5th November 2020 during which the soil form was slightly above the drained upper limit. Frequent rainfall events followed the planting which led to the soil water content rising above DUL which makes crop stress a real effect factor. Between the emergence and flowering growth stages the soil water was readily available for plant uptake and slightly above DUL. The amount of soil water kept increasing well above the drained upper limit which raises the possibility of plant stress. During the period from November 2020 to February 2021, the evapotranspiration demand increased as the growth stages progress towards the flowering stage, but due to the frequent high rainfall events, this increase had no real effect as the cotton water needs are rather low. During February 2021 a peak in soil water content is observed. The soil water content decreased slightly from February 2021 to March 2021 as the soil water needs of the cotton increased as the growth progressed to the boll formation and boll burst growth stages. In the period between boll formation and boll burst, the soil water content became constant up to harvest. In the period from boll burst commencement to harvest, the soil water content remained constant, but after harvest increased slightly.

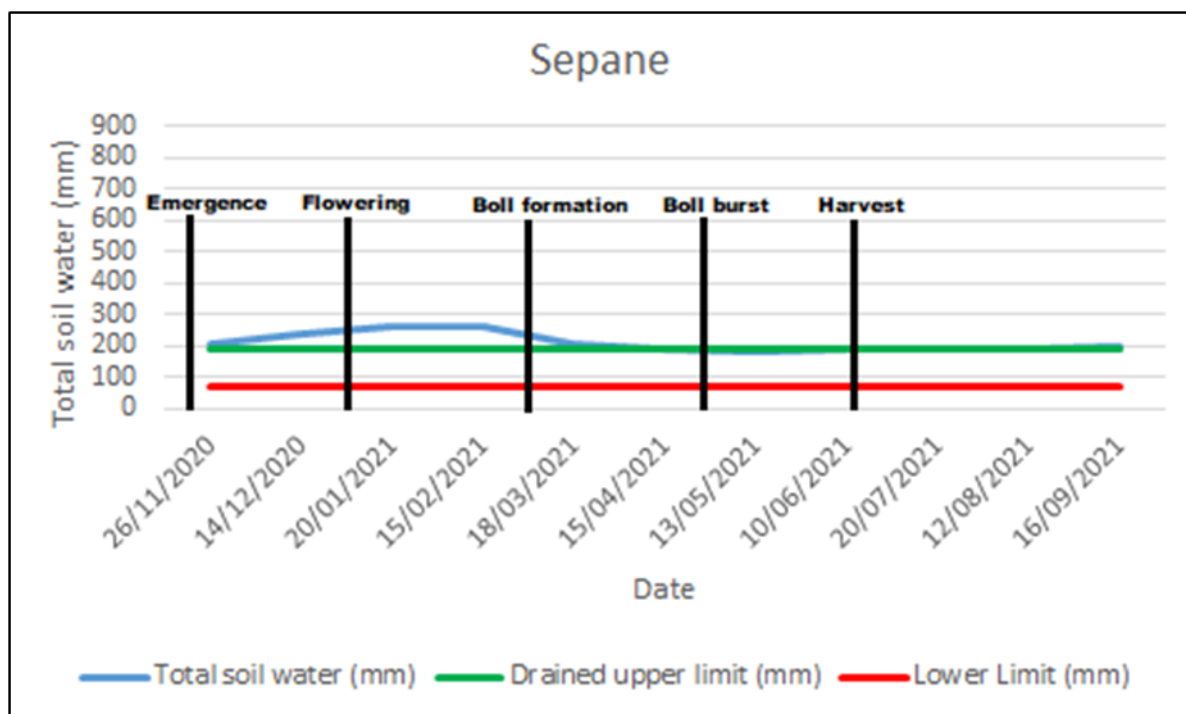


Figure 5-39: Soil water regime on the Sepane soil form in the Hoekblok.

5.3.8.6.4 Westleigh

Figure 5-40 illustrates the soil water fluctuation throughout the cotton production season of the Westleigh soil form. Throughout the season the total amount of soil water was slightly above the DUL, but higher for the Westleigh than Bloemdal or Sepane. During the beginning of November 2019, the first rain was observed which assured that planting can commence. The cotton was planted on the 5th November 2020 during which the soil form was well above the drained upper limit. Frequent rainfall events followed the planting which led to the soil water content rising above DUL which makes crop stress a real effect factor. Between the emergence and flowering growth stages the soil water was readily available for plant uptake and slightly above DUL. The amount of soil water kept increasing well above the drained upper limit which raises the possibility of plant stress. During the period from November 2020 to February 2021 the evapotranspiration demand increased as the growth stages progress towards the flowering stage, but due to the frequent high rainfall events this increase had no real effect as the cotton water needs are rather low. During January 2021 a peak in soil water content is observed which is earlier than that of the Bainsvlei and Sepane. The soil water content decreased from January 2021 to March 2021 as the soil water needs of the cotton increased as the growth progressed to the boll formation and boll burst growth stages. In the period between boll formation and boll burst the soil water content became constant, slightly decreasing after boll burst but remaining constant up to harvest. In the period from boll burst commencement to harvest the soil water content remained constant, but after harvest increased slightly.

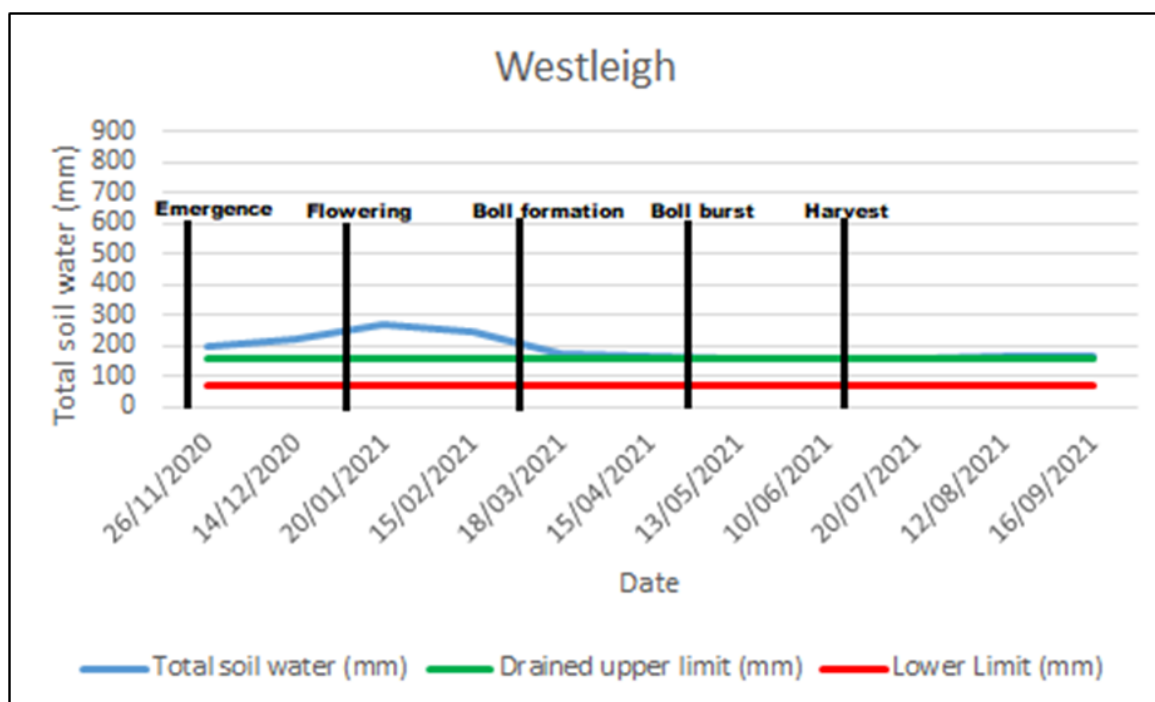


Figure 5-40: Soil water regime on the Westleigh soil form in the Hoekblok.

5.3.8.7 Teerpadblok Soil Water Regime

5.3.8.7.1 Avalon

Figure 5-41 illustrates the soil water fluctuation throughout the cotton production season of the Avalon soil form. During November 2020 the total amount of soil water was well above the lower limit which mean that water is readily available for plant uptake. During the beginning of November 2020, the first rain was observed which assured that planting can commence. The cotton was planted on the 2nd November 2020. Frequent rainfall events followed the planting which ensured that soil water was available for uptake during the emergence of the cotton. Between the emergence and flowering growth stages the soil water was readily available for plant uptake and waterlogged conditions was observed towards the end of January 2020 just before flowering commenced. During the period from November 2020 to January 2021 the evapotranspiration demand increased as the growth stages progress towards the flowering stage, but due to the frequent high rainfall events this increase had no real effect as the cotton water needs are rather low. During January 2021 a peak in soil water content is observed during the flowering growth stage. The soil water content decreased drastically from January 2021 to March 2021 as the soil water needs of the cotton increased as the growth progressed to the boll formation growth stage. In the period from boll burst commencement to harvest the soil water content increased slightly. The soil profile was never above DUL and as such no crop water stress was visible throughout the season.

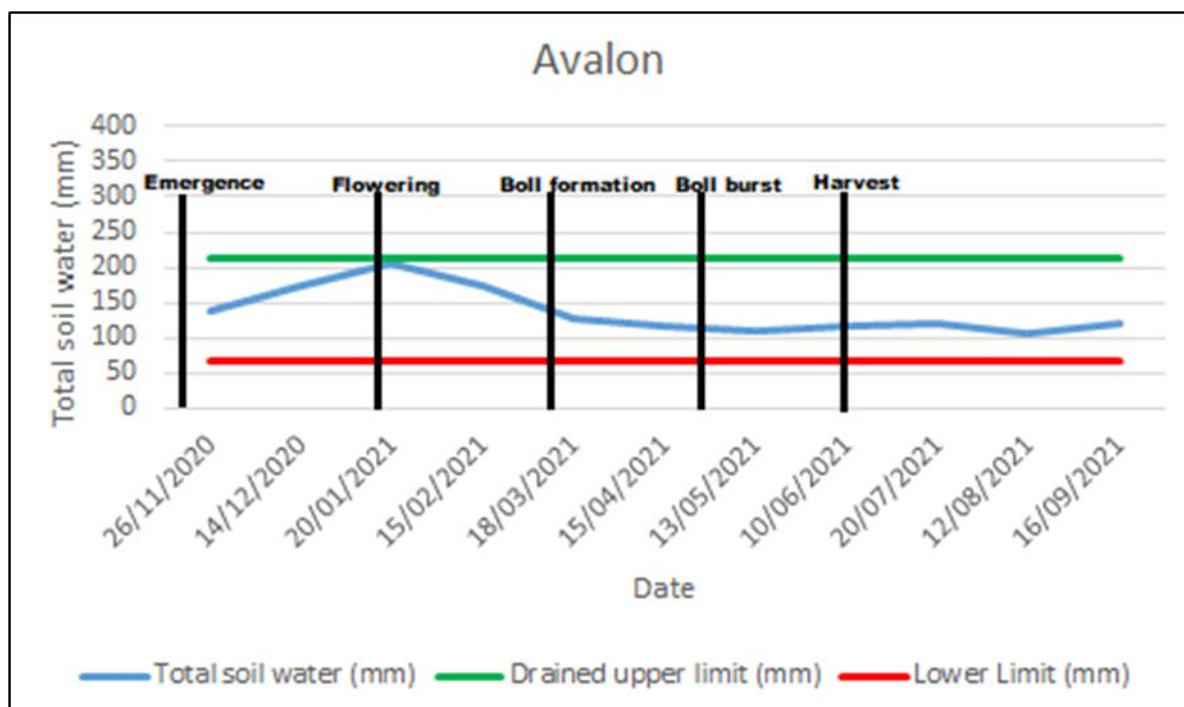


Figure 5-41: Soil water regime on the Avalon soil form in the Teerpadblok.

5.3.8.7.2 Tukulu

Figure 5-42 illustrates the soil water fluctuation throughout the cotton production season of the Tukulu soil form. During November 2020 the total amount of soil water was well above the drained upper limit. During the beginning of November 2020, the first rain was observed which assured that planting can commence. The cotton was planted on the 2nd of November 2020. Frequent rainfall events followed after planting which ensured that soil water was available for uptake during the emergence of the cotton. Between the emergence and flowering growth stages the soil water was readily available for plant uptake and soil water conditions above DUL is observed towards the end of March 2021 just before boll formation commenced. During the period from November 2020 to January 2021 the evapotranspiration demand increased as the growth stages progress towards the flowering stage, but due to the frequent high rainfall events this increase had no real effect as the cotton water needs are rather low. During January 2021 a peak in soil water content is observed during the flowering growth stage. The soil water content decreased drastically from January 2021 to March 2021 as the soil water needs of the cotton increased as the growth progressed to the boll formation growth stage. In the period from boll formation commencement to boll burst the soil water decreased slightly to below DUL. From boll burst to harvest the soil water increased to above DUL once again. From harvest the soil water content decreased once more to below DUL. The soil water content was above DUL throughout the season during critical growth stages and as such crop water stress could affect the yield and quality of the cotton.

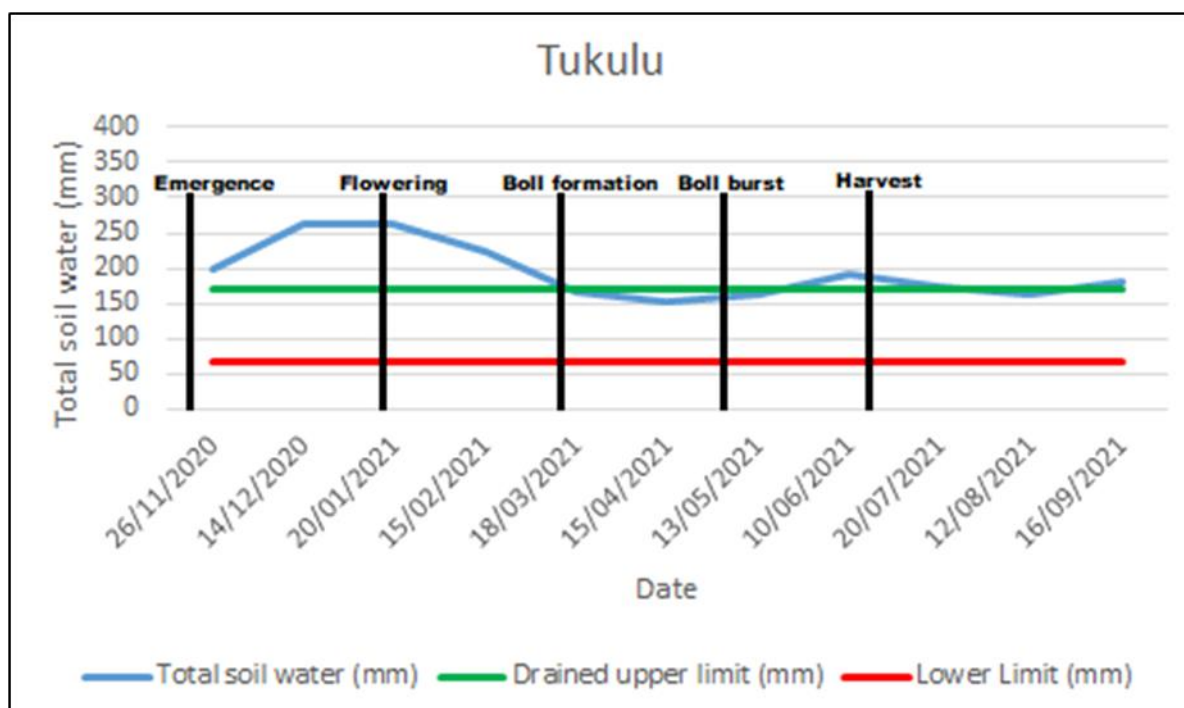


Figure 5-42: Soil water regime on the Tukulu soil form in the Teerpadblok.

5.3.8.7.3 Oakleaf

Figure 5-43 illustrates the soil water fluctuation throughout the cotton production season of the Oakleaf soil form. During November 2020 the total amount of soil water was well above the lower limit. During the beginning of November 2020, the first rain was observed which assured that planting can commence. The cotton was planted on the 2nd November 2020. Frequent rainfall events followed the planting which ensured that soil water was available for uptake during the emergence of the cotton. Between the emergence and flowering growth stages the soil water was readily available for plant uptake. During the period from November 2020 to January 2021 the evapotranspiration demand increased as the growth stages progress towards the flowering stage, but due to the frequent high rainfall events this increase had no real effect as the cotton water needs are rather low. During January 2021 a peak in soil water content is observed during the flowering growth stage. The soil water content decreased drastically from January 2021 to March 2021 as the soil water needs of the cotton increased as the growth progressed to the boll formation growth stage. In the period from boll formation commencement to boll burst the soil water decreased slightly. From boll burst to harvest the soil water increased slightly but is still below DUL and water is readily available for planting uptake. From harvest the soil water content decreased slightly. The soil profile was never waterlogged throughout the season and as such crop water stress does not affect the yield and quality of the cotton.

