THE EFFECTS OF SELECTED SOIL PHYSICAL PROPERTIES ON THE SOIL WATER BALANCE, SOIL WATER REDISTRIBUTION AND PYRROLIZIDINE ALKALOIDS LOADS IN TWO DIFERENT TEXTURED SOILS IN THE NIEUWOUDTVILLE ROOIBOS TEA PRODUCTION AREA

by

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Thesis presented in partial fulfilment of the requirements for the degree of

Master of Agricultural Sciences

at

Stellenbosch University

Soil Science Department, Faculty of AgriSciences

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March 2021

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ACKNOWLEDGEMENTS

- First and foremost, I will like to give thanks to the most high Jah Rastafari for providing me with strength towards completing this thesis.
- More thanks are given to my family and friends for words of encouragement and support, more particularly to my mom Mrs Gaoangwe M. Olifant, my wife Mrs Masego J. Olifant, my younger sister Mrs Nanki H. Bok and my friend Mr Sehunelo J. Rampho.
- I would like to grant my sincere gratitude to my supervisors, Dr Eduard Hoffman and Dr Ailsa Hardie, for their guidance, support and patience.
- I acknowledge the staff and post graduate students from Soil Science department at Stellenbosch University for advice and academic support. I thank the late Mr Nigel Robertson for support, guidance and encouragement in laboratory analysis as well as Mr Eric van Schalkwyk with his assistance in laboratory analysis.
- I convey my gratitude to my colleagues from Department of Agriculture, Land Reform and Rural Development, Mr Bogosi J. Shomoleile, Mr Chistiaan Harmse, the late Mr Moanaco Masisi, Mr Collen Paulus, Ms Mogadi Seshoka and Ms Annette Swanepoel.
- I sincerely thank Mr Hannes Gerber and Department of Agriculture, Land Reform and Rural Development for the opportunity to further my studies.

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ABSTRACT

Rooibos (*Aspalathus linearis*) is an endemic crop of South Africa produced only in the south western parts of the country. This includes the Northern Cape where the production was reported to have declined over past five years. The first aim of this study was to look at the soil water dynamics in relation to the Normalized Difference Vegetative Index (NDVI) on Rooibos plantation around Nieuwoudtville area in the Northern Cape. Pyrrolizidine alkaloids (PA's) contamination on Rooibos has been reported from several markets around the globe and pose a health risk towards consumers. Hence the second aim of the study was to investigate the PA's in Rooibos plantation.

Field trials were conducted at Rogland, Meulsteenvlei, Oorlogskloof and Klein Blomfontein farms near Nieuwoudtville while a pot trial was conducted at Vaalharts Research Station near Jan Kempdorp in the Northern Cape Province. Soil water content (SWC) was monitored at an hourly basis throughout the growing season (October 2017 to February 2019) using ECH$_2$O sensors in the field. At the end of 2018/19 growing season, soil water balance and NDVI of selected sites around Nieuwoudtville were determined.

The total rainfall received at Rogland, Meulsteenvlei, Oorlogskloof and Klein Blomfontein was 373, 495, 413 and 391 mm, respectively. The cumulative evapotranspiration (

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surrounded the Rooibos plants and known to contain PA's. Further investigation was conducted in pots to evaluate PA's uptake by Rooibos plant. Soil collected from Rogland was treated with three different weeds (*Chrysocoma oblingifolia* [0.225 ppm total PA's], *Othonna coronopifolia* [0.377 ppm total PA's] and *Raphanus rhaphnistrum* [46.008 ppm total PA's]). Weeds were applied at a rate of 1% of soil volume and replicated 6 times. The pots were planted with Rooibos seeds obtained from Oorlogskloof on the 25th of July 2018 and the experiment continued up until the 1st of February 2019.

The total weed population density between the study sites was not significantly different. However, the significant difference between the study sites was only found on *Arctotheca calendula*, *Chrysocoma oblongifolia*, *Cleretum papulosum*, *Cynodon dactylon*, *Ehrharta longiflora*, *Juncus capensis*, *Senecio arenarius*, and *Ursinia* weeds species. The dominant weeds species found to contain PA's at the study sites were *Arctotheca calendula*, *Chrysocoma oblongifolia*, *Othonna coronopifolia* and *Raphanus rhaphnistrum* with an average total PA's of 5, 75, 2 817 and 15 330 µg.kg^{-1}, respectively. The mean total PA's concentration in Rooibos plantation at the study sites was 7.2 ppm (Klein Blomfontein). 15.5 ppm (Meulsteenvlei), 16 ppm (Rogland) and 43.2 ppm (Oorlogskloof). The higher total mean PA's concentration at Oorlogskloof can be due to the high density of *Chrysocoma oblongifolia* as compared to the other study sites. The *Chrysocoma oblongifolia* could have released PA's in soil during decomposition which could have let to the uptake of PA's by Rooibos plants.

Furthermore, this study confirm that Rooibos itself cannot produce PA's but rather, it absorbs PA's from the soil. The lateral transfer of PA's from weeds to Rooibos was also found to be inconclusive.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
ASNAPP	Agribusiness in Sustainable Natural African Plant Products
ASTM	American Society for Testing and Material
Avg	Average
BfR	Bundesinstitut für Risikobewertung
CAF	Central Analytical Facilities
D	Deep drainage
DAFF	Department of Agriculture, Forestry and Fisheries
DNA	Deoxyribonucleic acid
E	Direct evaporation from the surface of the soil
EFSA	European Food Safety Authority
ET	Evapotranspiration
FC	Field Capacity
FSSA	Fertilizer Society of South Africa
GI	Geographical Information
GIMMS	Global Inventory, Monitoring and Modelling
GSD	Ground Sampling Distance
HDL	High – density lipoprotein
HIV	Human Immunodeficiency Virus
I	Irrigation
IPCC	International Panel for Climate Change
K_s	Saturated hydraulic conductivity
K_{us}	Unsaturated hydraulic conductivity
LDL	Low – density lipoprotein

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MT-4	Metallothionein 4
NDVI	Normalized Difference Vegetation Index
NRI	Near Infrared
OM	Organic matter
P	Precipitation
PA’s	Pyrrolizidine Alkaloids
PANO	Pyrrolizidine Alkaloids Necine – Oxides
PAW	Plant available water
PSM	Plant Secondary Metabolities
R	Runoff
R^2	Correlation co-efficient
R_{vr}	Visible red reflectance
SARC	South African Rooibos Council
SPSS	Statistical Program for Social Sciences
SWB	Soil water balance
SWC	Soil water content
SWD	Soil water dynamics
SWS	Soil water storage
TAA	Total Antioxidant Activity
TP	Total Polyphenol
Tr	Transpiration
TRIP’s	Trade – Related Aspects on Intellectual Property
U	Upward capillary flow into the plant root-zone
UAV	Unmanned Aerial Vehicle

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USA	United States of America
USDA	United States Department of Agriculture
WTO	World Trade Organization
	Change in soil water content
	Change in quantity of water in the vegetation biomass
	Cumulative evapotranspiration
	Cumulative precipitation
	Cumulative upward capillary flow into the plant root-zone

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CHAPTER 1: INTRODUCTION

1.1 Background and problem statement

Dryland Rooibos production is a common practice around Nieuwoudtville, with its Mediterranean type of climate and sandy soil. Currently very little information is available on the soil physical properties of the cultivated Rooibos lands in this region and how they affect soil water redistribution and the water balance. The area is known to have a variable rainfall from the north to the south, with the northern area experiencing higher rainfall compared to the southern area. Recently, water has become a scarce resource for south western parts of South Africa including Nieuwoudtville. Given the drought conditions that have prevailed, effective use of water for sustainability of Rooibos production is very important. Measuring the soil water balance in different scenarios can be used to gather more local information, while taking into account that soil physical and hydraulic properties might play a pivotal role towards the movement, storage and usage of water in the soil. The research on Rooibos production at Nieuwoudtville will assist the Rooibos producers by proving scientific solution on how to improve productivity which was reported declining for the past five year.

Furthermore, high levels of Pyrrolizidine Alkaloids (PA's) residues from Rooibos tea was confirmed by samples collected from retail markets in Switzerland (Mathon *et al*., 2014), Germany (Mädge *et al*., 2015), Belgium (Huybrenchts & Callebuat, 2015) and Israel (Shimshoni *et al*., 2015) and this situation is being monitored strictly by importers of Rooibos tea. It is well known that PA's occurs in numerous plant species, it is postulated by some that the PA's are actually accumulated from the decaying plant material in the soil, absorbed by the roots together with water and translocated to the areal parts of the plant.

1.2 Hypothesis and aims

The hypothesis of the study is that PA's derived from weeds occurring in Rooibos fields and are leached into soils and taken up by Rooibos plants. The concentration thereof are influenced by rainfall, soil textural class, hydraulic properties and weed species composition.

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The following aims will be investigated in the study, namely:

- Quantify the soil water balance in four different Rooibos tea plantations.
- Relate the soil water dynamics to Normalised Difference Vegetation Index of four cultivated Rooibos fields spread across a rainfall gradient.
- To evaluate the level PA's of Rooibos produced from these fields, quantify weed species and population density observed.
- To quantify amount absorbed of PA's by Rooibos from decaying weeds containing PA's in a pot trial.

1.3 Chapter overview

Chapter two, is an extensive literature review on Rooibos cultivation, soil physical properties needed to understand the soil water balance and PA's in Rooibos tea. Chapter three is the full soil morphological, physical description of the soils and Rooibos water dynamics of the study sites. Chapter four reports on the vegetation condition index and Rooibos PA's levels of the different sites. A conclusion of the study, recommendation and future research are given in Chapter five.

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CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Rooibos tea (*Aspalathus linearis*) is an evergreen leguminous shrub which belongs to Fabaceae family (Joubert & de Beer, 2011). Rooibos is an endemic crop of South Africa belonging to Fynbos Biome which is one of the five Mediterranean climatic regions of the world (Cowling *et al*., 1996; Lötter *et al*., 2014). Mediterranean climate represents a strong seasonal pattern of rainfall with aridity during summer months and most of the annual rainfall occuring during the winter months (Lötter *et al*., 2014).

In the twentieth century, Rooibos is one of the few of its own biome that has transitioned successfully from wild resource to an important agricultural plant (Lötter *et al*., 2014). Previously, Rooibos was used by the natives of the Cedarberg area not only for the production of tea but also for medicinal and health properties (Dahlgren, 1968). Since the commercialization of Rooibos, research has focussed on its health benefits rather than on the production aspects of Rooibos. Rainfed cultivation in semiarid Mediterranean zones around the world experience restrictions on plant water availability associated with soil properties and climate, primarily because of inconsistent rainfall and extreme erosive rainfall events (Rockström *et al*., 2010). Rainfall is a main important input and the leading source of risk and doubt in crop production (Rockström *et al*., 2010). One hundred percent of Rooibos is under rainfed agriculture in the production regions (SARC, 2017). Hence, the amount and distribution of periodic rainfall plays an important role in growth, water use efficiency and yield (Moret *et al*., 2007). Hewitson and Crane, (2006), IPCC, (2007) and Engelbrecht *et al*. (2009) predicted that climate changes will reduce rainfall over the western coast of South Africa by the end of the 21st century. Furthermore, Lötter *et al*. (2014) indicated that the changes in climate may add pressure on plants survival within an already resource-limited environment. Changing climatic condition may have a serious impact on Rooibos tea production (Archer *et al*., 2008). Hence, it is important to understand the eco-physiological behaviour of *Aspalathus linearis* relative to the given climatic and soil limitations (Lötter *et al*., 2014). On a study conducted by Stassen (1987), indicates that Rooibos have a preference on deep and cooler soils with high soil water storage.

Presently, there is a global concern regarding the occurrence of PA's in beverages and food products such as herbal tea (BfR, 2013; Mathon *et al*., 2014; Bodi *et al*., 2014; Shimshoni *et al*., 2015) and honey (Kempf *et al*., 2008; Kempf *et al*., 2010; Kempf *et al*., 2011;

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Martinello *et al*., 2014; Mathon *et al*., 2014). Reports on herbal teas, verified that PA's contamination is a common problem and not distinctive to Rooibos itself (Van Wyk *et al*., 2017). The European Food Safety Authority (EFSA) recently reported that the uppermost average level of PA's in Rooibos tea is at 7.99 µg/L tea infusion (Muller *et al*., 2015).

Pyrolizidine Alkaloids are known to be hepatotoxic to humans and animals (Bull *et al*., 1968; Mattocks, 1986) and could cause acute liver damage when consumed in large amounts (EFSA, 2011; BfR, 2013). On the other hand, the effect of low levels of PA's on health and safety is not entirely known (BfR, 2013; Allgaier & Franz, 2015). However, avoiding the uptake of PA's in the first place remains the best way to reduce the associated health risk (Boppré, 2011).

2.2 Background of Rooibos

2.2.1 Botany

Rooibos forms part of the genus *Aspalathus* which includes more than 200 species inherent to South Africa (Erickson, 2008). It has a strong taproot which can grow up to the depth of 2 m or more (Morton, 1983). Its branches are red-brown and reach a length of 60 cm (Morton, 1983) and its leaves are bright green and needle-shaped. These leaves range from 15 to 60 mm long and 0.4 to more than 1 mm thick (Van Niekerk & Viljoen, 2008). Flowers are yellow and are shaped like peas, and are single up to ten take place in racemes on the branch tips in summer and are followed by solitary pods (Van Niekerk & Viljoen, 2008). Nodules containing nitrogen fixing bacteria are established on the root systems and these bacteria convert nitrogen gas from the soil into a biological beneficial ammonia in a process known as nitrogen fixation (Erickson, 2008). Leaves are hair-like structure and used for tea production (Lötter, 2015). Unfermented tea remains green in colour while fermented tea changes to red during the oxidation of polyphenols (McKay & Blumberg, 2007).

Rooibos plants have a mean natural life of 6 years which provides 4 crops on average. In a complete cycle, the Rooibos plant provides an average yield of 18 000 kg/ha (SARC, 2016).

2.2.2 Geographical distribution of Rooibos in South Africa

Rooibos plantation extend from the Cedarberg and Sandveld regions of the Western Cape to the Bokkeveld region of the Northern Cape (O'Donoghue & Fox, 2009). It is

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commercially produced in Nieuwoudtville, Wuppertal, Van Rhynsdorp, Clanwilliam and Piketberg (Joubert & Schultz, 2006). The production extent of commercially cultivated Rooibos is shown in Figure 2.1. There are two types of Rooibos tea, namely, Green Rooibos Tea and Traditional Rooibos Tea (SARC, 2018). Green or unfermentated Rooibos is harvested and prepared without fermentation process. When served, it has a lighter colour compared to the tradition Rooibos (SARC, 2016).

Traditional Rooibos Tea (red tea) is prepared through a process of fermentation (O'Donoghue & Fox, 2009). This process involves the cutting, bruising and wetting of leaves with water. Damp leaves ferment for twelve hours (SARC, 2018) during which enzymatic oxidation occurs changing its colour from green to a typical amber hue and afterwards the Rooibos is spread out in the sun to dry (Rooibos Ltd, 2016).

Rooibos can also be produced as organic Rooibos (Tradition or Green Rooibos Tea) which is produced without any use of inorganic fertilizers or pesticides (SARC, 2018).

2.2.3 Production levels

Presently, 99.5% of the Rooibos produced is cultivated while the remainder is produced mostly by non-commercial farmers as wild-grown Rooibos (SARC, 2016). The cultivated land is approximately 95 000 ha with approximately 580 Rooibos growers in South Africa (SARC, 2016). However, the supply at Rooibos tea has decreased while the global demand has increased (Kruger, 2014). Therefore, it is important to produce as much Rooibos as possible from the cultivated area that is presently in use since the Rooibos production land is limited by environmental protection laws (Van Schalkwyk, 2018).

Global Rooibos tea demand increased from 524 tonnes in 1955 to 10 600 tonnes in 2003, with exports accounting for 6 400 tonnes (Joubert & Schultz, 2006). The position of Rooibos in the global market indicated the total production of ± 14 000 tonnes in 2007 which constituded below 0.3% of the global tea market and 10% of the global herbal tea market (DAFF, 2016). In 2015, the global Rooibos tea consumption was 15 000 tonnes with the major export markets being Germany at 30.5% , followed by the Netherlands at 15.7 %, Japan at 15.3% and United Kingdom at 11.9% (SARC, 2016). Locally, Rooibos tea consumption is approximately 4 500 to 5 000 tonnes with an 18% share of the local market (DAFF, 2016).

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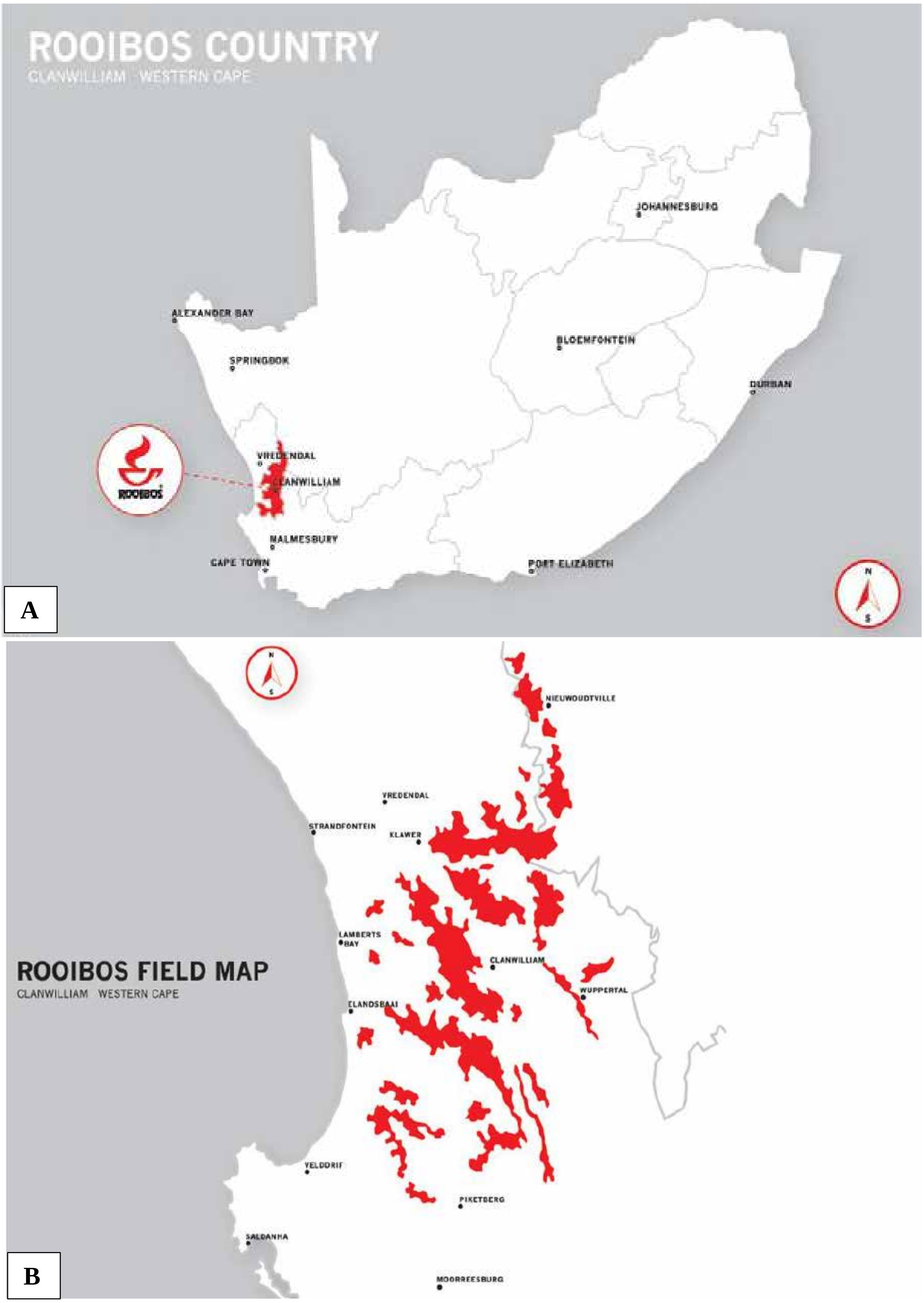

Figure 2.1: Map indicating Rooibos production South Africa (A) and within the Northern Cape and Western Cape (B), respectively (map was supplied by SARC).

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The Rooibos tea gross value of production was estimated to R118 million in 2006 and increased to approximately R155 million in 2007 (DAFF, 2016). However, there was a decline between 2008 to 2010 with 2010 experiencing the lowest gross value of production at an estimated value of R60 million (DAFF, 2016). This decline was influenced by the solid decline in producer price. The producer price decreased from R12.50/kg in 2006 to R4.50/kg in 2010 (DAFF, 2016) and then increased to R29.00/kg and R30.00/kg in 2015 and 2018, respectively (Van Heerden, 2019).

2.2.4 Geographical Indication (GI)

Unfair trade branding of the word ‘Rooibos’ in 1994 in United States of America (USA), which prohibited the free use of this word in marketing led to a legal fight to regain the name for South Africa, and provided motivation to the development of Geographical Indication (GI) for Rooibos (Gerz & Biénabe, 2006; SARC, 2016). A GI is a brand that is set aside for products which obtain their appearances and outlining qualities as a result of their geographical location (Grazioli, 2002). Rooibos matched all of the specifications for GI protection, as specified in the World Trade Organization (WTO) Agreement on the Trade-Related Aspects on Intellectual Property (TRIPs), as it is produced in a single part of the world where the properties of the plant remain a direct outcome of the distinctive geographical conditions in which it is cultivated (SARC, 2019).

Effective GI protection is perceived as a means to foster global trade for the benefit of the producer (Crespi & Marette, 2003). Advantages are both from the right to commercially use the name and to combat faking in trade (Biénabe & Marie-Vivien, 2017). Further than their economic potential, GIs bring the cultural identity of a place (Biénabe & Marie-Vivien, 2017). The status given to GI goods is linked with the expertise of the producers or processors as well as with the history, tradition and social behaviour of native people; and GIs can be a tool to impede outsiders taking product names that are part of the indigenous legacy (Addor & Grazzioli, 2002; Kamperman-Sanders, 2010; Gangjee, 2012).

2.2.5 Quality standards and control of Rooibos

Besides the quality standards relating to foreign matter, moisture content, insects, microbial contamination and pesticides residue levels (DAFF, 2015), there are no regulative quality standards or specifications pertaining to formation, active

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compounds or antioxidant activity for red and green Rooibos (Joubert & Schultz, 2006). Meanwhile, the taste, aroma and colour quality standards are given in unclear and worthless standings by indicating that the Rooibos should have characteristic taste, aroma and distinctive colour of Rooibos, without characterisations or reference standards for the words ‘characteristic’ and ‘distinctive’ (Joubert & de Beer, 2011).

On the other hand, there is a growing interest to provide green Rooibos extracts with exalted levels of aspalathin for the cosmetic and effective food market (Joubert & Schultz, 2006). However, the aspalathin content of green Rooibos is not measured regularly by processors and currently visual assessment of colour functions as the only quality control factor (Joubert & Schultz, 2006).

In addition, producers of extracts have introduced product specifications such as minimum Total Polyphenol (TP) content and Total Antioxidant Activity (TAA) as indicators of quality (Joubert & Schultz, 2006). Traditional Rooibos extract is standardized in terms of orientin and isoriented content (more than 0.5% total) (Joubert & de Beer, 2011) which have recently been presented for the useful food market and the green Rooibos which is standardized at 15% aspalathin content (Joubert & Schultz, 2006).

2.2.6 Traditional use and health benefits

Over 300 years ago, the native people of the Cedarberg and Elephants River discovered that the leaves of the Rooibos plant could be used as a tea, with a remarkable flavour and aroma (Van Niekerk & Viljoen, 2008). The first person to recognise the market potential of Rooibos as a herbal tea was Benjamin Ginsberg, a businessman from Clanwilliam, who began marketing it in 1904 (Joubert & de Beer, 2011). It was only in 1930 were the agricultural potential of Rooibos was realised by a health practitioner, P. Le Fras Nortier of Clanwilliam (Anon, 1985).

Currently, Rooibos tea is renowned for its anti-oxidant activity and is categorised as a healthy liquid refreshment (Morton, 1983). It is frequently used for children with sensitive skin conditions (Van Niekerk & Viljoen, 2008). In some of the rural black communities in South Africa, Rooibos is believed to stimulate the appetite, hence it is very popular among mothers whose children experience problems in breastfeeding (ASNAPP, 2008). Numerous studies have attested the health benefits of Rooibos in combating heart disease and early ageing, and in reducing the manifestation of cancer

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and diabetes (Joubert *et al*., 2008). Rooibos has high manganese and calcium levels, which raise levels of enzymes required to build and repair bones (Organic Facts, 2016). It also assists in fighting hypertension by decreasing blood pressure, and supports the development of high-density lipoprotein (HDL) cholesterol (good cholesterol) while decreasing the capability of low-density lipoprotein (LDL) cholesterol (bad cholesterol) to form a coating on the inside of the blood vessels (Joubert *et al*., 2008). Rooibos has been verified to contain minor estrogenic activity (Shimamura *et al*., 2006), restrained tumour advancement in mouse skin (Mamewick *et al.*, 2005) and did not affect iron absorption considerably compared to ordinary tea (Hesseling *et al*., 1979).

Rooibos is renowned for being naturally caffeine-free and for its low tannin content (Morton, 1983). It has approximately 4.4% tannin content (Marnewick *et al*., 2000) and does not have a bitter taste compared to *Camellia sinensis* (Green tea) (Erickson, 2008). Furthermore, the low tannin content found in Rooibos tea reduces the risk of iron absorption and the decrease in digestion and utilisation of proteins (Disler *et al*., 1975; Hallberg & Rossander, 1982; Butler, 1992; Bravo, 1998; Chung *et al*., 1998; Hurrell *et al*., 1999; Zijp *et al*., 2000; Samman *et al*., 2001).

Rooibos has high levels of flavonoids, phenolic acids, polyphenols, polysaccharides and oligosaccharides (Dos *et al*., 2005). The main flavonoids found in Rooibos tea are aspalathin, iso-orientin, orientin and rutin (Shimamura *et al*., 2006). Both flavoinoids and phenolic acids are strong anti-oxdants in Rooibos tea and can be utilized to protect deoxyribonucleic acid (DNA) from oxidative damage caused by peroxyl radicals (Lee & Jang, 2004). Polyphenols are organic chemicals with an excessive ability to inhibit iron absoption (Organic Facts, 2016). They have anti-inflammatory, anti-viral and anti-mutagenic properties which protects the body from free radicals that might cause cancer heart diseases (SARC, 2018). Furthermore, Rooibos have polyphenol aspalathin that is found exclusively in Rooibos and assists to balance blood sugar levels and improve the body cells glucose intake by breaking down the insulin resistance in cells (SARC, 2018).

In vitro and *in vivo* research revealed that Rooibos might improve immune function, but very few investigations has been done on this subject matter (Kunishiro *et al*., 2001). One study revealed that a polysaccharide in Rooibos might have anti-viral

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activity against the human immunodeficiency virus (HIV) by just binding full block virus to the human metallothionein 4 (MT-4) cells (Nakano *et al*., 1997). However, no evidence available to indicate that Rooibos can fight HIV (Erickson, 2008).

2.2.7 Value addition

Rooibos extracts produced in South Africa and overseas are reflected as intermediate value-added products in the value chain (Joubert & de Beer, 2011). Other than cosmetics, completed products use includes useful foods, beverages and nutraceuticals (Joubert & de Beer, 2011).

The initial use of Rooibos extract and its unstable portion was as a flavour component of yogurt by the then Van Riebeeck Dairies when the Rooibos instant tea powder was first established (Joubert, 1984). At that stage, the utilization of Rooibos as a useful component was not recognised and none of the instant Rooibos tea or yogurts got to the market (Joubert & de Beer, 2011). It was simply in 2000 that the producers of Rooibos pulverised extract materialised after changing consumers reactions concerning natural products which made it a feasible value-addition opportunity (Joubert & de Beer, 2011).

The use of medicinal goods applications of Rooibos as medicines has not yet been exploited, hence opportunities are likely to appear as a result of the trend in the direction of phytopharmaceuticals (Joubert & de Beer, 2011). Rooibos extracts are customarily merged with other ingredients and are obtainable in tablet form. However, these products belong in the class of nutritional additions (Joubert & de Beer, 2011).

The value-addition of Rooibos was initially introduced by Annetjie Theron who took cosmetic containing Rooibos extract to the market (Joubert & Schultz, 2006). Her range of merchandises is now distributed to 34 countries (Joubert & de Beer, 2011). Green Rooibos is used as a tea and for production of extracts for the food, cosmetic and beverage markets. The greater quantities of flavonoids (antioxidant) in green Rooibos, together with its caffeine-free status add to its universality in tea mixtures (Cosgrove, 2010) and cosmetic goods (Tiedtke & Marks, 2002; Otto et al., 2003). Aspalathin-enriched extracts can be produced from green Rooibos as this blend is obtainable in great quantities (Schulz et al., 2003; Manley et al., 2006). The level of enrichment highly influenced by the extraction circumstances and level of purification (Joubert & de Beer, 2011).

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2.3 Soil water dynamics

Soil water dynamics (SWD) are determined using numerical models and thus require precise field data to achieve high quality output (Jakubínský *et al*., 2019). Numerous models have been produced (Porter, 1993; Marinov & Marinov, 2014) and some scientists have reviewed them (Addiscott & Wagenet, 1985; Bastiaanssen *et al*., 2007; Greenwood *et al*., 2010). Soil water content models can be used separately in agriculture, and can also be combined with nutrient model for reproducing the soil-water-plant system (Jiménez-de-Santiago *et al*., 2019). Models are classed as grouped or diffused, with diffused models being deterministic or speculative (Jiménez-de-Santiago *et al*., 2019). Deterministic models postulate that a co-ordination or procedure functions such that the existence of a given set measures provide an exclusively definable result (Addiscott & Wagenet, 1985). According to Jiménez-de-Santiago *et al*. (2019), the speculative models are centred on the notion that the result will be uncertain, hence the model construction is built to report for this uncertainty. Moreover, deterministic models are partitioned into functional and mechanistic. Functional models are centred on a tipping bucket method and they remain uncomplicated and isolated in time, reproducing variations in the quantity of water content (Jiménez-de-Santiago *et al*., 2019). However, mechanistic models denote the integration of the most important procedure or devices that in the case of soil water dynamics includes the use mathematical models obtained from Darcy's Law, normally centred on rate parameters compelled by time (Jiménez-de-Santiago *et al*., 2019).

2.3.1 Soil physical properties that affects soil water dynamics

The capability of the soil to control the land freshwater supply is an important ecosystem service (O'Geen, 2013). Water infiltrating through soil is filtered, kept for plant use, and redistributed through movement pathways to groundwater and surface water bodies (O'Geen, 2013). In isolation, the viability of water supply is directly affected by soil (O'Geen, 2013). Hence, the majority aspects of land - and freshwater aquatic-life rely on the soil hydrologic processes (O'Geen *et al*., 2010)Water dynamics in soil are administered by numerous aspects that vary vertically with depth, laterally through landforms and secularly in response to climate (Swarowsky *et al*., 2011).

2.3.1.1 Soil texture

Soil is formed by three phases; namely the solid, liquid and gaseous phases (Hillel, 2004). The solids are formed by minerals subsequent to weathering of parent material and organic matter consisting of plant and/or animal remains

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as well as living organisms (Easton & Bock, 2016). The mineral solid portion of the soil is composed of sand, silt and clay with the certain relations which define the soil texture (Easton & Bock, 2016). According to United State Department of Agriculture (USDA) textural classification, the sand, silt and clay particles size range from 2 to 0.05, 0.05 to 0.002 and less than 0.002 mm in diameter, respectively (Hillel, 2004). However, larger particles (> 2.0 mm in diameter) are symbolised as rock fragments and are not reflected as part of soil texture despite the fact that they can influence soil structure and soil water relationships (Easton & Bock, 2016). After the clay, silt and sand contents of the soil is quatified, the textural triangle from USDA textural classification can be used to determine the textural class of the soil (Hillel, 2004). Soil texture determination is very essential since numerous soil properties are affected by texture (Easton & Bock, 2016).

Soil texture plays a vital role in the determination of pore size distribution in the soil, therefore influencing the water content at saturated, field capacity and permanent wilting point, and the amount of plant available water (PAW) (O'Geen, 2013). Coarse textured soils have low PAW due to the pore size distribution being dominated by large pores with restricted ability to retain water. Fine textured soils have moderate PAW due their pore size distribution dominated by micropores (O'Geen, 2013). Hultine *et al*., (2005) indicated that water in sandy soils infiltrates faster compared to clay soils. However, the change in soil water content in sandy soils is more rapid because of large and fewer pores (Dodd & Lauenroth, 1997).