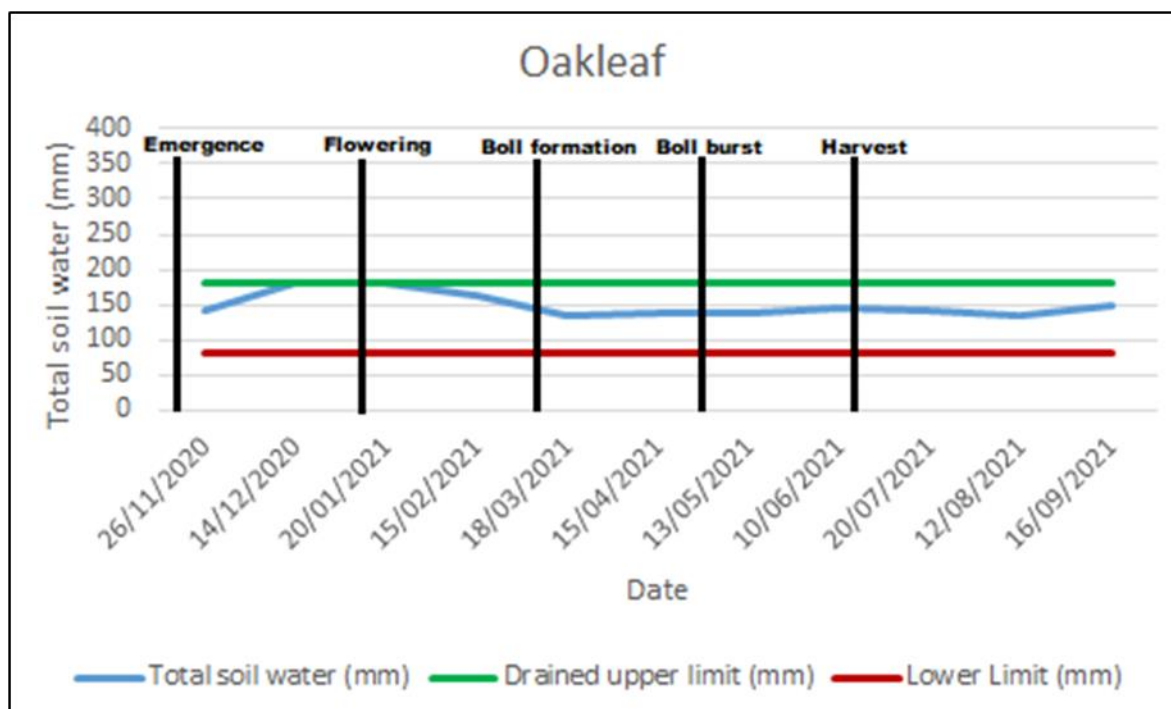


Figure 5-43: Soil water regime on the Oakleaf soil form in the Teerpadblok.

5.3.8.7.4 Westleigh

Figure 5-44 illustrates the soil water fluctuation throughout the cotton production season of the Westleigh soil form. Throughout the season the total amount of soil water was extremely high above the DUL. During the beginning of November 2020, the first rain was observed which assured that planting can commence. The cotton was planted on the 2nd November 2020 during which the soil form was well above drained upper limit. Frequent rainfall events followed the planting which ensured that the soil water content was above DUL which makes crop stress a real effect factor. Between the emergence and flowering growth stages the soil water was readily available for plant uptake and above DUL. The amount of soil water kept increasing well above the drained upper limit which raises the possibility of plant stress. During the period from November 2020 to January 2021 the evapotranspiration demand increased as the growth stages progress towards the flowering stage, but due to the frequent high rainfall events this increase had no real effect as the cotton water needs are rather low. During January 2021 a peak in soil water content is observed during the flowering stage. The soil water content decreased significant from January 2021 to March 2021 as the soil water needs of the cotton increased as the growth progressed to the boll formation and boll burst growth stages. In the period between boll formation and boll burst the soil water content decreased still, but in the period directly before boll burst the soil water content remained constant. In the period from boll burst commencement to harvest the soil water content increased slightly, but after harvest decreased once more.

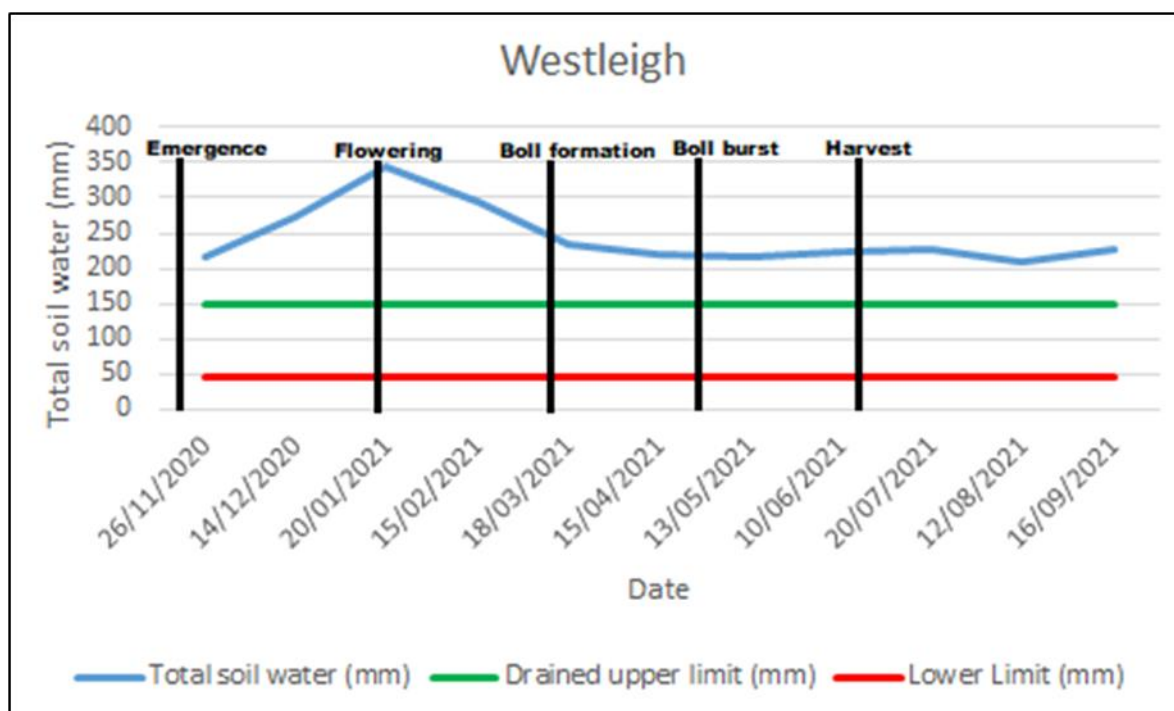


Figure 5-44: Soil water regime on the Westleigh soil form in the Teerpadblok.

5.3.9 Cotton Yield and Quality

5.3.9.1 Hoekblok Cotton Yield

Figure 5-45 illustrates the cotton yield data per soil form for the Hoekblok cotton field for the 2020/2021 production season. From Figure 5-45 it is evident that the Westleigh soil form produced the highest cotton yield at 3,15 ton/ha. The Sepane soil form produced the second highest yield with 2,64 ton/ha. The third highest producing soil form is the Bainsvlei soil form with 2,54 ton/ha. The lowest yield was measured on the Bloemdal soil form with 2,37 ton/ha. The average cotton yield for Pretorius Rust was 2,68 ton/ha.

No statistical differences in yield were produced between the four dominant soil forms of the Hoekblok. From the results it is evident that the sandy clay soils, Sepane and Westleigh, produced the highest yield in comparison with the sandy clay loam soils, Avalon and Bloemdal. The Hoekblok cotton field produced an above national average cotton yield in the 2020/2021 cotton season.

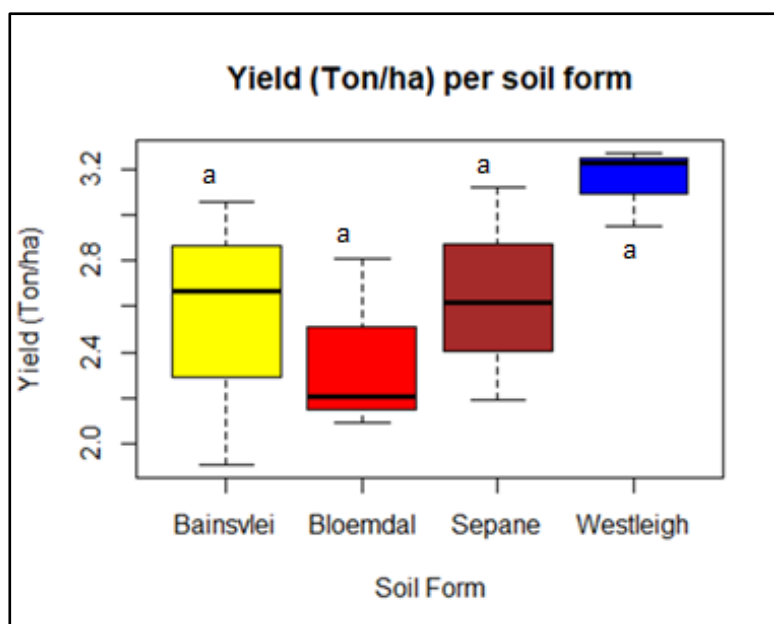


Figure 5-45: Hoekblok cotton yield (ton/ha) per soil form.

5.3.9.2 Teerpadblok cotton yield

Figure 5-46 illustrates the cotton yield data per soil form for the Teerpadblok cotton field for the 2020/2021 production season. From Figure 5-46 it is evident that the Oakleaf soil form produced the highest cotton yield at 3,60 ton/ha. The Westleigh soil form produced the second highest yield with 3,50 ton/ha. The third highest producing soil form is the Tukulu soil form with 3,20 ton/ha.

The lowest yield was measured on the Avalon soil form with 2,70 ton/ha. The average cotton yield for the Teerpadblok was 3,25 ton/ha.

No statistical differences in yield were produced between the four dominant soil forms of the Teerpadblok. From the results it is evident that the sandy clay soils, Oakleaf, Tukulu and Westleigh, produced the highest yield in comparison with the sandy clay loam soils such as the Avalon. The Teerpadblok cotton field produced a well above nation average cotton yield in the 2020/2021 cotton season.

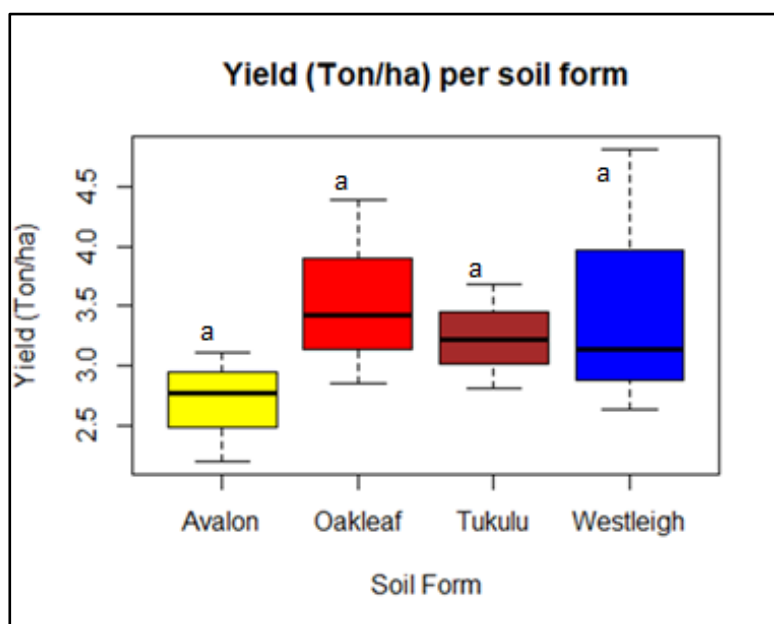


Figure 5-46: Teerpadblok cotton yield (ton/ha) per soil form.

5.3.9.3 Hoekblok Cotton Quality

Table 5-27 were generated by compiling averages of all the cotton quality parameters from the repetitive sampling points for each soil form. The data is discussed per soil property and assigned to a cotton quality class on basis of a classification scheme considering these quality properties and the current value of the specific cotton class. Statistical analysis revealed that there is distinct significant difference between the cotton quality parameters of the Hoekblok.

Statistical differences occurred between the soil forms for the upper half mean length (UHML) and for the strength. Table 5-28 illustrates the significance level by means of the p-value and the associated comparison with distinct differences.

Table 5-27: Hoekblok cotton fibre quality per soil form.

Soilform	UHML	Strength	Micronaire	Class	Price	Price Differential (%)
Bainsvlei	1,13 a	28,08 a	4,53 a	AO	R22,70	13,5
Bloemdal	1,18 b	31,55 b	4,73 a	AX	R23,20	16
Sepane	1,15 c	30,05 a	4,55 a	AO	R22,70	13,5
Westleigh	1,13 a	28,75 a	4,53 a	AO	R22,70	13,5

From Table 5-28 it is evident that distinct differences occur between the Bloemdal and Bainsvlei, and the Westleigh and Bloemdal in terms of the UHML and strength. The strength comparison between the Westleigh and Bloemdal yielded a p-value of 0,0983423 which is not statistically different by means of 95% confidence, but it is still significantly close.

Table 5-28: Tukey post-hoc comparison test of the UHML, Strength and Micronaire of the soil forms in the Hoekblok.

Comparison	P-value (UHML)	P-Value (Strength)	P-value (Micronaire)
Bloemdal-Bainsvlei	0,0275581 *	0,0301270 *	0.6266481
Sepane-Bainsvlei	0,5407486	0,3355318	0.9990526
Westleigh-Bainsvlei	0,9999919	0,9352615	0.9999922
Sepane-Bloemdal	0,3353366	0,5656353	0.7081679
Westleigh-Bloemdal	0,0292452 *	0,0983423	0.6432738
Westleigh-Sepane	0,5574660	0,6678526	0.9995163

* Indicates a statistically significant difference

It is evident that the Bloemdal soil form has the highest UHML with 1,18 inches. The second highest UHML is that of the Sepane soil form with 1,15 inches, followed by the Westleigh and Bainsvlei soil forms with 1,13 inches. The higher the UHML, the higher the spinning consistency will be, and a higher price value will be assigned to the cotton fibre batch.

The highest fibre strength is that of the Bloemdal soil form with 31,55 g/tex, followed by the Sepane soil form with 30,05 g/tex. The Westleigh soil form has the third strongest fibre strength with 28,75 g/tex. The Bainsvlei soil form has the least strong cotton fibre with a strength of 28,08 g/tex. All the above soil form strength values are categorized as medium strength. It is evident that the sandy clay loam soil, the Bloemdal, produced the strongest fibres, but the Sepane soil form which is a sandy clay produced almost the same strength cotton.

The soil form producing the highest micronaire value is the Bloemdal soil form with 4,73. The second highest micronaire produced is that of the Sepane soil form with 4,55. The third highest

micronaire is that of the Westleigh and Bainsvlei soil forms with 4,53. All the soil forms micronaire is classified as medium. It is evident that the sandy clay loam soil the Bloemdal, produced the highest micronaire cotton fibre in comparison with the sandy clay soils Sepane and Westleigh, and the other sandy clay loam soil the Bainsvlei.

By considering Table 5-28 it is evident that the best cotton quality by class (AX) was delivered by the sandy clay loam soil, the Bloemdal. All the other soil forms fall in the group O which is the second-best quality group. There is a slight price difference between the two classes but considering the yield these small differences accounts to a big sum of money.

Table 5-29 illustrates the difference in price based off the yield and quality classes. It is evident that the yield's influence in cotton production considering the rand value of the cotton lint a hectare is highly significant. A higher yield to the cost of slightly lower quality results in a higher rand value than a higher quality to the cost of a lower yield. By considering Table 5-29 the quality of the cotton does not influence the value of the cotton, but the yield. It is more profitable to farm the higher yield soils in comparison with the soils that produce higher quality.

Table 5-29: Hoekblok influence of cotton classes on the rand value of cotton lint (ton/ha).

Soil form	Yield (ton/ha)	Price (R/kg)	Rand value per ton/ha
Bainsvlei	2,54	R22,70	R57 658,00
Bloemdal	2,37	R23,20	R54 984,00
Sepane	2,64	R22,70	R59 928,00
Westleigh	3,15	R22,70	R71 505,00

5.3.9.4 Teerpadblok Cotton Quality

Table 5-30 were generated by compiling averages of all the cotton quality parameters from the repetitive sampling points for each soil form. The data is discussed per soil property and assigned to a cotton quality class on basis of a classification scheme considering these quality properties and the current value of the specific cotton class. Statistical analysis revealed that there is distinct significant difference between the cotton quality parameters of the Teerpadblok.

Statistically significant differences occur between the soil forms for the upper half mean length (UHML) and for the Strength. Table 5-31 illustrates the significance level by means of the p-value and the associated comparison with distinct differences. From Table 5-31 it is evident that distinct differences occur between the Westleigh and Oakleaf in terms of UHML. Statistically distinct differences occur between the Westleigh and Avalon, and Westleigh and Oakleaf in terms of

strength. The micronaire comparison between the Westleigh and Avalon yielded a p-value of 0,0871855 which is not statistically different by means of 95% confidence, but it is still significantly close.

Table 5-30: Teerpadblok cotton fibre quality per soil form.

Soil form	UHML	Strength	Micronaire	Class	Price	Price Differential (%)
Avalon	1,15 a	28,48 a	4,14 a	AO	R22,70	13,5
Tukulu	1,15 a	28,83 a	4,23 a	AO	R22,70	13,5
Oakleaf	1,13 b	28,36 b	4,34 a	AO	R22,70	13,5
Westleigh	1,17 c	29,80 c	4,35 a	AO+	R22,90	14,5

It is evident that the Westleigh soil form has the highest UHML with 1,17 inches. The second highest UHML is that of the Avalon and Tukulu soil form with 1,15 inches, followed by the Oakleaf soil form with 1,13 inches. The higher the UHML, the higher the spinning consistency will be, and a higher price value will be assigned to the cotton fibre batch.

Table 5-31: Tukey post-hoc comparison test of the UHML, Strength and Micronaire of the soil forms in the Teerpadblok.

Comparison	P-value (UHML)	P-Value (Strength)	P-value (Micronaire)
Oakleaf-Tukulu	0,3456826	0,9942085	0,0998341
Tukulu-Avalon	0,9999066	0,8807890	0,7194085
Westleigh-Avalon	0,1669731	0,0502762 *	0,0871855
Tukulu-Oakleaf	0,3774269	0,7569981	0,5180507
Westleigh-Oakleaf	0,0048062 *	0,0297453 *	0,9998680
Westleigh-Tukulu	0,1494101	0,2006973	0,4767415

* Indicates a statistically significant difference

The highest fibre strength is that of the Westleigh soil form with 29,80 g/tex, followed by the Tukulu soil form with 28,83 g/tex. The Avalon soil form has the third strongest fibre strength with 28,48 g/tex. The Oakleaf soil form has the least strong cotton fibre with a strength of 28,36 g/tex. All the above soil form strength values are categorized as a medium strength. It is evident that the sandy clay soil, the Westleigh, produced the strongest fibres.

The soil form producing the highest micronaire value is the Westleigh soil form with 4,35. The second highest micronaire produced is that of the Oakleaf soil form with 4,34 which is similar to the Westleigh micronaire. The third highest micronaire is that of the Tukulu soil form with 4,23. All the soil forms micronaire is classified as medium. It is evident that the sandy clay soils the Westleigh, produced the highest micronaire cotton fibre in comparison with the sandy clay loam soils Avalon and Oakleaf.

By considering Table 5-30 it is evident that the best cotton quality by class (AO+) was delivered by the sandy clay soil, the Westleigh. All the other soil forms fall in the group O which is the second-best quality group. There is a slight price difference between the two classes but considering the yield these small differences accounts to a big sum of money.

Table 5-32 illustrates the difference in price based off the yield and quality classes. It is evident that the yield's influence in cotton production considering the rand value of the cotton lint a hectare is highly significant. A higher yield to the cost of slightly lower quality results in a bigger rand value than a higher quality to the cost of a lower yield. In the Teerpadblok the highest yield and cotton quality was produced by the Oakleaf soil form, concluding a much higher amount per hectare. By considering Table 5-29 the quality of the cotton does not influence the value of the cotton, but the yield. It is more profitable to farm the higher yield soils in comparison with the soils that produce higher quality.

Table 5-32: Teerpadblok influence of cotton classes on the rand value of cotton lint (ton/ha).

Soil form	Yield (ton/ha)	Price (R/kg)	Rand value per ton/ha
Avalon	2,70	R22,70	R61 290,00
Tukulu	3,20	R22,70	R72 640,00
Oakleaf	3,60	R22,70	R81 720,00
Westleigh	3,50+	R22,90	R80 150,00

5.4 Season 2 Conclusions

5.4.1 Hoekblok

The Hoekblok dominant soil forms are physically different in terms of texture and as a result the soil water behaviour is different. Sandy clay loam and sandy clay soils was identified as the dominant texture in the various soil forms. The Sepane and Westleigh soil forms had the highest clay percentage in the horizons. Due to the distinct difference in soil profile depth the Bainsvlei soil form had the highest soil water content throughout the season. Considering the soil forms with the same soil profile depths the Sepane soil form had the highest soil water content throughout the production season. The Westleigh soil form had the same soil water content from emergence to boll formation as the Sepane, from where a more significant soil water loss occurred due to the interflow characteristics of the Westleigh soil form. The Bainsvlei soil form had the lowest clay percentage in the subsoil horizon but has the highest soil water content due to soil profile depth and the water table characteristics of the soft plinthic soil water limiting layer horizon. Interflow was visible post-season on the limiting layer horizon was visible in the Bainsvlei,

Bloemdal, Sepane and Westleigh soil with accumulation in the bottom 200–300 mm of the soil profiles since all the soil forms in the Hoekblok characteristic water table soil characteristics exhibit. Increases in soil water between harvest and post-season is visible in the sandy clay loam soils Bainsvlei and Bloemdal but decreases in soil water was visible in the sandy clay soils Westleigh and Sepane. All the soil forms were above DUL during the emergence, flowering, boll formation and boll burst stages during which the cotton is most sensitive to soil water stress. The Westleigh and Sepane soil forms were just higher above DUL during these periods than the Bloemdal soil form due to the higher clay percentages. The Bainsvlei is discussed separately as the soil profile depth is not comparable to the other soil forms. The sandy clay soils produced the highest yield in comparison with the sandy clay loam soils. The sandy clay loam soils delivered better quality cotton and higher micronaire cotton fibres than the sandy clay soils. Both the Westleigh and Sepane soil forms has a gleyic limiting horizon which is not favourable for plant roots due to waterlogged or anoxic conditions, and the cotton roots is situated in this section of the soil profile during boll formation. During the flowering and boll formation growth stages the Westleigh and Sepane was above DUL contributing to the anoxic conditions. However, the soil water content being above DUL was much lower than in the previous season sandy clay soils. A different cotton cultivar is planting in the Hoekblok which could have an effect as the rooting system is different in the different cultivars. This cultivar could possibly prefer a higher clay content soil profile. A higher yield to the cost of lower quality cotton accounts for much more than a better quality to the cost of lower yield. It is more profitable to farm the higher yield soils in comparison with the soils that produce higher quality.

5.4.2 Teerpadblok

The Teerpadblok dominant soil forms are physically uniform in terms of texture and as a result the soil water behaviour is mostly the same. Sandy clay soils dominate the Teerpadblok field. The Tukulu and Avalon soil forms had the highest clay percentage in the horizons. The Westleigh soil form has the lowest clay content of all the soil forms but has the highest soil water content throughout the production season. The Avalon which has the second highest clay percentage has the lowest soil water content throughout the production season. Both the Avalon and Tukulu soil forms soil water content increased from harvest to post-season due to the interflow characteristics, but the amount of soil water is less than what was available during planting. Both the Oakleaf and Westleigh soil forms increased in soil water content from harvest to post-season, and more soil water is available post-season than what was available during planting. Interflow was visible post-season on the limiting layer horizon in the Avalon, Tukulu, Oakleaf and Westleigh soil forms with accumulation of soil water in the bottom 200–300 mm of the soil profiles since all the soil forms in the Teerpadblok are characteristic water table soils as they exhibit water table

characteristics which is associated with internal drainage. The Avalon and Oakleaf soil forms soil water content was not below the LL during the season or above DUL which indicates that no planting stress would have occurred due to the good drainage capabilities. Both the Avalon and Oakleaf soil forms soil water content was just below DUL during the flowering and boll formation growth stages which indicates that the soil profile was waterlogged during these stages. The Tukulu soil form was above DUL during emergence, flowering, and boll formation growth stages during which the cotton is most sensitive to water stress. From boll burst to harvest the soil water content was just below DUL, but during these stages the soil water needs are low, and the soil water content remains constant. The Westleigh soil form soil water content was well above DUL throughout the season which might lead to soil water conditions above DUL that may cause water stress in the cotton. The Westleigh soil form produced the highest yield and the Avalon soil form the lowest yield. The Westleigh soil form also produced the best quality cotton in comparison with the other soil forms. The Westleigh produced the highest micronaire fibres in comparison with the other soil forms. A different cotton cultivar is planting in the Teerpadblok which could have an effect as the rooting system is different in the different cultivars. This cultivar could possibly prefer a higher clay content soil profile. A higher yield to the cost of lower quality cotton accounts for much more than a better quality to the cost of lower yield. It is more profitable to farm the higher yield soils in comparison with the soils that produce higher quality.

5.4.3 Combined Conclusions

The soil water content had significant differences depending on the physical characteristics of the soil forms. It was evident that in a field where similar soil properties occur in the various soil forms that the soil water content remained the same. Differences in the textural properties results in different soil water contents throughout the production season. The soils that contain a higher clay content has a higher soil water content, and in the case where a plinthic soil horizon occur the higher soil water content does not seem to be permanent as interflow occur in these horizons throughout the season. Water accumulation occurred in the bottom 200-300 mm of the soil profile post-season which indicates the occurrence of a water table in the fields. The most soil water is extracted from the topsoil to the section just above where water accumulates on the limiting layer because the accumulation zone due to the lack of oxygen in the accumulation zone. The highest yield was produced by the soils with more readily available plant water, characterized by good drainage and oxidized root zones. Different cotton cultivars were planted in the second season fields which may have caused differences in the response of the soil to the cultivar. A better cotton quality and higher micronaire was observed in the Hoekblok of the sandy clay loam soils in comparison with the Teerpadblok where a lower cotton quality and lower micronaire was observed by the sandy clay loam soils.

5.5 Season 1 and 2 Conclusions

Season 1 and 2 had similar trends in most of the characteristics studied. Common dominant soil forms found during season 1 and 2 is the Avalon, Bainsvlei, Oakleaf, Tukulu and Westleigh which corresponds to that of Jacobs *et al.* (2018). In fields with uniform dominant soil forms, the clay percentages in both the topsoil and subsoil are similar and concludingly not statistically different from one another, which concludes to similar water regimes. In fields with distinctly different soil forms, the clay percentages vary statistically concluding to different water regimes. It is evident that sandy clay soils such as the Westleigh and Tukulu are predominantly above DUL during the most critical growth stages (flowering and boll formation) which leads to lower yields. This is due to the gleyic subsoil horizon being prone to anoxic conditions and water logging. This has a detrimental effect on the root system not being able to produce more cotton bolls due to plant water stress. The sandy clay loam soils such as the Avalon, Bainsvlei and Oakleaf tend to be above DUL during short periods throughout the production season. The redox state being red mostly indicates short periods of saturation which is favourable for the cotton enabling the root system to extract more nutrients without any plant stress. The effect of the limiting layers in characteristic water table soils (Avalon, Tukulu, Bainsvlei, and Westleigh) is visible through clear soil water accumulation at the bottom of soil profiles. This in association with fallowing allows for more soil water left post-season than pre-season. This only applies to deeper than 1000 mm soil profiles. The Hoekblok and Teerpadblok soil profiles are much less deep, and it is evident that most of the soil forms in these fields was drier than during planting. The Pretorius Rust and Schietfontein fields soil profiles are deeper and concludingly more soil water was left post-season. It is important to note that cotton is a xerophyte and as such can survive without an excess of soil water. Speculations that cotton extract a big amount of soil water is inaccurate due to more soil water left in most soil profiles deeper than 1000 mm. It is evident that soil forms with a sandy clay texture (Westleigh and Tukulu) produce better quality cotton with higher micronaire fibres. Although the quality of the cotton on sandy clay soils is better the yield is the determining factor in the value of the cotton. Higher yields in association with slightly lower quality cotton has a much higher value than lower yield and better-quality cotton. Concluding the statement sandy clay loam soils, such as the Avalon, Bainsvlei and Oakleaf, produce more valuable cotton than sandy clay soils, such as the Westleigh and Tukulu.

CHAPTER 6 CONCLUSION AND RECOMMENDATIONS

The study investigated the effect of the different soil forms on the amount of soil water throughout the production season as well as the effect of the soil forms on the cotton quality and yield under dryland conditions. The study was divided into two seasons, each with two allocated cotton fields.

The first objective that was set is the identification of the measurement sites by analysing the soil point data provided. The objective was met as the sites was identified through spatial analysis using ArcMap. The dominant soil forms in each field were identified by assessing the following soil properties: Soil form, A horizon Clay %, B horizon Clay %, and Rooting depth, and limiting layer type.

The second objective was to measure the monthly soil water content by means of neutron scattering. This objective was met as the soil water was measured for each of the sites monthly from the month of October which is directly before the cotton is planted, to September in the following year after the cotton was harvested to determine the soil water content throughout the whole production season. The soil water measurements formed the basis for all the data analysis.

The third objective was to determine the water regimes of the various soil forms and assessing their associated soil water characteristics. This objective was met as the data obtained by measuring the soil water monthly was incorporated with the soil water characteristics and the various growth stages of the cotton. The soil water characteristics (DUL and LL) was determined by means of pressure plate extraction. By integrating the soil water data with the drained upper limit and lower limit, the soil water supply during the growth stages can be related with the cotton yield and quality produced at each site.

The fourth objective was to determine the cotton yield and quality. This objective was met as the yield data was obtained from the farmer and the cotton quality was determined by random sampling of cotton bolls within a five-meter radius of the measurement site and analysing the quality in the HVI system.

The last objective was to assess the effect of the soil forms on the cotton yield and quality by means of descriptive statistics. This objective was met as the soil property data, the cotton yield data, and cotton quality data was assessed by testing the analysis of variance (ANOVA) of the various properties and the relationship between the soil forms and the cotton properties. The accuracy of the model was also tested by assumptions testing the ANOVA model. This was integrated with the yield and quality data to obtain the link between soil forms, soil water and cotton production under dryland conditions.

6.1 Season 1 Conclusions

The Pretorius Rust field consisted of sandy clay loam soils (Bainsvlei and Avalon), as well as sandy clay soils (Westleigh and Tukulu). It was evident that the Westleigh soil form having the highest clay content in the A and B horizon had the highest soil water content throughout the season. The Avalon soil form had the lowest clay content in the A and B horizon but had a similar soil water content as the Westleigh soil form which illustrated the water table characteristics of the soil form. It is evident that statistically different soil water contents are linked to different soil forms. Soil water conditions above DUL were identified in all the soil forms due to the high rainfall during the season. The soil water conditions above DUL tend to have a negative impact on the yield in the areas consisting of sandy clay soils as the lowest yield was produced by these soil forms (2,93 ton/ha – Tukulu) due to the anoxic conditions ability to restrict the cotton to produce more bolls to result in a higher yield (Ninari *et al.*, 2004). The soil water conditions above DUL tend to benefit sandy clay loam soils as these soils recovered well due to good internal drainage in the subsoil horizons and produced the highest yield (3,96 ton/ha – Avalon). Although the yield is lower on sandy clay soils the quality tend to be better with the sandy clay soils producing higher micronaire cotton fibres and high-quality cotton with a better value than the sandy clay loam soils. However, calculations indicate that even with a better-quality cotton the yield remains the determining factor in the value of the cotton.

The Schietfontein field had a much more uniform soil form distribution, and as a result the physical properties does not vary much from one another and all the soil forms are considered sandy clay loam soils. With the small difference in the soil forms physical properties the Oakleaf and Tukulu soil forms had the highest clay contents in the horizons and as a result had the highest soil water content throughout the season. Soil water conditions above DUL were observed in the Oakleaf, Glencoe and Tukulu soil forms. The soil water conditions above DUL tend to benefit the Oakleaf soil form as the highest yield (2,61 ton/ha) was produced on this soil. The soil water conditions above DUL on the Tukulu soil form had a negative effect as the lowest yield (2,37 ton/ha) was produced on these soils. The negative effect is due to the anoxic conditions in the subsoil horizon limiting the growth of the cotton to produce more bolls which results in a higher yield (Ninari *et al.*, 2004). The best quality cotton was produced on the Glencoe and Avalon soil forms but the highest micronaire values was observed on the two soils with the higher clay content (Oakleaf and Tukulu). However, calculations indicate that even with a better-quality cotton the yield remains the determining factor in the value of the cotton. The total soil water content in both the Pretorius Rust and Schietfontein is higher post-season than pre-season with the soil profile depth averaging at 1100 mm. The cultivar planted in both the Pretorius Rust and Schietfontein sites is Candia.

6.2 Season 2 Conclusions

The Hoekblok consisted of sandy clay loam soils (Bainsvlei and Bloemdal, and sandy clay soils (Westleigh and Sepane). The Bainsvlei soil form root depth was much deeper than all the other soil forms' root depth which influences the discussion. The Bainsvlei soil form had the highest soil water content due to the deeper soil profile, but when excluding this soil form the Westleigh and Sepane soil forms had the highest clay content in the horizons which resulted in the highest soil water content throughout the season. The highest yield was produced by a sandy clay soil with the second highest soil water content – highest if the Bainsvlei soil form is excluded (3,15 ton/ha - Westleigh) and the lowest yield was produced by a sandy clay loam soil with the lowest soil water content (2,37 ton/ha – Bloemdal). The trend observed is that the higher the soil water content is, the higher the yield produced is. The Bloemdal soil form produced the best quality cotton and the highest micronaire fibre in comparison with the Westleigh soil form which produced the lowest quality cotton and lowest micronaire fibre. A trend is observed that the lower the soil water content, the better the cotton quality. However, calculations indicate that even with a better-quality cotton the yield remains the determining factor in the value of the cotton.

The Teerpadblok had a much more uniform soil form distribution with only sandy clay soils occurring in the field. Contrast is observed in this field as the Westleigh soil form had the lowest clay content but had the highest soil water content throughout the season due to interflow characteristics and the Tukulu soil form had the highest clay content but lowest soil water content. The highest yield was produced by the Oakleaf soil form (3,60 ton/ha) which had the most total soil water and the lowest yield by the Avalon soil form (2,70 ton/ha) which had the lowest soil water content. The trend observed is that the higher the soil water content is and drainage capacity, the higher is the yield produced. The Westleigh soil form produced the highest quality cotton and the highest micronaire fibre in comparison with the Avalon soil form which produced the lowest quality cotton and lowest micronaire fibre. A trend is observed that the lower the soil water content, the better the cotton quality. However, calculations indicate that even with a better-quality cotton the yield remains the determining factor in the value of the cotton. The total soil water content in both the Hoekblok and Teerpadblok was lower post-season than pre-season in most soil profiles with the average soil profile depth averaging 800 mm. The cultivar planted in the Hoekblok is DP 1240 and Teerpadblok DP 1541.

6.3 Final Conclusions

From all the above data interpretations and discussions, it is evident that as predicted in the hypothesis the soil forms do indeed influence the amount of soil water as well as the yield and quality of the cotton under dryland conditions. In summary the final findings are as follow:

- I. The soil water content does vary between the different soil forms and this is mainly due to differences in the clay content in the A and B horizons as well as root depth. The sandy clay soils tend to be above DUL for longer periods in comparison with sandy clay loam soils which tend to be above DUL only for a short period due to good internal drainage. Considering that the texture influences the soil water content the water regimes is different for each soil form. A clear difference in depth occurred between the four sites which influences the soil water content and the behavior of the soil forms. Shallower soil profiles do not stay above DUL for long periods and tend to dry out in comparison with the deeper soil profiles.
- II. It is evident that the soil water characteristics had an influence on the yield. The amount of plant available water was different between the various soil forms, and as such the yield is related to the soil water being more readily available throughout the production season. The cultivar has a clear influence as the first season only Candia was planted, and second season two DP cultivars was planted, one in each of the cotton fields. The crop management factors such as the planting density and fertilizers poses the possibility of influence. It is observed with the Teerpadblok field that the higher the clay content in the A and B horizons was the higher the yield was. When considering the quality of the cotton the contrary is observed. Soil water conditions above DUL on sandy clay soils tend to produce better quality cotton in comparison with soil water conditions above DUL on sandy clay loam soils which tend to produce lower quality cotton. The higher the clay content is the higher the micronaire of the fibre is which is visible in the sandy clay soils.