2.3.1.2 Soil bulk density

Bulk density is defined as the fraction of the mass of solids to the total volume (Hillel, 2004). Bulk density is reliant on soil texture and the compactness of soil mineral and organic matter particles, including the packing arrangement. It is usually expressed as grams per cubic centimeter (USDA, 2008). However, two soils having similar bulk density can have considerably various strengths if one is aggregated and the other is not aggregated (Horn & Peth, 2012).

Bulk density is essential in determining soil porosity by means of following equation:

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Soil porosity = (1- bulk density/particle density) …………………… Eq. 2.1.

Where;

Bulk density = Fraction of mass of solids to total volume

Particle density = Density of the solid particles that collectivelly make up a soil sample

It is specified as a fraction or as a percentage (Blake & Hartge, 1986).

However, the direct relationship of bulk density to the porosity influences soil water infiltration, hydraulic conductivity and soil water holding capacity (Alaoui *et al*., 2011). Furthermore, bulk density both in agriculture and civil engineering serves as an indicator for the degree of soil compaction (Voster, 2015).

Bulk density differs with the packing order of particles. Soils with a sandy nature pack more closely and the values range from 1.4 to 1.9 $g.cm^{-3}$ whereas clays tend to bond and cannot pack as compactly, giving values that range from 0.9 to 1.4 $g.cm^{-3}$ (Warrick, 2002). USDA in 2008 reflected that the ideal bulk density for plant growth is < 1.6, < 1.4 and < 1.1 $g.cm^{-3}$ for sandy, silty and clayey soils, respectively, while the bulk density restricting root growth for sandy, silty and clayey soils is > 1.80, > 1.65 and > 1.47 $g.cm^{-3}$, respectively.

A Study done on sandy soils at the Kandi areas of the Kashmir valley in India found that soils were less productive as the bulk density increased (Tanveera, 2016). However, the measured effects of sand content at Coimbatore towards soil bulk density was found to be greater than that of the other properties of the soil were clayey soils have a habit of lower soil bulk density and higher porosity as compared to sandy soils (Pravin *et al*., 2013).

2.3.1.3 Hydraulic conductivity

The understanding of soil hydraulic conductivity is essential in soil science, hydrology and other soil and water related fields (Dohnal *et al*., 2010). Hydraulic conductivity is a soil property which defines the rate at which water flows in the soil, and depends on the shape, size and the number of interconnected pores (Lal & Shukla, 2004). It is normally measured by the

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constant head or falling head method in the laboratory or infield using Darcy's Law (Voster, 2015). The constant head method is usually used on coarse soils. This technique permits the water to move through the soil under stable state head condition whereas the amount of water flowing through the soil specimen is evaluated over a period of time (Asadullah *et al*., 2014). The falling head method doesn't differ from the constant head method in the initial setup; nevertheless, the advantage of the falling head method is that it can be better used for fine grained soils (Asadullah *et al*., 2014). However, findings on a study conducted by Asadullah *et al*., (2014) suggested that the falling head method was more accurate compared to the constant head method.

Soil hydraulic conductivity is divided into unsaturated hydraulic conductivity (K_{us}) and saturated hydraulic conductivity (K_s). Water movement through the soil is naturally taking place under unsaturated and saturated conditions. Minidisk infiltrometers are extensively used for *in situ* inspection of soil hydralic properties such as K_{us} (Smettem & Clothier, 1989; Reynolds & Elrick, 1991). They have became popular because of the small amount of water they use during operation and also they have a compact size.

Saturated hydraulic conductivity takes place when all pores are filled with water (Decagon Devices, 2016). In spite of the similarity between soil K_s and soil infiltration rate in units ($cm.s^{-1}$), there is a clear difference between the two measurements (Fatehnia *et al*., 2016). Infiltration rate can be defined as the speed at which the water enters the soil and is directed by gravity and capillary action (Fatehnia *et al*., 2014). The K_s is a steady-state one-dimension infiltration speed when water is provided to the soil surface under zero pounded situations and the hydraulic gradient is equal to one (Fatehnia *et al*., 2014). According to the American Society for Testing and Material (ASTM) (2009), K_s and infiltration rate can be related directly provided the hydraulic boundary conditions, such as lateral flow of water and hydralic gradient, are known. The double ring infiltrometer is the more favoured choice than the single infitrometere which are commonly used *in situ* measurement of K_s or infiltration rate (Sharma *et al*., 1980; Bouwer, 1986; Ben-Hur & Assouline, 2002; Iwanek, 2008). The use of the outer ring of the double ring assists to

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reduce the error that might result from the lateral flow in the soil (Bouwer, 1986).

2.3.2 Parameters of importance in water dynamics

2.3.2.1 Soil water content

Soil water content (SWC) is an amount of water retained in the soil at a particular time and can be reported as gravimetric or volumetric water content (Easton & Bock, 2016). I can be measured by numerous direct or indirect techniques (Robinson *et al*., 2008; Shukla, 2013). The gravimetric method is the most common direct technique used, and it entails the oven drying of a soil sample up to stable mass (Gardner *et al*., 2000). Indirect SWC amounts can be attained from capacitance probes, renowned as frequency domain reflectometry, centred on soil and water insulator properties (Czarnomski *et al*., 2015).

According to Li *et al*. (2016), the SWC of bare sandy soil and covered sandy soil in Namibia under arid condition increased by 6 mm and 9 mm, respectively, after 7 mm of rain. However, Moret *et al*. (2006) indicated that the amount of adequate rainfall $^{-1}$) is important for contributing meaningfully to soil water storage (SWS), meanwhile lesser rainfall amounts are more expected to evaporate rapidly without contributing considerably to SWS. According to Verburg *et al*. (2012), fallowing can increase the SWS. The enhancement of SWS and water accessibility to plants at critical developmental stages escalates water use efficiency (Van Duivenbooden *et al*., 2000). Futhermore, Smika (1970) reported that fallowing with greater fallow efficiency provided higher yield in the following year, even though rainfall was under 100 mm. For that reason, it can be concluded that dryland crops are reliant on the quantity of water kept in the root zone during rainfall (Hoffman, 1997) and in the soil subsequent to fallowing (Feng *et al*., 2015).

2.3.2.2 Soil water balance

Soil water balance (SWB) is defined as an imperative tool to evaluate water shortage or surplus in crop systems (Fisher, 2012; Soldevilla-Martinez *et al*., 2014; Groh *et al*., 2015) whereas Reichardt and Timm (2004) and

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Libardi (2005) defined the SWB as the inputs and outputs of water in a specified control capacity and period interval. The main aim of SWB is to effectively manage soil water by monitoring and controlling the components of soil water (FSSA, 2007). Monitoring of soil water storage behaviour related to plant water requirements is reflected as an important tool for a various number of agricultural undertakings and the efficient usage of soil water resources (Frizzone *et al*., 2005; Souza & Gomes, 2007; Souza *et al*., 2016).

The largest and the most difficult component to measure directly from SWB is evapotranspiration (ET) (Hillel, 2004; Proporato *et al*., 2004). To obtain ET from the SWB equation, precise measurements of all the other components of soil water balance must be obtained (Hillel, 2004; Jakubínský *et al*., 2019). Furthermore, there is no direct way to quantify drainage, apart from using lysimeters (Jiménez-de-Santiago *et al*., 2019). On the other hand, it is challenging to install them without altering soil hydraulic behaviour (Lidón *et al*., 1999). As the amount of runoff water is normally minimal in agricultural fields, it is generally considered negligible in comparison with the main components of the SWB (Hillel, 2004).

The procedures used to compute soil water balance are established on the principle of mass conservation, accounting for inputs, outputs and changes in storage of the particular element in the environment (Hillel, 2004; Rose, 2004). According to Hillel (2004), the root-zone water balance is normally calculated by means of Equation 2.2.

Change in storage = Gain (inputs) –Losses (outputs)

– (R + D + E + Tr) ……………………….Eq. 2.2.

Where;

S	=	Change of soil water storage in the root-zone
V	=	Quantity of water combined in the vegetation biomass
P	=	Precipitation

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I	=	Irrigation
U	=	Upward capillary flow into the plants root-zone
R	=	Runoff
D	=	Deep drainage out of the root-zone
E	=	Direct evaporation from the surface of the soil
Tr	=	Transpiration from the plants

All amounts are stated in terms of water volume per unit of land during the period of measurement (Hillel, 2004).

2.4 Pyrrolizidine alkaloids

Plant preparations such as plant food supplements and teas are used extensively all over the world. Plants are exposed to the possibility of being attacked by insects and pathogens, and they have advanced to enormous collection mechanical and predominantly chemical means of protection (Boppré, 2011). The most prevalent chemical protection agents are stated as ‘plant secondary metabolites’(PSMs) (Boppré, 2011). Such PSMs play a vital part in the background of human food (Pfannhauser *et al*., 2001; Acamovic & Brooker, 2005), with both positive and negative influence, such as aromas, spice, condiments scents, remedies and antioxidants, and negative ones, such as often bitter repellents and toxicants (Boppré, 2011).

One of the PSMs group of plant chemicals obtained in food, feed and forage, and the most important one in the context of human and animal health are the pyrrolizidine alkaloids (PA’s) (Boppré, 2011). They are a set of naturally occurring alkaloids built on the structure of Pyrrolizidine and are well-known to be hepatotoxic to humans and animals (Eloff *et al*., 2003; Radominska-Pandya, 2010; El-Shazly & Wink, 2014), and can be found in up to 3% of flowering plant species (Smith & Culvenor, 1981). Pyrrolizidine alkaloids thus transpire in numerous, distinct families and represent a parallel attribute in the plant kingdom (Ober, 2003; Reimann *et al*., 2004; Langel *et al*., 2011). They are commonly found in Boraginaceae, Asteraceae, Orchidaceae and Fabaceae families (Smith & Culvenor, 1989; Hartmann, 1999; Bruneton, 2008; Radominska-Pandya, 2010; Margarita *et al*., 2012). Their content in plants material depends on a number of factors such as locality, season, species, plant organ *etc* (Molyneux *et al*., 1979; Culvenor *et al*., 1980; Johnson *et al*., 1985; These

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et al., 2013). Any known species of PA-producing plant generally produces a combination of up to a dozen or more diverse PA's in different measurable ratios (Boppré, 2011). However, the PA's variability in PA-producing plants has been investigated insufficiently, while the majority of chemical analyses have focussed intensive on merely identifying whether or not specific plant produce PA's, and defining the different molecular structures (Boppré, 2011).

Pyrrolizidine alkaloids normally occur in the form of free/tertiary bases and *N*-oxides with diverse responsiveness and solubility (Bruneton, 2008; Cunha, 2010; Valese *et al*., 2016). Both forms are substitutable and can also take place together (Johnson *et al*., 1985). Pyrrolizidine alkaloids are not constantly constitutive PSMs hence the increased production can be prompted by biotic or abiotic bringing about induced resistance (Frost *et al*., 2008). This includes soil-borne microorganisms (Joosten *et al*., 2009), root damage and aboveground herbivory (Hol *et al*., 2004) and mechanical leaf damage (Van Dam *et al*., 1993). This, hand in hand with genotypical difference between population (Witte *et al*., 1992; Macel *et al*., 2004) and phynotypical malleability induced by abiotic factors such as soil and climate (Frischknecht *et al*., 2001; Hol *et al*., 2003; Kirk *et al*., 2010) accounts for relatively large inconsistencies in amounts and pattern of PA's encountered (Boppré, 2011). These allelochemicals can also be unevenly spread within a single plant (Hartmann & Zimmer, 1986) with high concentration frequently obtained in the roots, which in numerous species of *Senecio*, are the producing organs (Hartmann *et al*., 1989). Production in roots can take place up to 100-fold more compared to aerial parts (Muetterlein & Arnold, 1993), or in seeds and flowers (Lüthy *et al*., 1980; Bortel *et al*., 1989; Chizzola *et al*., 2000).

The general term 'pyrrolizidine alkaloids'includes toxic and non-toxic PA's (Boppré, 2011). and 30 known PA's that are hepatotoxic (Rizk, 1990). There about 200 known plant species that secrete toxic PA's in the world today (Hirono, 1987). The most common source of PA's are plants such as yellow tarweed (*Amsinckia intermedia*), rattleweed (*Crotalaria retusa*), wolly groundsels (*Senecio redellii* and *Senecio longilobus*) and ragwort (*Senecio jacobaea*) (The Merck Veterinary Manual, 2008). The 1,2-dehydropyrrolizidine ester alkaloids such as supinidine, retronecine, heliotridine, crotanecine and otonecine are known to be carcinogenic, mutagenic, teratogenic, genotoxic and fetotoxic (Wiedenfeld *et al*., 2008; EFSA, 2011; Edgar *et al*., 2014; El-Shazly & Wink, 2014). Their severe poisoning in humans is related with high mortality and is more characterized by hepatic venoocclusive illness, while a prolonged onset may lead to liver cirrhosis and pulmonary arterial

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hypertension (EFSA, 2011).. Pyrrolizidine alkaloids in the absence 1,2-double bond, those with hastanecine, platynecine and rosmarinecine form (Wiedenfeld *et al*., 2008), which are characterised by a saturated necine base, are reflected to be harmless (Mohabbat *et al*., 1976; Stillman *et al*., 1977; Huxtable, 1980; Kakar *et al*., 2010; Wiednfeld & Edgar, 2011).

Recently, the incidence of dehydropyrrolizidine alkaloids in teas and medicinal herbs has received growing consideration from numerous national authorities in Europe. This is due to the frightening excessive dehydropyrrolizidine alkaloids levels obtained in commercially well-known teas and medicinal herbs in Switzerland and Germany with an amount up to 0.47 $mg.kg^{-1}$ and 5.6 $mg.kg^{-1}$, respectively (Bodi *et al*., 2014; Griffin *et al*., 2014; Mathon *et al*., 2014; Mädge *et al*., 2015). In the German and Israeli markets, Rooibos tea samples were amongst the most seriously tainted herbal teas with dehydropyrrolizidine alkaloids detected in all samples analysed with the mean value of 1.86 $mg.kg^{-1}$ and 0.31 $mg.kg^{-1}$ for German and Israeli markets, respectively (Shimshoni *et al*., 2015). The mean value of the dehydropyrrolizidine alkaloids found in Rooibos at above-mentioned two markets are extremely high, exceeding the suggested maximum acceptable daily consumption of 0.0005 mg dehydropyrrolizidine alkaloids for a 70 kg adult (EFSA, 2011; Mädge *et al*., 2015). In addition, Sinisalo *et al*., (2010) indicated the hepatotoxic effect in a patient who consumed fairly large quantities of Rooibos tea.

There is a limited research on the uptake of PA's by the Rooibos plant. According to Van Wyk *et al*. (2017), Rooibos plant absorbed PA's from the soil where *Senecio* plants occurred in the Rooibos plantation. Furthermore, the authors indicated that the soil at root depth of *Senecio* species contained high levels senecionine and senecionine *N*-oxide that the Rooibos plant can absorb from the soil. However, Chen *et al*. (2017) submitted that the presence of PA's in (herbal) teas were originated from the contamination of weeds comprising PA's during harvesting. According to Van Wyk *et al*. (2017), *Senecio angustifolius* is the leading pyrrolizidine-bearing weeds in the plantation of Rooibos tea.

2.5 Conclusions

Rooibos is an endemic crop of South Africa which is produced in the Mediterranean climate of the fynbos biome of the Northern and Western Cape provinces under dryland conditions. Consequently, water is the limiting factor for crop production and has an impact on the economic activities on Rooibos production. Prediction indicates that the climate change will reduce the rainfall over the western coast of South Africa by the end of 21st century. This

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area does includes the area where Rooibos in being produced. The dryness forecast will put more pressure on the Rooibos production on the already limited resource environment. However, for effective Rooibos farming, understanding of SWD is vital in addressing the deteriorating of Rooibos production.

Moreover, literature suggests that crop production is negatively influenced by high soil bulk density which results in low soil porosity and low water holding capacity. The sound knowledge of soil and water will enable Rooibos producers to utilize water effectively and efficiently. Up to date, little information with regard to the soil physical properties of the fields producing Rooibos is known.

Dehydropyrrolizidine alkaloids have been found to occur in Rooibos tea and are known to be hepatotoxic to both humans and animals. Information regarding the source of pyrrolizidine alkaloids contamination on Rooibos tea is very limited. Pyrrolizidine alkaloids contamination on Rooibos tea resulted from the contamination of weeds comprising with pyrrolizidine alkaloids during harvesting, hence it was also indicated that the Rooibos on its own could not produce pyrrolizidine alkaloids. Then the conclusion is, producers must control weeds regularly and be careful not to contaminate Rooibos tea during weed control.

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CHAPTER 3: SOIL MORPHOLOGICAL, PHYSICAL DESCRIPTIONS AND ROOIBOS SOIL WATER DYNAMICS

3.1 Introduction

Rooibos is produced under dryland conditions (SARC, 2017) were water is a limiting factor for crop production in the Mediterranean climatic region (Larcher, 2000; Sardans *et al*., 2006; Li *et al*., 2009). Little rainfall and high temperatures in dryland agriculture reduce soil water content (SWC) (van Schalkwyk, 2018). The shortage of SWC influence the plant available water and plant water absorpion (Gupta, 1986). It is important that the farmers farming with Rooibos under dryland conditions avoid excessive water depletion and water stress (van Schalkwyk, 2018).

Soil depth can influence the SWC and the amount of water stored (van Schalkwyk, 2018). Monitoring of soil water storage behaviour related with plant water requirements is reflected as an important tool for a various number of agricultural undertakings and the efficient usage of soil water resources (Frizzone *et al.*, 2005; Souza & Gomes, 2007; Souza *et al.*, 2016). Frequent ET is the major parameter of the soil water balance in the ecosystem (Gentine *et al*., 2007).

Evapotranspiration (ET) is the most difficult component to measure directly in the soil water balance (SWB) equation. To obtain ET from the SWB, precise measurements of all other components of the SWB must be obtained (Hillel, 2004).

The aim of this chapter is to describe the soil morphology, selected physical properties that affects soil hydrology and soil water dynamics of four sites that are selected for the study. The following aspects are presented in this chapter, namely: soil classification and morphological description, soil texture, bulk density, unsaturated hydraulic conductivity, saturated hydraulic conductivity, soil water content and soil water balance.

3.2 Material and methods

3.2.1 Study area

3.2.1.1 Location

A one-year old Rooibos plantations were randomly selected near Nieuwoudtville on the Bokkeveld Plateau, Northern Cape, South Africa (Figure 3.1). The experimental sites were situated at Rogland (31° 13’ 36.109’’

S; 19° 01’ 14.227’’ E), Meulsteenvlei (31° 21’ 40.281’’ S; 19° 01’ 59.811’’ E), Oorlogskloof (31° 27’ 34.288’’ S; 19° 05’ 45.068’’ E), and Klein Blomfontein (31° 42’ 27.308’’ S; 19° 07’ 11.979’’ E) farms. The elevation of the area is 700 m to 820 m above sea level.

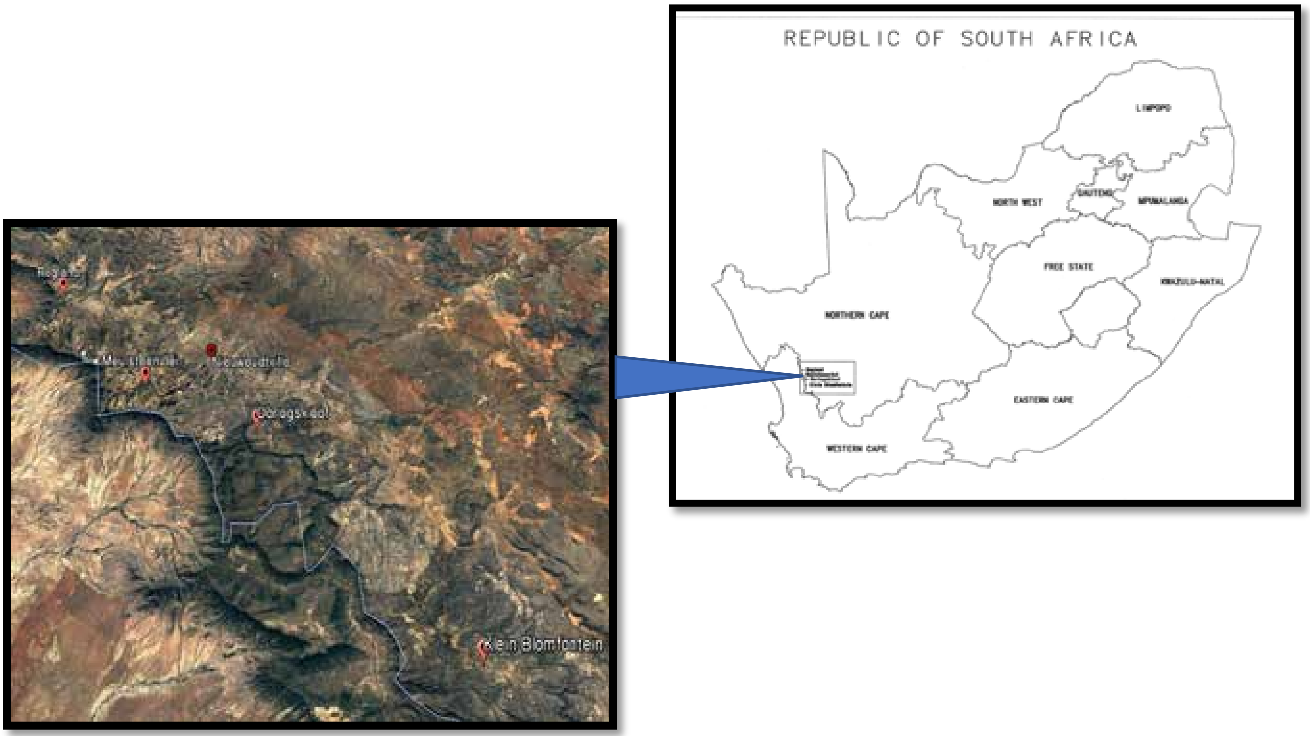

Figure 3.1: Location of the study area on the map of South Africa (right). A satellite image indicating the location of the study sites near Niewoudtville (left).

3.2.1.2 Climate

The study area falls within the winter rainfall region of South Africa with an annual rainfall ranging from 350 mm to 650 mm. Most of the rain is received from May to August with occasional thunderstorms occurring during spring and summer (Manning & Goldblatt, 1997). The long term mean for monthly rainfall and temperature at Nieuwoudtville for the period from 1990 to 2012 shows that rainfall (Fig. 3.2) and temperature (Fig. 3.3) were highest in July and February, respectively (The World Bank Group, 2016).

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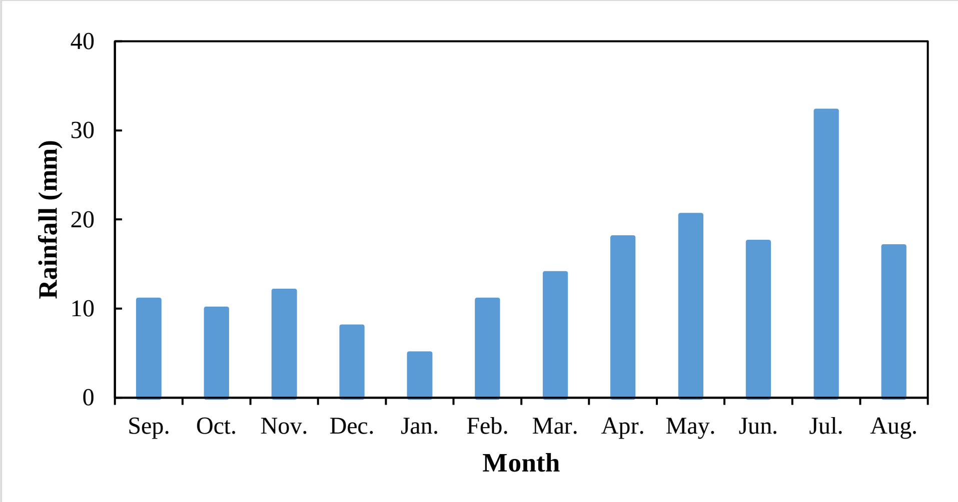

Figure 3.2: Monthly average rainfall in Nieuwoudtville area from 1990 to 2012 (The World Bank Group, 2016).

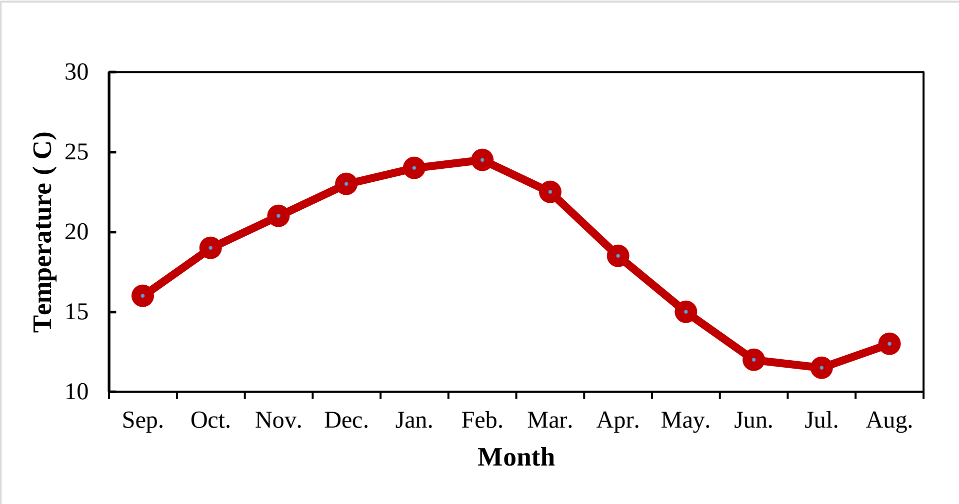

Figure 3.3: Monthly average temperature of Nieuwoudtville from 1990 to 2012 (The World Bank Group, 2016).

3.2.2 Soil description and mapping

A full classification of the soil was done according to the South African soil classification system (Soil Classification Working Group, 1991) and Field Book for the classification of South African soils (South African Soil Surveyors Organisation, 2013) in October 2017. Classifiaction was done on 5, 15, 7 and 6 profile pits at Rogland, Meulsteenvlei, Oorlogskloof and Klein Blomfontein respectively. All these plots are located near Nieuwoudtville in the main production region for Rooibos. Profile pits of 1 meter depth were excavated. Some of the pits were shallower where the underlying bedrock or hard plinthic was reached. A comprehensie profile description was done for each soil profile pit. The colour of each and soil layer was determined according to the revised Munsell Soil Color Charts (Munsell Color, 2009).

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The different horizons were identified and their morphological properties assessed. Maps of the different soil depth, soil forms and contour lines for Rogland, Meulsteenvlei, Oorlogskloof and Klein Blomfontein were drawn using the latest Survey and Engeneering Software (14.0) developed by Model Maker Systems. Different layers were projected over each other in order to draw the soil boundries as accurately as possible. Soil depths were measured at an interval of 50 m from each other using an Edeman of soil auger. Soil was augered to the depth of 2 m or to the depth were auger was restricted for penetration.

3.2.3 Soil physical properties

Particle size distribution, bulk density, saturated hydraulic conductivity and unsaturated hydraulic conductivity were measured. Measurements were taken at five depth increments (0 – 200 mm, 200 – 400 mm, 400 – 600 mm, 600 – 800 mm & 800 – 1 000 mm), except for Klein Blomfontein which had three depth increments (0 – 200 mm, 200 – 400 mm & 400 – 600 mm). This was due to shallow depth at this particular site. An illustration of the position and soil depth layers where measurements were taken is given in Figure 3.4.

Figure 3.4: Illustration of the position and soil depth layers where measurements and collection of soil samples were conducted.

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3.2.3.1 Particle size distribution

The soil texture was determined using the standard pipette method as prescribed by Gee and Or (2002). Soil samples of 40 g each were used. The sample contained only particles that were less than 2 mm in diameter. The soil was treated with 5 ml of 35% H_2O_2 solution to remove organic matter (OM) before the analysis. The mass of the sample after the removal of OM was recorded. Dispersal of soil particle was conducted by adding 10 cm^3 of calgon (Na_2 [Na_4 $(PO_3)_6$]) to the dried soil sample after removal of OM. The mixture was stirred mechanically for 10 minutes using laboratory mixer set at a high speed. The dispersed samples were washed over a 0.053 mm mesh sieve to separate the clay and silt fractions from the sand fraction into 1 dm^3 sedimentation cylinder using distilled water. The sand fraction was dried and separated into different sand fractions using sieves with mesh diameters of 1.000, 0.500, 0.250, 0.106 and 0.053 mm. The weight of each sand fraction was expressed as a percentage of the soil sample after the removal of OM. The clay and fine silt in the 1 dm^3 cylinder was determined using the sedimentation method (Fig. 3.5) and Lowey pipette according to *Stokes' Law*. The coarse silt percentage was calculated after clay and silt percentage was determined.

Figure 3.5: Illustration of 1 dm^3 cylinder which was used during the sedimentation method to determine the clay and fine silt percentage in the soil.

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3.2.3.2 Bulk density

Soil bulk density was determined *in situ* by making use of the modified core method described by Blake and Hartge (1986). A cylinder which had a volume of 102.1 cm^3 was hammered into the soil to collect undisturbed sample. Samples were carefully removed, placed into a marked paper bag and put in an oven at 105 C to obtain its dry mass. The volume of the cylinder and the dry mass of the sample was used to calculate the bulk density of the sample.

3.2.3.3 Unsaturated hydraulic conductivity

Unsaturated hydraulic conductivity was measured on undisturbed soil layers at depth interval of 20 cm. A Mini Disk Infiltrometer from Decagon Devices (Fig. 3.6) was used for measurements.

Figure 3.6: A Minidisk Infiltrometer from Decagon Devices was used to measure unsaturated hydraulic conductivity *in situ*.

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The infiltrometer was set at a constant suction of -1 cm to accommodate compacted layers which had the slow water infiltration. A further reason for selecting the suction of -1 cm was to simulate the water flow through micro and meso-pores since these pores are mostly responsible for water movement in unsaturated state (Hillel, 2004). The top 1 cm of the soil was removed with a spatula and sieved through a 2 mm diameter mesh sieve onto the measured point to prepare the flat surface with sufficient contact between the soil and sintered steel base of the infiltrometer. The water volume in the infiltrometer was recorded at an every of 30 seconds immediately after the infiltrometer had made contact with the soil. A minimum amount of 15 to 20 mL of water was allowed to infiltrate every 30 seconds in order to obtain an accurate calculation of hydraulic conductivity (Decagon Devices, 2016). A specialized Microsoft Excel spreadsheet created by Decagon was used to calculate the unsaturated hydraulic conductivity. Measurements were replicated five times at each soil depth layer.

3.2.3.4 Saturated hydraulic conductivity and saturated water content

Saturated hydraulic conductivity *in situ* was conducted from 2nd to the 27th of October 2017. An adjusted double ring prescribed by Parr and Bertrand (1960) was used. The smaller and the bigger ring with a diameter of 16 cm and 25 cm, respectively, were used to accommodate the less amount of water. Both rings were driven 2 cm into the soil. Plastic covers were cut to the size of the rings and were placed inside the rings to prevent soil disturbance during water placement and to allow an even infiltration of water when plastic covers are removed. Saturated hydraulic conductivity was measured according to the falling head method in the field using the *Darcy's Law*. The water was placed in both rings at 7 cm above the soil surface at an amount of 1 407 and 2 029 ml for inner and outer ring, respectively. Measurement was taken in the inner ring as the outer ring was used to prevent lateral water movement from the inner ring. Three consecutive constant infiltration time was used as a saturated point. Thereafter, saturated hydraulic conductivity was calculated using the *Darcy's equation* (Hillel, 2004).

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3.2.4 Parameters of importance in water dynamics

3.2.4.1 Calibration of the ECH_2O sensors

The two different ECH2O (5-TM and EC-20) sensors were calibrated specifically to the type of soil and soil depth layer which they were positioned. The sensors were calibrated in the laboratory at Department of Soil Science at Stellenbosch University. Soil samples collected from the position of the soil moisture sensors were air dried and placed into 3 litre pots. The soil in pots were packed at a density of 1.3 g.cm^{-3}, thereafter, treated with four water increments (0, 250, 500 and 750 mm) for each soil layer. After the water was allowed to spread evenly to the soil in the pots, ECH2O 5-TM and EC-20 were placed into pots that contained soil. Pro Check device from Decagon Devices was used to measure raw count of the sensor in the soil pots (Fig. 3.7). Raw count in the pots was used to determine the scaled frequency from the scaled frequency equation (Eq 3.1) prescribed by Sentek (2011). Gravimetric water content was determined and multiplied by soil bulk density of the pots to obtain soil volumetric water content. Both soil volumetric water content and scaled frequency were used in Microsoft excel to determine calibration curves and equations.