6.4 Recommendations

The variation in soil properties from one site to another varies a considerable amount. In this regard only two sites should be allocated for both studied seasons in a similar study to this instead of two per season to keep the soil physical data the same and ease the discussion process.

The climatic data varies between regions, and as a result weather stations should be installed at each site which could provide more valuable. Evaporation rates could also enhance the dataset and provide valuable information for discussion of the cotton soil water consumption.

The cultivar planting in the two seasons should be the same in both the fields as the variance in growth patterns influences the soil water needs. Furthermore, the study can be expanded to nutrient level since sandy clay soils produce better quality cotton, especially higher micronaire values which might be influenced by the availability of nutrients in the soil horizons.

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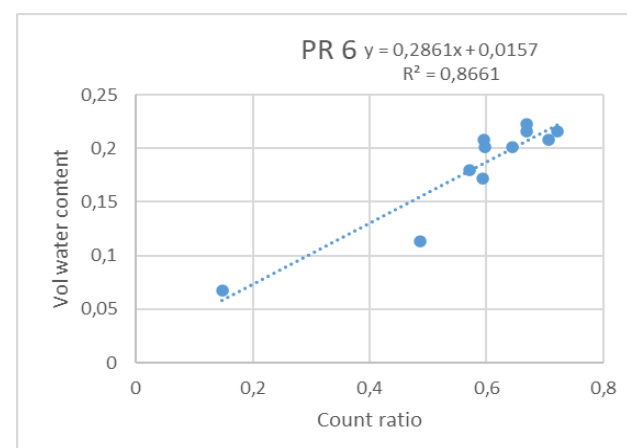
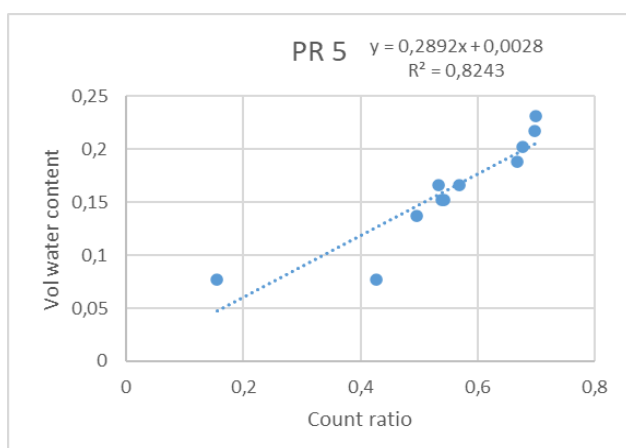
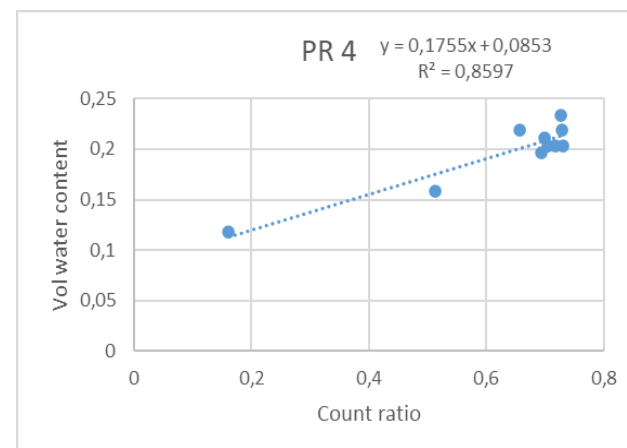
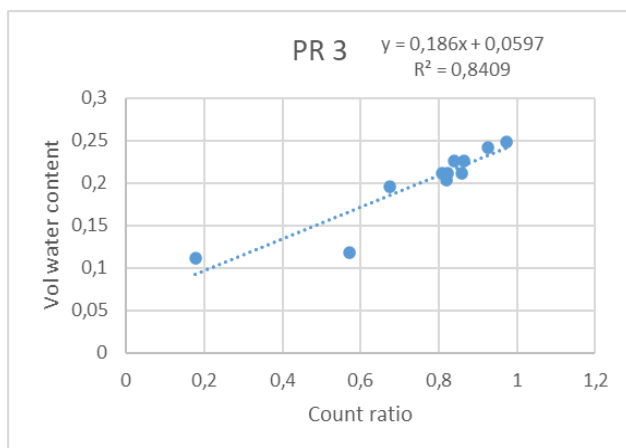
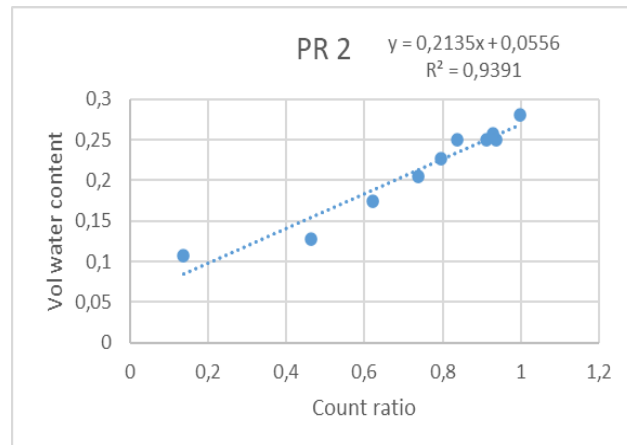
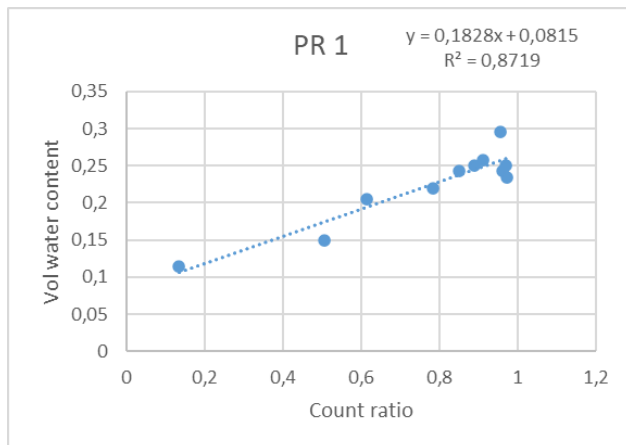
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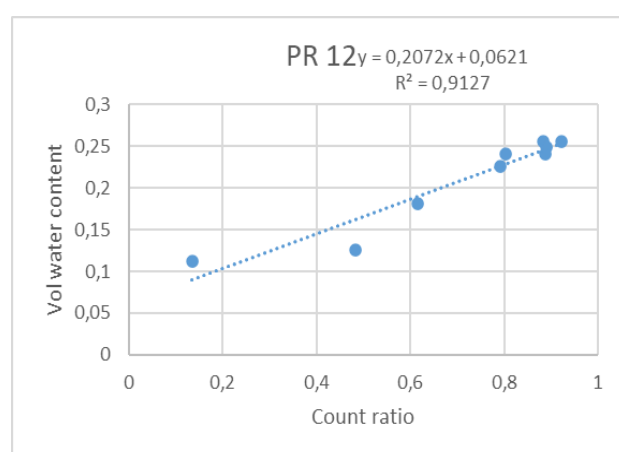
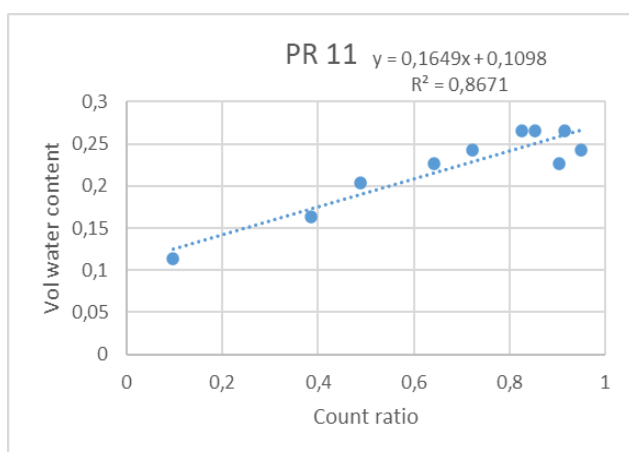
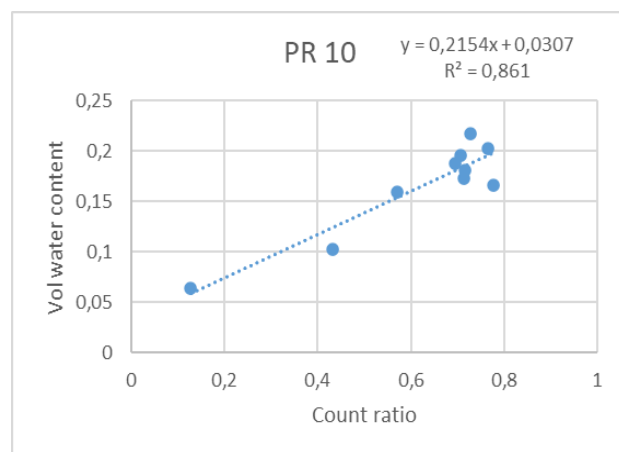
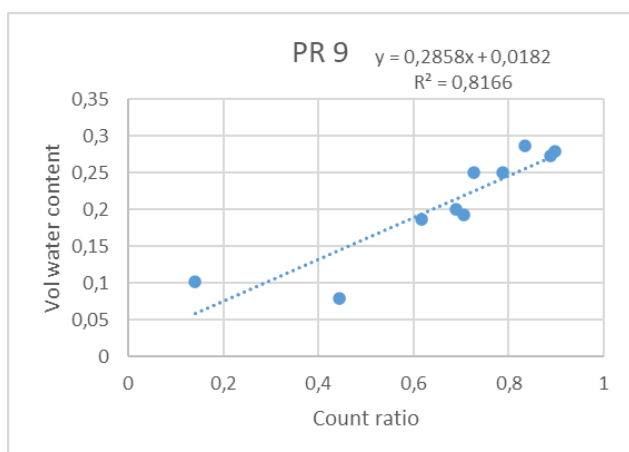
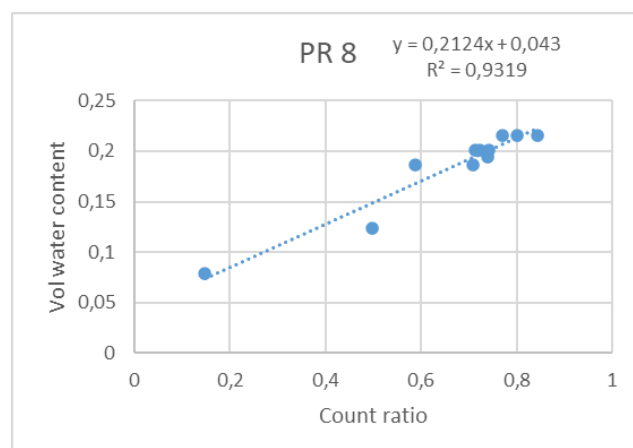
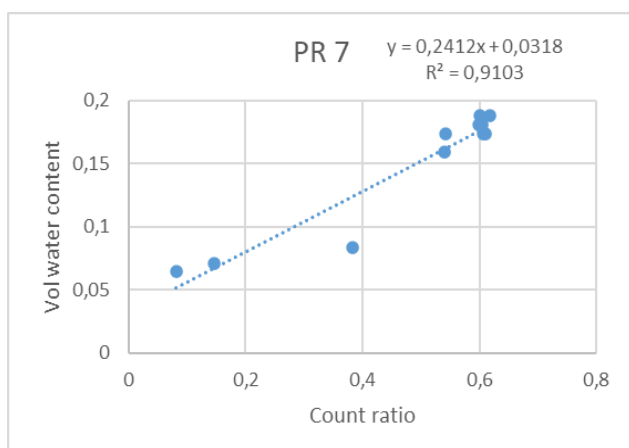
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ANNEXURE A: LINEAR REGRESSION CALIBRATION GRAPHS