……………………………………….. Eq 3.1

Where:

SF = Scaled Frequencies

FA = Raw count of the sensor while suspended in air (Air Count)

FW = Raw count of the sensor in a water bath (Water Count)

FS = Raw count of the sensor in the soil pot (Soil Count)

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Figure 3.7: Pro Check device in operation during the ECH2O sensor calibration in the laboratory.

3.2.4.2 Soil water content

ECH_2O 5 TM and ECH_2O EC-20 sensors from Decagon Devices were used to measure SWC up to a depth of 1 m at Muelsteenvlei, Rogland and Oorlogskloof, and up to 0.5 m at Klein Blomfontein. ECH_2O 5 TM sensors were installed at 50, 150 and 250 mm soil depth for all four sites. EC-20 sensors were placed at 550 and 850 mm soil depth at Meulsteenvlei, Rogland and Oorlogskloof, and at 350 and 450 mm soil depth at Klein Blomfontein due to the shallow depth. The was one Em 50 ECH_2O data logger with 5 sensor ports and 1 communication port at each site to collect the data. Data was logged on an hourly basis. A software ECH_2O utility from Decagon Devices was used to download the raw SWC data from Em 50 ECH_2O data loggers every two weeks (Fig. 3.8).

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Figure 3.8: Em 50 ECH2O data logger used for collection of the soil water content data from the ECH2O 5TM and ECH2O EC-20 sensors. The figure shows the downloading of soil water content data in progress from the field.

The SWC at field capacity (FC) was determined *in situ* as described by Or and Wraith (2002). The soil was wetted using double ring method until three consecutive constant time was observed to determine saturated point. Soil samples were collected after the soil was allowed to drain for approximately 24 hours. The mass of the moist and oven dried samples were determined. Thereafter the FC of every layer was determined.

3.2.4.3 Soil water balance

The SWC and precipitation (P) was used in the SWB equation (Eq 2.2) of Hillel (2004). A gain in SWC was considered as a negative value in order to permit the SWB equation to work correctly. Given the nature of the rainfall in the region, runoff (R) was assumed to be negligible. An increase of SWC

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below the rootzone was noticed and regarded as deep drainage. Capillary rise was detected in the SWC and calculated.

The SWB function was calculated based on the following assumptions

than the precipitation (P) throughout the same period, there was no capillary

as more that the precipitation (P) during the

precipitation (P). The reasonableness of this is that, if the SWC is greater than the precipitation, then the excess water should be coming from somewhere, therefore it should be from the capillary rise. Drainage (D) was determine by calculating the change in SWC at the depth lower than the rootzone for all sites. Evapotranspiration (ET) was not directly determined by measurements but calculated from the soil water balance equation. Calculation of ET during the same period which capillary rise did occur was impossible to calculate, hence the ET and D were considered as zero in order to solve the SWB equation. In an event were D was more

was also regarded as as zero. The ET was calculated as follows:

………..………………………………… Eq 3.2

As a result, evapotranspiration (ET) is equivalent to the sum of change in soil

minus drainage

(D) (Hillel, 2004).

The SWB balance was measured for 486 days from 27 October 2017 to 24 February 2019. The days after commence of SWB that were used to observe the difference between the growing season were day 106, 216, 311, 341, 371 and 451. The first and the last dates were selected based on the vegetation analysis dates while the second and the third dates were selected based on the most meaningful rainfall occurred. Day 341 and 371 were chosen based on flowering since the prime flowering occurs in October.

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3.2.4.4 Growing season

The SWB started on 27 October 2017 and ended on 28 February 2019. The total rainfall during this period was 372.8, 495.3, 413.0 and 391.3 mm for Rogland, Meulsteenvlei, Oorlogskloof and Klein Blomfontein, respectively.

3.3 Results and discussion

3.3.1 Soil description and mapping

Detailed soil description information for the different profile pits are attached and can be seen in *Appendix 1*. The profiles have an A-horizon depth ranging from 130 to 300 mm. The thickness of E horizon for all study sites ranges from 200 to 520 mm. The B-horizon was found from the depth of 170 to 300 mm for Dresden soil form and 300 to 900 mm for both Longlands and Wasbank soil forms in all study sites. The R-horizon was also observed below the depth ranging from 170 to 200 mm for the Mispah soil form for both Meulsteenvlei and Oorlogskloof.

Main soil forms and soil families observed during the profile descriptions were: Wasbank Lynedoch, Longlands Ermelo, Dresden Hilldrop and Mispah Gulu (Table 3.1 to 3.4). There is a South East to North West slope at Rogland and Oorlogskloof whereas at Meulsteenvlei and Klein Blomfontein there is East to West slope. The slopes at Rogland, Meulsteenvlei, Oorlogskloof and Klein Blomfontein range between 2.8 to 4.2%, 0.1 to 5.0%, 3.1 to 4.1% and 3.2 to 5.6%, respectively.

Table 3.1: Soil form at Rogland study site.

Soil form	Topsoil	Subsoil 1	Subsoil 2
Wasbank	Orthic A	E-horizon	Hard plinthic

Table 3.2: Soil form at Meulsteenvlei study site.

Soil form	Topsoil	Subsoil 1	Subsoil 2
Wasbank	Orthic A	E-horizon	Hard plinthic
Dresden	Orthic A	Hard plinthic	N/A
Mispah	Orthic A	Hard rock	N/A

Table 3.3: Soil forms at Oorlogskloof study site.

Soil form	Topsoil	Subsoil 1	Subsoil 2
Wasbank	Orthic A	E-horizon	Hard plinthic
Longlands	Orthic A	E-horizon	Soft plinthic
Mispah	Orthic A	Hard rock	N/A

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Table 3.4: Soil forms at Klein Blomfontein study site.

Soil form	Topsoil	Subsoil 1	Subsoil 2
Wasbank	Orthic A	E-horizon	Hard plinthic
Dresden	Orthic A	Hard plinthic	N/A

The soil forms, soil depth and surface contour maps are given Figures 3.9 to 3.20.

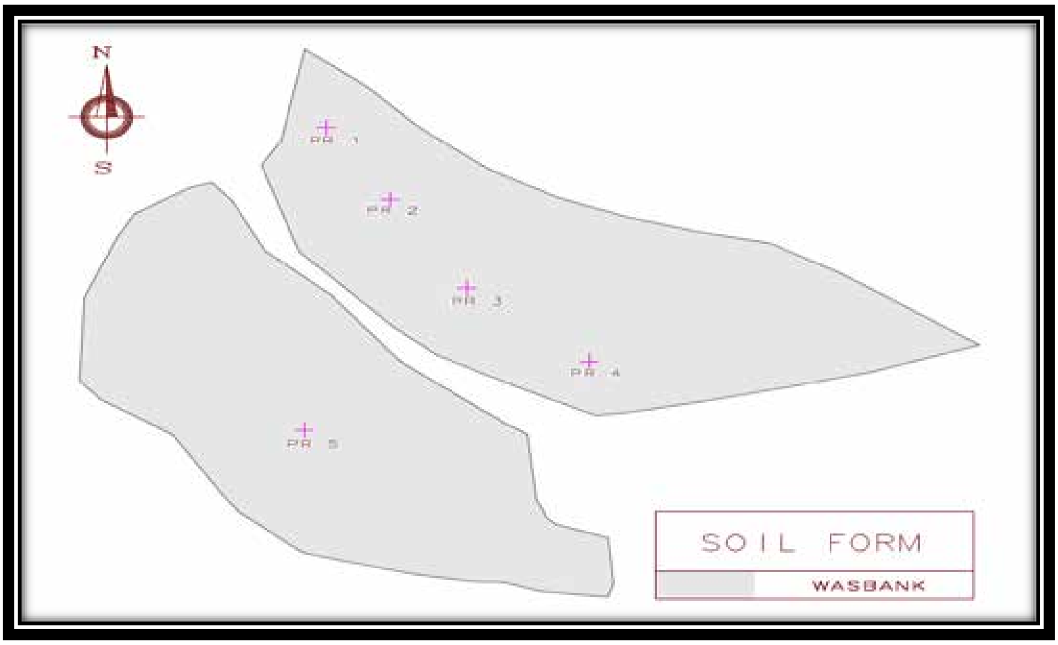

Figure 3.10: Soil form map of the Rogland study site indicating the position of the profile pits.

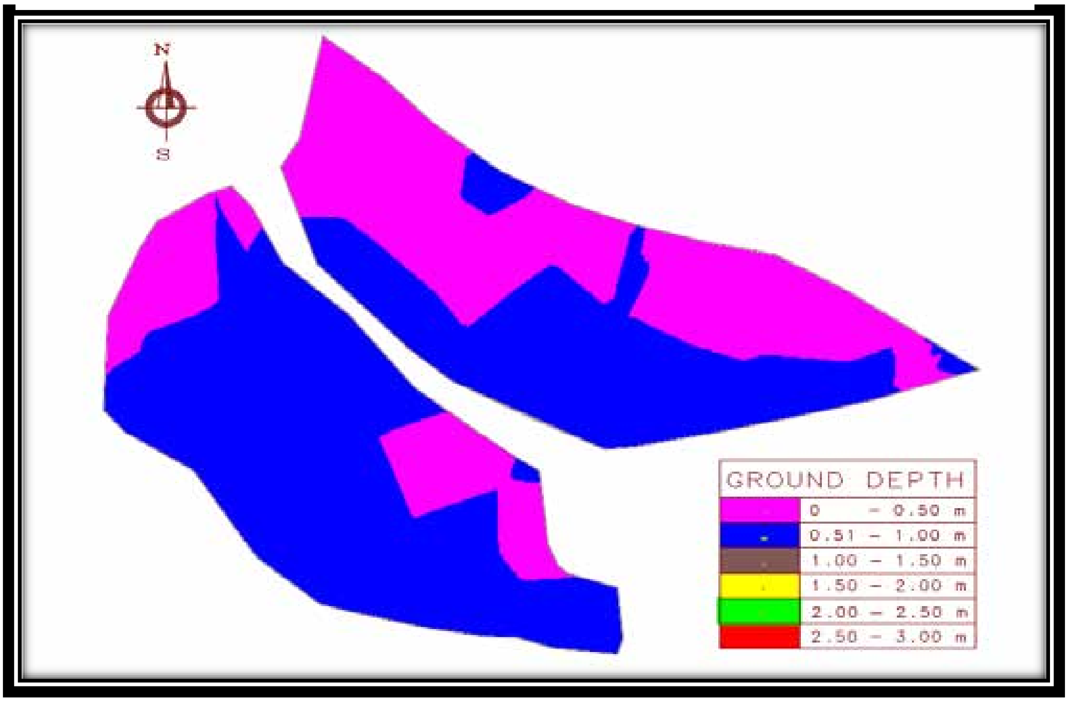

Figure 3.9: Soil depth map of the Rogland study site.

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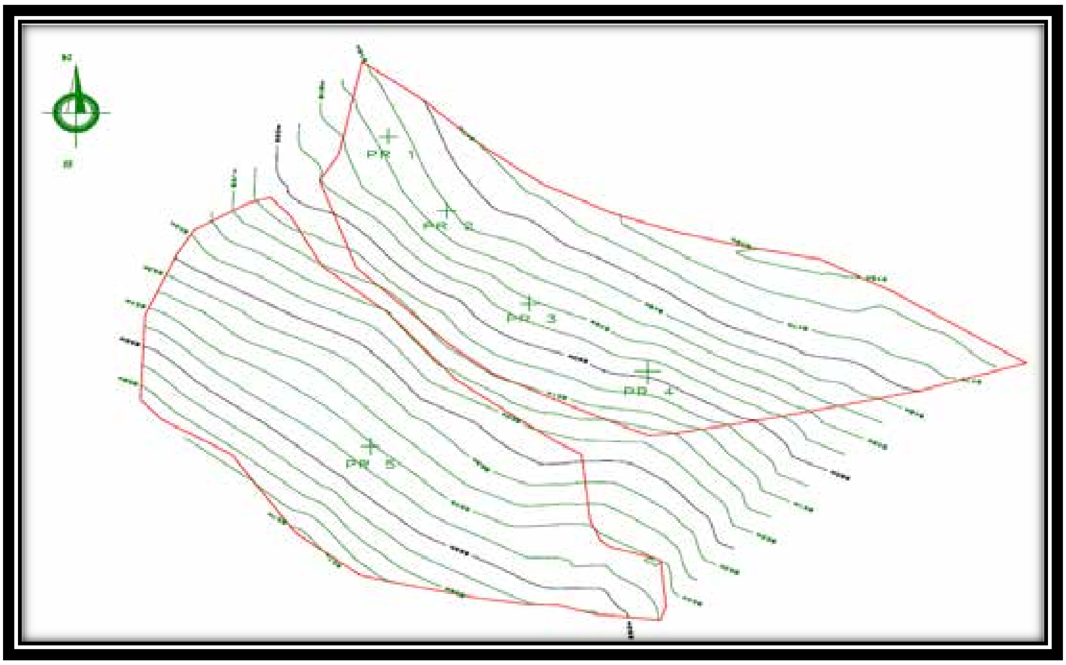

Figure 3.12: Contour lines of the study site at Rogland.

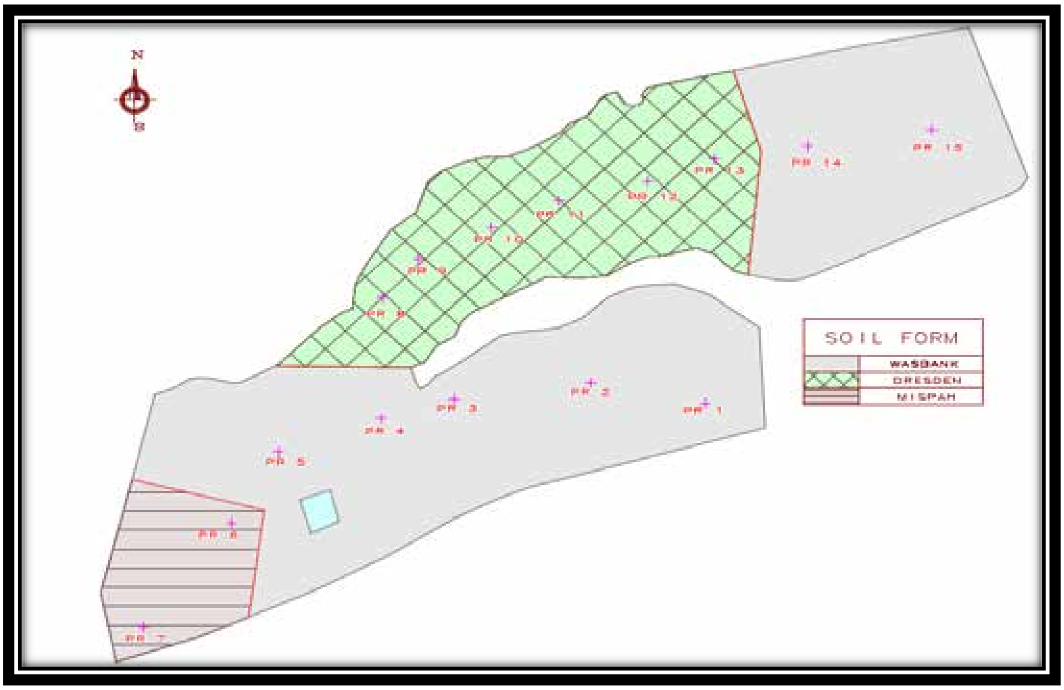

Figure 3.11: Soil form map of the Meulsteenvlei study site indicating the position of the profile pits.

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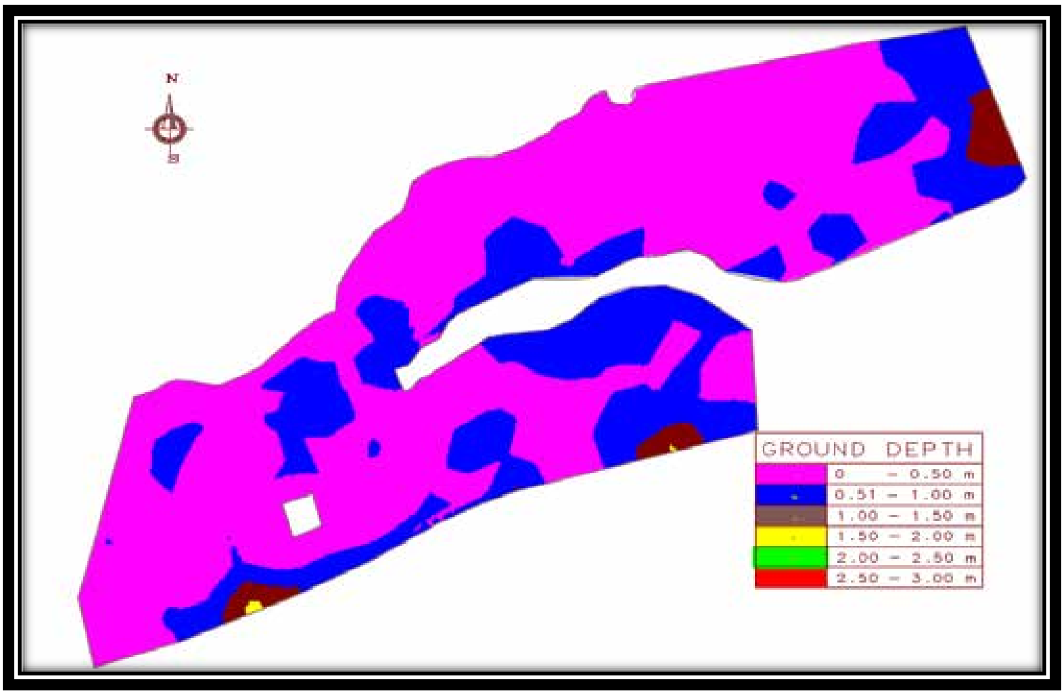

Figure 3.14: Soil depth map of the Meulsteenvlei study site.

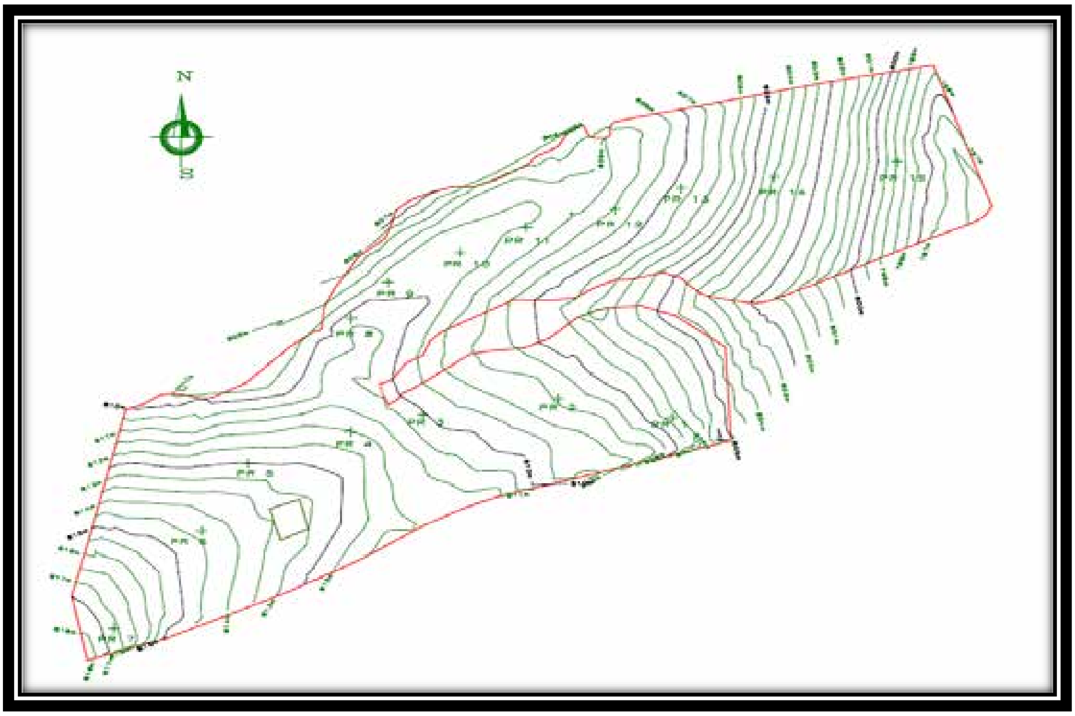

Figure 3.13: Contour lines of the study site at Meulsteenvlei.

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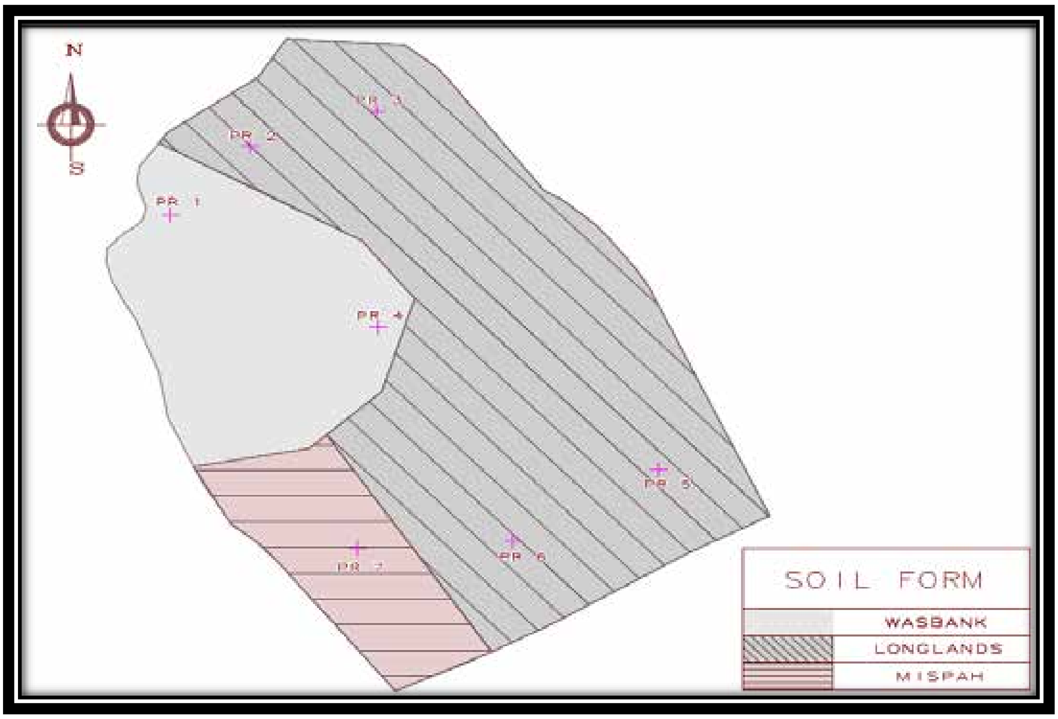

Figure 3.15: Soil form map of the Oorlogskloof study site indicating the position of the profile pits.

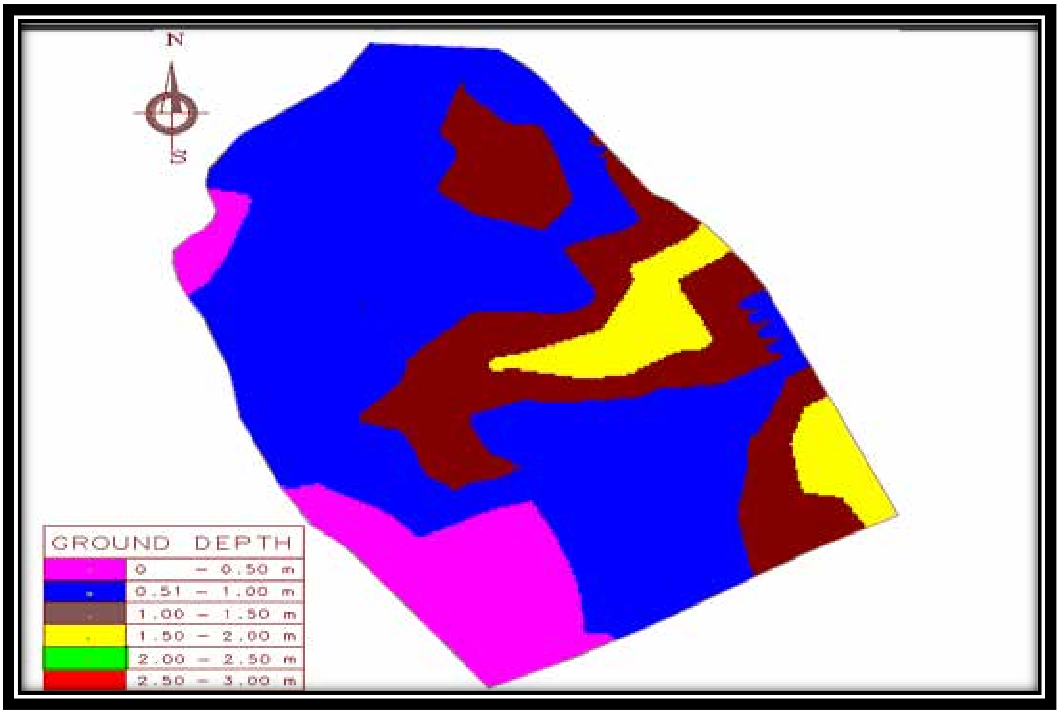

Figure 3.16: Soil depth map at the Oorlogskloof study site.

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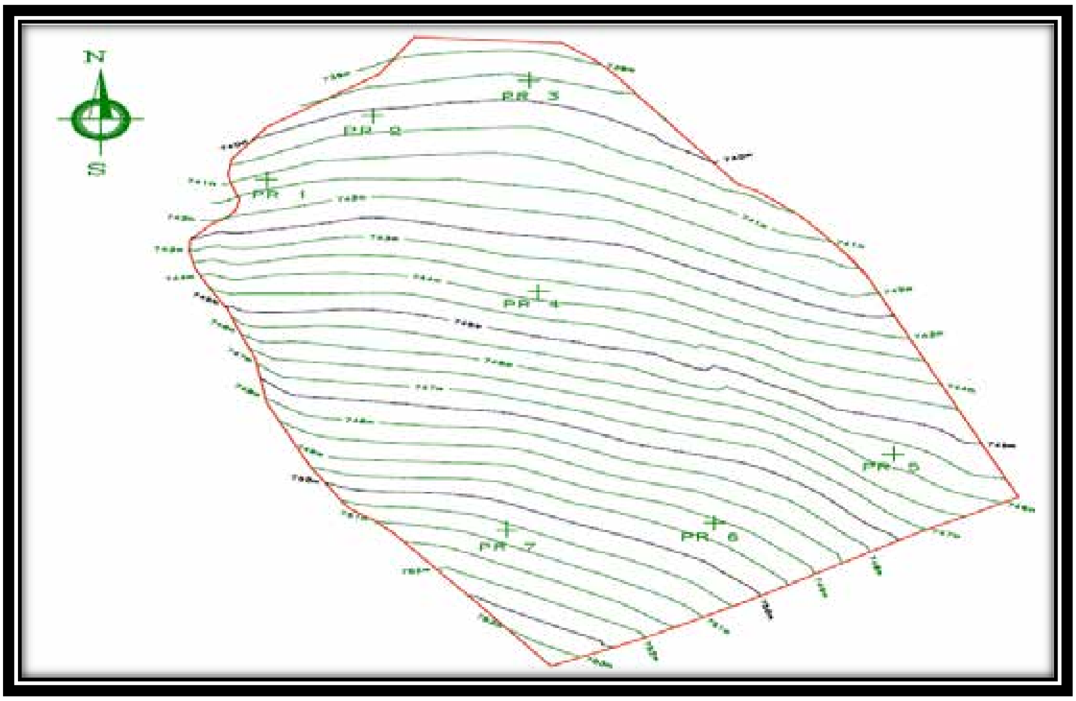

Figure 3.17: Contour lines of the study site at Oorlogskloof.

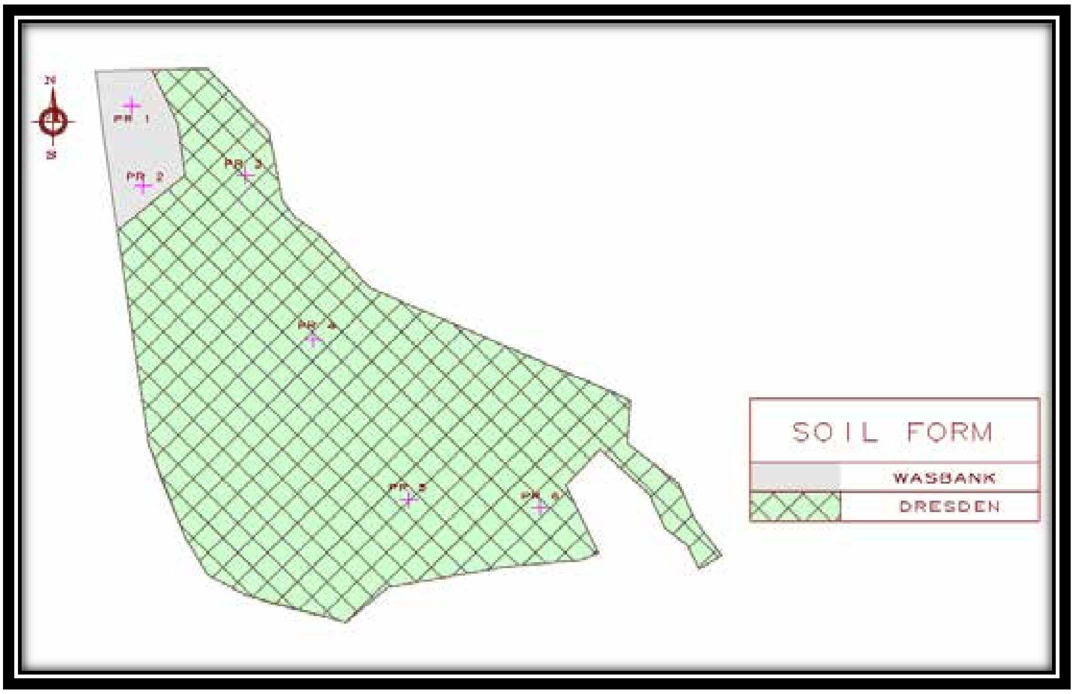

Figure 3.18 Soil form map at the Klein Blomfontein study site indicating the position of profile pits.

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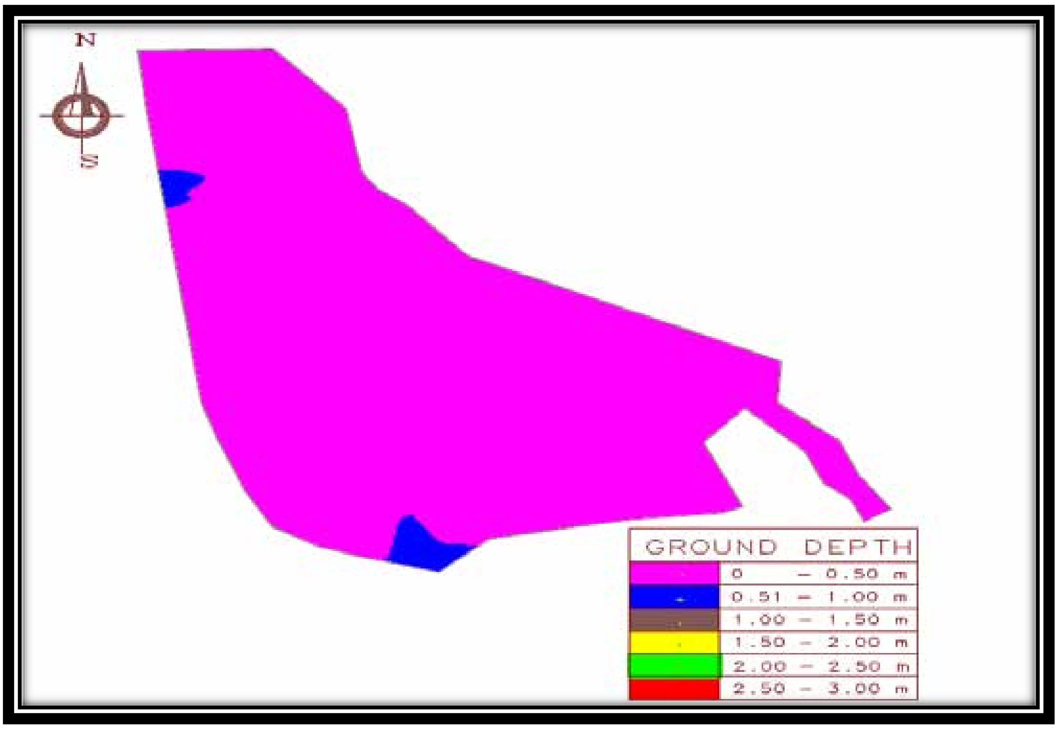

Figure 3.19: Soil depth map at the Klein Blomfontein study site.

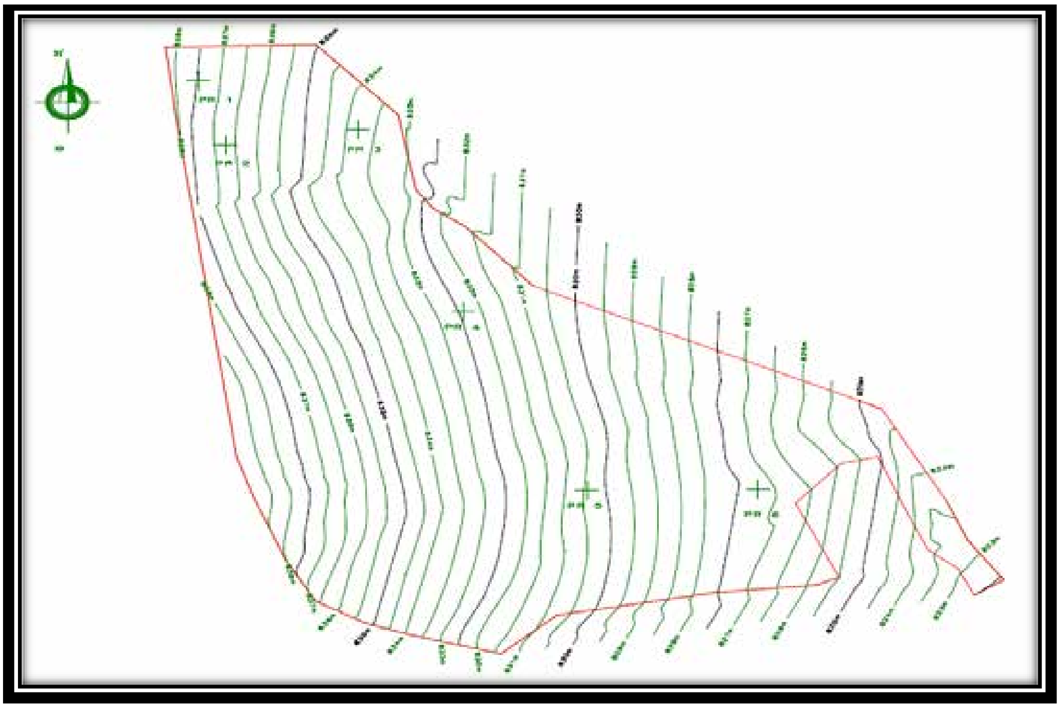

Figure 3.20: Contour lines of the study site at Klein Blomfontein,

3.3.2 Soil physical properties

3.3.2.1 Particle size distribution

The soil texture analyses indicates that the soil from all four sites is predominantly sand. The total average sand content for the Rogland, Meulsteenvlei, Oorlogskloof and Klein Blomfontein sites is 93.41, 93.39, 91.91 and 69.27%, respectively. Due to high very coarse sand at Meulsteenvlei and Oorlogskloof; and high coarse sand at Rogland and Klein Blomfontein (Table 3.5), the experimental sites were classified as very coarse sandy soils for Meulsteenvlei and Oorlogskloof; and coarse sandy soils for Rogland and Klein Blomfontein. The average silt percentage ranged between 2.14 – 3.92% while the clay percentage ranged between 4.46 – 26.83% with Klein Blomfontein having the highest silt and clay content. The total average sand and silt content for all depths (Fig 3.21) were similar to the sand of 91 – 98% and silt of 0.89 – 3.65% reported by van Schalkwyk (2018) for Rooibos plantations in Clanwilliam except for Klein Blomfontein which had lower sand percentage. Clay content measured for the study sites was higher compared to a clay percentage of 0.10 – 2.20% reported by van Schalkwyk (2018) and 2.9 – 3.2% reported by Smith (2014) for Rooibos plantations in Clanwillian.

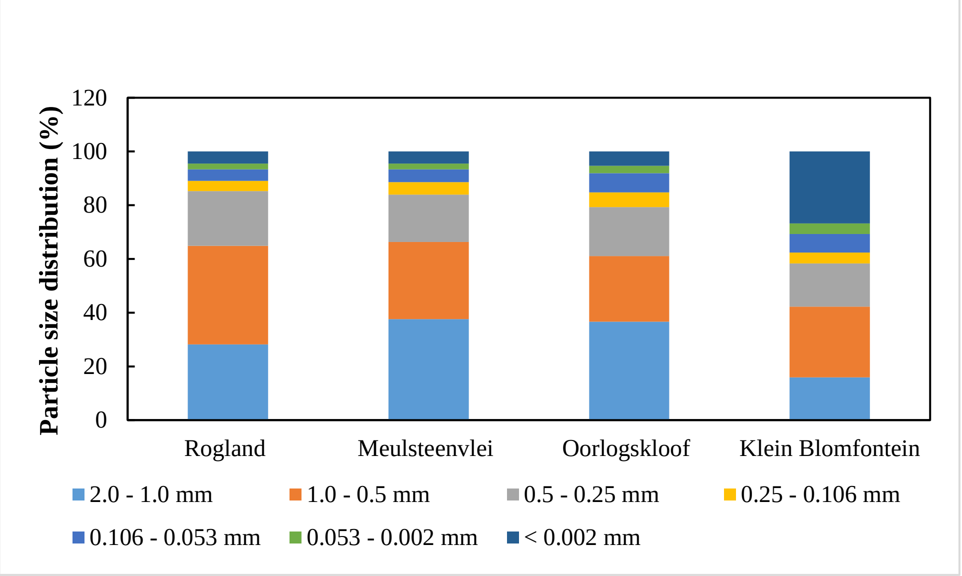

Figure 3.21: Total average particle size distribution for all depths of the Rogland, Meulsteenvlei, Oorlogskloof and Klein Blomfontein sites.

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Table 3.5: Average soil particle size distribution (%) of the Rogland, Meulsteenvlei, Oorlogskloof and Klein Blomfontein study sites.

Study Site	Soil depth (cm)	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay
Rogland	0 – 20	28.7	39.4	19.6	3.9	5.6	0.9	1.9
	20 – 40	28.6	39.0	20.7	3.7	4.5	0.9	2.6
	40 – 60	26.0	39.1	23.3	3.9	5.8	1.0	0.9
	60 – 80	30.2	34.9	23.1	5.2	3.2	2.5	0.9
	80 – 100	27.2	30.8	15.5	2.4	2.7	5.4	16.0
Meulsteenvlei	0 – 20	37.4	28.6	16.5	4.9	5.7	2.2	4.7
	20 – 40	36.2	29.5	17.2	5.1	6.1	1.1	4.8
	40 – 60	44.5	25.3	14.4	4.8	3.0	2.2	5.8
	60 – 80	34.9	29.4	21.3	4.6	4.9	2.1	2.8
	80 – 100	34.7	30.8	18.7	3.9	4.5	3.1	4.3
Oorlogskloof	0 – 20	37.1	25.4	18.6	5.8	7.1	2.3	3.7
	20 – 40	38.4	26.0	17.8	5.3	6.6	2.3	3.6
	40 – 60	36.2	24.0	18.5	5.7	6.4	3.8	5.4
	60 – 80	35.6	22.9	18.8	5.6	8.2	2.8	6.1
	80 – 100	36.1	24.0	16.9	4.9	7.6	2.5	8.0
Klein Blomfontein	0 – 20	21.8	36.6	22.0	4.7	9.7	1.4	3.8
	20 – 40	20.0	36.1	20.5	5.3	6.5	4.5	7.1
	40 – 60	6.1	6.3	5.7	1.9	4.6	5.8	69.6

3.3.2.2 Bulk density

Bulk density ($g.cm^{-3}$) of the Rogland, Meulsteenvlei, Oorlogskloof and Klein Blomfontein is presented in Table 3.6. The average bulk density of the Rogland, Meulsteenvlei, Oorlogskloof and Klein Blomfontein ranged between 1.58 to 1.66, 1.59 to 1.70, 1.69 to 1.81 and 1.56 to 1.76 $g.cm^{-3}$, respectively. The soils were not compacted since the mean bulk density was lower 1.80 $g.cm^{-3}$ except for the Oorlogskloof study site at 60 to 80 cm soil depth (USDA, 2008).

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Table 3.6: Average bulk densities of four sites used in the experiment.

Study Sites	Soil depth (cm)	Bulk density ($g.cm^{-3}$)
Rogland	0 – 20	1.60
	20 – 40	1.66
	40 – 60	1.65
	60 – 80	1.58
	80 – 100	1.61
Meulsteenvlei	0 – 20	1.70
	20 – 40	1.67
	40 – 60	1.59
	60 – 80	1.63
	80 – 100	1.70
Oorlogskloof	0 – 20	1.69
	20 – 40	1.75
	40 – 60	1.78
	60 – 80	1.81
	80 – 100	1.77
Klein Blomfontein	0 – 20	1.71
	20 – 40	1.76
	40 – 60	1.56

3.3.2.3 Unsaturated hydraulic conductivity

Average unsaturated hydraulic conductivity, K_{us}, is shown in Table 3.7. The total average at the Meulsteenvlei study site (31.7 $mm.hour^{-1}$) was higher compared to the Rogland (22.3 $mm.hour^{-1}$), Oorlogskloof (5.8 $mm.hour^{-1}$) and Klein Blomfontein (4.5 $mm.hour^{-1}$) study sites. This variation could be due to variation in the soil water content were coarse textured soils with high water content will have high K_{us} compared to coarse textured soils with low water content (Hopmans, 2002).

An unsaturated hydraulic conductivity increased with the increasing depth up to plinthic layers. This could be due to the increased water content in the lower soil layers. The decrease in K_{us} in plinthic layers might be due to the compactness soil which limited the water movement.

Table 3.7: Average unsaturated hydraulic conductivity of Rogland, Meulsteenvlei, Oorlogskloof and Klein Blomfontein.

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Study Site	Soil depth (cm)	Hydraulic conductivity ($mm.hour^{-1}$)
Rogland	0 – 20	14.6
	20 – 40	16.7
	40 – 60	51.6
	60 – 80	21.7
	80 – 100	6.9
	Total average	**22.3**
Meulsteenvlei	0 – 20	20.4
	20 – 40	24.7
	40 – 60	44.7
	60 – 80	48.8
	80 – 100	20
	Total average	**31.7**
Oorlogskloof	0 – 20	2.7
	20 – 40	3.7
	40 – 60	4.1
	60 – 80	9.1
	80 – 100	9.2
	Total average	**5.8**
Klein Blomfontein	0 – 20	3.6
	20 – 40	5.5
	40 – 60	4.3
	Total average	**4.5**

3.3.2.4 Saturated hydraulic conductivity

The mean saturated hydraulic conductivity, K_s, per layer of four sites is given in Table 3.8. The highest K_s, 3.4 x 10^{-2} $cm.s^{-1}$ was recorded in the Rogland study site at the soil depth 0 to 20 cm. The second highest K_s of all treatments at the soil depth 0 to 20 cm was 2.3 x 10^{-2} $cm.s^{-1}$ observed at the Oorlogskloof study site. The K_s decreased with the increasing depth for most of the layers. The lowest K_s 2.1 x 10^{-3} $cm.s^{-1}$, was observed in the Rogland study site at the soil depth 80 to 1 000 cm. This was followed by 2.8 x 10^{-3} $cm.s^{-1}$ at the Klein Blomfontein study site. The results are similar with the findings obtained by Perkins *et al*. (2014) for the coarse sand and sand K_s approximate to 10^{-2} and 10^{-3} $m.s^{-1}$.

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Table 3.8: The mean saturated hydraulic conductivity of Rogland Meulsteenvlei, Oorlogskloof and Klein Blomfontein.

Study Sites	Soil depth (cm)	K_s ($cm.s^{-1}$)
Rogland	0 – 20	3.4×10^{-2}
	20 – 40	2.5×10^{-2}
	40 – 60	2.0×10^{-2}
	60 – 80	1.4×10^{-2}
	80 – 100	2.1×10^{-3}
Meulsteenvlei	0 – 20	1.6×10^{-2}
	20 – 40	1.4×10^{-2}
	40 – 60	1.1×10^{-2}
	60 – 80	1.3×10^{-2}
	80 – 100	1.0×10^{-2}
Oorlogskloof	0 – 20	2.3×10^{-2}
	20 – 40	1.6×10^{-2}
	40 – 60	1.1×10^{-2}
	60 – 80	1.6×10^{-2}
	80 – 100	1.1×10^{-2}
Klein Blomfontein	0 – 20	1.4×10^{-2}
	20 – 40	8.7×10^{-3}
	40 – 60	2.8×10^{-3}

3.3.3 Parameters of importance in water dynamics

3.3.3.1 Calibration of the ECH2O sensors

The linear regression equations of the five depths of four sites are presented in Table 3.9 while the detailed graphs are presented in *Annexure 2*. The linear regression correlation of all depth layers of Rogland and Klein Blomfontein study sites were highly correlated with R^2 ranging from 0.8184 to 0.9998. Meulsteenvlei and Oorlogskloof had linear regression equations that were highly correlated for 5-TM sensor at the depth of 50, 150 and 250 mm. The calibration values of EC-20 sensor for soil depth 550 and 850 mm at the Meulsteenvlei and Oorlogskloof study sites were moderately correlated with R^2 ranging from 0.6877 to 0.7987.

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Table 3.9: Linear regression equations and correlation coefficient (R^2) of different soil depths at the Rogland, Meulsteenvlei, Oorlogskloof and Klein Blomfontein study sites.

Study site	Soil depth (mm)	Type of ECHO sensors	Linear regressions equations	R^2
Rogland	50	5TM	y = 1.0869x - 0.0198	0.9262
	150	5TM	y = 1.116x - 0.0484	0.9909
	250	5TM	y = 0.9748x - 0.041	0.9973
	550	EC-20	y = 0.5699x - 0.0171	0.8184
	850	EC-20	y = 0.6243x - 0.0299	0.8842
Meulsteenvlei	50	5TM	y = 0.827x - 0.0158	0.9602
	150	5TM	y = 0.7994x - 0.0129	0.9925
	250	5TM	y = 0.9194x - 0.0219	0.9682
	550	EC-20	y = 0.6433x - 0.0337	0.7987
	850	EC-20	y = 0.6542x - 0.022	0.6877
Oorlogskloof	50	5TM	y = 1.0409x - 0.0531	0.9695
	150	5TM	y = 1.16x - 0.054	0.9925
	250	5TM	y = 0.9027x - 0.0235	0.9769
	550	EC-20	y = 0.6595x - 0.0341	0.7792
	850	EC-20	y = 0.7733x - 0.048	0.7271
Klein Blomfontein	50	5TM	y = 1.1478x - 0.0535	0.9868
	150	5TM	y = 0.9321x - 0.0427	0.9998
	250	5TM	y = 1.0324x - 0.0493	0.9812
	350	EC-20	y = 0.7755x - 0.0508	0.8242
	450	EC-20	y = 0.9949x - 0.1181	0.8195

y: Soil volumetric water content ($mm.mm^{-1}$); x: Scaled frequency

3.3.3.2 Soil water content

Table 3.10 shows the uncalibrated monthly average rainfall, total rainfall, highest rainfall per day, lowest rainfall and total rainfall at the Rogland, Meulsteenvlei, Oorlogskloof and Klein Blomfontein study sites. The total rainfall during the period of the study was 373, 495, 413 and 391 mm for Rogland, Meulsteenvlei, Oorlogskloof and Klein Blomfontein, respectively. In 2018, the total rainfall at Rogland (360.5 mm), Meulsteenvlei (448.4 mm), Oorlogskloof (386.2 mm) and Klein Blomfontein (353.8 mm) was high compared to the total rainfall of approximately 100 mm reported for Clanwilliam Rooibos plantation (van Schalkwyk, 2018). As expected, highest rainfall in 2018 was obtained in winter (June to August) and accounts for 39 and 50% of the total rainfall in that particular year. The lowest total rainfall recorded was during summer (December to February) of the 2018/19 season.

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Table 3.10: Rainfall data for the 2017/18 and 2018/19 growing seasons.

Time	Units	Rainfall (mm)			
		Rogland	Meulsteenvlei	Oorlogskloof	Klein Blomfontein
Oct-17	Average	0.2	5.0	0.0	0.0
	Total	1.1	23.1	0.0	0.0
	Highest	1.1	8.1	0.0	0.0
	Lowest	0.0	1.7	0.0	0.0
Nov-17	Average	0.2	0.4	0.7	1.1
	Total	6.7	10.8	20.8	33.0
	Highest	2.8	6.4	18.0	18.0
	Lowest	0.0	0.0	0.0	0.0
Dec-17	Average	0.0	0.0	0.0	0.0
	Total	0.0	0.4	0.0	0.0
	Highest	0.0	0.2	0.0	0.0
	Lowest	0.0	0.0	0.0	0.0
Jan-18	Average	0.9	0.8	0.8	0.7
	Total	28.4	25.2	25.6	22.5
	Highest	18.6	15.0	18.6	18.6
	Lowest	0.0	0.0	0.0	0.0
Feb-18	Average	1.0	0.6	0.6	1.0
	Total	29.1	17.8	16.1	29.1
	Highest	23.1	7.4	5.0	23.1
	Lowest	0.0	0.0	0.0	0.0
Mar-18	Average	0.5	0.8	0.5	0.5
	Total	15.3	25.0	16.0	16.8
	Highest	11.7	20.6	16.0	14.7
	Lowest	0.0	0.0	0.0	0.0
Apr-18	Average	0.6	0.8	0.9	0.8
	Total	16.5	22.8	27.0	24.9
	Highest	6.9	9.6	12.0	9.3
	Lowest	0.0	0.0	0.0	0.0
May-18	Average	1.6	2.3	2.5	1.9
	Total	48.3	69.8	77.0	58.5
	Highest	24.3	19.8	31.0	22.5
	Lowest	0.0	0.0	0.0	0.0
Jun-18	Average	2.6	2.9	2.0	1.2
	Total	75.3	87.4	61.0	35.4
	Highest	38.1	25.0	17.0	9.3
	Lowest	0.0	0.0	0.0	0.0
Jul-18	Average	0.4	1.8	2.2	1.6
	Total	13.5	54.4	68.0	51.0
	Highest	8.4	38.4	38.0	30.9
	Lowest	0.0	0.0	0.0	0.0
Aug-18	Average	1.7	2.5	1.1	1.7
	Total	54.0	78.0	35.0	54.0
	Highest	22.0	20.8	11.0	20.0
	Lowest	0.0	0.0	0.0	0.0
Sep-18	Average	2.1	1.5	1.7	1.4
	Total	64.2	44.8	49.5	43.0
	Highest	36.0	26.2	21.0	10.0
	Lowest	0.0	0.0	0.0	0.0
Oct-18	Average	0.0	0.2	0.3	0.1
	Total	1.5	5.6	8.0	4.2
	Highest	1.5	3.6	5.0	3.3
	Lowest	0.0	0.0	0.0	0.0
Nov-18	Average	0.2	0.3	0.0	0.2
	Total	6.3	8.6	0.0	6.3
	Highest	6.3	6.8	0.0	6.3
	Lowest	0.0	0.0	0.0	0.0
Dec-18	Average	0.3	0.3	0.1	0.3
	Total	8.1	9.0	3.0	8.1
	Highest	5.7	4.2	3.0	5.7
	Lowest	0.0	0.0	0.0	0.0
Jan-19	Average	0.1	0.3	0.2	0.1
	Total	4.5	8.6	6.0	4.5
	Highest	4.5	6.4	4.0	3.3
	Lowest	0.0	0.0	0.0	0.0
Feb-19	Average	0.0	0.0	0.0	0.0
	Total	0.0	4.0	0.0	0.0
	Highest	0.0	0.0	0.0	0.0
	Lowest	0.0	0.0	0.0	0.0
Total		372.8	495.3	413.0	391.3

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The average SWC at FC for each soil depth at all study sites is given in Table 3.11. The average SWC at FC for soil depth from 0 to 300 mm at the Rogland, Meulsteenvlei, Oorlogskloof and Klein Blomfontein study sites were 27, 26.6, 22.7 and 28.3 mm.layer^{-1}, respectively. Though the average SWC at FC remained the same for the first three layers, it started to increase with layers from 300 mm soil depth for all sites. This was due to the thicker layers that were below 300 mm compared to the first three layers which were thinner. However, Klein Blomfontein had similar size of thickness in layers but its SWC at FC increased with depth due to the increased clay content between 300 to 400 mm and 400 to 500 mm.

Table 3.11: Average field capacity at the Rogland, Meulsteenvlei, Oorlogskloof and Klein Blomfontein study sites.

Site	Soil depth (mm)	Field capacity (mm/layer)
Rogland	0 – 100	27
	100 – 200	27
	200 – 300	27
	300 – 600	72.4
	600 – 1 000	114.0
Meulsteenvlei	0 – 100	26.6
	100 – 200	26.6
	200 – 300	26.6
	300 – 600	62.6
	600 – 1 000	109.2
Oorlogskloof	0 – 100	22.7
	100 – 200	22.7
	200 – 300	22.7
	300 – 600	69.1
	600 – 1 000	97.7
Klien Blomfontein	0 – 100	28.3
	100 – 200	28.3
	200 – 300	28.3
	300 – 400	30.5
	400 – 500	30.5

3.3.3.2.1 Soil water content at the Rogland study site

The average, highest and lowest SWC per layer is presented in Table 3.12. The total SWC ranged from 108.6 to 465.8 mm. The highest SWC was observed in October 2018 due to substantial rainfall

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received during the winter. This led to a soil water table due to low saturated hydraulic conductivity and high clay content (> 10%) observed on the 80 to 100 cm soil layer. Increased SWC was observed after rainfall events. Rainfall lower than 10 mm only showed an increase in SWC of the 0 to 300 mm soil depth. The SWC was high in November 2018 compared to November 2017. This was most probably due to the higher rainfall measured in the winter of 2018.

The SWC started to decrease in October 2018 and it was similar to the findings reported by Lötter (2015) and van Schalkwyk (2018). The decrease was likely due to high Rooibos water demand during flowering.

3.3.3.2.2 Soil water content at the Meulsteenvlei study site

The measured SWC at Meulsteenvlei is presented in Table 3.13. The total profile SWC ranged from 83.4 to 204.7 mm as the soil had homogeneous soil texture of very coarse sand with a clay content of less than 10%, and normal bulk density less than 1.8 $g.cm^{-3}$ (Hazelton & Murphy, 2007), there was no water table was present. In November 2017, the SWC content ranged from 84.5 to 125.1 mm while in November 2018 the SWC was from 44.8 to 46.0 mm (Table 3.13). The higher SWC in 2017 could have been due to the fallow efficiency. The SWC increased with the depth from 0 to 100 mm, 100 to 200 mm and 200 to 300 mm throughout the duration of the experiment.

3.3.3.2.3 Soil water content at the Oorlogskloof study site

Table 3.14 shows the SWC at the Oorlogskloof. The total SWC throughout the experiment went from 62.1 to 204.4 mm. The SWC in the 0 to 100 mm soil layer was generally higher. This was most likely due to less rainfall (< 5 mm) per day received which could not be redistributed to the lower layers. However, in winter and early spring, the SWC was increasing with the depth. The lower SWC on upper layers was influenced by atmospheric demand.

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Table 3.12: Average, maximum and minimum soil water content per month at the Rogland study site from October 2017 to February 2019 (refer to Figure A3-1 to A3-4 of Appendix 3 for detailed SWC).

Time	Unit	Soil water content (mm)					
		0 - 100 mm	100 - 200 mm	200 - 300 mm	300 - 600 mm	600 - 1000 mm	Total
	Average	5.0	2.5	1.7	26.7	89.6	125.5
Oct-17	Highest	5.1	2.5	1.8	27.0	90.4	126.8
	Lowest	4.9	2.4	1.6	26.7	89.2	124.8
	Average	5.7	2.4	2.1	27.6	88.4	126.2
Nov-17	Highest	7.1	3.1	3.4	29.7	91.2	134.5
	Lowest	4.8	1.8	1.6	26.7	81.2	116.1
	Average	5.2	2.8	1.6	26.7	76.8	113.1
Dec-17	Highest	5.6	3.1	2.0	27.6	80.4	118.7
	Lowest	5.0	2.5	1.5	26.1	76.0	111.1
	Average	5.8	2.8	1.7	26.1	75.5	111.9
Jan-18	Highest	8.0	3.6	2.7	26.7	76.0	117.0
	Lowest	4.9	2.3	1.4	25.2	74.8	108.6
	Average	6.7	3.9	2.5	29.4	77.2	119.7
Feb-18	Highest	9.5	4.8	3.9	34.2	80.4	132.8
	Lowest	3.8	2.9	1.6	25.8	74.8	108.9
	Average	4.1	3.7	3.3	27.6	88.0	126.7
Mar-18	Highest	6.5	4.3	4.7	30.3	80.0	125.8
	Lowest	3.1	3.2	2.9	26.1	86.0	121.3
	Average	5.0	3.4	4.8	30.3	89.6	133.1
Apr-18	Highest	5.7	3.6	5.5	31.8	90.0	136.6
	Lowest	3.1	3.1	3.8	28.2	88.0	126.2
	Average	7.2	4.4	6.3	26.1	87.2	131.2
May-18	Highest	23.4	7.4	13.5	46.2	88.0	178.5
	Lowest	3.5	3.4	3.7	20.1	85.6	116.3
	Average	13.0	7.2	11.0	52.5	154.4	238.1
Jun-18	Highest	22.4	9.4	14.4	72.3	226.0	344.5
	Lowest	7.1	5.3	8.2	38.4	85.6	144.6
	Average	8.7	8.4	14.8	126.0	222.4	380.3
Jul-18	Highest	21.4	11.3	15.8	138.6	227.2	414.3
	Lowest	5.1	5.8	13.2	75.6	209.2	308.9
	Average	7.8	9.6	13.9	119.7	197.2	348.2
Aug-18	Highest	16.9	17.0	15.7	133.2	208.0	390.8
	Lowest	5.1	6.2	12.7	107.7	186.4	318.1
	Average	11.1	13.8	18.7	132.3	188.8	364.7
Sep18	Highest	18.2	17.3	20.8	148.2	202.8	407.3
	Lowest	6.4	10.6	14.8	123.9	184.4	340.1
	Average	5.3	5.8	12.7	113.7	202.8	340.3
Oct-18	Highest	6.9	12.3	17.6	150.6	278.4	465.8
	Lowest	4.6	3.6	5.9	69.9	182.0	266.0
	Average	4.3	3.6	5.0	59.4	178.8	251.1
Nov-18	Highest	5.7	3.9	8.2	72.6	217.6	308.0
	Lowest	3.5	3.1	3.7	46.8	152.8	209.9
	Average	3.6	3.4	3.6	35.1	125.2	170.9
Dec-18	Highest	4.3	3.6	4.3	47.1	150.8	210.1
	Lowest	3.2	3.2	3.5	28.5	108.8	147.2
	Average	3.7	3.5	4.1	28.5	105.6	145.4
Jan-19	Highest	5.3	3.6	7.8	30.0	108.8	155.5
	Lowest	2.9	3.2	3.4	27.0	102.4	138.9
	Average	2.8	3.2	3.4	30.0	101.6	141.0
Feb-19	Highest	3.0	3.4	3.5	32.7	102.4	145.0
	Lowest	2.6	3.0	3.3	27.3	101.2	137.4

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Table 3.13: Average, maximum and minimum soil water content per month at the Meulsteenvlei study site from October 2017 to February 2019 (refer to Figure A3-5 to A3-8 of Appendix 3 for detailed SWC).

Time	Unit	Soil water content (mm)					
		0 - 100 mm	100 - 200 mm	200 - 300 mm	300 - 600 mm	600 - 1000 mm	Total
	Average	2.3	7.7	22.8	13.5	49.2	95.5
Oct-17	Highest	2.4	7.7	22.9	13.8	49.2	96.0
	Lowest	2.3	7.6	22.6	13.5	48.8	94.8
	Average	5.0	9.4	20.4	14.7	48.0	97.5
Nov-17	Highest	17.9	18.0	24.7	15.3	49.2	125.1
	Lowest	2.3	7.6	13.9	13.5	47.2	84.5
	Average	2.4	7.0	13.5	16.2	47.6	86.7
Dec-17	Highest	2.7	8.3	15.1	17.4	48.4	91.9
	Lowest	2.3	6.3	12.6	15.0	47.2	83.4
	Average	5.8	10.1	14.4	18.9	47.2	96.4
Jan-18	Highest	17.1	17.8	17.0	20.1	48.4	120.4
	Lowest	2.5	6.3	12.5	17.1	46.4	84.8
	Average	5.4	9.4	15.3	19.8	46.4	96.3
Feb-18	Highest	18.4	16.8	16.1	20.7	46.8	118.8
	Lowest	2.5	7.4	14.5	18.9	46.0	89.3
	Average	4.2	8.1	14.1	19.2	45.2	90.8
Mar-18	Highest	16.0	16.5	17.0	20.1	46.0	115.6
	Lowest	2.2	6.8	12.9	18.6	44.8	85.3
	Average	3.7	8.2	14.8	19.8	44.8	91.3
Apr-18	Highest	7.6	10.5	17.5	20.7	45.2	101.5
	Lowest	2.9	7.4	13.7	19.2	43.6	86.8
	Average	6.9	11.4	17.6	28.2	49.6	113.7
May-18	Highest	14.7	18.5	20.6	40.8	65.2	159.8
	Lowest	4.7	8.5	16.3	20.1	44.4	94.0
	Average	12.4	16.0	19.3	40.8	73.6	162.1
Jun-18	Highest	23.4	26.8	22.3	45.3	77.2	195.0
	Lowest	4.6	8.4	15.8	36.9	66.4	132.1
	Average	8.0	11.8	17.2	39.6	71.6	148.2
Jul-18	Highest	20.5	24.5	23.1	53.4	83.2	204.7
	Lowest	4.9	8.0	14.0	30.3	59.6	116.8
	Average	11.2	15.6	18.5	32.4	54.4	132.1
Aug-18	Highest	20.8	25.7	24.5	45.0	62.0	178.0
	Lowest	4.9	8.0	13.9	27.3	51.2	105.3
	Average	10.8	15.5	19.8	42.0	71.2	159.3
Sep-18	Highest	19.2	24.2	23.8	48.6	75.2	191.0
	Lowest	5.4	9.1	17.4	36.9	62.8	131.6
	Average	4.5	8.6	14.3	25.2	52.0	104.6
Oct-18	Highest	7.1	9.9	17.0	36.0	61.6	131.6
	Lowest	3.8	8.1	13.3	20.7	44.8	90.7
	Average	6.2	9.5	13.6	21.3	45.2	95.8
Nov-18	Highest	10.2	11.3	13.9	21.3	46.0	102.7
	Lowest	4.6	8.7	13.4	21.0	44.8	92.5
	Average	4.7	9.5	13.5	21.3	44.0	93.0
Dec-18	Highest	11.4	11.3	13.8	23.1	45.2	104.8
	Lowest	3.9	8.8	13.2	20.4	43.6	89.9
	Average	5.3	11.2	13.6	21.0	43.6	94.7
Jan-19	Highest	16.5	12.2	14.1	26.4	45.2	114.4
	Lowest	3.5	9.6	13.0	20.1	42.8	89.0
	Average	4.6	10.8	13.4	21.3	42.8	92.9
Feb-19	Highest	13.9	12.0	13.8	22.2	43.6	105.5
	Lowest	3.2	10.4	12.9	20.7	42.4	89.6

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Table 3.14: Average, maximum and minimum soil water content per month at the Oorlogskloof study site from October 2017 to February 2019 (refer to Figure A3-9 to A3-12 of Appendix 3 for detailed SWC).