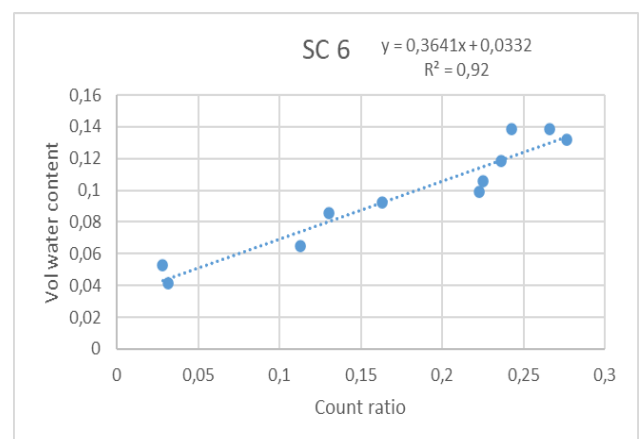
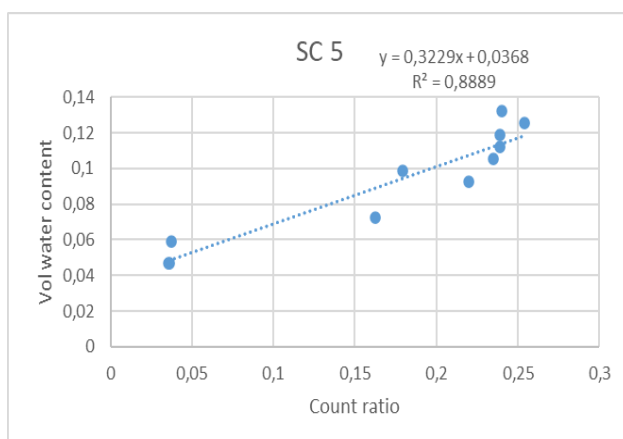
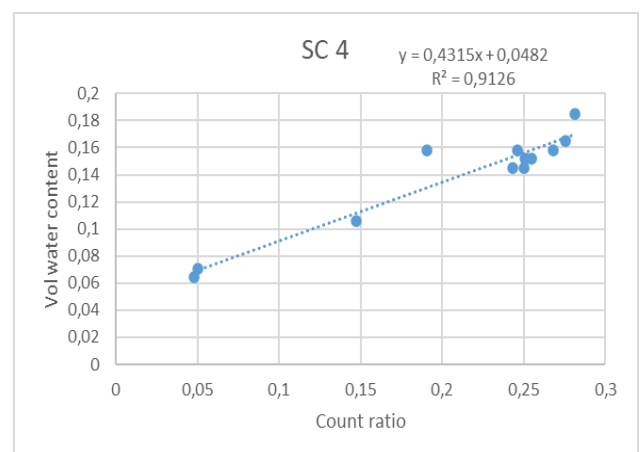
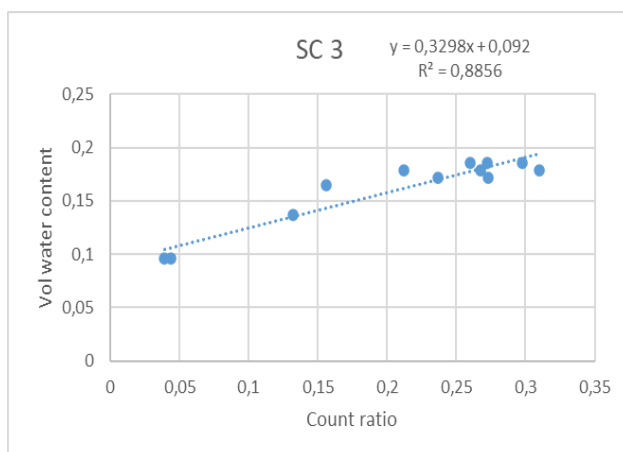
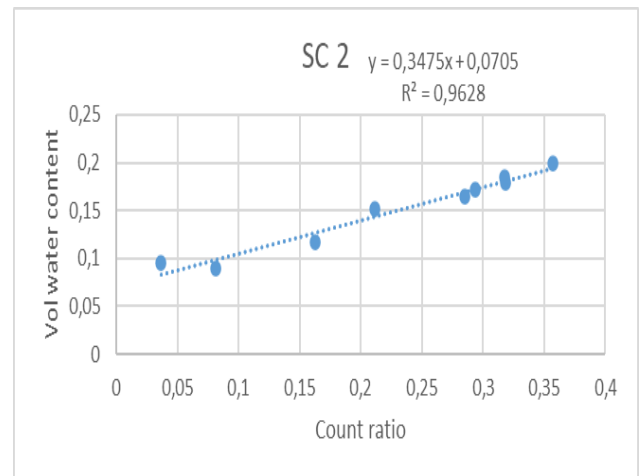
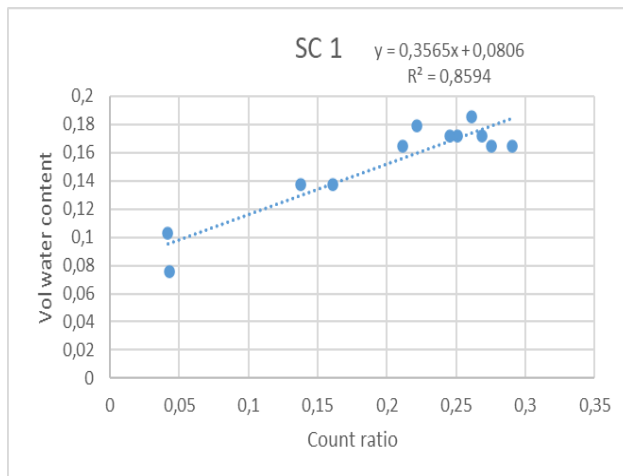
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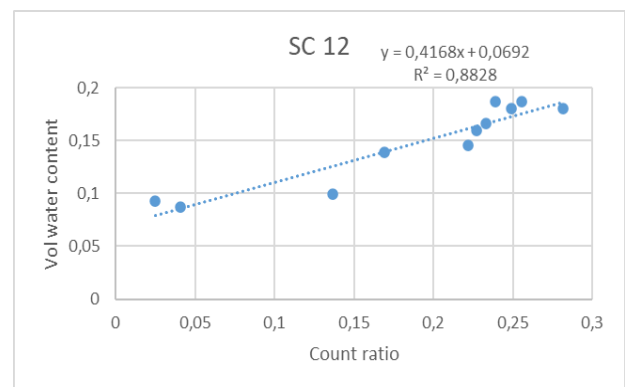
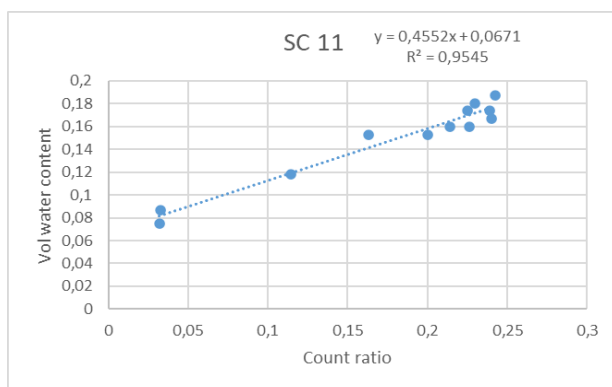
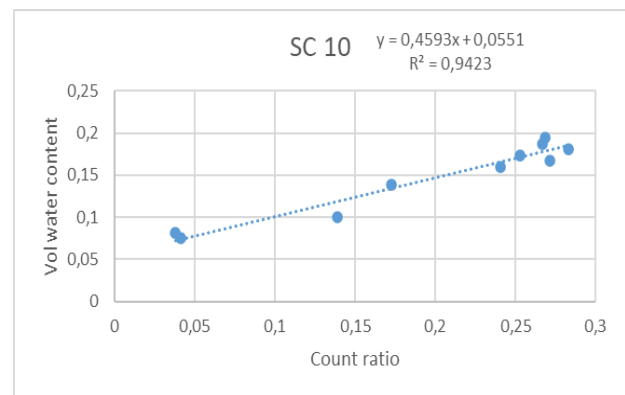
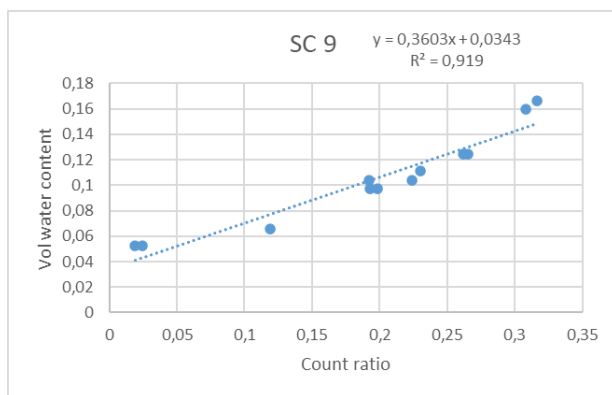
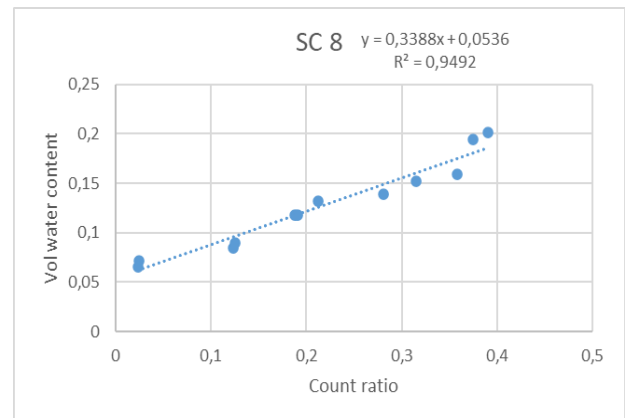
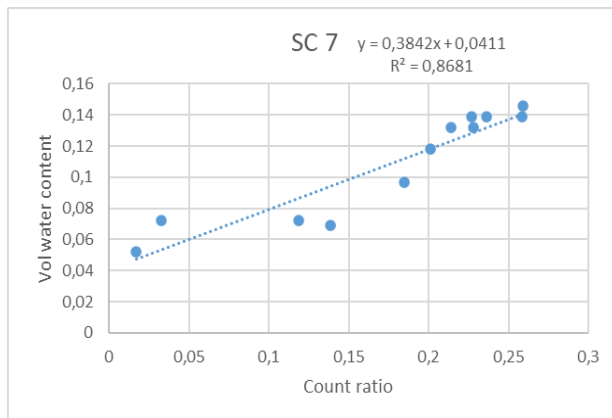
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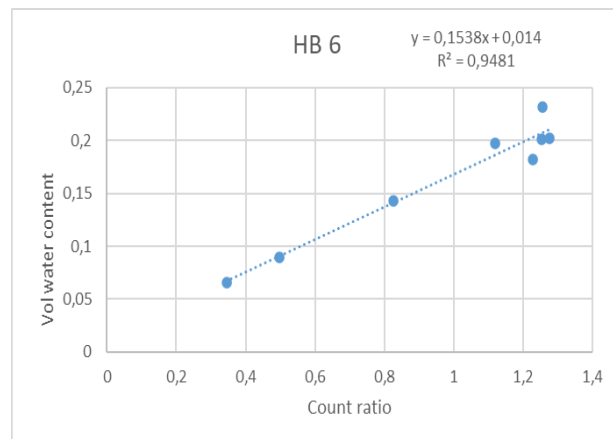
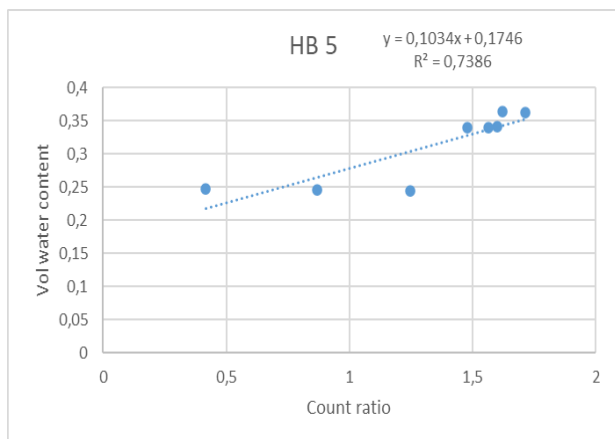
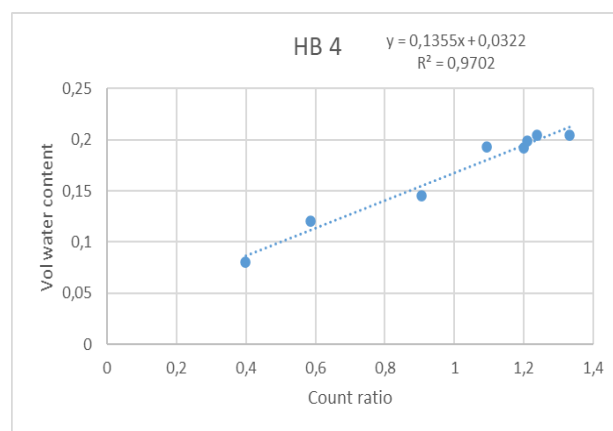
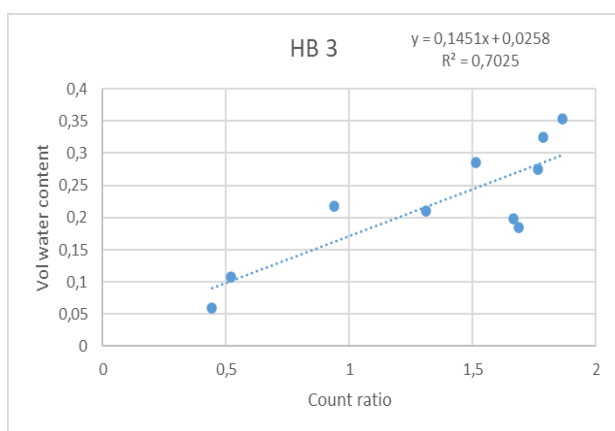
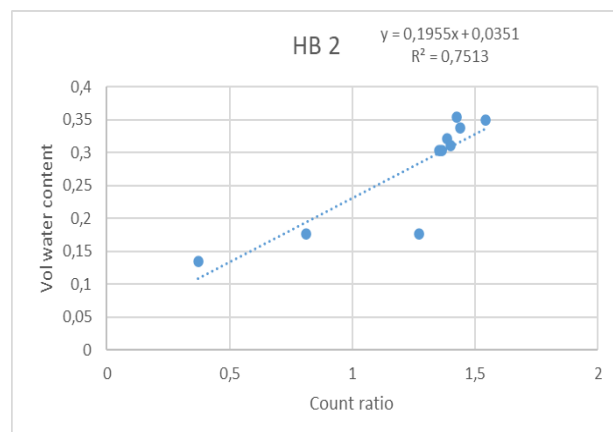
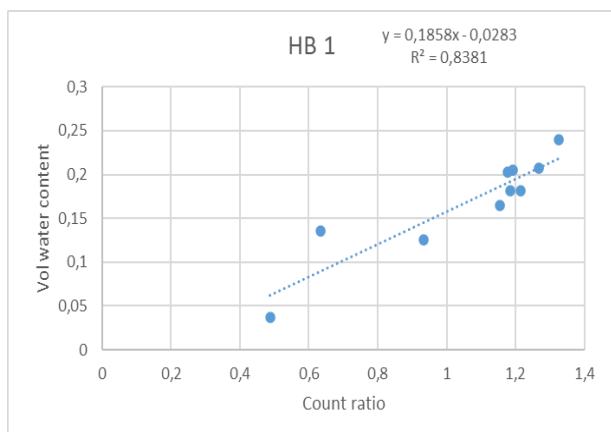
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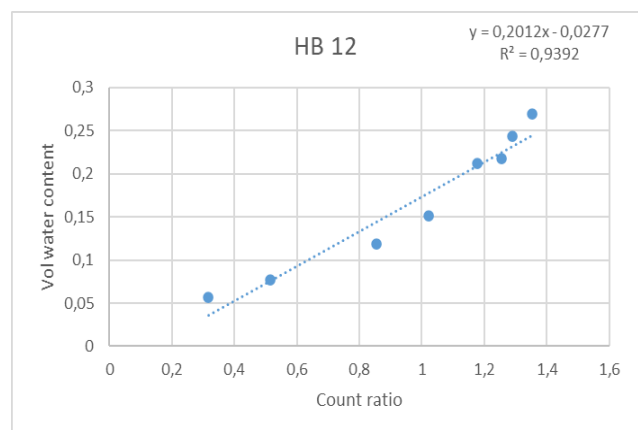
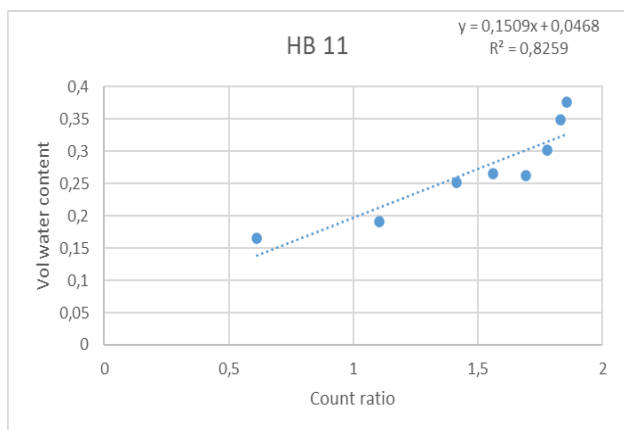
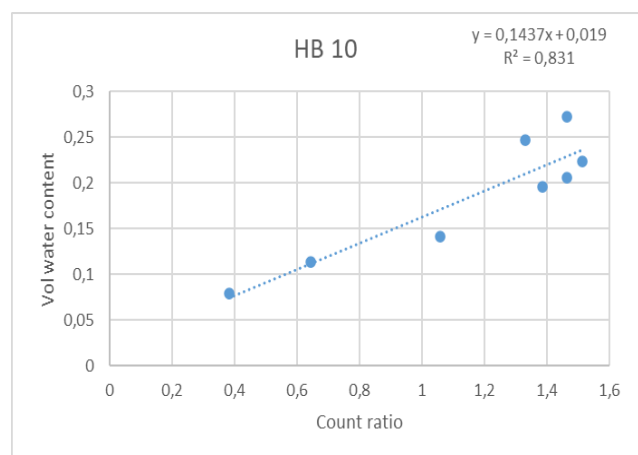
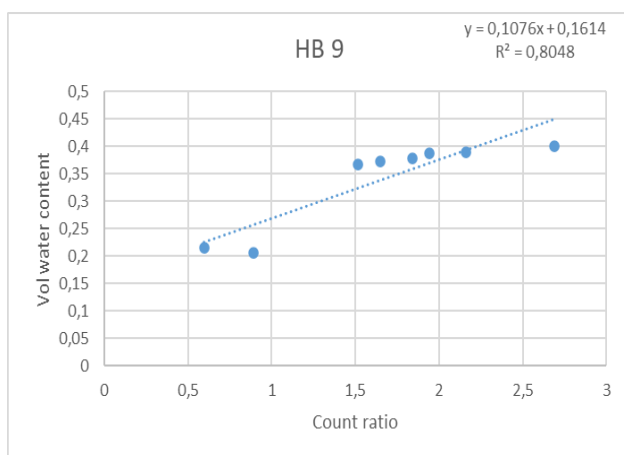
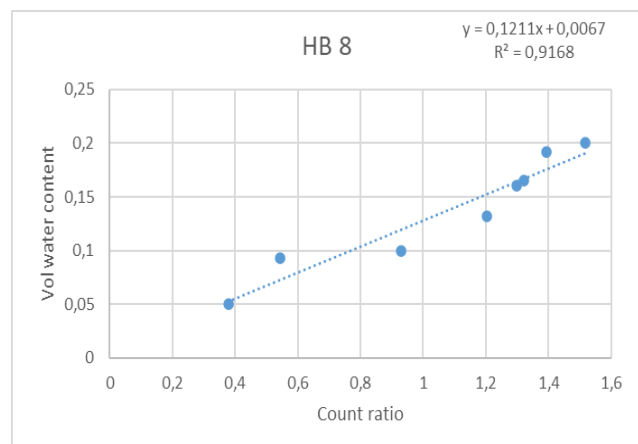
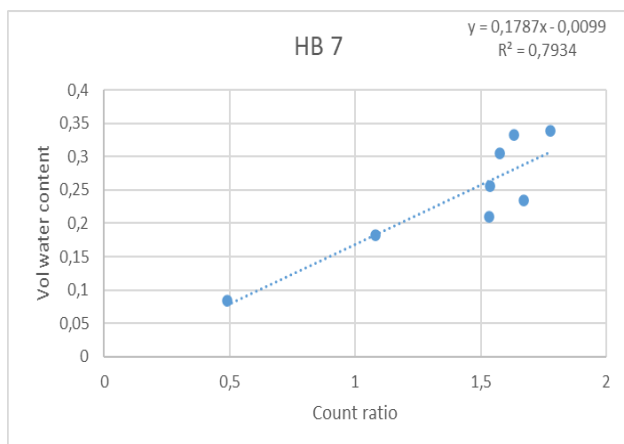
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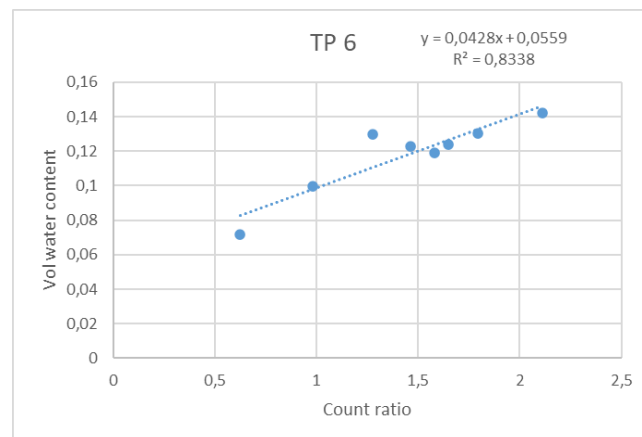
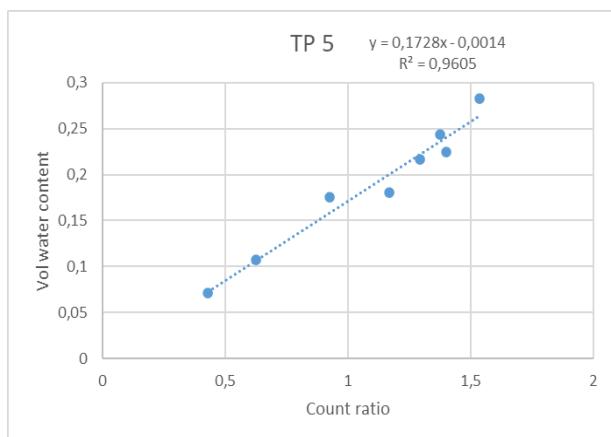
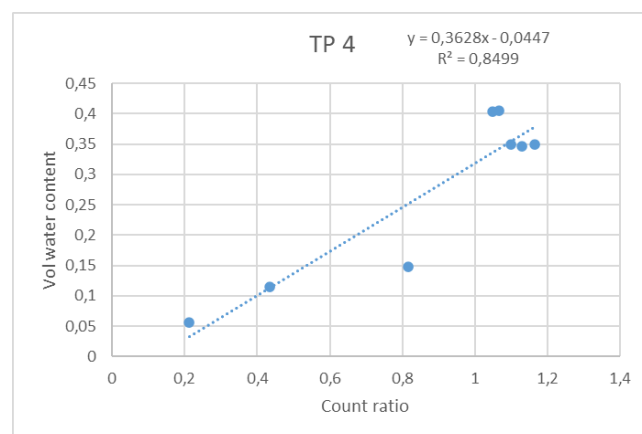
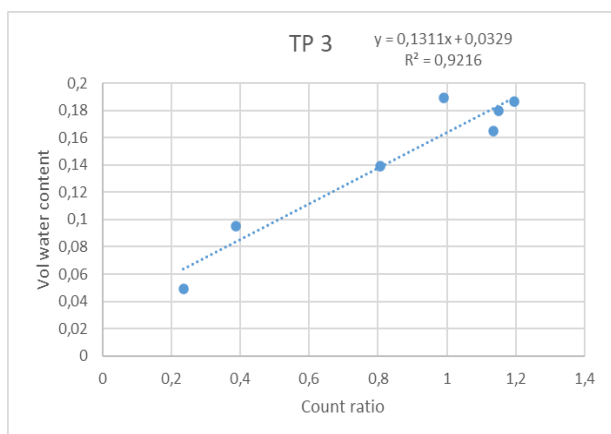
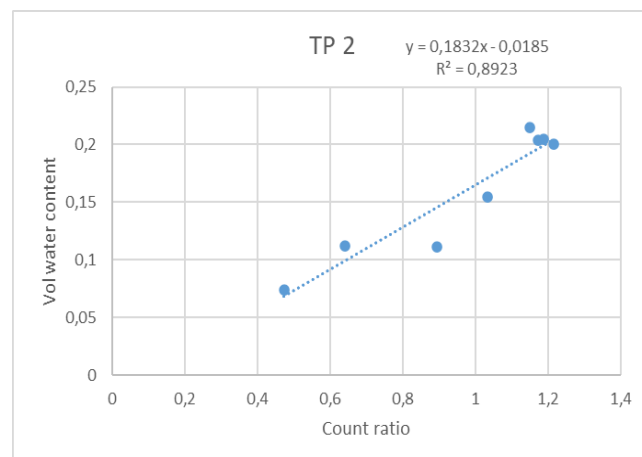
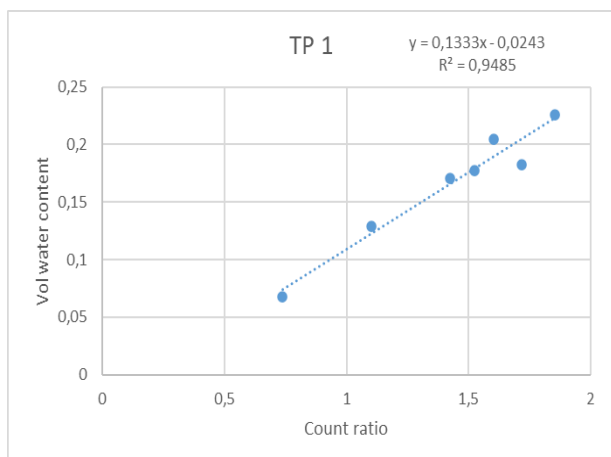
Hoekblok calibration graphs:



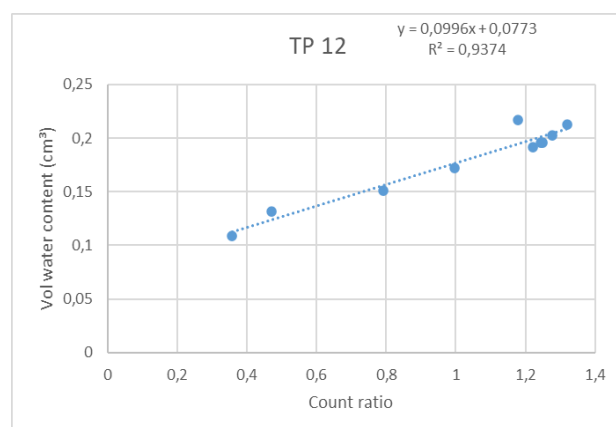
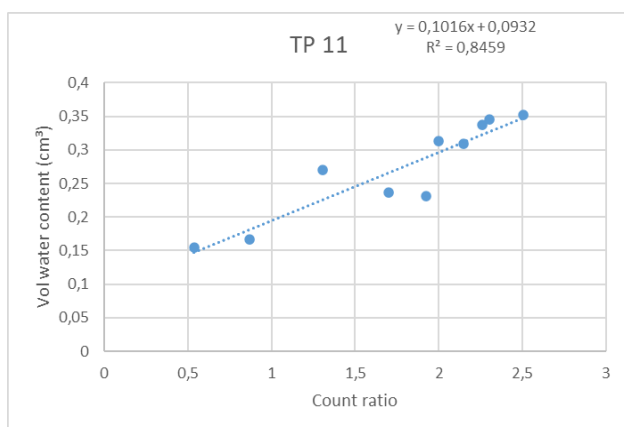
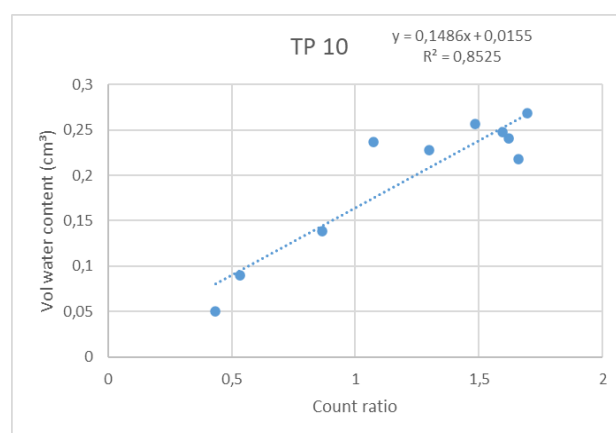
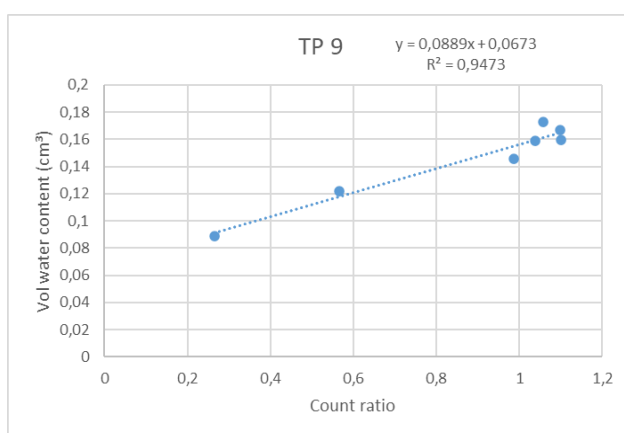
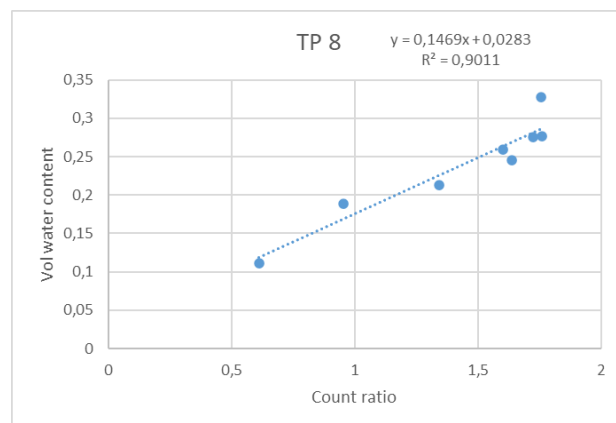
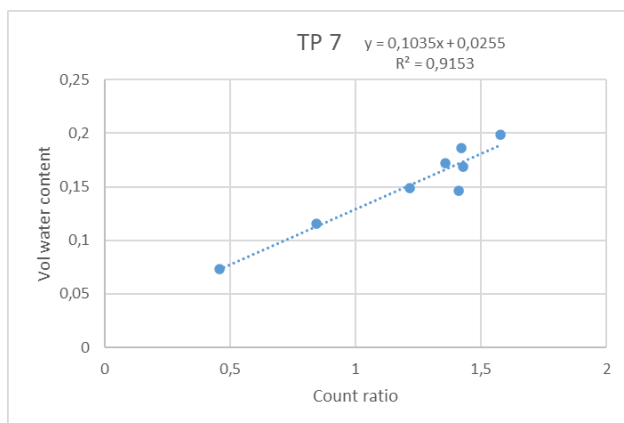
Hoekblok calibration graphs (continued):



Teerpadblok calibration graphs:



Teerpadblok calibration graphs (continued):



ANNEXURE B: MEASUREMENT SITES LOCATIONS

Table 6-1: Pretorius Rust measurement sites locations

Site point	Soilform	X	Y
PR 1	Westleigh	25,46745	-27,211226
PR 2	Westleigh	25,469628	-27,21558
PR 3	Tukulu	25,47184	-27,219185
PR 4	Tukulu	25,476695	-27,208585
PR 5	Avalon	25,480692	-27,218221
PR 6	Bainsvlei	25,481549	-27,218328
PR 7	Avalon	25,481584	-27,216544
PR 8	Bainsvlei	25,481477	-27,211404
PR 9	Bainsvlei	25,481941	-27,208906
PR 10	Avalon	25,486224	-27,213332
PR 11	Westleigh	25,490472	-27,209977
PR 12	Tukulu	25,490864	-27,215366

Table 6-2: Schietfontein measurement sites locations

Site point	Soil form	X	Y
SC 1	Tukulu	25,322335	-26,922563
SC 2	Tukulu	25,326384	-26,915573
SC 3	Tukulu	25,323749	-26,924759
SC 4	Avalon	25,324379	-26,925638
SC 5	Avalon	25,335093	-26,917712
SC 6	Avalon	25,326995	-26,917731
SC 7	Glencoe	25,323386	-26,924244
SC 8	Glencoe	25,334883	-26,918992
SC 9	Glencoe	25,33389	-26,924568
SC 10	Oakleaf	25,326155	-26,926765
SC 11	Oakleaf	25,324952	-26,923155
SC 12	Oakleaf	25,326556	-26,926555

Table 6-3: Hoekblok measurement sites locations

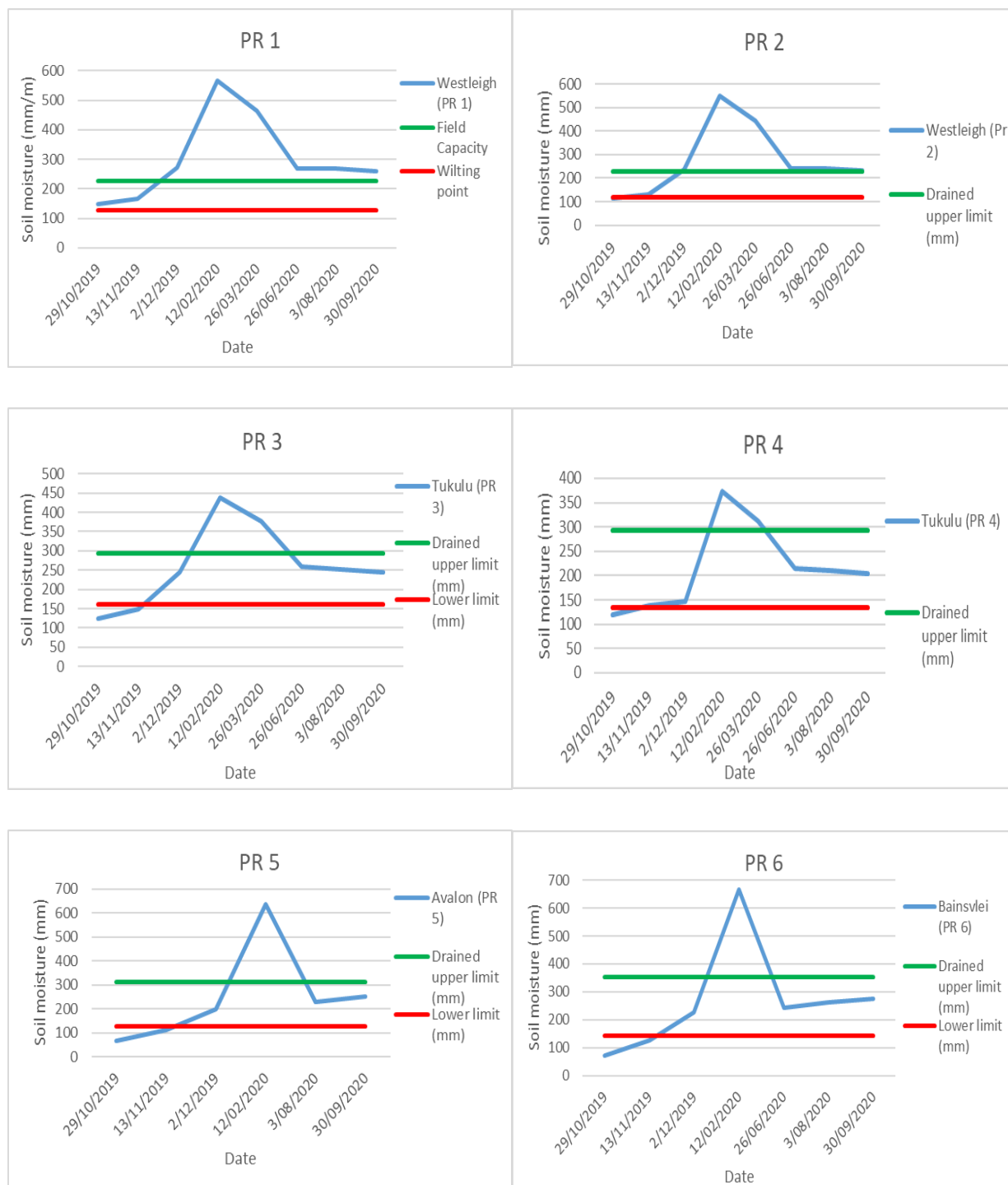
Site point	Soil form	X	Y
HB 1	Bainsvlei	25,452388	-27,178026
HB 2	Bainsvlei	25,452401	-27,177123
HB 3	Bainsvlei	25,451392	-27,177112
HB 4	Bloemdal	25,444303	-27,178839
HB 5	Bloemdal	25,444290	-27,179741
HB 6	Bloemdal	25,443306	-27,177925
HB 7	Sepane	25,441313	-27,176098
HB 8	Sepane	25,447430	-27,171652
HB 9	Sepane	25,446421	-27,171641
HB 10	Westleigh	25,449411	-27,174382
HB 11	Westleigh	25,450290	-27,174415
HB 12	Westleigh	25,449423	-27,173480

Table 6-4: Teerpadblok measurement sites locations

Site point	Soil form	X	Y
TP 1	Avalon	25,451241	-27,161496
TP 2	Avalon	25,448194	-27,162307
TP 3	Avalon	25,450398	-27,161994
TP 4	Tukulu	25,448239	-27,159026
TP 5	Tukulu	25,445034	-27,157709
TP 6	Tukulu	25,445670	-27,157337
TP 7	Oakleaf	25,446823	-27,158815
TP 8	Oakleaf	25,447674	-27,158313
TP 9	Oakleaf	25,447106	-27,157474
TP 10	Westleigh	25,449219	-27,170310
TP 11	Westleigh	25,447292	-27,169272
TP 12	Westleigh	25,451256	-27,164813

ANNEXURE C: SOIL WATER REGIMES

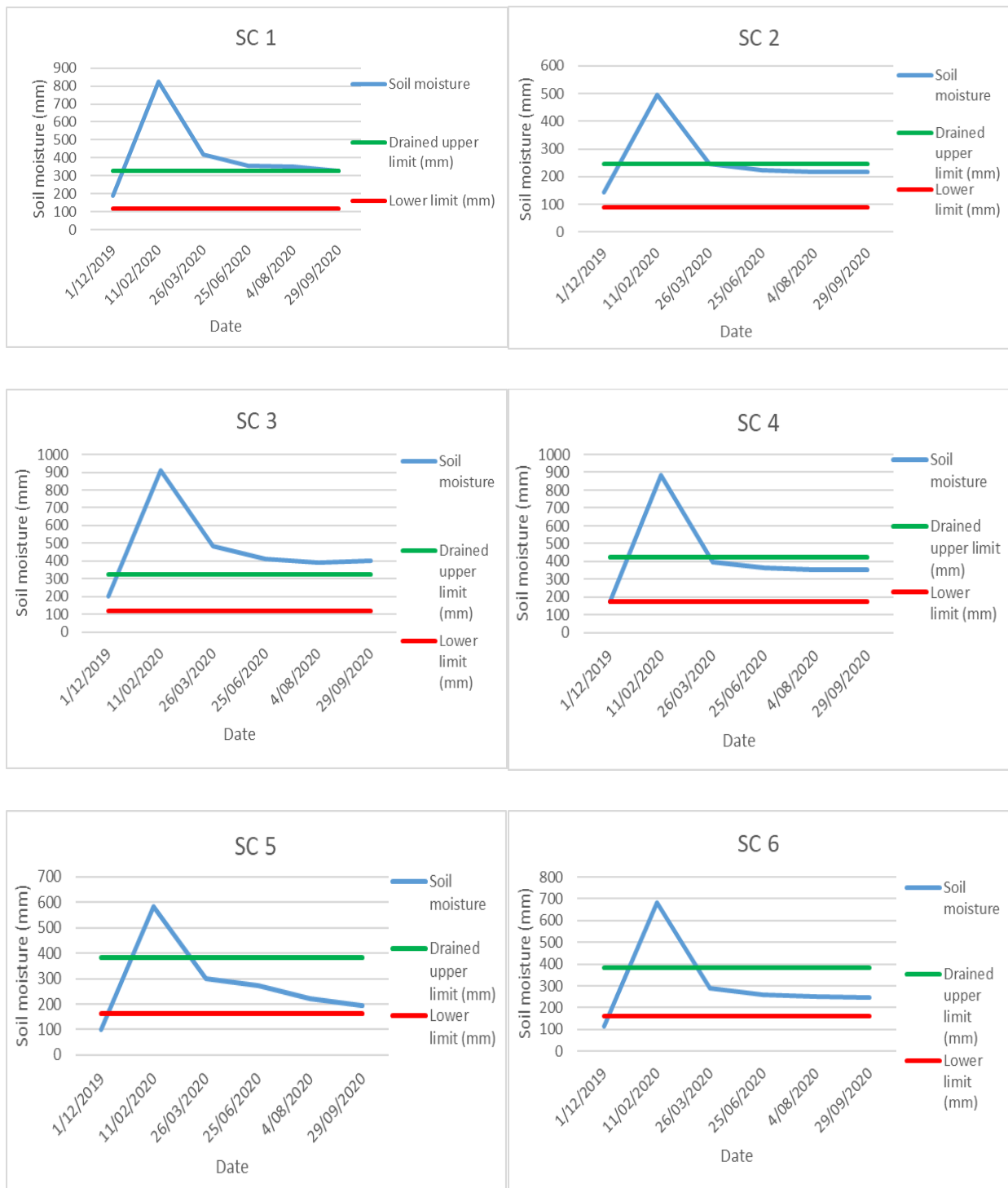
Pretorius Rust soil water regimes:



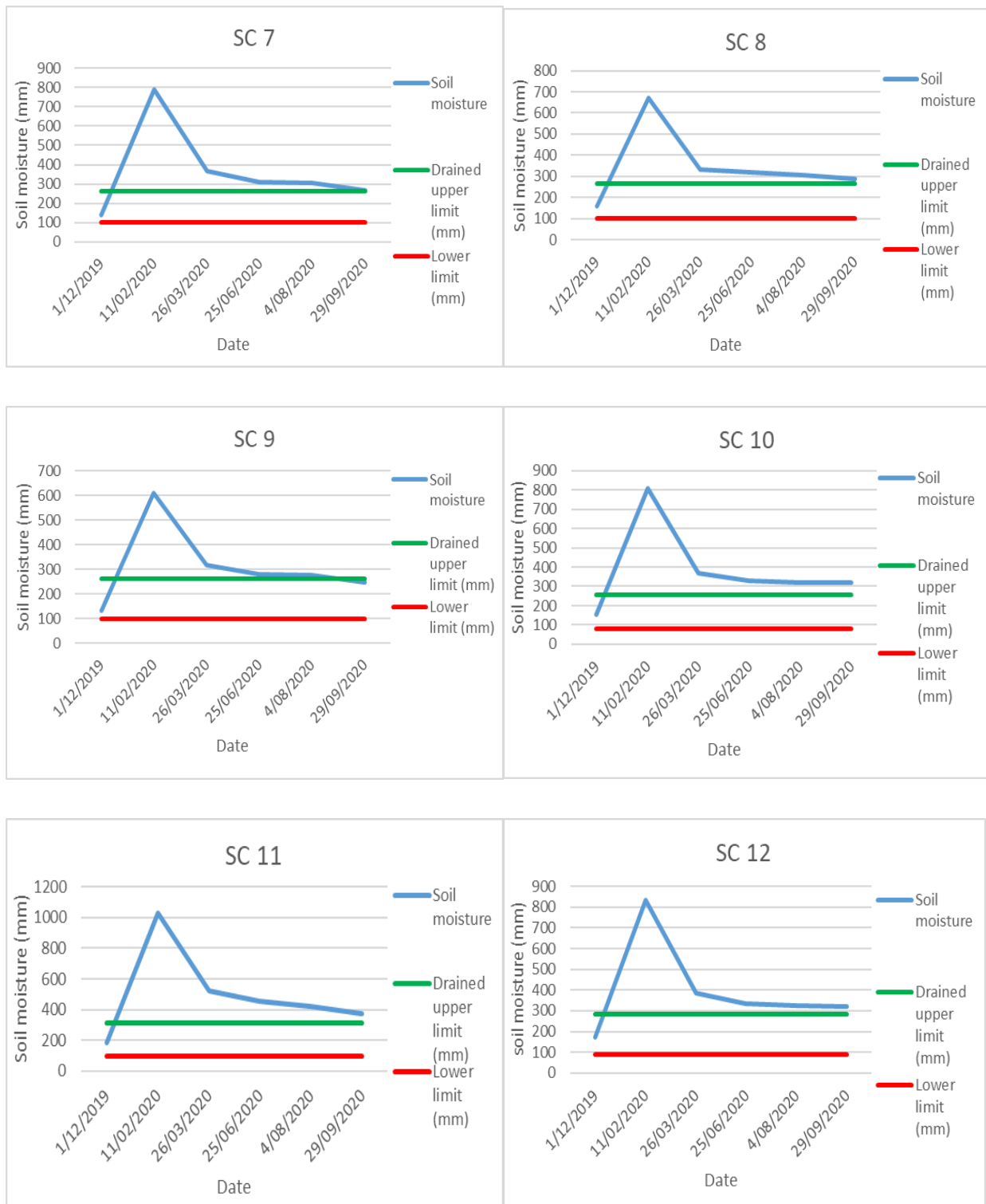
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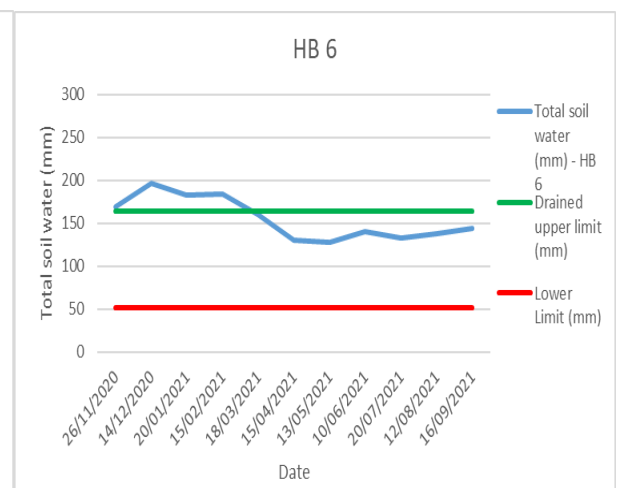
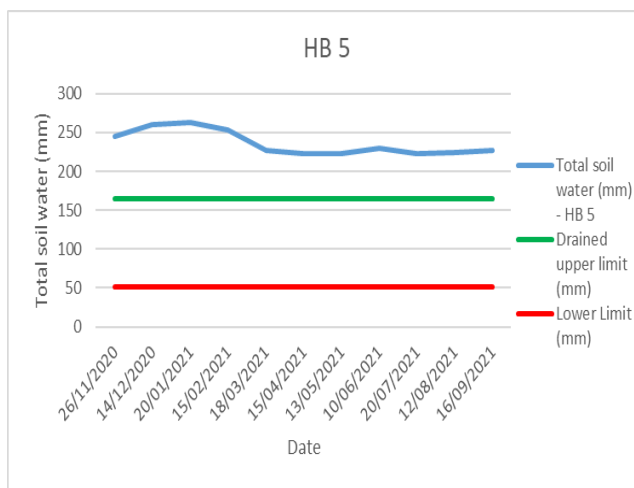
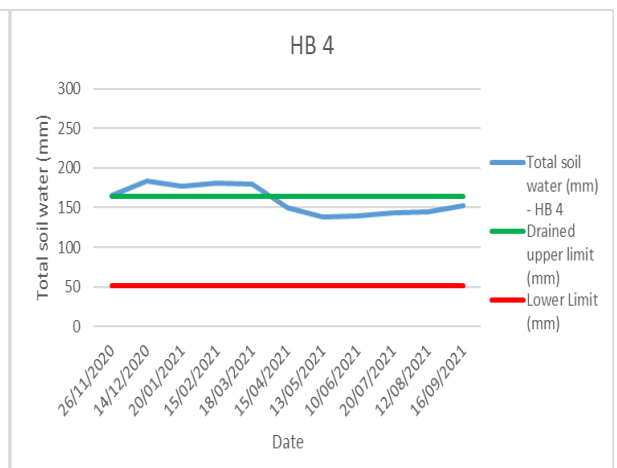
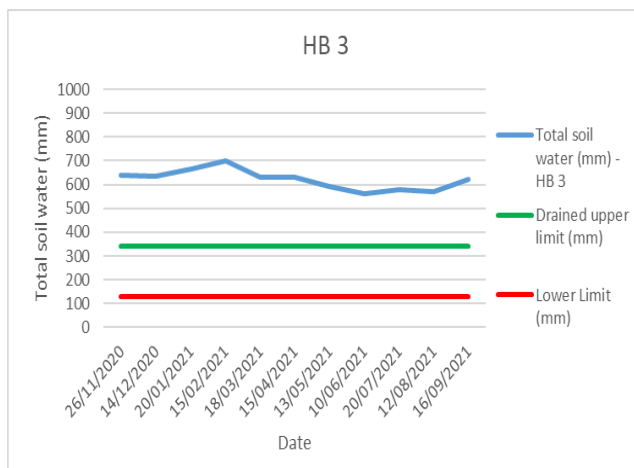
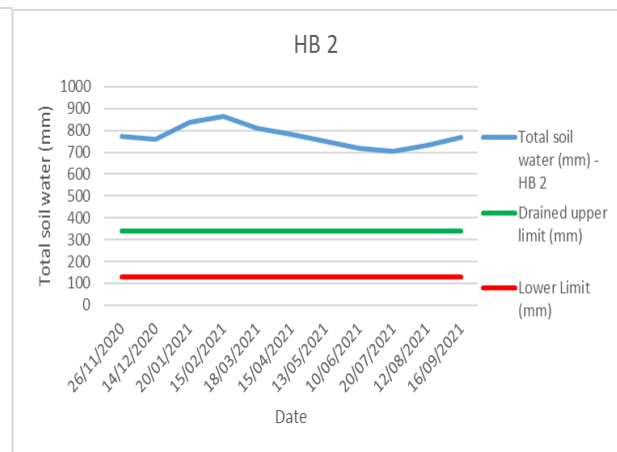
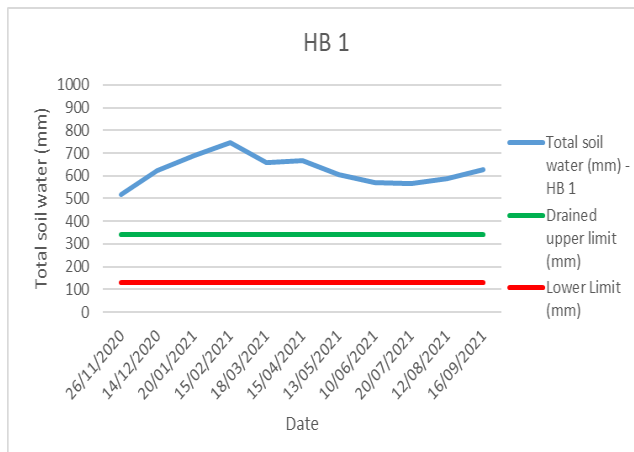
Schieftefontein soil water regimes:



Schietfontein soil water regimes (continued):



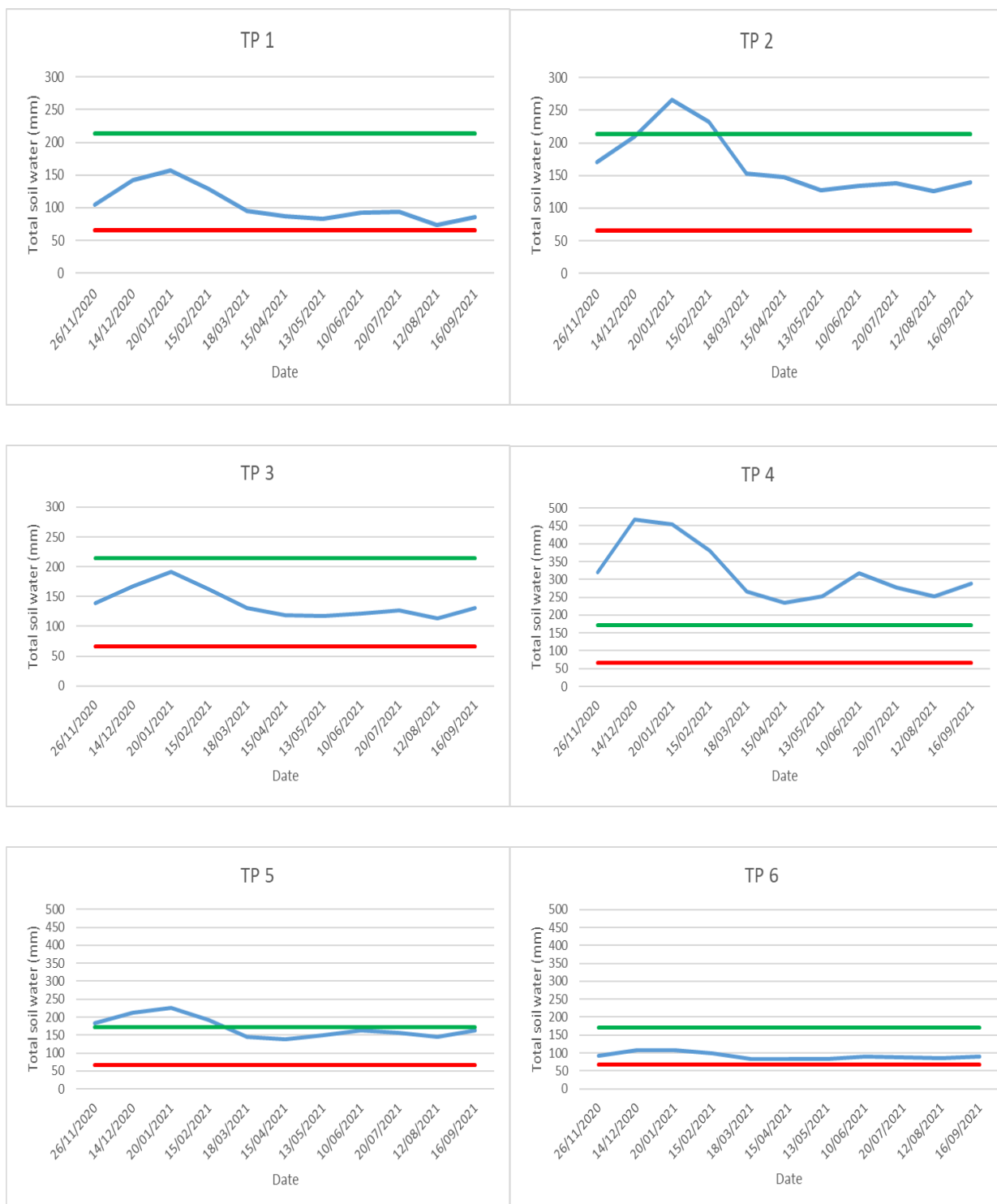
Hoekblok soil water regimes:



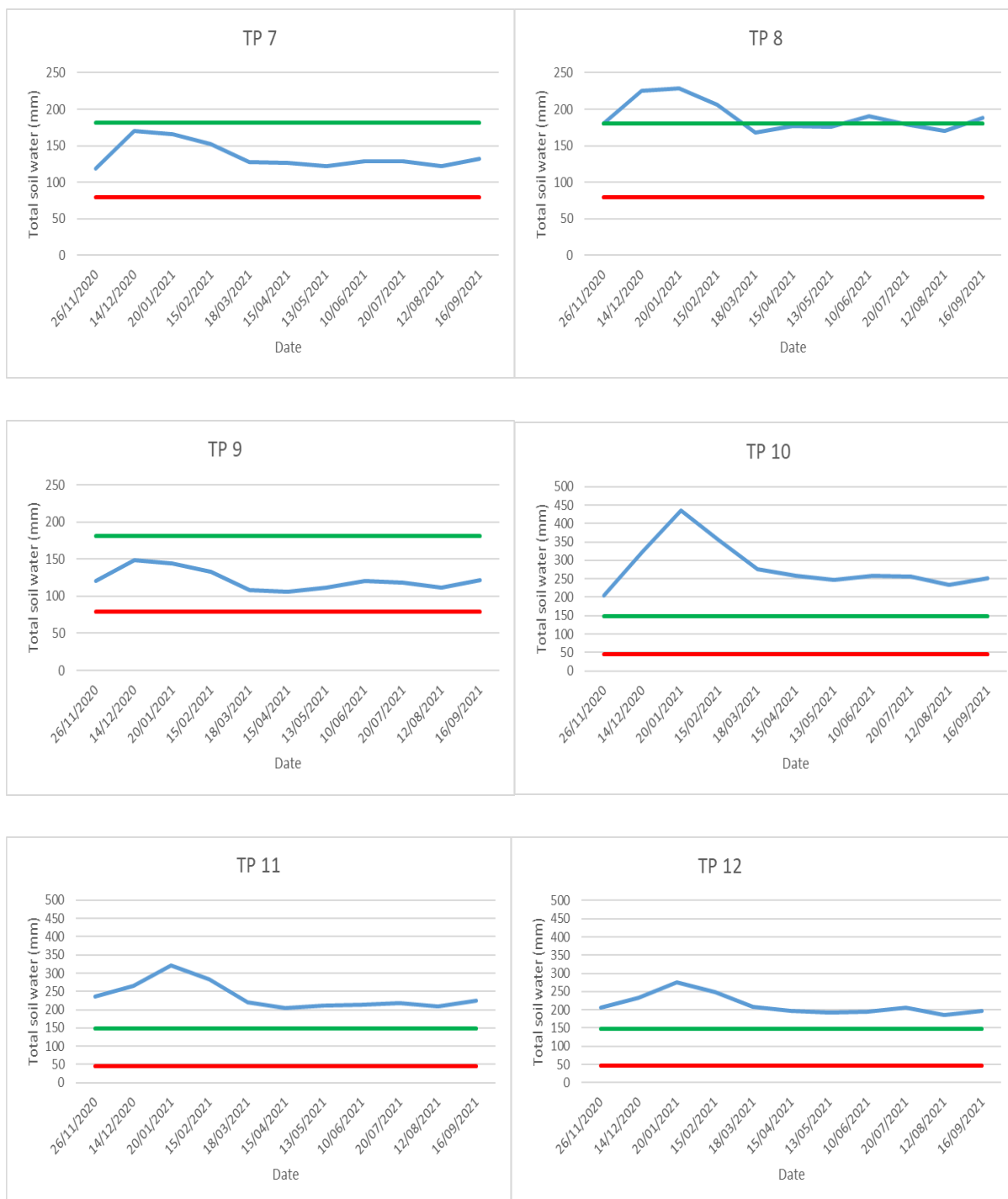
Hoekblok soil water regimes (continued):