Time	Unit	Soil water content (mm)					
		0 - 100 mm	100 - 200 mm	200 - 300 mm	300 - 600 mm	600 - 1000 mm	Total
	Average	4.7	1.8	3.2	16.5	37.6	63.8
17-Oct	Highest	4.8	1.8	3.3	17.1	38.0	65.0
	Lowest	4.5	1.6	3.1	16.5	37.6	63.3
	Average	4.2	2.0	3.4	17.1	38.4	65.1
17-Nov	Highest	6.7	2.4	3.7	17.7	38.4	68.9
	Lowest	2.7	1.8	3.2	16.8	38.0	62.5
	Average	2.2	2.7	4.9	18.6	37.6	66.0
17-Dec	Highest	3.5	3.1	5.1	19.8	38.0	69.5
	Lowest	1.6	2.2	3.7	17.4	37.2	62.1
	Average	3.2	3.7	5.2	21.6	36.4	70.1
18-Jan	Highest	7.4	5.8	5.4	21.9	37.2	77.7
	Lowest	1.6	3.0	4.8	19.8	36.0	65.2
	Average	3.5	4.8	5.5	22.2	36.4	72.4
18-Feb	Highest	5.5	5.5	5.6	22.2	36.4	75.2
	Lowest	2.4	4.1	5.4	21.9	36.0	69.8
	Average	2.7	4.0	5.3	21.9	36.0	69.9
18-Mar	Highest	9.5	9.3	5.5	22.2	36.0	82.5
	Lowest	1.9	3.3	5.0	21.6	35.6	67.4
	Average	6.5	6.4	5.4	21.9	35.6	75.8
18-Apr	Highest	8.4	8.5	5.7	21.9	35.6	80.1
	Lowest	4.1	4.9	5.1	21.3	35.2	70.6
	Average	6.6	7.0	7.5	22.8	35.6	79.5
18-May	Highest	14.9	11.6	16.6	33.9	42.4	119.4
	Lowest	3.7	4.9	5.1	21.6	35.2	70.5
	Average	10.0	10.3	15.5	40.5	70.0	146.3
18-Jun	Highest	13.2	13.2	17.8	46.2	79.2	169.6
	Lowest	5.9	6.4	13.5	34.5	47.6	107.9
	Average	7.7	8.6	12.5	45.3	77.2	151.3
18-Jul	Highest	14.7	15.7	18.9	57.9	97.2	204.4
	Lowest	4.8	5.3	6.2	33.9	61.6	111.8
	Average	7.2	6.3	6.3	30.3	56.4	106.5
18-Aug	Highest	11.0	9.1	9.0	35.4	61.6	126.1
	Lowest	4.8	5.3	5.9	28.5	52.0	96.5
	Average	8.7	8.7	11.6	42.9	66.0	137.9
18-Sep	Highest	13.0	12.8	13.2	43.5	71.2	153.7
	Lowest	5.9	6.0	9.1	36.0	53.6	110.6
	Average	3.1	5.0	6.3	43.5	41.6	99.5
18-Oct	Highest	5.3	5.8	8.9	43.5	60.8	124.3
	Lowest	1.8	4.4	5.3	43.5	35.2	90.2
	Average	3.8	4.6	5.5	43.5	34.8	92.2
18-Nov	Highest	4.3	4.8	5.6	43.5	35.6	93.8
	Lowest	3.3	4.3	5.2	39.3	34.0	86.1
	Average	4.0	4.9	5.5	43.5	34.0	91.9
18-Dec	Highest	4.3	4.9	5.6	43.5	34.8	93.1
	Lowest	3.7	4.8	5.4	43.5	33.6	91.0
	Average	3.6	4.6	5.6	43.2	33.2	90.2
19-Jan	Highest	4.6	4.8	5.7	43.5	33.6	92.2
	Lowest	2.9	4.3	5.4	39.3	32.8	84.7
	Average	3.1	4.1	5.6	22.8	37.2	72.8
19-Feb	Highest	3.4	4.3	5.8	23.1	37.6	74.2
	Lowest	2.8	3.9	5.4	22.2	36.8	71.1

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3.3.3.2.4 Soil water content at the Klein Blomfontein study site

The SWC presented in Table 4.6 ranged from 49.3 to168.6 mm throughout the duration of the experiment. Both clay content and SWC increased with the increasing depth. The SWC remained almost constant throughout season except after significant amount of rainfall (> 10 mm) received. The increased SWC lasted between 2 and 9 days after meaning rainfall. The rapid loss of moisture was due to the shallowness of the soil which was exposed to the environmental factors influencing atmospheric water demand. Water table observed was due to high clay content in soil layer 400 to 500 mm and shallow soil depth.

3.3.3.3 Soil water balance

The soil water balance (SWB) of the Rogland, Meulsteenvlei, Oorlogskloof and Klein Blomfontein study sites are presented from Table 3.17 to 3.36. The green blocks in this tables indicates the increase in total SWC in the rootzone depth while the blue blocks indicates the presence of water table. The water tables were only observed at Rogland, Oorlogskloof and Klein Blomfontein during the period of measurement. Water table was observed at Rogland from day 236 on soil layer 600 to 1 000 mm and extended to soil layer 300 to 600 mm on day 251. This water table lasted up until day 366 on soil layer 300 to 600 mm and day 416 on soil layer 600 to 1 000 mm. At Oorlogskloof, the water table was only present at soil layer 600 to 1 000 mm from day 316 to 321. At Klein Blomfontein the water table was at soil layer 400 to 500 mm from day 211 to 271, day 286 and day 306 to 326. The water table at Klein Blomfontein moved to soil layer 300 to 400 mm only on day 251. At Meulsteenvlei, no water table was detected throughout the duration of the experiment.

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Table 3.15: Average, maximum and minimum soil water content per month at the Klein Blomfontein study site from October 2017 to February 2019 (refer to Figure A3-13 to A3-16 of Appendix 3 for detailed SWC).

Time	Unit	Soil water content (mm)					
		0 - 100 mm	100 - 200 mm	200 -300 mm	300 -400 mm	400 - 500 mm	Total
	Average	1.5	3.8	5.4	12.0	28.0	50.7
Oct-17	Highest	1.6	3.9	5.6	12.1	28.3	51.5
	Lowest	1.5	3.7	5.2	11.9	27.7	50.0
	Average	3.8	4.4	5.8	12.6	27.8	54.4
Nov-17	Highest	7.6	5.9	6.9	13.5	28.8	62.7
	Lowest	1.4	3.5	5.4	11.9	27.2	49.4
	Average	3.1	5.4	6.9	13.5	27.8	56.7
Dec-17	Highest	3.7	6.0	7.6	13.7	29.0	60.0
	Lowest	3.0	4.9	6.5	13.3	26.8	54.5
	Average	3.9	4.9	6.3	13.6	26.2	54.9
Jan-18	Highest	6.6	5.7	6.5	13.8	26.7	59.3
	Lowest	3.0	4.6	6.1	13.4	25.9	53.0
	Average	5.5	7.0	7.9	14.0	25.9	60.3
Feb-18	Highest	7.2	8.5	9.0	14.3	26.0	65.0
	Lowest	3.7	5.5	6.6	13.7	25.6	55.1
	Average	5.3	7.4	8.1	13.8	25.7	60.3
Mar-18	Highest	6.9	8.3	9.0	13.9	25.9	64.0
	Lowest	4.4	6.5	7.1	13.5	25.3	56.8
	Average	7.1	7.8	8.1	13.5	25.3	61.8
Apr-18	Highest	7.4	8.2	8.7	13.7	25.5	63.5
	Lowest	6.7	6.8	7.3	13.4	25.0	59.2
	Average	7.3	9.8	10.5	16.3	29.9	73.8
May-18	Highest	8.9	15.5	16.7	26.1	53.2	120.4
	Lowest	6.4	7.0	7.3	13.4	25.3	59.4
	Average	9.2	15.5	15.0	23.1	38.2	101.0
Jun-18	Highest	10.9	16.1	16.6	26.5	50.8	120.9
	Lowest	7.8	14.0	13.3	20.3	33.1	88.5
	Average	9.0	13.5	13.9	23.3	43.0	102.7
Jul-18	Highest	12.8	16.8	19.2	38.0	81.8	168.6
	Lowest	6.9	7.8	8.6	14.4	29.0	66.7
	Average	8.0	10.3	11.5	17.8	30.0	77.6
Aug-18	Highest	10.0	12.5	14.7	23.5	39.0	99.7
	Lowest	6.9	7.6	8.0	13.9	27.2	63.6
	Average	9.8	12.3	13.8	21.3	34.0	91.2
Sep-18	Highest	13.6	13.7	16.1	26.9	55.6	125.9
	Lowest	7.7	9.1	10.8	16.1	27.0	70.7
	Average	5.2	6.6	7.1	14.2	21.6	54.7
Oct-18	Highest	7.5	8.4	9.8	15.4	25.9	67.0
	Lowest	3.7	5.6	6.2	13.8	20.6	49.9
	Average	4.1	5.8	6.2	14.0	21.5	51.6
Nov-18	Highest	5.0	6.0	6.5	14.1	22.0	53.6
	Lowest	3.7	5.4	5.9	13.7	20.6	49.3
	Average	4.1	5.6	6.9	14.2	22.1	52.9
Dec-18	Highest	5.0	5.8	7.2	14.3	22.3	54.6
	Lowest	3.7	5.3	6.5	13.9	21.7	51.1
	Average	3.8	5.3	7.2	14.3	22.3	52.9
Jan-19	Highest	4.3	5.5	7.3	14.4	22.5	54.0
	Lowest	3.6	5.1	6.9	14.2	22.1	51.9
	Average	3.6	5.1	7.0	14.3	22.4	52.4
Feb-19	Highest	3.9	5.3	7.2	14.4	22.5	53.3
	Lowest	3.4	4.9	6.9	14.2	22.3	51.7

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The total rootzone SWC at the Rogland the study site ranged from 35.5 mm on Day 1 to 37.8 mm on Day 486 of collection, while at the Meulsteenvlei, Oorlogskloof and Klein Blomfontein study sites the total rootzone SWC ranged from 46.5 – 48.2, 25.9 – 34.9 and 22.3 – 29.9 mm, respectively. The smallest total SWC difference between the study sites was observed between Oorlogskloof and Klein Blomfontein with 0.1 mm on Day 171, 191 and 196. The largest total SWC difference occurred on day 341 between Rogland and Klein Blomfontein with 146.9 mm. At the end of the study, Meulsteenvlei lost 3.8 mm of water while Rogland, Oorlogskloof and Klein Blomfontein stored 13.7, 8.6 and 1.8 mm more water, respectively.

With respect to soil layer, the 0 to 100 mm soil layer of Rogland had the highest SWC on Day 231 with a maximum of 22.4 mm. The higher SWC mainly due to high rainfall received during that period and high plant density which reduce the influence of direct environmental factors such as sunlight and wind speed. The lowest maximum SWC at the 0 to 100 mm soil depth was observed at the Oorlogskloof study site on Day 236. This was due the low plant density and high coarse fraction on the surface. The SWC in soil layer 100 to 200 and 200 to 300 mm was high at Meulsteenvlei compared to three other study sites with a maximum of 22.6 and 24.3 mm, respectively. At the deep sites, Rogland had higher SWC in soil layer 300 to 600 and 600 to 1 000 mm compared to Meulsteenvlei and Oorlogskloof with the maximum SWC of 150.6 and 227.3 mm, respectively. This high SWC was influenced by shallow hard plinthic which eventually caused a shallow water table after heavy rainfall.

From Day 1 to Day 106, the highest total SWC increase in the rootzone was observed at the Oorlogskloof study site with an increase of 9.7 mm. The second and third highest increase in total SWC occurred at the Klein Blomfontein and Rogland study sites with an amount of 8.4 and 2.2 mm, respectively. The Meulsteenvlei study site happened to be the only site with the decrease in total SWC during this period. The decrease was amounts to 1.3 mm.

During the period from 106 to 216 days, total SWC increased by 45.0, 37.3, 34.8 and 33.4 mm at Meulsteenvlei, Oorlogskloof, Rogland and Klein Blomfontein, respectively.

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From Day 216 to Day 311 of the SWB and the period of significant rainfall amounts, total SWC increased by 84.3 at Rogland while it decreased by 10.4, 9.7 and 7.2 mm at Oorlogskloof, Klein Blomfontein and Meulsteenvlei, respectively.

During the period from Day 311 to Day 341, total SWC increased at Rogland by 29.5 mm while the decreased was at Meulsteenvlei with 16.5 mm, Klein Blomfontein with 15.1 mm and Oorlogskloof with 3.3 mm.

Throughout the prime flowering period from Day 341 to Day 371, total SWC decreased mostly at Rogland by 101.4 mm compared to Oorlogskloof with 21.2 mm, Meulsteenvlei with 14.9 mm and Klein Blomfontein with 9.8 mm.

From Day 371 to Day 451, an increase in total SWC was observed at Meulsteenvlei (4.8 mm) and Klein Blomfontein (1.0 mm) while a decrease was observed at Rogland (43.8 mm) and Oorlogskloof (1.1 mm).

Meulsteenvlei with 508.0 mm at the end of the study compared to Rogland (404.5 mm), Oorlogskloof (363.4 mm) and Klein Blomfontein (353.2 mm). During the period of 425.1, 360.7, 319.4 and 301.8 mm for Meulsteenvlei, Rogland, Oorlogskloof and Klein Blomfontein, respectively. The percentage water usage during this period amounts to 83.7, 85.5, 87.9 and 89.2% to the total water usage for Meulsteenvlei, Klein Blomfontein, Oorlogskloof and Rogland, respectively.

During the meaningful rainfall period (Day 216 to 311), the water usage was higher as compared to the peak of the flowering stage (Day 341 to 371). The percentage water usage for meaningful rainfall period for Oorlogskloof, Meulsteenvlei, Klein Blomfontein and Rogland were 46.8, 45.6, 34.1 and 29.4 %, respectively. During the peak of the flowering stage the percentage of water usage was 16.1% (Rogland), 8.0% (Oorlogskloof), 3.8% (Klein Blomfontein) and 3.6% (Meulsteenvlei). According to Gardner *et al.* (1999), the water usage is higher on the wetted soil than the drier soil. Therefore, low percentage of water usage during flowering was due to the drier soil and low amounts of rainfall received during that period.

A summary of SWB for four sites from 27 October 2017 to 28 February 2019 is presented in Table 3.16. The soils were wetter at the end of the study than at the beginning of the study. Water usage during active growth of Rooibos (day 311 to 461)

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was 156.0, 94.7, 81.0 and 79.5 mm at Rogland, Meulsteenvlei, Oorlogskloof and Klein Blomfontein, respectively. T f 319.2 to 440.1 mm in 2018 of these sandy soils

found at Clanwilliam (van Schalkwyk, 2018).

Table 3.16: Summary of the soil water balance (mm) for all four sites from October 2017 to February 2019.

Site	Rootzone depth (mm)	SWC-start	SWC-end	S				ET
Rogland	0 to 600	35.5	37.8	2.3	372.8	128.8	187.8	404.5
Meulsteenvlei	0 to 600	46.5	48.2	1.7	495.3	58.1	61.7	508.0
Oorlogskloof	0 to 600	25.9	34.9	9.0	413.0	24.4	66.7	363.4
Klein Blomfontein	0 to 400	22.3	29.9	7.6	391.3	30.1	119.5	353.2

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Table 3.17: Soil water balance of Rooibos at the Rogland study site for Day 1 to 101. The red block indicates the rootzone depth, green blocks indicates an increase soil water content (SWC) between the two measured dates. All values are in mm.

No. of days	1	6	11	16	21	26	31	36	41	46	51	56	61	66	71	76	81	86	91	96	101
Date / **Depth (mm)**	**2017/10/27**	**2017/11/01**	**2017/11/06**	**2017/11/11**	**2017/11/16**	**2017/11/21**	**2017/11/26**	**2017/12/01**	**2017/12/06**	**2017/12/11**	**2017/12/16**	**2017/12/21**	**2017/12/26**	**2017/12/31**	**2018/01/05**	**2018/01/10**	**2018/01/15**	**2018/01/20**	**2018/01/25**	**2018/01/30**	**2018/02/04**
0 – 100	4.9	5.0	5.2	5.0	5.5	6.2	7.1	5.6	5.4	5.2	5.3	5.4	5.1	5.2	5.3	5.5	5.2	5.3	7.0	7.4	6.6
100 - 200	2.4	2.4	2.3	2.3	1.8	2.6	3.0	3.1	3.1	2.9	2.8	2.8	2.5	2.6	2.6	2.5	2.7	2.7	2.7	3.6	3.4
200 - 300	1.6	1.7	1.7	1.7	1.9	2.6	2.9	1.8	1.8	1.6	1.6	1.6	1.5	1.5	1.5	1.5	1.5	1.5	2.4	2.2	1.9
300 - 600	26.6	27.0	27.0	27.0	27.3	28.8	28.3	27.6	27.4	26.6	26.2	26.6	26.2	26.4	26.1	26.8	26.3	25.9	25.5	26.6	26.3
600 - 1 000	90.3	89.4	89.0	89.0	87.2	90.5	84.9	80.2	78.4	76.5	76.2	76.0	76.0	76.0	75.8	75.5	75.5	75.3	75.0	75.6	75.3
Total SWC at rootdepth	35.5	36.1	36.3	36.0	36.5	40.2	41.2	38.2	37.7	36.3	35.9	36.4	35.3	35.7	35.6	36.4	35.7	35.5	37.7	39.8	38.3
		-0.7	-0.1	0.3	-0.5	-3.7	-1.1	3.0	0.5	1.4	0.3	-0.5	1.1	-0.4	0.2	-0.8	0.7	0.2	-2.2	-2.1	1.5
P		1.1	1.7	0.0	0.0	2.2	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	4.8	0.0	2.0	20.4	0.0	0.0
		1.1	2.8	2.8	2.8	5.0	7.8	7.8	7.8	7.8	7.8	7.8	7.8	7.8	9.0	13.8	13.8	15.8	36.2	36.2	36.2
U		0.0	0.0	0.0	0.5	1.5	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.4	0.0	0.0	0.0	0.0	0.0	2.1	0.0
		0.0	0.0	0.0	0.5	2.0	2.0	2.0	2.0	2.0	2.0	2.5	2.5	2.9	2.9	2.9	2.9	2.9	2.9	5.0	5.0
D		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ET		0.4	1.6	0.3	0.0	0.0	1.7	3.0	0.5	1.4	0.3	0.0	1.1	0.0	1.4	4.0	0.7	2.2	18.2	0.0	1.5
Avg ET/day		0.09	0.31	0.05	0.00	0.00	0.35	0.61	0.10	0.28	0.06	0.00	0.22	0.00	0.27	0.80	0.14	0.44	3.64	0.00	0.30
T		0.4	2.0	2.3	2.3	2.3	4.0	7.1	7.6	9.0	9.3	9.3	10.4	10.4	11.8	15.8	16.5	18.7	36.9	36.9	38.4

flow; D: drainage; cumulative drainage; E .

Table 3.18: Soil water balance of Rooibos at the Rogland study site for Day 106 to 206. The red block indicates the rootzone depth, green blocks indicates an increase soil water content (SWC) between the two measured dates. All values are in mm.

No. of days	106	111	116	121	126	131	136	141	146	151	156	161	166	171	176	181	186	191	196	201	206
Date / **Depth (mm)**	**2018/02/09**	**2018/02/14**	**2018/02/19**	**2018/02/24**	**2018/03/01**	**2018/03/06**	**2018/03/11**	**2018/03/16**	**2018/03/21**	**2018/03/26**	**2018/03/31**	**2018/04/05**	**2018/04/10**	**2018/04/15**	**2018/04/20**	**2018/04/25**	**2018/04/30**	**2018/05/05**	**2018/05/10**	**2018/05/15**	**2018/05/20**
0 – 100	6.4	8.6	7.5	4.8	3.7	3.3	3.3	3.1	6.2	4.7	3.5	3.1	5.1	5.5	5.0	5.4	5.7	6.2	4.6	4.3	5.5
100 - 200	3.2	4.0	4.7	4.4	3.9	3.6	3.4	3.2	4.3	3.8	3.6	3.4	3.3	3.4	3.3	3.2	3.4	4.0	3.9	3.7	3.9
200 - 300	1.8	3.0	2.8	2.6	3.8	3.4	3.1	3.1	3.0	2.9	4.5	3.9	4.8	4.6	5.0	5.4	5.5	5.5	4.3	3.9	3.8
300 - 600	26.3	31.1	32.4	30.7	30.4	29.2	27.7	27.2	26.7	26.2	27.9	30.2	30.7	31.7	30.9	29.9	28.1	24.6	20.7	25.5	22.9
600 - 1 000	75.6	78.5	79.7	77.2	90.1	89.3	88.1	87.7	86.9	86.6	87.7	90.1	89.7	90.1	89.7	88.9	88.1	88.0	87.4	86.6	86.6
Total SWC at rootdepth	37.7	46.7	47.4	42.4	41.7	39.5	37.6	36.6	40.2	37.6	39.5	40.7	44.0	45.2	44.2	43.9	42.7	40.3	33.5	37.5	36.1
	0.6	-9.0	-0.7	5.0	0.7	2.3	1.9	1.0	-3.6	2.6	-1.9	-1.1	-3.3	-1.2	1.0	0.3	1.2	2.4	6.8	-4.0	1.3
P	0.0	29.1	0.0	0.0	0.0	0.0	0.0	0.9	0.0	2.7	11.7	0.0	0.0	0.0	5.4	6.9	4.2	0.3	1.5	0.0	11.4
	36.2	65.3	65.3	65.3	65.3	65.3	65.3	66.2	66.2	68.9	80.6	80.6	80.6	80.6	86.0	92.9	97.1	97.4	98.9	98.9	110.3
U	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	3.6	0.0	0.0	1.1	3.3	1.2	0.0	0.0	0.0	0.0	0.0	4.0	0.0
	5.0	5.0	5.7	5.7	5.7	5.7	5.7	5.7	9.3	9.3	9.3	10.4	13.8	15.0	15.0	15.0	15.0	15.0	15.0	19.0	19.0
D	0.3	2.8	0.0	0.0	12.9	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	0.3	3.2	3.2	3.2	16.0	16.0	16.0	16.0	16.0	16.0	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2	17.2
ET	0.2	17.2	0.0	5.0	0.0	2.3	1.9	1.9	0.0	5.3	8.6	0.0	0.0	0.0	6.4	7.2	5.4	2.7	8.3	0.0	12.7
Avg ET/day	0.05	3.45	0.00	1.00	0.00	0.46	0.38	0.38	0.00	1.06	1.72	0.00	0.00	0.00	1.27	1.44	1.09	0.54	1.67	0.00	2.54
T	38.6	55.9	55.9	60.9	60.9	63.1	65.0	66.9	66.9	72.3	80.9	80.9	80.9	80.9	87.2	94.4	99.9	102.6	110.9	110.9	123.6

Total SWC:

: cumulative evapotranspiration.

Table 3.19: Soil water balance of Rooibos at the Rogland study site for Day 211 to 311. The red block indicates the rootzone depth, blue blocks indicates the presence of water table, green blocks indicates an increase soil water content (SWC) between the two measured dates. All values are in mm.

No. of days	211	216	221	226	231	236	241	246	251	256	261	266	271	276	281	286	291	296	301	306	311
Date / Depth (mm)	2018/05/25	2018/05/30	2018/06/04	2018/06/09	2018/06/14	2018/06/19	2018/06/24	2018/06/29	2018/07/04	2018/07/09	2018/07/14	2018/07/19	2018/07/24	2018/07/29	2018/08/03	2018/08/08	2018/08/13	2018/08/18	2018/08/23	2018/08/28	2018/09/02
0 – 100	9.0	15.3	12.5	8.8	22.4	17.0	12.2	16.6	16.5	10.9	6.4	5.5	5.4	5.3	5.2	6.8	6.4	8.2	8.3	12.3	7.5
100 – 200	5.1	6.4	6.5	5.9	8.3	8.6	7.9	8.0	9.9	9.5	9.1	8.6	6.6	6.3	6.4	9.8	8.8	11.0	9.7	12.1	10.6
200 – 300	8.7	10.7	9.5	8.7	14.4	12.1	12.3	12.7	15.6	15.8	15.5	14.9	14.0	13.3	12.9	14.3	13.5	14.0	13.3	15.6	14.8
300 – 600	24.4	40.0	43.3	39.1	53.3	50.6	60.2	72.3	138.5	131.5	132.6	130.0	126.1	118.5	117.7	117.4	118.1	124.4	122.9	130.6	123.9
600 - 1 000	86.6	85.7	89.8	90.6	111.8	222.4	223.2	222.4	224.4	227.3	222.4	227.3	221.5	212.2	205.8	205.3	200.6	197.7	189.6	187.8	184.9
Total SWC at rootdepth	47.3	72.4	71.8	62.4	98.5	88.4	92.6	109.5	180.5	167.7	163.6	159.0	152.1	143.3	142.3	148.3	146.8	157.6	154.3	170.5	156.8
	-11.2	-25.1	0.5	9.4	-36.1	10.1	-4.3	-16.9	-71.0	12.8	4.1	4.5	6.9	8.8	1.0	-6.1	1.5	-10.7	3.3	-16.2	13.7
P	6.0	28.5	6.0	0.3	45	16.2	0.3	8.1	11.7	1.5	0.3	0.0	0.0	0.0	0.0	17.0	0.0	15.0	0.0	22.0	36.0
	116.3	144.8	150.8	151.1	196.1	212.3	212.6	220.7	232.4	233.9	234.2	234.2	234.2	234.2	234.2	251.2	251.2	266.2	266.2	288.2	324.2
U	5.2	0.0	0.0	0.0	0.0	0.0	4.0	8.8	59.3	0.0	0.0	4.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	24.2	24.2	24.2	24.2	24.2	24.2	28.1	36.9	96.2	96.2	96.2	100.7	100.7	100.7	100.7	100.7	100.7	100.7	100.7	100.7	100.7
D	0.0	0.0	4.1	0.9	21.2	110.6	0.0	0.0	0.0	2.9	0.0	4.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	17.2	17.2	21.3	22.1	43.3	153.9	153.9	153.9	153.9	156.8	156.8	161.7	161.7	161.7	161.7	161.7	161.7	161.7	161.7	161.7	161.7
ET	0.0	3.4	2.5	8.9	0.0	0.0	0.0	0.0	0.0	11.4	0.0	4.1	6.9	8.8	1.0	10.9	1.5	4.3	3.3	5.8	49.7
Avg ET/day	0.00	0.69	0.49	1.77	0.00	0.00	0.00	0.00	0.00	2.29	0.00	0.82	1.38	1.76	0.21	2.19	0.30	0.86	0.65	1.16	9.94
T	123.6	127.1	129.5	138.4	138.4	138.4	138.4	138.4	138.4	149.8	149.8	153.9	160.9	169.7	170.7	181.6	183.1	187.4	190.7	196.5	246.2

flow; E .

Table 3.20: Soil water balance of Rooibos at the Rogland study site for Day 316 to 416. The red block indicates the rootzone depth, blue blocks indicates the presence of water table, green blocks indicates an increase soil water content (SWC) between the two measured dates. All values are in mm.

No. of days	316	321	326	331	336	341	346	351	356	361	366	371	376	381	386	391	396	401	406	411	416
Date / **Depth (mm)**	**2018/09/07**	**2018/09/12**	**2018/09/17**	**2018/09/22**	**2018/09/27**	**2018/10/02**	**2018/10/07**	**2018/10/12**	**2018/10/17**	**2018/10/22**	**2018/10/27**	**2018/11/01**	**2018/11/06**	**2018/11/11**	**2018/11/16**	**2018/11/21**	**2018/11/26**	**2018/12/01**	**2018/12/06**	**2018/12/11**	**2018/12/16**
0 – 100	16.9	12.3	6.9	11.3	6.6	6.2	5.5	5.4	5.3	5.2	4.9	4.8	5.1	4.9	4.0	3.7	3.5	4.3	3.6	4.1	3.8
100 – 200	15.7	13.8	12.7	14.0	12.9	12.0	7.3	4.9	4.5	4.3	3.9	3.6	3.6	3.9	3.7	3.6	3.4	3.2	3.4	3.6	3.6
200 – 300	20.6	19.4	18.3	19.3	17.9	17.5	16.4	14.8	12.9	10.9	7.7	7.2	8.2	5.0	4.1	4.1	3.9	3.7	3.6	3.7	3.6
300 – 600	126.8	131.9	129.6	133.1	130.4	150.6	132.6	131.1	123.9	105.5	79.5	69.3	64.7	65.4	57.2	57.8	53.5	47.2	42.0	41.7	33.7
600 - 1 000	190.2	202.9	187.0	186.7	185.5	183.8	182.0	184.4	197.7	201.8	220.3	217.1	200.6	173.6	174.8	165.2	156.8	151.0	145.8	135.6	116.8
Total SWC at rootdepth	180.1	177.3	167.5	177.7	167.9	186.3	161.9	156.2	146.6	125.8	96.0	84.9	81.5	79.2	69.1	69.2	64.3	58.4	52.6	53.0	44.6
	-23.3	2.8	9.8	-10.2	9.8	-18.4	24.4	5.6	9.6	20.8	29.8	11.1	3.4	2.3	10.1	-0.2	4.9	5.9	5.8	-0.4	8.4
P	17.5	2.0	0.0	7.5	0.0	2.7	0.0	0.0	0.0	0.0	0.0	0.0	6.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	341.7	343.7	343.7	351.2	351.2	353.9	353.9	353.9	353.9	353.9	353.9	353.9	360.2	360.2	360.2	360.2	360.2	360.2	360.2	360.2	360.2
U	5.8	0.0	0.0	2.7	0.0	15.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.4	0.0
	106.5	106.5	106.5	109.2	109.2	124.9	124.9	124.9	124.9	124.9	124.9	124.9	124.9	124.9	124.9	125.0	125.0	125.0	125.0	125.4	125.4
D	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3	0.0	4.1	18.6	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0
	161.7	161.7	161.7	161.7	161.7	161.7	161.7	164.0	164.0	168.1	186.6	186.6	186.6	186.6	187.8	187.8	187.8	187.8	187.8	187.8	187.8
ET	0.0	4.8	9.8	0.0	9.8	0.0	24.4	3.3	9.6	16.7	0.0	11.1	9.7	2.3	9.0	0.0	4.9	5.9	5.8	0.0	8.4
Avg ET/day	0.00	0.96	1.95	0.00	1.97	0.00	4.88	0.66	1.92	3.35	0.00	2.21	1.93	0.47	1.80	0.00	0.98	1.19	1.15	0.00	1.67
T	246.2	251.0	260.8	260.8	270.6	270.6	295.0	298.3	307.9	324.7	324.7	335.7	345.4	347.7	356.7	356.7	361.6	367.5	373.3	373.3	381.7

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Table 3.21: Soil water balance of Rooibos at the Rogland study site for Day 421 to 486. The red block indicates the rootzone depth, green blocks indicates an increase soil water content (SWC) between the two measured dates. All values are in mm.

No. of days	421	426	431	436	441	446	451	456	461	466	471	476	481	486
Date / **Depth (mm)**	**2018/12/21**	**2018/12/26**	**2018/12/31**	**2019/01/05**	**2019/01/10**	**2019/01/15**	**2019/01/20**	**2019/01/25**	**2019/01/30**	**2019/02/04**	**2019/02/09**	**2019/02/14**	**2019/02/19**	**2019/02/24**
0 – 100	3.2	3.2	4.0	3.1	3.5	5.1	4.5	3.1	2.9	2.9	2.9	2.9	2.8	2.7
100 – 200	3.6	3.5	3.6	3.5	3.2	3.5	3.5	3.4	3.4	3.2	3.3	3.3	3.2	3.2
200 – 300	3.5	3.5	4.1	3.6	3.4	6.7	4.0	3.5	3.5	3.5	3.5	3.5	3.4	3.5
300 – 600	30.0	28.6	29.0	28.3	27.7	28.5	29.0	28.5	28.5	29.0	29.8	30.5	28.8	28.4
600 - 1 000	111.2	110.1	108.9	107.5	106.3	105.7	105.4	103.1	102.2	102.0	102.0	101.7	101.7	101.7
Total SWC at rootdepth	40.3	38.8	40.7	38.4	37.8	43.9	41.1	38.5	38.2	38.5	39.5	40.2	38.2	37.8
	4.4	1.4	-1.9	2.3	0.6	-6.0	2.8	2.6	0.3	-0.3	-1.0	-0.6	1.9	0.4
P	5.7	0.0	2.4	0.0	0.0	4.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	365.9	365.9	368.3	368.3	368.3	372.8	372.8	372.8	372.8	372.8	372.8	372.8	372.8	372.8
U	0.0	0.0	0.0	0.0	0.0	1.5	0.0	0.0	0.0	0.3	1.0	0.6	0.0	0.0
	125.4	125.4	125.4	125.4	125.4	126.9	126.9	126.9	126.9	127.2	128.2	128.8	128.8	128.8
D	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	187.8	187.8	187.8	187.8	187.8	187.8	187.8	187.8	187.8	187.8	187.8	187.8	187.8	187.8
ET	10.1	1.4	0.5	2.3	0.6	0.0	2.8	2.6	0.3	0.0	0.0	0.0	1.9	0.4
Avg ET/day	2.01	0.29	0.10	0.46	0.12	0.00	0.56	0.51	0.05	0.00	0.00	0.00	0.38	0.09
	391.7	393.2	393.7	395.9	396.5	396.5	399.3	401.9	402.2	402.2	402.2	402.2	404.1	404.5

: cumulative upward capillary flow;

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Table 3.22: Soil water balance of Rooibos at the Meulsteenvlei study site for Day 1 to 101. The red block indicates the rootzone depth, green blocks indicates an increase soil water content (SWC) between the two measured dates. All values are in mm.

No. of days	1	6	11	16	21	26	31	36	41	46	51	56	61	66	71	76	81	86	91	96	101
Date / **Depth (mm)**	**2017/10/27**	**2017/11/01**	**2017/11/06**	**2017/11/11**	**2017/11/16**	**2017/11/21**	**2017/11/26**	**2017/12/01**	**2017/12/06**	**2017/12/11**	**2017/12/16**	**2017/12/21**	**2017/12/26**	**2017/12/31**	**2018/01/05**	**2018/01/10**	**2018/01/15**	**2018/01/20**	**2018/01/25**	**2018/01/30**	**2018/02/04**
0 – 100	2.4	10.3	4.1	2.4	3.0	17.9	5.5	2.7	2.5	2.3	2.4	2.6	2.3	2.4	2.6	6.7	3.0	2.7	10.8	4.1	2.6
100 – 200	7.7	8.7	8.7	8.1	7.6	11.2	10.8	8.3	7.8	7.1	6.9	6.9	6.5	6.4	7.8	12.0	8.6	7.4	14.9	10.4	8.3
200 – 300	22.9	23.8	24.3	23.2	23.3	14.0	16.3	15.1	14.4	13.9	12.9	12.9	12.6	12.9	13.1	13.6	14.0	14.4	16.8	16.3	15.8
300 – 600	13.5	13.8	13.8	15.1	14.9	15.1	15.2	15.4	15.4	15.4	16.1	16.1	17.2	17.2	17.4	18.1	19.7	19.7	19.3	20.1	19.7
600 - 1 000	49.2	49.2	48.7	48.7	47.8	47.5	47.0	47.5	47.5	47.5	47.0	47.3	47.8	48.3	47.0	47.0	46.8	47.5	46.8	47.0	46.8
Total SWC at rootdepth	46.5	56.6	50.9	48.8	48.9	58.1	47.8	41.5	40.2	38.7	38.3	38.5	38.7	38.9	40.9	50.4	45.2	44.3	61.8	50.9	46.3
		-10.2	5.7	2.1	-0.1	-9.3	10.3	6.3	1.3	1.5	0.4	-0.2	-0.1	-0.2	-2.1	-9.5	5.2	1.0	-17.5	10.9	4.5
P		23.1	1.2	0.0	2.8	6.4	0.4	0.0	0.4	0.0	0.0	0.0	0.0	0.0	2.2	3.2	0.0	0.0	19.8	0.0	0.0
		23.1	24.3	24.3	27.1	33.5	33.9	33.9	34.3	34.3	34.3	34.3	34.3	34.3	36.5	39.7	39.7	39.7	59.5	59.5	59.5
U		0.0	0.0	0.0	0.0	2.9	0.0	0.0	0.0	0.0	0.0	0.2	0.1	0.2	0.0	6.3	0.0	0.0	0.0	0.0	0.0
		0.0	0.0	0.0	0.0	2.9	2.9	2.9	2.9	2.9	2.9	3.1	3.2	3.4	3.4	9.7	9.7	9.7	9.7	9.7	9.7
D		0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.2	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1.2	1.2	1.4	1.4
ET		12.9	6.9	2.1	2.7	0.0	10.7	5.8	1.7	1.5	0.4	0.0	0.0	0.0	0.1	0.0	5.2	0.3	2.3	10.7	4.5
Avg ET/day		2.59	1.38	0.43	0.54	0.00	2.14	1.17	0.34	0.29	0.08	0.00	0.00	0.00	0.03	0.00	1.04	0.05	0.45	2.14	0.90
		12.9	19.8	22.0	24.7	24.7	35.4	41.2	42.9	44.4	44.8	44.8	44.8	44.8	44.9	44.9	50.1	50.4	52.6	63.3	67.8

Table 3.23: Soil water balance of Rooibos at the Meulsteenvlei study site for Day 106 to 206. The red block indicates the rootzone depth, green blocks indicates an increase soil water content (SWC) between the two measured dates. All values are in mm.

No. of days	106	111	116	121	126	131	136	141	146	151	156	161	166	171	176	181	186	191	196	201	206
Date / **Depth (mm)**	**2018/02/09**	**2018/02/14**	**2018/02/19**	**2018/02/24**	**2018/03/01**	**2018/03/06**	**2018/03/11**	**2018/03/16**	**2018/03/21**	**2018/03/26**	**2018/03/31**	**2018/04/05**	**2018/04/10**	**2018/04/15**	**2018/04/20**	**2018/04/25**	**2018/04/30**	**2018/05/05**	**2018/05/10**	**2018/05/15**	**2018/05/20**
0 – 100	2.5	9.1	3.0	13.4	2.8	2.4	2.4	2.5	2.2	7.1	10.2	3.1	3.0	2.9	4.0	3.6	5.0	5.0	4.9	4.8	14.7
100 – 200	7.4	11.8	8.2	7.8	8.0	7.4	7.1	7.0	6.8	9.3	14.1	8.0	7.9	7.9	8.8	7.4	8.6	8.6	8.9	8.6	18.5
200 – 300	15.3	15.4	15.2	14.7	14.9	14.5	13.9	13.7	13.3	12.9	17.0	14.6	14.0	13.9	14.7	14.0	16.9	16.9	16.5	16.3	20.6
300 – 600	20.1	20.4	19.0	19.2	19.0	19.0	19.3	19.7	19.5	19.2	20.1	20.2	19.9	19.6	19.3	19.3	20.4	20.2	20.2	20.2	40.4
600 - 1 000	46.8	46.6	46.3	46.3	45.8	45.6	45.4	45.1	45.1	44.9	44.9	44.9	44.0	44.9	44.9	44.9	44.9	44.4	44.4	44.4	54.8
Total SWC at rootdepth	45.2	56.7	45.3	55.1	44.7	43.3	42.7	42.9	41.9	48.4	61.3	45.9	44.8	44.3	46.7	44.3	50.9	50.7	50.5	49.9	94.3
	1.1	-11.4	11.3	-9.7	10.4	1.3	0.6	-0.2	1.0	-6.5	-12.9	15.4	1.1	0.5	-2.4	2.4	-6.7	0.3	0.2	0.6	-44.4
P	0.0	14.2	0.2	3.4	0.0	0.0	0.0	0.4	0.2	1.8	22.6	0.0	0.2	0.0	7.0	5.8	9.8	0.2	2.0	0.0	32.0
	59.5	73.7	73.9	77.3	77.3	77.3	77.3	77.7	77.9	79.7	102.3	102.3	102.5	102.5	109.5	115.3	125.1	125.3	127.3	127.3	159.3
U	0.0	0.0	0.0	6.3	0.0	0.0	0.0	0.0	0.0	4.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.4
	9.7	9.7	9.7	16.0	16.0	16.0	16.0	16.0	16.0	20.8	20.8	20.8	20.8	20.8	20.8	20.8	20.8	20.8	20.8	20.8	33.1
D	0.0	0.2	0.2	0.0	0.5	0.2	0.2	0.2	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0
	1.4	1.7	3.1	3.1	3.6	3.8	4.0	4.2	4.2	4.4	4.4	4.4	5.3	5.3	5.3	5.3	5.3	5.8	5.8	5.8	5.8
ET	1.1	2.5	11.3	0.0	9.9	1.1	0.4	0.0	1.2	0.0	9.7	15.4	0.4	0.5	4.6	8.2	3.1	0.0	2.2	0.6	0.0
Avg ET/day	0.22	0.50	2.26	0.00	1.99	0.22	0.07	0.00	0.24	0.00	1.93	3.08	0.09	0.10	0.92	1.64	0.63	0.00	0.43	0.13	0.00
T	68.9	71.5	82.8	82.8	92.7	93.8	94.2	94.1	95.4	95.4	105.0	120.4	120.9	121.4	126.0	134.2	137.4	137.3	139.5	140.1	140.1

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Table 3.24: Soil water balance of Rooibos at the Meulsteenvlei study site for Day 211 to 311. The red block indicates the rootzone depth, green blocks indicates an increase soil water content (SWC) between the two measured dates. All values are in mm.

No. of days	211	216	221	226	231	236	241	246	251	256	261	266	271	276	281	286	291	296	301	306	311
Date / **Depth (mm)**	**2018/05/25**	**2018/05/30**	**2018/06/04**	**2018/06/09**	**2018/06/14**	**2018/06/19**	**2018/06/24**	**2018/06/29**	**2018/07/04**	**2018/07/09**	**2018/07/14**	**2018/07/19**	**2018/07/24**	**2018/07/29**	**2018/08/03**	**2018/08/08**	**2018/08/13**	**2018/08/18**	**2018/08/23**	**2018/08/28**	**2018/09/02**
0 - 100	6.8	13.0	13.6	4.9	4.6	18.6	12.0	9.5	15.6	9.2	5.6	5.2	5.0	5.2	5.0	15.0	8.8	14.5	13.2	14.5	8.0
100 - 200	14.8	16.5	16.3	8.6	8.4	22.6	16.3	14.0	19.5	14.3	9.4	8.6	8.3	8.3	8.1	19.5	14.0	18.7	17.4	19.0	13.8
200 - 300	18.4	19.8	19.8	17.2	15.8	22.1	19.6	18.9	20.8	19.3	17.8	15.5	14.5	14.2	14.0	20.4	18.7	19.1	19.2	20.8	19.4
300 - 600	40.4	40.9	40.5	38.7	36.8	45.3	42.5	40.9	47.3	43.5	41.6	38.9	34.5	31.3	29.3	27.3	31.1	31.3	30.7	44.2	41.8
600 - 1 000	54.4	65.1	69.7	72.1	70.9	76.7	76.2	75.5	80.3	76.5	73.8	71.4	66.3	61.5	57.4	54.5	53.6	52.8	51.9	51.6	63.2
Total SWC at rootdepth	80.4	90.2	90.2	69.4	65.6	108.6	90.4	83.3	103.2	86.3	74.4	68.2	62.2	58.9	56.4	82.3	72.6	83.5	80.5	98.6	83.0
	13.9	-9.8	0.0	20.8	3.8	-43.0	18.2	7.1	-19.9	16.8	12.0	6.2	6.0	3.3	2.5	-25.9	9.7	-11.0	3.0	-18.1	15.6
P	0.4	35.2	8.8	0.2	25.2	44.8	0.2	1.6	59.4	0.0	0.8	0.0	0.0	0.8	1.2	31.2	0.0	7.6	2.6	35.4	26.4
	159.7	194.9	203.7	203.9	229.1	273.9	274.1	275.7	335.1	335.1	335.9	335.9	335.9	336.7	337.9	369.1	369.1	376.7	379.3	414.7	441.1
U	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.4	0.0	0.0	0.0
	33.1	33.1	33.1	33.1	33.1	33.1	33.1	33.1	33.1	33.1	33.1	33.1	33.1	33.1	33.1	33.1	33.1	36.5	36.5	36.5	36.5
D	0.0	10.7	4.6	2.4	0.0	5.8	0.0	0.0	4.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.6
	5.8	16.5	21.1	23.5	23.5	29.3	29.3	29.3	34.1	34.1	34.1	34.1	34.1	34.1	34.1	34.1	34.1	34.1	34.1	34.1	45.7
ET	14.3	14.7	4.2	18.6	29.0	0.0	18.4	8.7	34.7	16.8	12.8	6.2	6.0	4.1	3.7	5.3	9.7	0.0	5.6	17.3	30.5
Avg ET/day	2.86	2.93	0.85	3.72	5.80	0.00	3.67	1.75	6.94	3.36	2.56	1.24	1.19	0.82	0.75	1.06	1.94	0.00	1.13	3.46	6.09
	154.4	169.1	173.3	191.9	220.9	220.9	239.3	248.0	282.7	299.5	312.3	318.5	324.4	328.5	332.3	337.6	347.3	347.3	352.9	370.2	400.7

Table 3.25: Soil water balance of Rooibos at the Meulsteenvlei study site for Day 316 to 416. The red block indicates the rootzone depth, green blocks indicates an increase soil water content (SWC) between the two measured dates. All values are in mm.

No. of days	316	321	326	331	336	341	346	351	356	361	366	371	376	381	386	391	396	401	406	411	416
Date / **Depth (mm)**	**2018/09/07**	**2018/09/12**	**2018/09/17**	**2018/09/22**	**2018/09/27**	**2018/10/02**	**2018/10/07**	**2018/10/12**	**2018/10/17**	**2018/10/22**	**2018/10/27**	**2018/11/01**	**2018/11/06**	**2018/11/11**	**2018/11/16**	**2018/11/21**	**2018/11/26**	**2018/12/01**	**2018/12/06**	**2018/12/11**	**2018/12/16**
0 - 100	15.5	10.4	5.5	9.6	6.3	5.5	4.6	4.2	4.0	4.0	3.9	4.9	8.2	7.1	5.3	5.4	5.2	4.7	4.5	4.1	4.0
100 - 200	19.9	15.8	9.6	15.5	10.4	10.1	10.4	10.4	10.5	10.9	10.9	12.1	14.2	13.9	13.0	12.9	13.0	13.7	14.3	14.4	14.2
200 - 300	21.4	20.0	18.4	19.4	17.8	16.0	14.5	14.1	13.9	13.9	13.8	13.5	13.5	13.8	13.8	13.6	13.5	13.6	13.7	13.6	13.4
300 - 600	46.9	43.7	41.4	39.6	37.7	35.0	29.1	23.6	21.5	20.9	20.9	21.1	21.3	21.3	21.1	21.1	21.1	21.3	21.1	20.4	22.8
600 - 1 000	75.3	74.5	73.1	70.9	66.3	61.0	56.7	53.8	49.9	46.3	45.1	46.1	45.1	44.9	45.1	44.9	45.6	44.9	44.2	43.7	43.9
Total SWC at rootdepth	103.7	89.9	74.9	84.2	72.2	66.5	58.6	52.4	49.9	49.8	49.6	51.6	57.2	56.1	53.2	53.0	52.9	53.3	53.5	52.5	54.4
	-20.7	13.8	15.1	-9.3	12.0	5.6	7.9	6.3	2.5	0.1	0.2	-2.0	-5.6	1.1	2.9	0.2	0.1	-0.5	-0.2	1.0	-1.9
P	6.0	0.4	0.8	8.6	0.6	3.4	0.0	0.2	0.4	0.0	0.0	3.6	6.8	0.0	0.2	1.0	0.2	0.4	0.4	4.6	1.2
	447.1	447.5	448.3	456.9	457.5	460.9	460.9	461.1	461.5	461.5	461.5	465.1	471.9	471.9	472.1	473.1	473.3	473.7	474.1	478.7	479.9
U	14.7	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.7
	51.2	51.2	51.2	52.0	52.0	52.0	52.0	52.0	52.0	52.0	52.0	52.0	52.0	52.0	52.0	52.0	52.0	52.0	52.0	52.0	52.8
D	12.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.2	0.0	0.7	0.0	0.0	0.0	0.0
	57.7	57.7	57.7	57.7	57.7	57.7	57.7	57.7	57.7	57.7	57.7	58.7	58.7	58.7	58.9	58.9	59.6	59.6	59.6	59.6	59.6
ET	0.0	14.2	15.9	0.0	12.6	9.0	7.9	6.5	2.9	0.1	0.2	0.6	1.2	1.1	2.8	1.2	0.0	0.0	0.2	5.6	0.0
Avg ET/day	0.00	2.84	3.17	0.00	2.53	1.81	1.58	1.29	0.57	0.03	0.04	0.13	0.23	0.23	0.57	0.25	0.00	0.00	0.04	1.12	0.00
	400.7	414.9	430.7	430.7	443.4	452.4	460.3	466.8	469.6	469.8	469.9	470.6	471.7	472.9	475.7	476.9	476.9	476.9	477.1	482.7	482.7

flow;

evapotranspiration.

Table 3.26: Soil water balance of Rooibos at the Meulsteenvlei study site for Day 421 to 486. The red block indicates the rootzone depth, green blocks indicates an increase soil water content (SWC) between the two measured dates. All values are in mm.

No. of days	421	426	431	436	441	446	451	456	461	466	471	476	481	486
Date / **Depth (mm)**	**2018/12/21**	**2018/12/26**	**2018/12/31**	**2019/01/05**	**2019/01/10**	**2019/01/15**	**2019/01/20**	**2019/01/25**	**2019/01/30**	**2019/02/04**	**2019/02/09**	**2019/02/14**	**2019/02/19**	**2019/02/24**
0 - 100	3.9	3.9	5.1	3.8	5.1	6.9	3.9	3.6	3.5	3.4	3.5	6.2	3.8	3.5
100 - 200	14.3	15.0	16.7	15.7	16.1	18.0	18.0	18.1	17.4	10.5	10.6	10.5	10.6	10.4
200 - 300	13.5	13.4	13.6	13.6	13.2	14.1	13.7	13.6	13.3	13.1	13.2	13.8	13.8	13.5
300 - 600	20.4	20.8	20.4	20.6	20.6	20.4	20.8	21.1	20.8	20.9	20.9	20.8	20.8	20.8
600 - 1 000	44.2	43.9	43.4	43.7	43.9	43.7	43.2	43.4	42.9	42.5	43.8	43.7	43.7	43.7
Total SWC at rootdepth	52.2	53.0	55.8	53.7	55.0	59.4	56.4	56.4	55.0	47.9	48.2	51.3	49.0	48.2
	2.2	-0.8	-2.8	2.1	-1.3	-4.4	3.0	0.0	1.4	7.1	-0.3	-3.1	2.3	0.8
P	0.2	0.0	2.6	0.2	0.0	8.4	0.0	0.0	0.0	0.0	4.0	0.0	0.0	0.0
	480.1	480.1	482.7	482.9	482.9	491.3	491.3	491.3	491.3	491.3	495.3	495.3	495.3	495.3
U	0.0	0.8	0.2	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0	3.1	0.0	0.0
	52.8	53.6	53.7	53.7	55.0	55.0	55.0	55.0	55.0	55.0	55.0	58.1	58.1	58.1
D	0.2	0.0	0.0	0.2	0.0	0.0	0.0	0.2	0.0	0.0	1.3	0.0	0.0	0.0
	59.9	59.9	59.9	60.1	60.1	60.1	60.1	60.4	60.4	60.4	61.7	61.7	61.7	61.7
ET	2.2	0.0	0.0	2.0	0.0	4.0	3.0	0.0	1.4	7.1	2.4	0.0	2.3	0.8
Avg ET/day	0.44	0.00	0.00	0.41	0.00	0.80	0.60	0.00	0.28	1.42	0.48	0.00	0.46	0.16
	484.9	484.9	484.9	487.0	487.0	491.0	494.0	494.0	495.4	502.5	504.9	504.9	507.2	508.0

: cumulative evapotranspiration.

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Table 3.27: Soil water balance of Rooibos at the Oorlogskloof study site for Day 1 to 101. The red block indicates the rootzone depth, green blocks indicates an increase soil water content (SWC) between the two measured dates. All values are in mm.

No. of days	1	6	11	16	21	26	31	36	41	46	51	56	61	66	71	76	81	86	91	96	101
Date / **Depth (mm)**	**2017/10/27**	**2017/11/01**	**2017/11/06**	**2017/11/11**	**2017/11/16**	**2017/11/21**	**2017/11/26**	**2017/12/01**	**2017/12/06**	**2017/12/11**	**2017/12/16**	**2017/12/21**	**2017/12/26**	**2017/12/31**	**2018/01/05**	**2018/01/10**	**2018/01/15**	**2018/01/20**	**2018/01/25**	**2018/01/30**	**2018/02/04**
0 - 100	4.8	4.3	3.9	3.1	2.8	3.5	6.1	3.5	2.9	2.2	1.9	1.9	1.7	1.7	2.5	2.3	1.8	1.8	7.4	6.1	4.6
100 - 200	1.6	1.8	2.0	2.0	1.8	2.1	2.4	2.3	2.3	2.8	2.9	3.1	3.0	3.0	3.5	3.4	3.2	3.2	4.1	5.7	5.2
200 - 300	3.1	3.2	3.4	3.5	3.2	3.5	3.6	3.7	3.7	5.0	5.0	5.0	4.9	4.9	5.2	5.2	5.2	5.2	5.1	5.4	5.5
300 - 600	16.4	16.8	17.2	17.2	17.0	17.3	17.5	17.7	17.7	17.7	18.6	19.8	19.6	19.8	21.8	21.8	21.8	21.8	21.4	22.0	22.0
600 - 1 000	37.5	38.1	38.4	38.4	38.1	38.1	38.1	38.1	38.1	38.1	37.8	37.5	37.2	37.2	37.0	36.7	36.7	36.4	36.1	36.4	36.1
Total SWC	25.9	26.1	26.5	25.8	24.8	26.4	29.6	27.2	26.6	27.7	28.4	29.8	29.2	29.4	33.0	32.7	32.0	32.0	38.0	39.2	37.3
		-0.2	-0.4	0.7	1.0	-1.6	-3.2	2.4	0.6	-1.1	-0.7	-1.4	0.6	-0.2	-3.6	0.3	0.7	0.0	-6.0	-1.2	1.9
P		1.1	1.7	0.0	2.2	0.0	15.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.5	1.5	0.0	2.0	18.6	0.0	0.0
		1.1	2.8	2.8	5.0	5.0	20.8	20.8	20.8	20.8	20.8	20.8	20.8	20.8	24.3	25.8	25.8	27.8	46.4	46.4	46.4
U		0.0	0.0	0.0	0.0	1.6	0.0	0.0	0.0	1.1	0.7	1.4	0.0	0.2	0.1	0.0	0.0	0.0	0.0	1.2	0.0
		0.0	0.0	0.0	0.0	1.6	1.6	1.6	1.6	2.7	3.4	4.8	4.8	5.0	5.1	5.1	5.1	5.1	5.1	6.3	6.3
D		0.6	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		0.6	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
ET		0.3	1.0	0.7	3.2	0.0	12.6	2.4	0.6	0.0	0.0	0.0	0.6	0.0	0.0	1.8	0.7	2.0	12.6	0.0	1.9
Avg ET/day		0.06	0.20	0.14	0.64	0.00	2.52	0.48	0.12	0.00	0.00	0.00	0.12	0.00	0.00	0.36	0.14	0.40	2.52	0.00	0.38
		0.3	1.3	2.0	5.2	5.2	17.8	20.2	20.8	20.8	20.8	20.8	21.4	21.4	21.4	23.2	23.9	25.9	38.5	38.5	40.4

:

evapotranspiration.

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Table 3.28: Soil water balance of Rooibos at the Oorlogskloof study site for Day 106 to 206. The red block indicates the rootzone depth, green blocks indicates an increase soil water content (SWC) between the two measured dates. All values are in mm.

No. of days	106	111	116	121	126	131	136	141	146	151	156	161	166	171	176	181	186	191	196	201	206
Date / **Depth (mm)**	**2018/02/09**	**2018/02/14**	**2018/02/19**	**2018/02/24**	**2018/03/01**	**2018/03/06**	**2018/03/11**	**2018/03/16**	**2018/03/21**	**2018/03/26**	**2018/03/31**	**2018/04/05**	**2018/04/10**	**2018/04/15**	**2018/04/20**	**2018/04/25**	**2018/04/30**	**2018/05/05**	**2018/05/10**	**2018/05/15**	**2018/05/20**
0 - 100	2.9	4.2	3.1	2.5	2.4	2.1	1.9	2.4	2.1	2.3	8.6	6.7	5.1	4.7	8.4	8.0	7.2	4.5	3.8	3.7	4.9
100 - 200	4.9	4.8	4.6	4.3	4.2	3.9	3.6	3.6	3.4	3.3	8.5	6.0	5.2	5.1	7.1	7.9	8.0	6.0	5.2	5.1	5.0
200 - 300	5.6	5.6	5.5	5.5	5.5	5.4	5.3	5.2	5.2	5.1	5.0	5.7	5.5	5.4	5.1	5.2	5.2	5.3	5.3	5.1	5.1
300 - 600	22.2	22.2	22.2	22.2	21.9	22.2	21.9	21.9	21.9	21.6	21.6	21.9	21.9	21.9	21.6	21.6	21.3	21.6	21.6	21.6	21.6
600 - 1 000	36.4	36.4	36.0	36.0	36.0	36.0	35.6	35.6	35.6	35.6	35.6	35.6	35.6	35.6	35.6	35.6	35.2	35.2	35.2	35.2	35.2
Total SWC	35.6	36.8	35.4	34.5	34.0	33.6	32.7	33.1	32.6	32.3	43.7	40.3	37.7	37.1	42.2	42.7	41.7	37.4	35.9	35.5	36.6
	1.7	-1.2	1.4	0.9	0.5	0.4	0.9	-0.4	0.5	0.3	-11.4	3.4	2.6	0.6	-5.1	-0.5	1.0	4.3	1.5	0.4	-1.1
P	0.0	16.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.0	0.0	6.0	0.0	12.0	0.0	9.0	0.0	0.0	0.0	0.0
	46.4	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	78.5	78.5	84.5	84.5	96.5	96.5	105.5	105.5	105.5	105.5	105.5
U	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	1.1
	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7	7.2	7.2	7.2	7.2	7.2	8.3
D	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
ET	1.4	14.9	1.4	0.9	0.5	0.4	0.9	0.0	0.5	0.3	4.6	3.4	8.6	0.6	6.9	0.0	10.0	4.3	1.5	0.4	0.0
Avg ET/day	0.28	2.98	0.28	0.18	0.10	0.08	0.18	0.00	0.10	0.06	0.92	0.68	1.72	0.12	1.38	0.00	2.00	0.86	0.30	0.08	0.00
	41.8	56.7	58.1	59.0	59.5	59.9	60.8	60.8	61.3	61.6	66.2	69.6	78.2	78.8	85.7	85.7	95.7	100.0	101.5	101.9	101.9

Total SWC: total soil water

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Table 3.29: Soil water balance of Rooibos at the Oorlogskloof study site for Day 211 to 311. The red block indicates the rootzone depth, green blocks indicates an increase soil water content (SWC) between the two measured dates. All values are in mm.

No. of days	211	216	221	226	231	236	241	246	251	256	261	266	271	276	281	286	291	296	301	306	311
Date / **Depth (mm)**	**2018/05/25**	**2018/05/30**	**2018/06/04**	**2018/06/09**	**2018/06/14**	**2018/06/19**	**2018/06/24**	**2018/06/29**	**2018/07/04**	**2018/07/09**	**2018/07/14**	**2018/07/19**	**2018/07/24**	**2018/07/29**	**2018/08/03**	**2018/08/08**	**2018/08/13**	**2018/08/18**	**2018/08/23**	**2018/08/28**	**2018/09/02**
0 - 100	9.9	12.5	11.8	7.3	5.9	13.2	10.5	9.0	12.5	9.6	7.2	5.9	5.1	4.9	4.8	7.9	7.3	6.8	6.5	10.3	8.6
100 - 200	9.4	11.1	11.1	8.8	6.4	13.2	11.2	10.0	13.8	11.2	8.4	6.4	5.5	5.3	5.3	5.8	6.1	5.8	5.8	9.0	8.2
200 - 300	11.0	16.6	16.3	14.7	13.5	17.8	16.0	14.9	17.4	15.7	14.2	12.5	8.1	6.4	6.1	6.0	6.1	6.1	6.1	7.1	9.1
300 - 600	22.5	32.7	37.2	37.6	37.6	46.3	43.7	43.5	52.4	49.6	48.0	45.9	40.9	35.5	32.0	29.6	29.6	29.4	29.0	30.1	36.6
600 - 1 000	35.6	36.4	61.9	66.0	65.1	79.0	79.3	77.6	89.8	84.8	80.2	75.6	69.2	63.4	60.8	58.4	57.9	55.8	53.8	52.6	53.8
Total SWC	52.8	72.9	76.5	68.4	63.4	90.5	81.3	77.4	96.1	86.1	77.7	70.8	59.6	52.2	48.3	49.2	49.1	48.0	47.4	56.5	62.5
	-16.2	-20.1	-3.6	8.1	5.1	-27.1	9.2	3.9	-18.7	10.0	8.4	6.9	11.2	7.4	3.9	-0.9	0.1	1.0	0.7	-9.2	-6.0
P	24.0	22.0	31.0	2.0	13.0	44.0	2.0	0.0	68.0	0.0	0.0	0.0	0.0	0.0	0.0	15.0	0.0	0.0	0.0	20.0	22.0
	129.5	151.5	182.5	184.5	197.5	241.5	243.5	243.5	311.5	311.5	311.5	311.5	311.5	311.5	311.5	326.5	326.5	326.5	326.5	346.5	368.5
U	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3	8.3
D	0.4	0.8	25.5	4.1	0.0	13.9	0.3	0.0	12.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2
	1.6	2.4	27.9	32.0	32.0	45.9	46.2	46.2	58.4	58.4	58.4	58.4	58.4	58.4	58.4	58.4	58.4	58.4	58.4	58.4	59.5
ET	7.4	1.1	1.9	6.0	18.1	3.0	10.9	3.9	37.1	10.0	8.4	6.9	11.2	7.4	3.9	14.1	0.1	1.0	0.7	10.8	14.9
Avg ET/day	1.48	0.22	0.37	1.20	3.61	0.60	2.18	0.79	7.42	2.00	1.68	1.38	2.24	1.48	0.78	2.81	0.03	0.21	0.13	2.17	2.97
	109.3	110.4	112.3	118.3	136.3	139.3	150.2	154.1	191.2	201.2	209.6	216.5	227.7	235.1	239.0	253.1	253.2	254.3	254.9	265.8	280.6

cumulative upward capillary flow;

evapotranspiration.

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Table 3.30: Soil water balance of Rooibos at the Oorlogskloof study site for Day 316 to 416. The red block indicates the rootzone depth, blue blocks indicates the presence of water table, green blocks indicates an increase soil water content (SWC) between the two measured dates. All values are in mm.

No. of days	316	321	326	331	336	341	346	351	356	361	366	371	376	381	386	391	396	401	406	411	416
Date / **Depth (mm)**	**2018/09/07**	**2018/09/12**	**2018/09/17**	**2018/09/22**	**2018/09/27**	**2018/10/02**	**2018/10/07**	**2018/10/12**	**2018/10/17**	**2018/10/22**	**2018/10/27**	**2018/11/01**	**2018/11/06**	**2018/11/11**	**2018/11/16**	**2018/11/21**	**2018/11/26**	**2018/12/01**	**2018/12/06**	**2018/12/11**	**2018/12/16**
0 - 100	12.3	9.5	7.0	7.6	6.2	5.1	3.3	3.1	3.4	2.1	1.8	3.4	3.8	3.4	3.8	4.2	4.2	4.3	4.2	3.9	3.8
100 - 200	12.4	10.1	7.4	7.4	6.4	5.7	5.5	5.2	5.1	4.8	4.5	4.5	4.6	4.5	4.5	4.7	4.7	4.8	4.9	4.8	4.8
200 - 300	13.1	12.9	12.1	11.7	10.3	8.4	6.6	6.2	5.9	5.9	5.6	5.4	5.2	5.6	5.5	5.5	5.5	5.5	5.5	5.5	5.5
300 - 600	47.2	47.0	45.4	45.2	43.3	40.0	32.4	27.2	25.9	25.5	25.1	24.8	24.4	24.6	24.4	24.0	24.0	24.0	24.0	24.0	24.0
600 - 1 000	116.5	123.3	73.8	72.4	68.9	62.8	52.6	46.8	44.5	43.1	42.2	41.6	41.3	40.2	39.9	39.9	39.3	39.3	39.3	39.6	38.4
Total SWC	85.0	79.5	71.9	71.9	66.2	59.2	47.7	41.7	40.2	38.4	37.0	38.0	38.0	38.0	38.3	38.4	38.5	38.7	38.7	38.3	38.2
	-22.5	5.5	7.7	0.0	5.7	7.0	11.4	6.1	1.5	1.9	1.3	-1.0	0.0	0.0	-0.3	-0.1	-0.1	-0.2	0.1	0.4	0.1
P	7.5	0.0	0.0	20.0	0.0	0.0	0.0	0.0	5.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0
	376.0	376.0	376.0	396.0	396.0	396.0	396.0	396.0	401.0	401.0	401.0	404.0	404.0	404.0	404.0	404.0	404.0	404.0	404.0	404.0	407.0
U	15.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.1	0.1	0.2	0.0	0.0	0.0
	23.3	23.3	23.3	23.3	23.3	23.3	23.3	23.3	23.3	23.3	23.3	23.3	23.3	23.3	23.6	23.7	23.8	24.0	24.0	24.0	24.0
D	0.0	6.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	59.5	66.3	66.3	66.3	66.3	66.3	66.3	66.3	66.3	66.3	66.3	66.3	66.3	66.3	66.3	66.3	66.3	66.3	66.3	66.3	66.3
ET	0.0	0.0	7.7	20.0	5.7	7.0	11.4	6.1	6.5	1.9	1.3	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4	3.1
Avg ET/day	0.00	0.00	1.53	4.00	1.15	1.40	2.28	1.21	1.29	0.38	0.27	0.41	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.07	0.62
	280.6	280.6	288.3	308.3	314.0	321.0	332.4	338.5	345.0	346.8	348.2	350.2	350.2	350.2	350.2	350.2	350.2	350.2	350.3	350.7	353.8

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Table 3.31: Soil water balance of Rooibos at the Oorlogskloof study site for Day 421 to 486. The red block indicates the rootzone depth, green blocks indicates an increase soil water content (SWC) between the two measured dates. All values are in mm.