Teerpadblok soil water regimes:



Teerpadblok soil water regimes (continued):



ANNEXURE C: COTTON QUALITY

Pretorius Rust cotton quality:

Site nr	Soil form	Test	UHML	Strength	Micronaire
PR 1	Westleigh	1	1,13	27,51	4,06
		2	1,15	27,48	4,08
PR 2	Westleigh	1	1,16	27,17	3,72
		2	1,16	27,59	3,67
PR 3	Tukulu	1	1,13	26,72	3,92
		2	1,13	26,59	4,05
PR 4	Tukulu	1	1,21	26,25	3,26
		2	1,21	26,29	3,26
PR 5	Avalon	1	1,16	26,38	3,66
		2	1,13	26,91	3,60
PR 6	Bainsvlei	1	1,12	27,24	3,30
		2	1,14	28,38	3,25
PR 7	Avalon	1	1,16	26,12	3,31
		2	1,18	26,29	3,33
PR 8	Bainsvlei	1	1,16	25,58	3,17
		2	1,15	24,96	3,16
PR 9	Bainsvlei	1	1,15	26,81	3,70
		2	1,16	26,09	3,62
PR 10	Avalon	1	1,17	26,16	3,05
		2	1,17	25,72	3,07
PR 11	Westleigh	1	1,17	25,52	3,46
		2	1,17	26,09	3,42
PR 12	Tukulu	1	1,18	26,07	3,32
		2	1,21	26,71	3,32

Schietfontein cotton quality:

Site nr	Soil form	Test	UHML	Strength	Micronaire
SC 1	Tukulu	1	1,16	26,02	4,27
		2	1,18	26,39	4,25
SC 2	Tukulu	1	1,15	27,55	4,44
		2	1,13	27,44	4,45
SC 3	Tukulu	1	1,21	29,09	4,28
		2	1,18	28,50	4,25
SC 4	Avalon	1	1,16	27,19	4,54
		2	1,16	28,06	4,51
SC 5	Avalon	1	1,21	29,54	3,01
		2	1,21	27,82	3,01
SC 6	Avalon	1	1,18	28,06	4,61
		2	1,17	27,77	4,46
SC 7	Glencoe	1	1,22	27,53	4,35
		2	1,21	26,92	4,31
SC 8	Glencoe	1	1,18	26,68	3,25
		2	1,18	26,53	3,21
SC 9	Glencoe	1	1,21	28,54	3,85
		2	1,21	27,88	3,71
SC 10	Oakleaf	1	1,13	27,07	4,37
		2	1,11	26,55	4,38
SC 11	Oakleaf	1	1,19	28,42	4,05
		2	1,21	28,10	4,10
SC 12	Oakleaf	1	1,14	26,82	3,66
		2	1,15	27,07	3,68

Hoekblok cotton quality:

Site nr	Soil form	Test	UHML	Strength	Micronaire
HB 1	Bainsvlei	1	1,14	28,57	4,85
	Bainsvlei	2	1,15	28,93	4,85
HB 2	Bainsvlei	1	1,11	27,72	4,52
	Bainsvlei	2	1,10	27,06	4,51
HB 3	Bainsvlei	1	1,15	28,20	4,24
	Bainsvlei	2	1,14	28,01	4,19
HB 4	Bloemdal	1	1,19	31,22	4,76
	Bloemdal	2	1,19	30,71	4,73
HB 5	Bloemdal	1	1,17	29,90	4,48
	Bloemdal	2	1,18	29,65	4,45
HB 6	Bloemdal	1	1,17	34,41	5,00
	Bloemdal	2	1,19	33,39	4,96
HB 7	Sepane	1	1,16	30,53	4,07
	Sepane	2	1,18	31,44	4,05
HB 8	Sepane	1	1,14	29,16	4,54
	Sepane	2	1,15	28,03	4,56
HB 9	Sepane	1	1,16	27,91	5,04
	Sepane	2	1,14	33,23	5,03
HB 10	Westleigh	1	1,08	26,31	4,41
	Westleigh	2	1,07	24,84	4,40
HB 11	Westleigh	1	1,16	31,21	4,63
	Westleigh	2	1,19	31,31	4,56
HB 12	Westleigh	1	1,14	29,95	4,57
	Westleigh	2	1,15	28,87	4,62

Teerpadblok cotton quality:

Site nr	Soil form	Test	UHML	Strength	Micronaire
TP 1	Avalon	1	1,15	28,97	3,96
	Avalon	2	1,15	29,44	3,89
TP 2	Avalon	1	1,15	28,23	4,29
	Avalon	2	1,14	28,25	4,31
TP 3	Avalon	1	1,15	28,43	4,21
	Avalon	2	1,15	27,56	4,18
TP 4	Tukulu	1	1,16	29,31	4,16
	Tukulu	2	1,14	29,48	4,06
TP 5	Tukulu	1	1,14	28,40	4,44
	Tukulu	2	1,12	28,13	4,42
TP 6	Tukulu	1	1,15	28,43	4,14
	Tukulu	2	1,16	29,21	4,14
TP 7	Oakleaf	1	1,12	29,02	4,20
	Oakleaf	2	1,14	27,95	4,18
TP 8	Oakleaf	1	1,15	28,62	4,36
	Oakleaf	2	1,15	28,73	4,45
TP 9	Oakleaf	1	1,11	28,27	4,43
	Oakleaf	2	1,11	27,57	4,44
TP 10	Westleigh	1	1,14	31,12	4,46
	Westleigh	2	1,18	30,54	4,48
TP 11	Westleigh	1	1,18	30,75	4,28
	Westleigh	2	1,20	29,93	4,25
TP 12	Westleigh	1	1,15	28,17	4,31
	Westleigh	2	1,15	28,28	4,30

ANNEXURE D: R CODE FOR STATISTICAL ANALYSIS

Baseline codes for statistical analysis:

Test name:	R code:
One-way ANOVA	oneway.test(Y~factor (Groupvec))
Normal Distribution (Graphical)	qqnorm(myaov\$residuals) qqline(myaov\$residuals)
Normal Distribution (Quantative)	Shapiro.test()
Homogeneity	bartlett.test(myaov\$residuals, factor(Groupvec))
Rejection of assumptions	Kruscal.test((Y~factor (Groupvec))
Groupwise differences	TukeyHSD(myaov)

Example of the code with results in R studio:

```
rm(list = ls())
library(ggplot2)
library(ggpubr)
library(tidyverse)

## -- Attaching packages ----- tidyverse
1.3.1 --

## v tibble 3.1.2      v dplyr 1.0.7
## v tidyr 1.1.3      v stringr 1.4.0
## v readr 1.4.0      v forcats 0.5.1
## v purrr 0.3.4

## -- Conflicts ----- tidyverse_confli
cts() --
## x dplyr::filter() masks stats::filter()
## x dplyr::lag() masks stats::lag()

library(broom)
library(AICcmmodavg)
library(readxl)
Properties = read_xlsx("G:/Data/Season 1_2019-2020/Final data/Season 1 R st
```

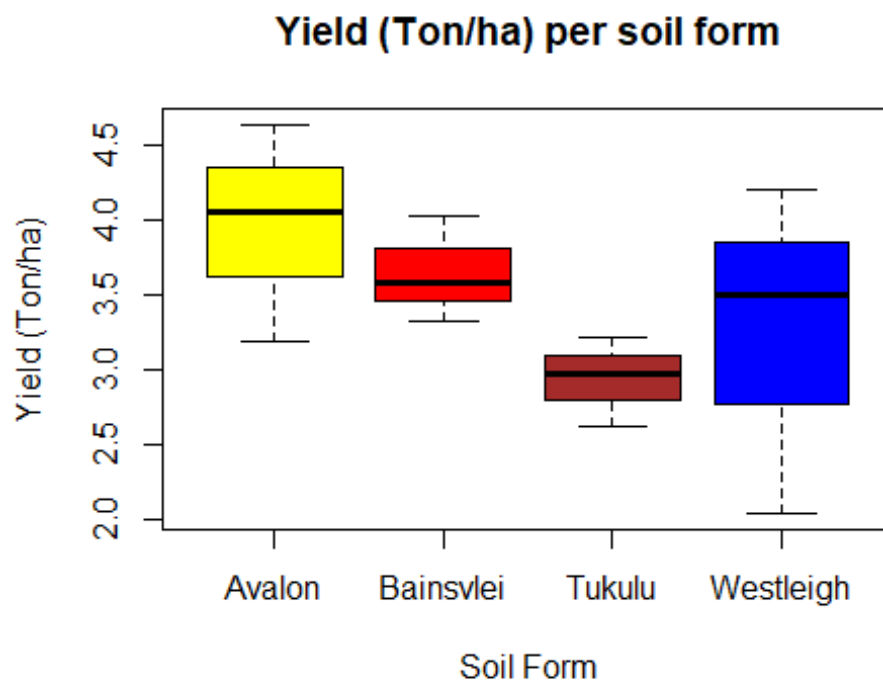
```
atistics/Pretorius Rust/Properties.xlsx")
```

```
summary(Properties)
```

```
## Soil form          Clay A          Clay B          Root depth
## Length:12         Min.   :13.40      Min.   :27.60      Min.   :1000
## Class :character   1st Qu.:14.45      1st Qu.:29.12      1st Qu.:1100
## Mode  :character   Median :14.80      Median :30.25      Median :1100
##                               Mean   :15.14      Mean   :31.38      Mean   :1125
##                               3rd Qu.:15.57      3rd Qu.:32.95      3rd Qu.:1200
##                               Max.   :18.30      Max.   :37.10      Max.   :1200
## Yield
## Min.   :2.039
## 1st Qu.:3.133
## Median :3.413
## Mean   :3.449
## 3rd Qu.:4.042
## Max.   :4.643
```

```
# Yield vs. Soil form
```

```
plot(Properties$Yield~factor(Properties$`Soil form`),xlab="Soil Form",ylab="Yield (Ton/ha)",main="Yield (Ton/ha) per soil form",col=c("yellow","red","brown","blue"))
```



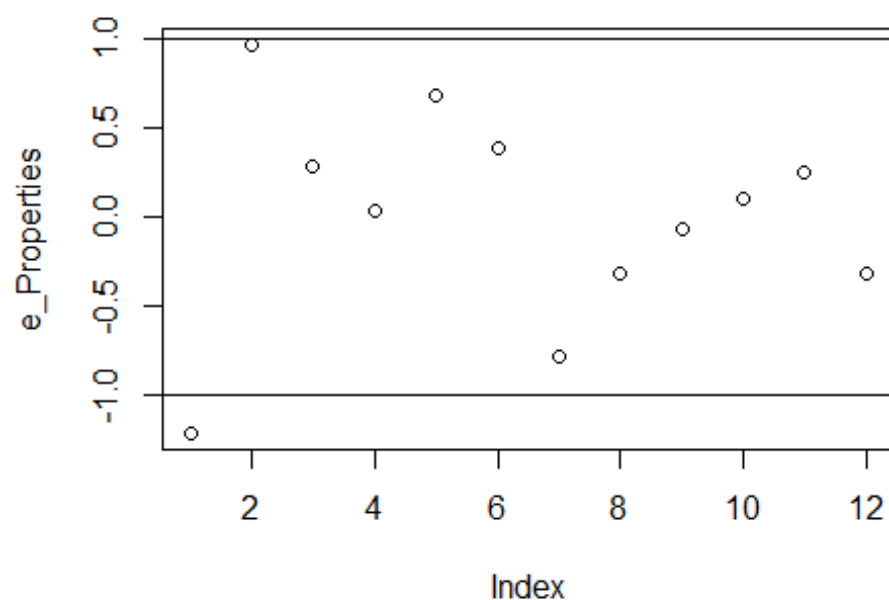
```
aov1 = aov(Properties$Yield ~ factor(Properties$`Soil form`))
summary(aov1)
```

```
## Df Sum Sq Mean Sq F value Pr(>F)
## factor(Properties$`Soil form`) 3 1.829 0.6096 1.229 0.361
## Residuals 8 3.968 0.4960
```

```
e_Properties = aov1$residuals
qqnorm = (e_Properties)
qqline = (e_Properties)
shapiro.test(e_Properties)

##
##  Shapiro-Wilk normality test
##
## data:  e_Properties
## W = 0.97441, p-value = 0.9511

plot(e_Properties)
abline(1,0)
abline(-1,0)
```



```
bartlett.test(e_Properties, factor(Properties$`Soil form`))

##
##  Bartlett test of homogeneity of variances
##
## data:  e_Properties and factor(Properties$`Soil form`)
## Bartlett's K-squared = 3.4048, df = 3, p-value = 0.3333

kruskal.test(Properties$Yield ~ factor(Properties$`Soil form`))

##
##  Kruskal-Wallis rank sum test
##
## data:  Properties$Yield by factor(Properties$`Soil form`)
## Kruskal-Wallis chi-squared = 3.7179, df = 3, p-value = 0.2936
```

```

influence.measures(aov1)

## Influence measures of
##   aov(formula = Properties$Yield ~ factor(Properties$`Soil form`)) :
##
##      dfb.1_ dfb.f.P..Sf..B dfb.f.P..Sf..T dfb.f.P..Sf..W  dffit cov.r
## 1  1.37e-15   -7.90e-16   -1.39e-15   -1.47e+00 -2.0839 0.101
## 2  1.28e-15   -1.10e-15   -1.03e-15    9.72e-01  1.3748 0.455
## 3 -7.24e-17    2.58e-17    2.33e-01    7.91e-17  0.3290 2.265
## 4  6.65e-18   -6.88e-18    3.10e-02   -4.22e-18  0.0439 2.553
## 5  8.60e-01   -6.08e-01   -6.08e-01   -6.08e-01  0.8603 1.188
## 6  0.00e+00    3.24e-01    1.10e-17    2.20e-17  0.4579 2.028
## 7 -1.02e+00    7.19e-01    7.19e-01    7.19e-01 -1.0174 0.908
## 8  0.00e+00   -2.65e-01   -9.02e-18   -1.80e-17 -0.3752 2.185
## 9  0.00e+00   -5.44e-02   -1.85e-18   -3.70e-18 -0.0770 2.542
## 10 1.12e-01   -7.95e-02   -7.95e-02   -7.95e-02  0.1124 2.522
## 11 9.75e-17   -1.26e-16   -7.19e-17    2.03e-01  0.2876 2.331
## 12 -5.69e-17    5.89e-17   -2.65e-01    5.41e-17 -0.3752 2.186
##      cook.d   hat inf
## 1 0.553729 0.333  *
## 2 0.350659 0.333
## 3 0.029998 0.333
## 4 0.000549 0.333  *
## 5 0.174558 0.333
## 6 0.056530 0.333
## 7 0.228259 0.333  *
## 8 0.038675 0.333
## 9 0.001689 0.333  *
## 10 0.003596 0.333  *
## 11 0.023093 0.333
## 12 0.038665 0.333

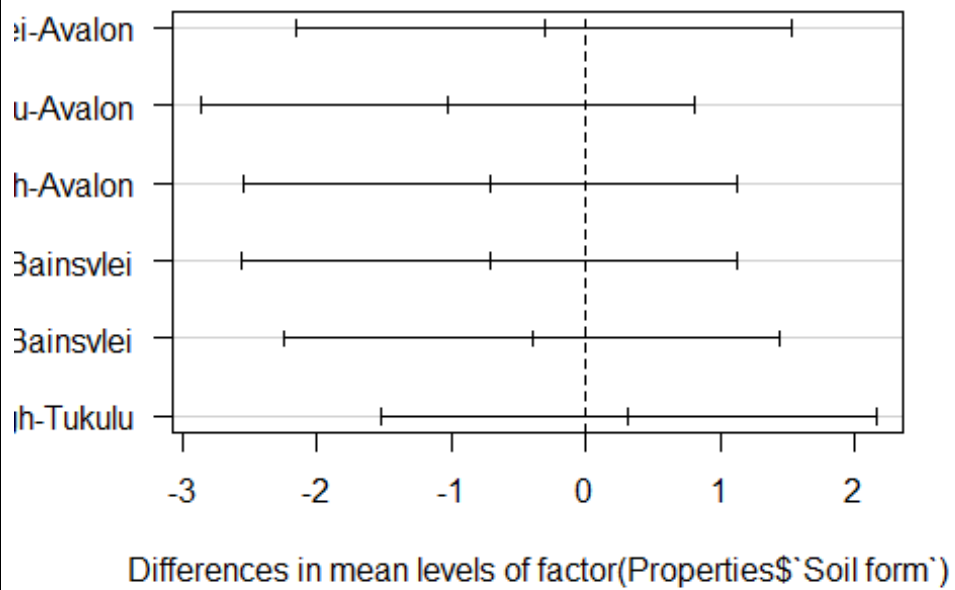
TukeyHSD(aov1)

## Tukey multiple comparisons of means
##   95% family-wise confidence level
##
## Fit: aov(formula = Properties$Yield ~ factor(Properties$`Soil form`))
##
## $`factor(Properties$`Soil form`)`
##      diff      lwr      upr      p adj
## Bainsvlei-Avalon -0.3144801 -2.156022 1.5270620 0.9448233
## Tukulu-Avalon -1.0292734 -2.870815 0.8122687 0.3439183
## Westleigh-Avalon -0.7143335 -2.555876 1.1272086 0.6199903
## Tukulu-Bainsvlei -0.7147933 -2.556335 1.1267488 0.6195426
## Westleigh-Bainsvlei -0.3998534 -2.241395 1.4416887 0.8960694
## Westleigh-Tukulu 0.3149399 -1.526602 2.1564820 0.9446043

plot(TukeyHSD(aov1), las = 1)

```

95% family-wise confidence level



```
# Clay A % vs. Soil form
plot(Properties$`Clay A`~factor(Properties$`Soil form`), xlab="Soil Form", y
lab="Clay (%)", main="Clay A horizon (%) per soil form", col=c("yellow", "red"
, "brown", "blue"))
```