No. of days	421	426	431	436	441	446	451	456	461	466	471	476	481	486
Date / **Depth (mm)**	**2018/12/21**	**2018/12/26**	**2018/12/31**	**2019/01/05**	**2019/01/10**	**2019/01/15**	**2019/01/20**	**2019/01/25**	**2019/01/30**	**2019/02/04**	**2019/02/09**	**2019/02/14**	**2019/02/19**	**2019/02/24**
0 - 100	3.9	4.0	3.8	3.6	3.7	4.5	3.5	3.3	3.4	3.2	3.2	3.1	3.3	3.0
100 - 200	4.9	4.9	4.8	4.7	4.7	4.7	4.7	4.5	4.3	4.2	4.1	4.1	4.2	3.9
200 - 300	5.6	5.6	5.6	5.6	5.5	5.4	5.5	5.5	5.6	5.5	5.7	5.6	5.5	5.5
300 - 600	23.8	23.8	23.6	23.5	23.3	22.9	23.1	23.1	23.1	22.9	23.1	23.1	22.7	22.5
600 - 1 000	38.1	37.8	37.5	37.5	37.2	37.0	37.2	37.2	37.3	37.2	37.5	37.2	37.0	37.0
Total SWC	38.2	38.3	37.9	37.4	37.2	37.5	36.9	36.5	36.4	35.8	36.1	35.9	35.7	34.9
	0.0	-0.1	0.4	0.5	0.2	0.0	0.6	0.4	0.1	0.6	-0.3	0.2	0.2	0.8
P	0.0	0.0	0.0	0.0	0.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	407.0	407.0	407	407.0	407.0	413.0	413.0	413.0	413.0	413.0	413.0	413.0	413.0	413.0
U	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0
	24.0	24.1	24.06	24.1	24.1	24.1	24.1	24.1	24.1	24.1	24.4	24.4	24.4	24.4
D	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.1	0.0	0.0	0.0	0.0	0.0
	66.3	66.3	66.3	66.3	66.3	66.3	66.6	66.6	66.7	66.7	66.7	66.7	66.7	66.7
ET	0.0	0.0	0.4	0.5	0.2	6.0	0.3	0.4	0.0	0.6	0.0	0.2	0.2	0.8
Avg ET/day	0.00	0.00	0.07	0.10	0.05	1.20	0.07	0.08	0.00	0.12	0.00	0.04	0.04	0.16
	353.8	353.8	354.2	354.6	354.9	360.9	361.2	361.6	361.6	362.2	362.2	362.4	362.6	363.4

E : cumulative evapotranspiration.

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Table 3.32: Soil water balance of Rooibos at the Klein Blomfontein study site for Day 1 to 101. The red block indicates the rootzone depth, green blocks indicates an increase soil water content (SWC) between the two measured dates. All values are in mm.

No. of days	1	6	11	16	21	26	31	36	41	46	51	56	61	66	71	76	81	86	91	96	101
Date / **Depth (mm)**	**2017/10/27**	**2017/11/01**	**2017/11/06**	**2017/11/11**	**2017/11/16**	**2017/11/21**	**2017/11/26**	**2017/12/01**	**2017/12/06**	**2017/12/11**	**2017/12/16**	**2017/12/21**	**2017/12/26**	**2017/12/31**	**2018/01/05**	**2018/01/10**	**2018/01/15**	**2018/01/20**	**2018/01/25**	**2018/01/30**	**2018/02/04**
0 - 100	1.5	1.5	1.6	1.4	5.4	4.4	7.4	3.7	3.3	3.1	3.1	3.2	3.0	3.0	3.1	3.6	3.1	3.2	5.4	6.1	4.3
100 - 200	3.7	3.8	3.8	3.8	3.7	4.9	5.5	5.9	5.7	5.8	5.4	5.2	5.0	5.0	5.0	4.9	4.9	4.9	4.7	5.5	5.9
200 - 300	5.2	5.5	5.5	5.6	5.4	5.9	6.4	6.9	7.1	7.3	7.1	6.8	6.5	6.5	6.4	6.2	6.2	6.4	6.2	6.5	6.9
300 - 400	11.9	12.2	12.0	12.1	12.7	12.6	13.4	13.4	13.5	13.6	13.7	13.7	13.4	13.6	13.6	13.4	13.5	13.7	13.4	13.8	13.8
400 - 500	28.2	28.3	27.7	27.7	27.2	27.9	27.8	29.0	28.7	28.1	27.7	27.5	26.9	26.8	26.7	26.3	26.2	26.1	25.9	26.0	25.9
Total SWC at the rootzone	22.3	23.1	23.0	22.9	27.1	27.8	32.8	30.0	29.7	29.8	29.2	28.8	27.9	28.1	28.1	28.1	27.7	28.1	29.7	32.0	30.9
		-0.8	0.1	0.1	-4.2	-0.7	-5.0	2.8	0.3	-0.2	0.6	0.4	0.9	-0.1	0.0	-0.1	0.5	-0.4	-1.7	-2.2	1.1
P		0.0	0.0	0.0	15.0	0.0	18.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	2.7	0.0	0.0	18.6	0.0	0.0
		0.0	0.0	0.0	15.0	15.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0	33.0	34.2	36.9	36.9	36.9	55.5	55.5	55.5
U		0.8	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.4	0.0	2.2	0.0
		0.8	0.8	0.8	0.8	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.6	1.6	1.6	1.6	2.0	2.0	4.3	4.3
D		0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		0.0	0.0	0.0	0.0	0.0	0.0	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
ET		0.0	0.1	0.1	10.8	0.0	13.0	1.6	0.3	0.0	0.6	0.4	0.9	0.0	1.2	2.6	0.5	0.0	16.9	0.0	1.1
Avg ET/day		0.00	0.03	0.02	2.16	0.00	2.60	0.32	0.06	0.00	0.12	0.08	0.19	0.00	0.24	0.53	0.09	0.00	3.39	0.00	0.22
		0.0	0.1	0.2	11.0	11.0	24.0	25.6	26.0	26.0	26.6	26.9	27.9	27.9	29.1	31.7	32.2	32.2	49.1	49.1	50.2

D: drai

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Table 3.33: Soil water balance of Rooibos at the Klein Blomfontein study site for Day 106 to 206. The red block indicates the rootzone depth, green blocks indicates an increase soil water content (SWC) between the two measured dates. All values are in mm.

No. of days	106	111	116	121	126	131	136	141	146	151	156	161	166	171	176	181	186	191	196	201	206
Date / **Depth (mm)**	2018/02/09	2018/02/14	2018/02/19	2018/02/24	2018/03/01	2018/03/06	2018/03/11	2018/03/16	2018/03/21	2018/03/26	2018/03/31	2018/04/05	2018/04/10	2018/04/15	2018/04/20	2018/04/25	2018/04/30	2018/05/05	2018/05/10	2018/05/15	2018/05/20
0 - 100	3.7	5.7	6.9	5.75	6.87	5.82	5.22	4.95	4.62	4.41	6.01	7.26	6.93	7.32	6.87	7.13	7.32	7.06	6.54	6.48	6.80
100 - 200	5.8	5.9	8.4	8.30	8.30	8.10	7.59	7.28	7.07	6.71	6.60	7.64	7.69	7.84	7.74	7.84	8.15	8.15	7.69	7.28	10.50
200 - 300	7.2	7.2	8.8	8.77	9.00	8.83	8.32	7.97	7.69	7.28	7.11	8.03	8.09	8.26	8.09	8.15	8.66	8.77	8.32	7.74	7.63
300 - 400	14.1	14.1	14.1	14.02	13.95	13.95	13.80	13.80	13.73	13.66	13.51	13.66	13.51	13.58	13.44	13.44	13.36	13.51	13.44	13.44	15.26
400 - 500	26.0	25.7	25.9	25.85	25.76	25.85	25.67	25.67	25.57	25.48	25.29	25.48	25.29	25.29	25.20	25.11	25.20	25.39	25.29	25.29	26.41
Total SWC at the rootzone	30.7	32.9	38.1	36.8	38.1	36.7	34.9	34.0	33.1	32.1	33.2	36.6	36.2	37.0	36.1	36.6	37.5	37.5	36.0	34.9	40.2
	0.2	-2.2	-5.3	1.3	-1.3	1.4	1.8	0.9	0.9	1.0	-1.2	-3.3	0.4	-0.8	0.9	-0.4	-0.9	0.0	1.5	1.1	-5.3
P	0.0	29.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	15.0	0.0	9.3	5.4	2.7	4.2	3.3	0.0	1.8	0.0	30.3
	55.5	84.6	84.6	84.6	84.6	84.6	84.6	84.6	84.6	86.4	101.4	101.4	110.7	116.1	118.8	123.0	126.3	126.3	128.1	128.1	158.4
U	0.0	0.0	5.3	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	4.3	4.3	9.6	9.6	10.8	10.8	10.8	10.8	10.8	10.8	10.8	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2	14.2
D	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	1.1
	1.3	1.3	1.3	1.3	1.3	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.5	1.5	1.5	1.5	2.6
ET	0.1	26.9	0.0	1.3	0.0	1.3	1.8	0.9	0.9	2.8	13.8	0.0	9.7	4.6	3.6	3.8	2.3	0.0	3.3	1.1	23.9
Avg ET/day	0.02	5.39	0.00	0.26	0.00	0.27	0.35	0.18	0.18	0.57	2.76	0.00	1.93	0.92	0.72	0.76	0.45	0.00	0.66	0.21	4.78
	50.3	77.2	77.2	78.5	78.5	79.8	81.6	82.5	83.4	86.3	100.1	100.1	109.7	114.4	117.9	121.7	124.0	124.0	127.3	128.3	152.3

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Table 3.34: Soil water balance of Rooibos at the Klein Blomfontein study site for Day 211 to 311. The red block indicates the rootzone depth, blue blocks indicates the presence of water table, green blocks indicates an increase soil water content (SWC) between the two measured dates. All values are in mm.

No. of days	211	216	221	226	231	236	241	246	251	256	261	266	271	276	281	286	291	296	301	306	311
Date / Depth (mm)	**2018/05/25**	**2018/05/30**	**2018/06/04**	**2018/06/09**	**2018/06/14**	**2018/06/19**	**2018/06/24**	**2018/06/29**	**2018/07/04**	**2018/07/09**	**2018/07/14**	**2018/07/19**	**2018/07/24**	**2018/07/29**	**2018/08/03**	**2018/08/08**	**2018/08/13**	**2018/08/18**	**2018/08/23**	**2018/08/28**	**2018/09/02**
0 - 100	8.17	8.81	9.76	8.17	7.78	10.94	9.57	8.61	12.24	10.32	8.81	8.10	7.45	7.06	6.87	7.91	8.23	7.65	7.97	10.01	8.61
100 - 200	12.82	14.90	15.85	15.49	14.03	16.11	15.85	15.44	16.51	16.29	15.80	14.12	9.36	8.05	7.74	9.81	11.38	10.70	10.16	12.39	12.10
200 - 300	14.00	15.90	15.39	14.10	13.31	16.56	15.08	14.15	18.04	16.35	14.98	13.58	11.27	9.11	8.32	13.10	12.57	11.71	11.05	14.57	13.15
300 - 400	19.69	24.49	23.40	21.37	20.28	26.53	23.55	22.09	33.30	27.62	24.57	21.73	17.66	14.82	14.24	19.11	18.60	17.29	16.13	23.48	20.49
400 - 500	33.78	48.62	40.13	34.25	33.13	50.77	36.58	34.16	80.73	45.45	39.29	35.37	32.10	29.86	28.28	31.45	30.33	28.74	27.81	37.14	30.98
Total SWC at the rootzone	54.7	64.1	64.4	59.1	55.4	70.1	64.0	60.3	80.1	70.6	64.2	57.5	45.7	39.0	37.2	49.9	50.8	47.3	45.3	60.4	54.4
	-14.5	-9.4	-0.3	5.3	3.7	-14.8	6.1	3.7	-19.8	9.5	6.4	6.6	11.8	6.7	1.9	-12.8	-0.8	3.4	2.0	-15.1	6.1
P	2.7	23.7	5.4	0.6	9.9	16.8	1.2	1.5	50.1	0.0	0.9	0.0	0.0	0.0	8.0	20.0	0.0	3.0	5.0	18.0	8.0
	161.1	184.8	190.2	190.8	200.7	217.5	218.7	220.2	270.3	270.3	271.2	271.2	271.2	271.2	279.2	299.2	299.2	302.2	307.2	325.2	333.2
U	11.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0
	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.0	26.8	26.8	26.8	26.8	26.8
D	0.0	14.8	0.0	0.0	0.0	17.6	0.0	0.0	46.6	0.0	0.0	0.0	0.0	0.0	0.0	3.2	0.0	0.0	0.0	9.3	0.0
	2.6	17.5	17.5	17.5	17.5	35.1	35.1	35.1	81.7	81.7	81.7	81.7	81.7	81.7	81.7	84.8	84.8	84.8	84.8	94.2	94.2
ET	0.0	0.0	5.1	5.9	13.6	0.0	7.3	5.2	0.0	9.5	7.3	6.6	11.8	6.7	9.9	4.1	0.0	6.4	7.0	0.0	14.1
Avg ET/day	0.00	0.00	1.02	1.18	2.72	0.00	1.46	1.05	0.00	1.90	1.47	1.33	2.36	1.34	1.98	0.81	0.00	1.29	1.41	0.00	2.82
	152.3	152.3	157.4	163.2	176.9	176.9	184.2	189.4	189.4	198.9	206.2	212.9	224.6	231.4	241.2	245.3	245.3	251.7	258.8	258.8	272.8

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Table 3.35: Soil water balance of Rooibos at the Klein Blomfontein study site for Day 316 to 416. The red block indicates the rootzone depth, blue blocks indicates the presence of water table, green blocks indicates an increase soil water content (SWC) between the two measured dates. All values are in mm.

No. of days	316	321	326	331	336	341	346	351	356	361	366	371	376	381	386	391	396	401	406	411	416
Date / **Depth (mm)**	2018/09/07	2018/09/12	2018/09/17	2018/09/22	2018/09/27	2018/10/02	2018/10/07	2018/10/12	2018/10/17	2018/10/22	2018/10/27	2018/11/01	2018/11/06	2018/11/11	2018/11/16	2018/11/21	2018/11/26	2018/12/01	2018/12/06	2018/12/11	2018/12/16
0 - 100	13.09	10.94	8.68	10.20	8.17	7.26	6.34	5.08	4.75	4.55	4.28	3.94	3.74	4.75	4.14	3.94	3.87	3.81	3.81	5.02	4.35
100 - 200	13.47	13.47	12.20	12.72	10.99	8.05	7.12	6.60	6.29	6.23	6.13	5.60	5.39	5.92	5.97	5.76	5.76	5.55	5.44	5.55	5.76
200 - 300	16.10	14.93	13.31	13.84	12.14	9.05	7.40	6.82	6.59	6.65	6.53	6.12	5.94	6.29	6.24	6.18	6.41	6.53	6.70	6.82	7.05
300 - 400	26.90	23.91	20.86	20.20	17.80	14.96	14.38	14.02	13.95	14.02	14.02	13.80	13.73	14.02	14.09	14.02	14.09	14.09	14.09	14.09	14.16
400 - 500	55.62	36.68	31.54	29.96	28.46	24.64	21.75	21.19	21.19	21.09	20.81	20.63	20.72	21.37	21.65	21.75	21.93	21.93	21.93	21.93	22.12
Total SWC at the rootzone	69.6	63.3	55.0	57.0	49.1	39.3	35.2	32.5	31.6	31.4	31.0	29.5	28.8	31.0	30.4	29.9	30.1	30.0	30.0	31.5	31.3
	-15.2	6.3	8.2	-1.9	7.9	9.8	4.1	2.7	1.0	0.1	0.5	1.5	0.7	-2.2	0.5	0.5	-0.2	0.2	-0.1	-1.4	0.2
P	20.0	0.0	0.3	12.0	1.2	2.1	0.0	0.0	0.3	0.0	0.0	3.3	6.3	0.0	0.0	0.0	0.0	0.0	0.0	5.7	0.0
	353.2	353.2	353.5	365.5	366.7	368.8	368.8	368.8	369.1	369.1	369.1	372.4	378.7	378.7	378.7	378.7	378.7	378.7	378.7	384.4	384.4
U	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	0.0	0.0	0.2	0.0	0.1	0.0	0.2
	26.8	26.8	26.8	26.8	26.8	26.8	26.8	26.8	26.8	26.8	26.8	26.8	26.8	29.0	29.0	29.0	29.2	29.2	29.3	29.3	29.5
D	24.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.3	0.1	0.0	0.0	0.0	0.0	0.0
	118.8	118.8	118.8	118.8	118.8	118.8	118.8	118.8	118.8	118.8	118.8	118.8	118.9	118.9	119.2	119.3	119.3	119.3	119.3	119.3	119.3
ET	0.0	6.3	8.5	10.1	9.1	11.9	4.1	2.7	1.3	0.1	0.5	4.8	6.9	0.0	0.3	0.5	0.0	0.2	0.0	4.3	0.4
Avg ET/day	0.00	1.26	1.70	2.02	1.81	2.37	0.82	0.54	0.25	0.02	0.10	0.96	1.37	0.00	0.05	0.09	0.00	0.03	0.00	0.85	0.08
	272.8	279.1	287.6	297.7	306.8	318.7	322.7	325.5	326.7	326.8	327.3	332.1	339.0	339.0	339.3	339.7	339.7	339.9	339.9	344.1	344.5

Table 3.36: Soil water balance of Rooibos at the Klein Blomfontein study site for Day 421 to 486. The red block indicates the rootzone depth, green blocks indicates an increase soil water content (SWC) between the two measured dates. All values are in mm.

No. of days	421	426	431	436	441	446	451	456	461	466	471	476	481	486
Date / **Depth (mm)**	**2018/12/21**	**2018/12/26**	**2018/12/31**	**2019/01/05**	**2019/01/10**	**2019/01/15**	**2019/01/20**	**2019/01/25**	**2019/01/30**	**2019/02/04**	**2019/02/09**	**2019/02/14**	**2019/02/19**	**2019/02/24**
0 - 100	4.01	3.94	3.94	3.74	3.67	4.21	3.81	3.67	3.60	3.53	3.67	3.67	3.81	3.60
100 - 200	5.71	5.60	5.55	5.44	5.23	5.23	5.39	5.33	5.23	5.07	5.12	5.07	5.12	5.01
200 - 300	7.11	7.17	7.23	7.23	7.11	6.99	7.11	7.17	7.11	6.94	7.11	7.05	7.05	6.99
300 - 400	14.24	14.24	14.31	14.31	14.31	14.24	14.24	14.31	14.31	14.24	14.38	14.38	14.31	14.31
400 - 500	22.21	22.31	22.31	22.31	22.31	22.21	22.21	22.31	22.40	22.31	22.49	22.40	22.40	22.40
Total SWC at the rootzone	31.1	30.9	31.0	30.7	30.3	30.7	30.5	30.5	30.2	29.8	30.3	30.2	30.3	29.9
	0.3	0.1	-0.1	0.3	0.4	-0.4	0.1	0.0	0.2	0.5	-0.5	0.1	-0.1	0.4
P	0.0	0.0	2.4	0.0	0.0	4.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	384.4	384.4	386.8	386.8	386.8	391.3	391.3	391.3	391.3	391.3	391.3	391.3	391.3	391.3
U	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.1	0.0
	29.5	29.5	29.5	29.5	29.5	29.5	29.5	29.5	29.5	29.5	30.0	30.0	30.1	30.1
D	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
	119.4	119.4	119.4	119.4	119.4	119.4	119.4	119.4	119.5	119.5	119.5	119.5	119.5	119.5
ET	0.2	0.1	2.3	0.3	0.4	4.1	0.1	0.0	0.1	0.5	0.0	0.1	0.0	0.4
Avg ET/day	0.03	0.02	0.46	0.06	0.08	0.83	0.03	0.00	0.03	0.09	0.00	0.02	0.00	0.08
	344.7	344.8	347.1	347.5	347.9	352.0	352.1	352.1	352.3	352.7	352.7	352.8	352.8	353.2

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3.4 Conclusion

The soil forms of the study sites specifies that the Rogland study site has the Wasbank soil form while the Meulsteenvlei, Oorlogskloof and Klein Blomfontein study sites were dominated by Wasbank, Longlands and Dresden soil forms, respectively. The soils were sandy soils dominated by very coarse sand at Meulsteenvlei and Oorlogskloof; and coarse sand at Rogland and Klein Blomfontein. Soil bulk density of the study sites shows no restriction on root growth except for the Oorlogskloof study site at the soil depth 60 to 80 cm. Unsaturated hydraulic conductivity was high at the Meulsteenvlei study site ranging from 20 to 48.8 $mm.hour^{-1}$ compared to the Rogland, Oorlogskloof and Klein Blomfontein study sites which ranged from 6.9 to 51.6, 2.7 to 9.2 and 3.6 to 5.5 $mm.hour^{-1}$. Saturated hydraulic conductivity occurred to be higher at the soil surface and lower at the lower soil depths. The lower saturated hydraulic conductivity occurred at the Rogland and Klein Blomfontein study sites at the soil depth of 80 to 100 and 40 to 60 cm, respectively.

The rainfall pattern displayed dry summer and wet winter. The total rainfall received in 2018 was 331.4, 448.4, 386.2 and 353.8 mm for Rogland, Meulsteenvlei, Oorlogskloof and Klein Blomfontein, respectively. The monthly rainfall was above the average rainfall of Nieuwoudtville from January to September 2018 for all sites except for Rogland in April and July 2018. Most rainfall in 2018 occurred during winter which constituted between 39 and 50% of the total rainfall received in 2018.

Evapotranspiration pattern was similar to the rainfall pattern with less rainfall associated with low evapotranspiration and high rainfall associated with high evapotranspiration. The total evapotranspiration occurred in 2018 was 383.3, 440.1, 332.8 and 319.2 mm for Rogland, Meulsteenvlei, Oorlogskloof and Klein Blomfontein, respectively. The percentage of water usage in 2018 was high in winter (June to August) with 46.8, 45.6, 34.1 and 29.1% at the Oorlogskloof, Meulsteenvlei, Klein Blomfontein and Rogland study sites, respectively.

It can be concluded that the high evapotranspiration during winter at Oorlogskloof was due to slow water redistribution in the 0 to 200 mm and 200 to 400 mm layers while at Meulsteenvlei could be due to the exposure of the surface to sun and wind. At Rogland, the water was redistributed faster to the plinthic layer and stored for use during the active growth stage by Rooibos.

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CHAPTER 4: THE WEEDS AND ROOIBOS PYRROLIZIDINE ALKALOIDS CONCENTRATION, THE UPTAKE OF PYRROLIZIDINE ALKALOIDS BY ROOIBOS PLANT AND THE VEGETATION CONDITION INDEX OF THE SELECTED SITES AT NIEUWOUDTVILLE.

4.1 Introduction

Rooibos is an evergreen leguminous shrub and endemic crop of South Africa which belongs to Fynbos Biome (Lötte *et al*., 2014). Rooibos plant was initially used as tea and medicinal properties by the natives of the Cederburg area (Dahlgren, 1968). Recently, Rooibos tea was confirmed to have high levels of Pyrrolizidine Alkaloids (PA's) from the samples that were collected from retail markets in Switzerland (Mathon *et al*., 2014), Germany (Mädge *et al*., 2015), Belgium (Huybrechts & Callebuat, 2015) and Israel (Shimshoni *et al*., 2015).

The senecionine *N*-oxide was the leading compound and was followed by small amounts of senecionine, retrorsine *N*-oxide, restrorsine, seneciphylline *N*-oxide, senecivernine *N*-oxide and senkirkine that yielded up to 500 $\mu g.kg^{-1}$ of the total PA's (Mathon *et al*., 2014).

Apart from the PA's found in Rooibos tea, PA's are also known to be produced by plants as a defensive mechanism against insects (Radominska-Pandya, 2010). Cunha (2010) and Bodi *et al*. (2014), indicated that more than 660 Pyrrolizidine Alkaloids are present as a free bases or N-oxide and have been identified in over 6 000 plants. These Alkaloids are soluble in water (Trapp, 2000) and can be absorbed together with water by the PA's acceptor plants (Nowak & Selmar, 2016).

Diverse conditions of the terrestrial ground can be evaluated by satellite-derived landscape limitations (Coppin *et al*., 2004). One of the limitations is the Normalized Difference Vegetation Index (NDVI) (Forkel et al., 2013). NDVI is a remote-sensed extent of plants greenness and is associated to anatomical stuff of the plants such as leaf area index (Turner et al., 1999) and the raw vegetation (Gamon, et al., 1995). Furthermore, NDVI is also

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associated with the properties of plant production such as the captivated photosynthetic energetic emission and folia nitrogen (Gamon, et al., 1995; Fensholt, et al., 2004).

4.2 Objectives

- To do infield evaluation of species composition, population density and PA's availability on dominate weeds.
- To evaluate the PA's levels of Rooibos plant of the selected study sites.
- To correlate the known weeds containing PA's with the PA's level of Rooibos plant.
- To evaluate the absorption of PA's by Rooibos from decaying weeds containing PA's using potting trials.
- To evaluate the vegetation change and the difference between the selected study sites.

4.3 Material and methods

4.3.1 Site description

Soil depth differed from one study site to another while Wasbank soil type was common in all sites (as described in Chapter 3). Furthermore, three other soil types (Longlands, Dresden and Mispah) were observed within the study sites. Dresden was common between Meulsteenvlei and Klein Blomfontein while Mispah was common between Meulsteenvlei and Oorlogskloof. Longlands only appeared at Oorlogskloof.

The cumulative ET at the study sites differed from one another with an amount of 404.5, 508.0, 363.4, 353.2 mm from October 2017 to February 2019 at Rogland, Meulsteenvlei, Oorlogskloof and Klein Blomfontein, respectively (as described in Chapter 3).

4.3.2 Pot trial

The experiment was carried out at Vaalharts Research Station in Northern Cape, South Africa (27° 57' 19.5'' S; 24° 50' 42.45'' E). The area falls within the summer rainfall area with an average rainfall of 450 mm per annum. The minimum temperature is approximately 1.6°C in winter while the maximum temperature is approximately 33.6°C in summer. The humidity of the area ranges from 21 to 95%.

4.3.3 Experimental design

4.3.3.1 Field experiment

A complete randomised design with 10 replicates was used to evaluate weed density and its effect on Rooibos tea. A quadrant of 1 m x 1 m was used to

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count the number of weeds surrounding the Rooibos tea plant (Fig 4.1). A total of 19 weeds were observed in the quadrants and classified according to Problem Plants of South Africa book prescribed by Bromilow (1995). Three samples per species from 10 dominate species were collected for PA's analyses. Both dominate weeds collected and Rooibos samples from the quadrants were air dried, chopped and sent to Central Analytical Facilities (CAF) at Stellenbosch University for PA's analysis. Total PA's of Rooibos plants were correlated with the number of dominant weeds and weeds specified by Van Wyk *et al*. (2017) that are known to contain PA's and which found in the quadrants. Figure 4.2 illustrates some of the dominate weeds species observed during investigation.

Figure 4.1: Quadrant demarcating the area around a Rooibos plant.

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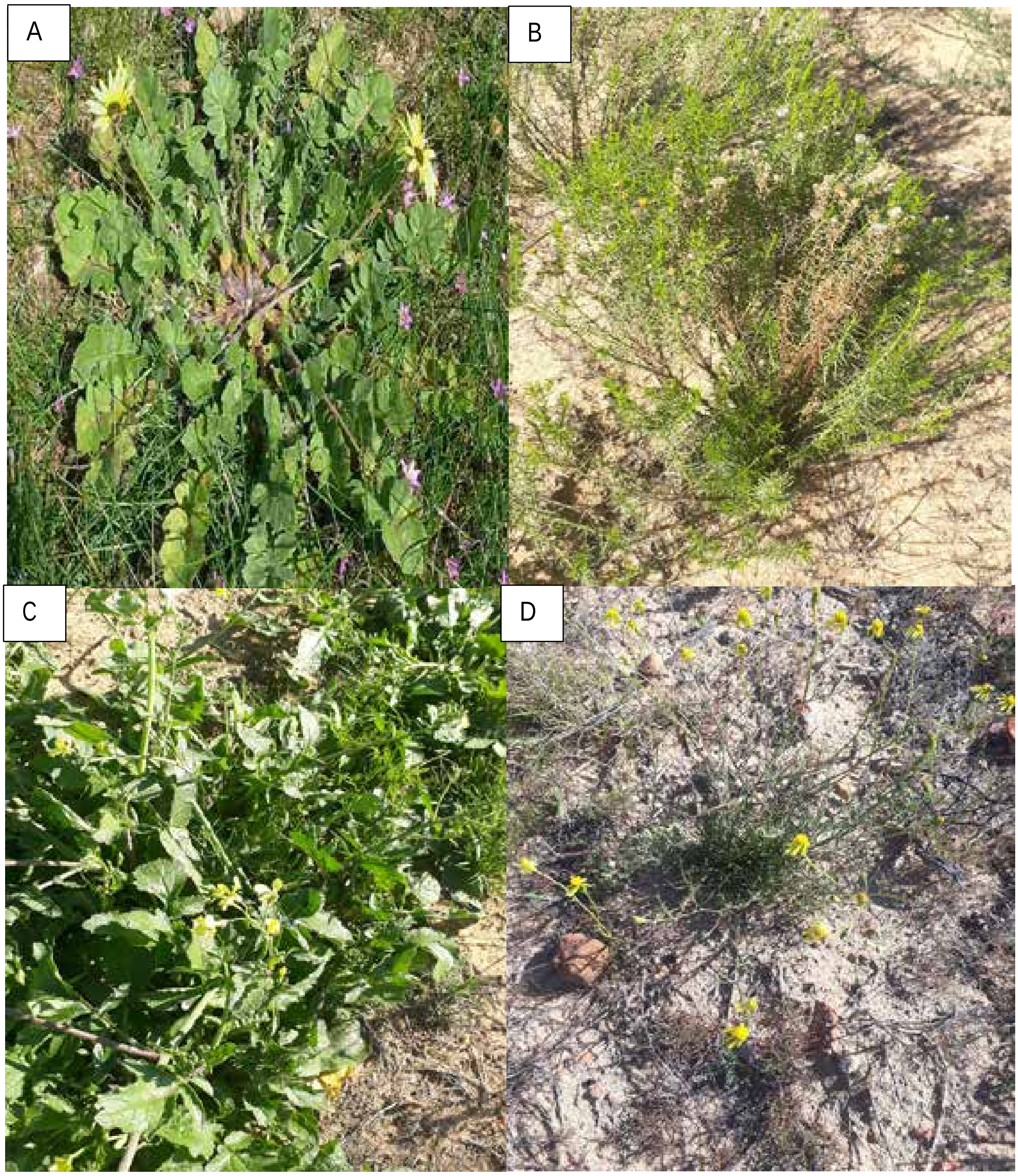

Figure 4.2: Illustration of some of the dominant weeds found in the Rooibos plantation. A: *Arctotheca calendula*, B: *Crysocoma oblongifolia*, C: *Raphanus raphanistrum* and D: *Othonna coronopifolia*.

4.4.3.1 Pot experiment

A single factorial experiment layout was produced by using a control treatment and three weeds (*Chrysocoma Oblongifolia*, *Raphanus Raphnistrum and Othonna Coronopifolia)* that were collected in Rooibos plantaion. The control treatment was the soil without weeds. The weeds treatment contained the total PA's concentration ranging from 229 to 45 987 $\mu g.kg^{-1}$ (Table 4.1).

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Table 4.1: Pyrrolizidine Alkaloids content of the weeds used in the pot trial.

Weeds	**Senecionine-N-oxide (µg.kg^{-1})**	**Retrorsine (µg.kg^{-1})**	**Retrosine-N-oxide (µg.kg^{-1})**	**Senecionine (µg.kg^{-1})**	**Senkirkin (µg.kg^{-1})**	**Seneciphylline-N-oxide (µg.kg^{-1})**	**Senecivirnine-N-oxide (µg.kg^{-1})**	**Senecivirnine (µg.kg^{-1})**	**Total PA's (µg.kg^{-1})**
Chrysocoma Oblongifolia	10	4	199	9	-	3	4	-	229
Raphanus Raphnistrum	11 700	2 459	10 788	2 752	350	-	4 388	13 865	45 987
Othonna Coronopifolia	100	18	59	30	-	-	53	118	378

The Field Capacity (FC) was determined by the method described by Brady and Weil (2008). The pots of 0.0038 m^3 volume were packed with 5 kg of air dried soil. In the pots, the soil volume was 0.0029 m^3. The soil in the pots was then saturated with water until it started to drain. The soil was allowed to drain for two days before FC was determined. After two days, the water content at FC was determined for all of the pots. The weight of the pot before water was added was subtracted from the weight of the pot at FC to determine the mass of water. The mass of water was divided by the mass of soil in the pot and thereafter, the ratio was multiplied by the soil bulk density of the pot in order to obtain volumetric water content at FC.

After determining water content at FC, *Chrysocoma Oblongifolia*, *Raphanus Raphnistrum and Othonna Coronopifolia* were applied separately to three pots at the rate of 50 g per pot. The chopped up weeds were thoroughly mixed with the soil to ensure equal distribution of PA's into the entire pots. Treatments were replicated six times and each pot was planted with 14 seeds of Rooibos.

A weighing scale was used to measure the mass of the pots on a daily basis in the morning between 07h00 and 08h00 to determine the evapotranspiration per day. The water from the pots was allowed to deplete

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by 40% before being refilled to FC. This experiment started on the 25th of July 2018 and ended on the 1st of February 2019. Thereafter, Rooibos plants were removed from the soil with their roots, washed with tab water, chopped and air dried for 2 days. A Rooibos sample of 30 g per pot was collected and packed into a sampling bag before it was sent for PA's analyses at CAF.

4.4.3.2 NDVI assessment

In order to determine the vegetation condition index scores for the sites, the subsequent surveys were embarked upon using an Unmanned Aerial Vehicle (UAV) of the type eBee by the company SenseFly. The UAV was a light-weight fixed-wing one that could cover relatively large areas during one flight. A total of 24 imaging flights were conducted, each with a period of 15-20 minutes and approximately 19-222 images per flight were generated. The ground sampling distance (GSD) was between 4 and 15 cm. Flights were carried out before harvest in April 2017, February 2018 and January 2019.

The onboard multi-spectral sensor was the high-end system of SenseFly called the multispec 4C. The multispec 4C sensor with its four bands (Blue, Red, Green and Near-Infrared) was used to calculate the Normalized Difference Vegetation Index (NDVI) at each study site using Equation 5.1:

$NDVI = (NIR – R) / (NIR + R_{vr})$ ………………......……………….Eq. 5.1

Where:

NDVI	=	Normalized Difference Vegetation Index
NRI	=	Near-Infrared
Rvr	=	Visible red reflectance

4.3.4 Statistical analysis

Statistical analyses were performed using SPSS (version 25) software package produced by IBM Company. A one-way analysis of variance (ANOVA) was used to test the significance difference of weeds species and PA's in Rooibos plants between the selected study sites (Rogland, Meulsteenvlei, Oorlogskloof & Klein Blomfontein) at a 95% confidence level. Tukey's honestly significance difference was used as a post hoc test to compare the difference between the mean at 95%

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confidence interval. Microsoft Excel 2016 was used to plot linear regression and bar graphs.

4.4 Results and discussion

4.4.1 Weeds screening

The average density of specific weeds species for Rogland, Meulsteenvlei, Oorlogskloof and Klein Blomfontein is given in Table 4.2. The total average weeds population density of the study sites ranged from 15.2 to 25.7 plants.m^{-2} .There were no difference between the total weed species observed at all the study sites. However, *Arctotheca calendula*, *Chrysocoma oblongifolia*, *Cleretum papulosum*, *Cynodon dactylon*, *Ehrharta longiflora*, *Juncus capensis*, *Senecio arenarius* and *Ursinia anthemoides* differed between the sites. From these species, Rogland produced more species with the highest density of (*Cynodon dactylon*, *Ehrharta longiflora*, *Juncus capensis* and *Ursinia anthemoides*). This was followed by Meulsteenvlei with two species (*Arctotheca calendula* & *Cleretum papulosum*). Then Oorlogskloof and Klein Blomfontein with *Chrysocoma oblongifolia* and *Senecio arenarius*, respectively.

Pyrrolizidine alkaloids concentration (µg.kg^{-1}) of the dominant weeds collected from the Rooibos tea plantation are presented in Table 4.3. Weeds which tested positive for PA's were *Arctotheca calendula, Chysocoma oblongifolia, Othonna coronofolia* and *Raphanus raphanistrum*. These particular weeds form part of the Asteraceae family which was reported as one of those families that produce PA's as a defensive mechanism against insects herbivores (Smith & Culvenor, 1981; Hartmann, 1999; Bruneton, 2008; Radominska-Pandya, 2010; Margarita *et al*., 2012).

The average total PA's for *Arctotheca calendula, Chysocoma oblongifolia, Othonna coronofolia* and *Raphanus raphanistrum* were 5, 75, 2 817 and 15 330 µg.kg^{-1}, respectively (Table 4.3). Consistently in all these weeds except for *Arctotheca calendula*, the concentration of Pyrrolizidine Alkaloids Necine-Oxides (PANOs) were more than the concentration of tertiary PA's. The ratio between the tertiary PA's and PANOs of *Othonna coronofolia* was 27:73 and had a similar ratio ranged between 10:90 to 30:70 for *Senecio vulgaris L*. reported by Flade *et al*., (2019) while for *Chysocoma oblongifolia* (05:95) and *Raphanus raphanistrum* (42:58) was higher and lower, respectively.

Table 4.2: Average weed population density of different selected sites (refer to Appendix 4 for detailed weeds population density).

Sites \ Species	*Arctotheca calendula*	*Bulbinella caudafelis*	*Chaetobromus involueratus*	*Chrysocoma oblongifolia*	*Cleretum papulosum*	*Cynodon dactylon*	*Ehrharta longiflora*	*Grielum humifusum*	*Heliophilia africana*	*Juncus capensis*	Othonna coronopifolia	*Oxalis oculifera*	Oxalis pes-capre	*Psammotropha spicata*	*Raphanus raphanistrum*	*Rumex cordatus*	*Selago inaequifolia*	*Senecio angustifolia*	*Senecio arenarius*	*Senecio erosus*	*Spergula arvensis*	*Ursinia anthemoides*	**Total average**
Rogland	0.0^{a}	0.0	0.0	0.5^{ab}	0.0^{a}	1.9^{b}	4.5^{b}	0.9	0.2	0.5^{b}	0.0	0.0	0.1	2.1	0.0	0.2	0.1	0.5	0.0^{a}	0.0	0.0	14.2^{b}	25.7^{a}
Meulsteenvlei	4.7^{b}	0.0	0.0	0.0^{a}	7.5^{b}	0.0^{a}	0.4^{a}	0.1	0.0	0.0^{a}	0.0	0.0	0.0	0.0	1.1	0.3	0.1	0.0	0.0^{a}	0.0	0.2	10.0^{ab}	24.4^{a}
Oorlogskloof	1.4^{a}	0.5	0.0	2.8^{b}	0.0^{a}	0.7^{ab}	1.2^{ab}	3.5	0.0	0.0^{a}	0.0	0.2	0.0	0.3	1.2	0.0	0.6	0.6	0.2^{a}	0.2	0.0	1.8^{a}	15.2^{a}
Klein Blomfontein	0.0^{a}	0.2	0.2	0.0^{a}	0.6^{a}	0.0^{a}	3.9^{b}	2.8	0.1	0.0^{a}	0.7	0.0	0.0	0.1	1.2	0.0	0.4	0.1	2.2^{b}	2.0	0.8	5.4^{ab}	20.7^{a}

Note: Alphabetical letters symbolise statistical difference between the study sites. Similar letters denote absence of significant difference.

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Table 4.3: Pyrrolizidine alkaloids (PA's) concentration (μg.kg^{-1}) of the dominate weeds.

SPECIES										TOTAL PA'S
	-	-	-	-	-	5	-	-	-	5
	-	-	-	-	-	-	-	-	-	-
	3	1	66	-	3	-	1	1	-	75
	-	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-	-
OTHONNA CORONOPIFOLIA	790	35	1 173	-	71	39	-	89	620	2 817
	-	-	-	-	-	-	-	-	-	-
	3 900	820	3 596	-	917	12	-	1 463	4 622	15 330
	-	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-	-

4.4.2 Rooibos PA's screening

The mean PA's concentration of Rooibos plant for Rogland, Meulsteenvlei, Oorlogskloof and Klein Blomfontein is presented in Figure 4.3 and 4.4. Senecivirnine-*N*-oxide was higher than most of other PA's for all study sites. However, senecivirnine-*N*-oxide and senecionine were the dominant PA's found in Rooibos plants of the study sites compared to senecionine *N*-oxide reported by Mathon et al. (2014) on the alkaloid profile of Rooibos tea. Moreover, senecivirnine-*N*-oxide was substantially higher at Oorlogskloof compared to Meulsteenvlei and Klein Blomfontein (Fig. 4.3).

The total concentration of PA's at Oorlogskloof was substantially higher than the total concentration of PA's found at Klein Blomfontein (Fig. 4.4). This might be due to the high significant amount of *Chysocoma oblogifolia* at Oorlogskloof as compared to Klein Blomfontein. Although *Chysocoma oblogifolia* was low at Meulsteenvlei, the insignificance difference of total concentration of PA's between Meulsteenvlei and Oorlogskloof could be due to high *Arctotheca calendula* that was observed at Meulsteenvlei.

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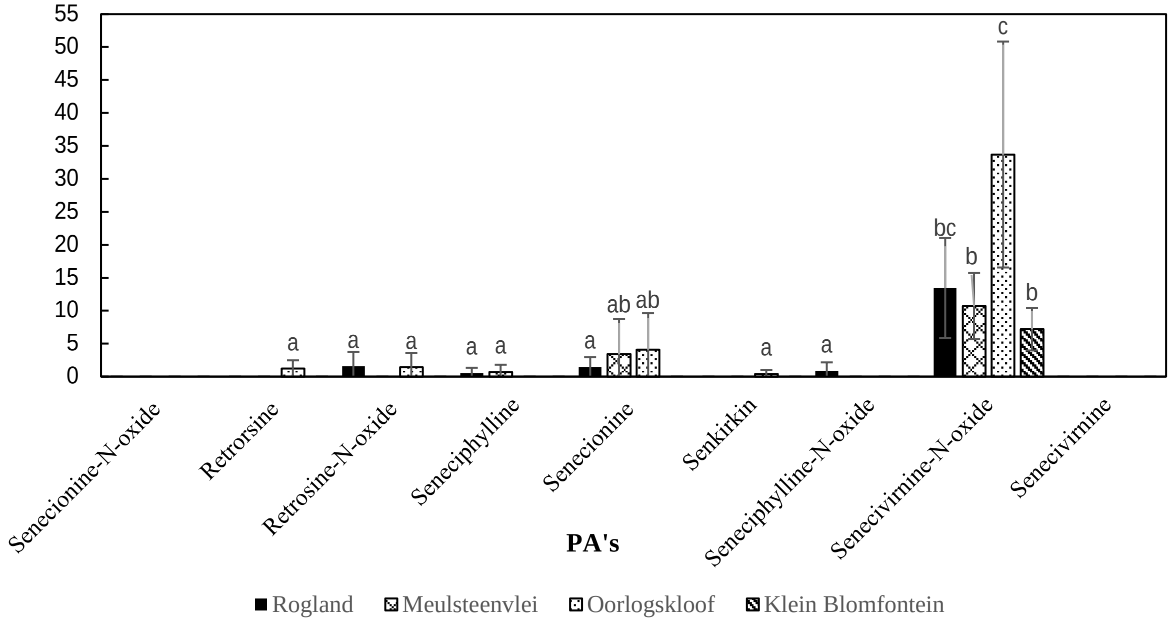

Figure 4.3: PA's concentration (mean ± SE) of Rooibos plant at Rogland, Meulsteenvlei, Oorlogskloof and Klein Blomfontein. Bars with different letters indicates a significance difference at 95% confidence interval.

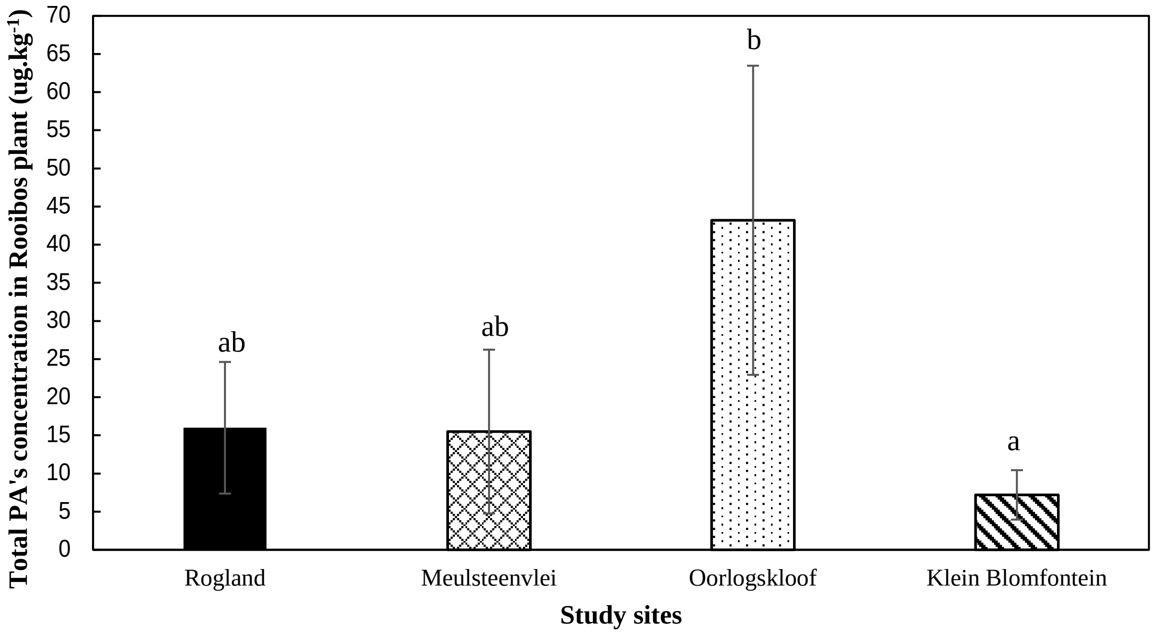

Figure 4.4: Total PA's concentration (mean ± SE) of Rooibos plant at Rogland, Meulsteenvlei, Oorlogskloof and Klein Blomfontein. Bars with different letters indicates a significance difference at 95% confidence interval.

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Number of weeds containing PA's showed no correlation with the PA's concentration in Rooibos plant (Fig 4.5). Given that the mass of the PA containing weeds was not determined, it is possible that a better correlation would have been obtained using that data rather than the number of weeds.

In the pot study, the Rooibos plants from where *Raphanus raphnistrum* was incorporated into the soil had higher PA compared to the rest of the plants (Fig. 4.6). This was likely due to high PA's concentration found in *Raphanus raphnistrum* as compared to *Chrysocoma oblongifolia* and *Othonna coronopifolia* from other treatments (Table 4.1).

Only senecivirnine-*N*-oxide was observed in Rooibos plants were the soil was treated with weed that contained high concentration of senecivirnine-*N*-oxide. Similar findings were reported by van Wyk *et al*., (2017) indicating that the soil can be contaminated with PA's that offers the presence of PA's in Rooibos tea plant.

4.4.3 NDVI assesment

The vegetation condition index for Rogland, Meulsteenvlei, Oorlogskloof and Klein Blomfontein is shown in Figures 4.7 to 4.30. High difference in vegetation index between the study sites was observed at Oorlogskloof throughout the duration of the study (2017 -2019). Positive NDVI trends (greening) within the study sites were observed on the deep soils while the negative NDVI trends (browning) was observed on the shallow soils.

4.4.3.3 Rogland study site

Vegetation was decreased between 2017 and 2018 (Fig. 4.10). The decrease was due to stunting of plants. Further investigation exposed a clarification for the stunting of Rooibos plant from the shallow soils, namely that most observed plants died on the shallow soils had the root band laterally on the restrictive layer. The stunting of the Rooibos plant from both shallow and deeper was due to the banding of roots towards the direction of the ground surface which might be led by incorrect transplant technique used during Rooibos transplantation. An increase of vegetation between 2018 and 2019 (Fig. 4.11) was due to the meaningful rainfall received during that season (refer to section 3.3.3.2) which provided a better plant stand. Moreover, the

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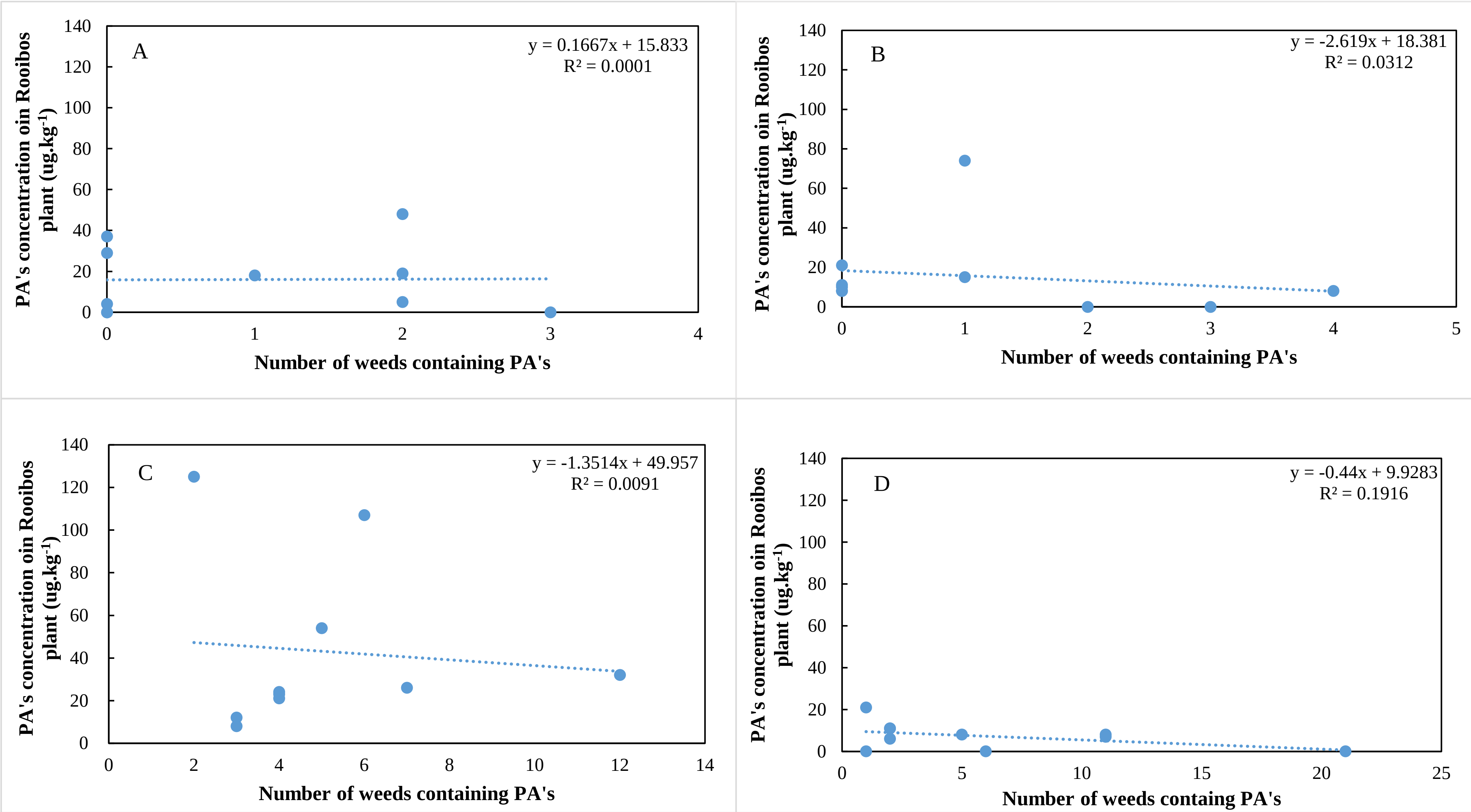

Figure 4.5: Correlation between PA's concentration in Rooibos plant and number of weeds containing PA's. (Study sites: A: Rogland; B: Meulsteenvlei; C: Oorlogskloof and D: Klein Blomfontein).

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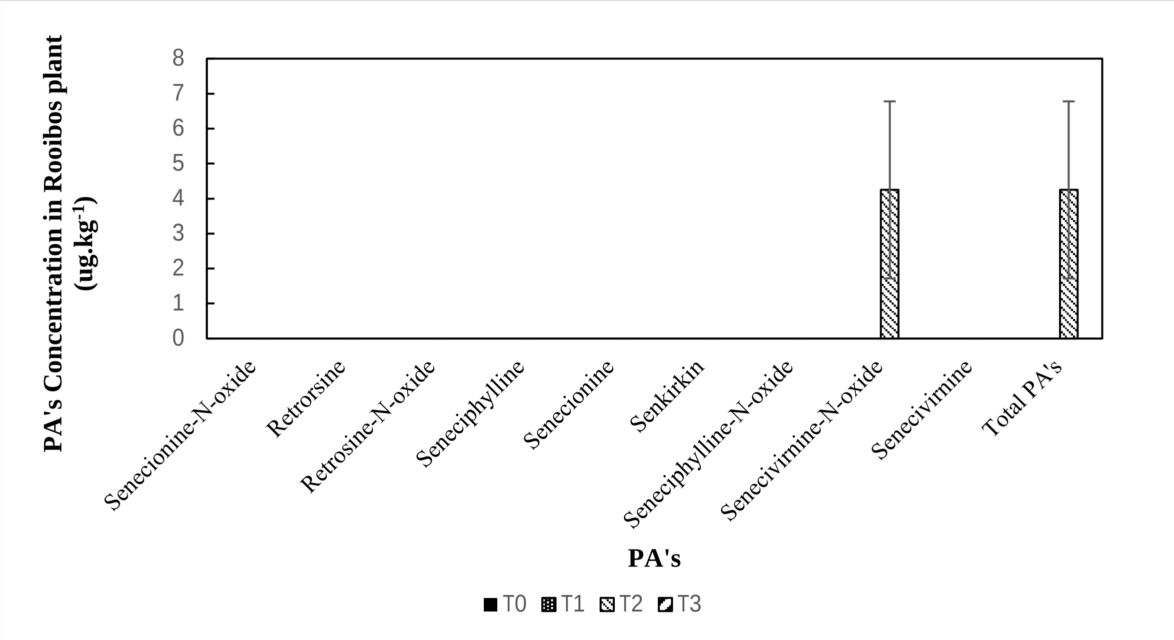

Figure 4.6: Mean PA's concentration in Rooibos plant of control and weed treatments from the pot-trail. (Treatments: T0: Control; T1: *Chrysocoma Oblongifolia*; T2: *Raphanus Raphnistrum* and T3: *Othonna Coronopifolia*).

increase of vegetation from the bare areas was in line with the weeds that invaded the bare spaces created after the Rooibos plants died.

4.4.3.4 Meulsteenvlei study site

An increase in vegetation was observed between 2017 and 2018 (Fig. 4.16). The increase could be due to the adequate amounts of rainfall that were received during flowering period when water requirement was too high (refer to section 3.3.3.2). The decrease in vegetation between 2018 and 2019 (Fig. 4.17) was due to the effects of shallow soils on the root growth. However, the overall vegetative growth showed a positive NDVI trend between 2017 and 2019 (Fig. 4.18).

4.4.3.5 Oorlogskloof study site

An increase in vegetative growth was observed between 2017 and 2018 (Fig. 4.22). Nevertheless, the site experienced higher positive NDVI trend as compared to the other sites. Even though less rainfall received during that season, the higher vegetation change witnessed at this side might be due to the deeper soils with plinthics underneath that stored water that was later utilized effectively during production (refer to section 3.3.1). However, the decline in NDVI trend was detected during the growth season of 2018-2019

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(Fig. 4.23). The decline was due to plant stress caused by frost between June 2018 and August 2018.

4.4.3.6 Klein Blomfontein

A slight increase in vegetation growth was observed between 2017 and 2018 (Fig. 4.28) while the pronounced increase in vegetation growth was observed between 2018 and 2019 (Fig. 4.29). The pronounced increase in vegetation growth could be due to more rainfall received during 2018/19 growth season as the compared to 2017/18 growth season (refer to section 3.3.3.2).

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Figure 4.7: NDVI map of the Rogland study site on the 4th April 2017.

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Figure 4.8: NDVI map of the Rogland study site on the 10th February 2018.

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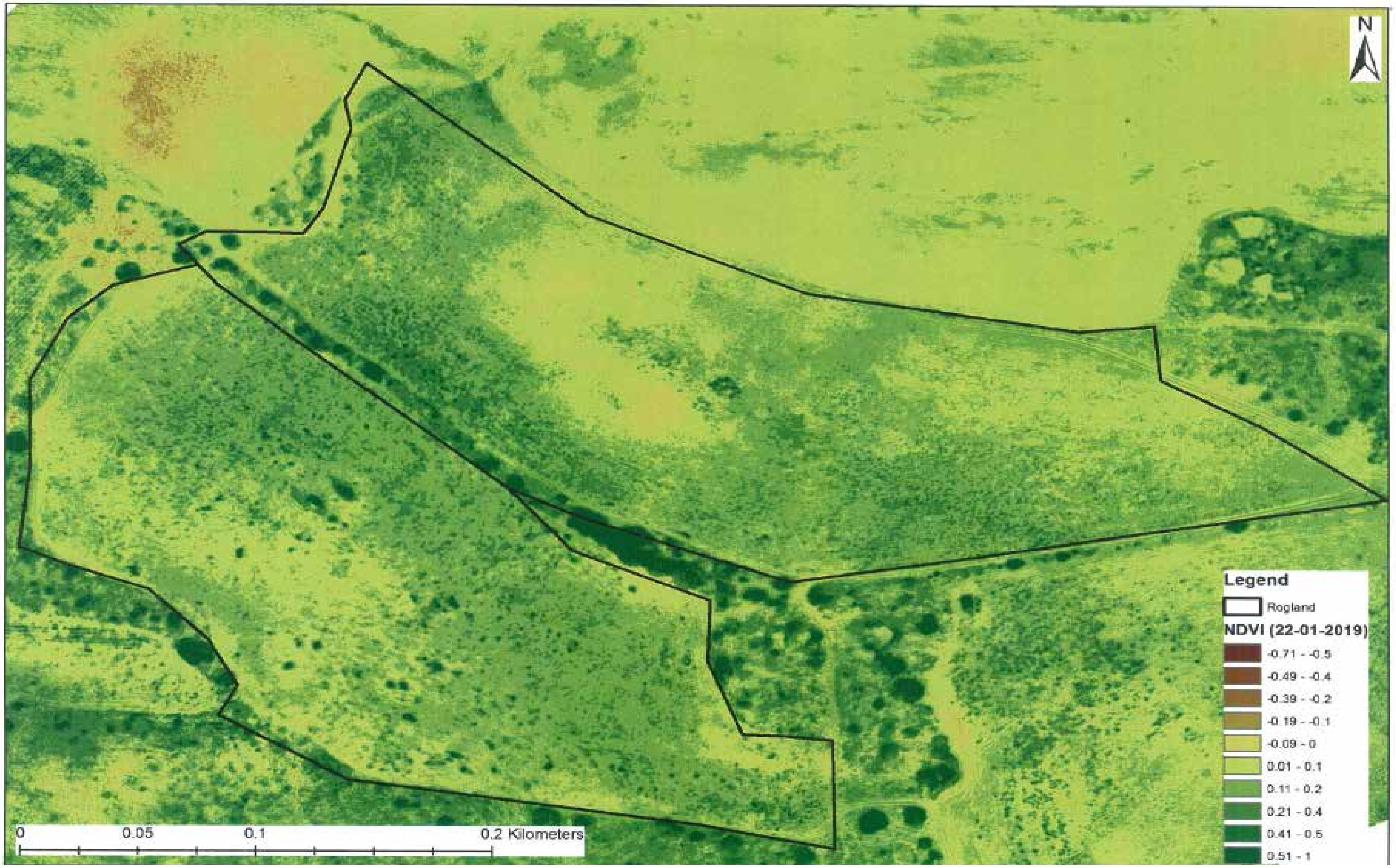

Figure 4.9: NDVI map of the Rogland study site on the 22nd January 2019.

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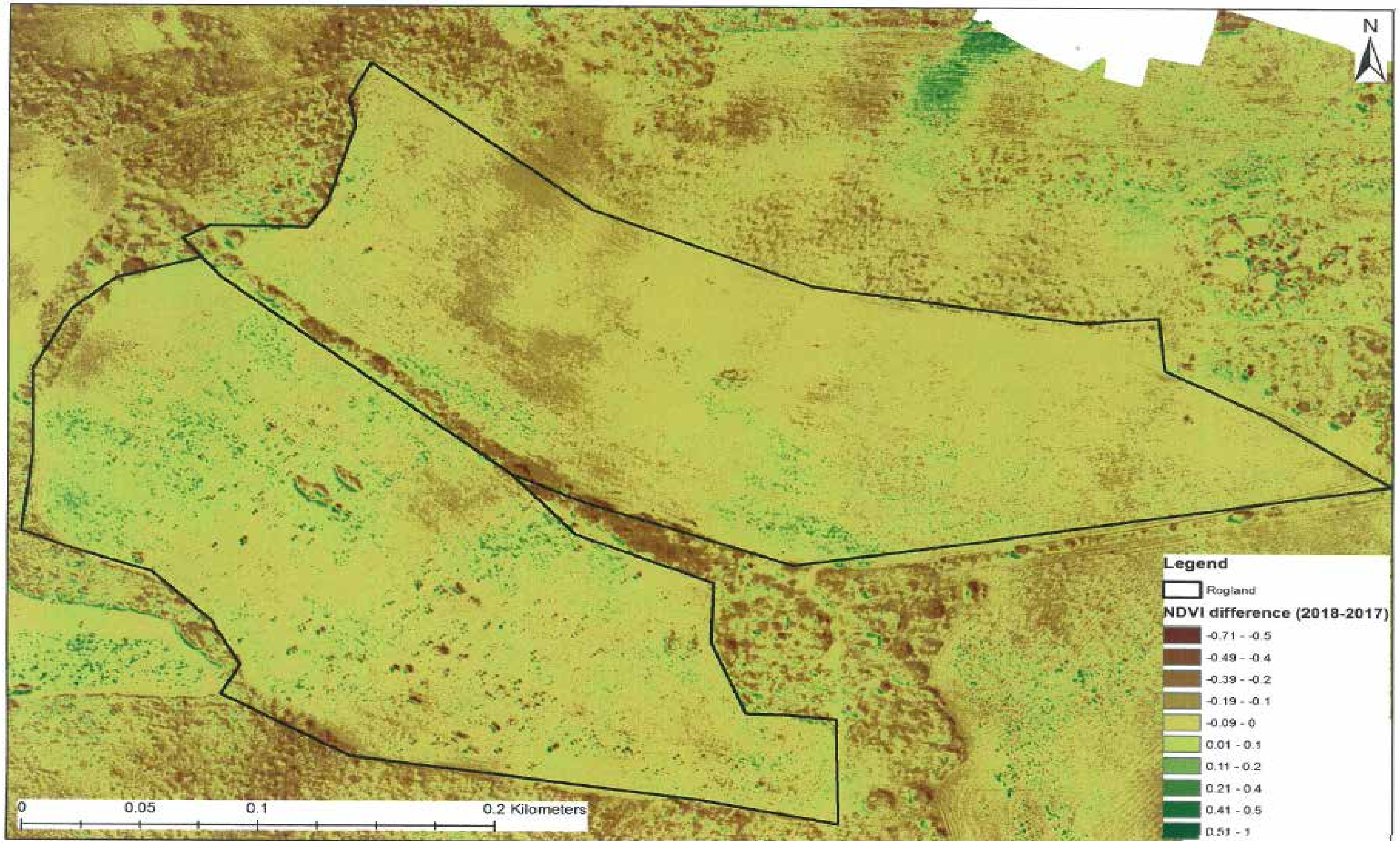

Figure 4.10: NDVI map of the Rogland study site showing the difference in vegetation between 4th April 2017 and 10th February 2018.

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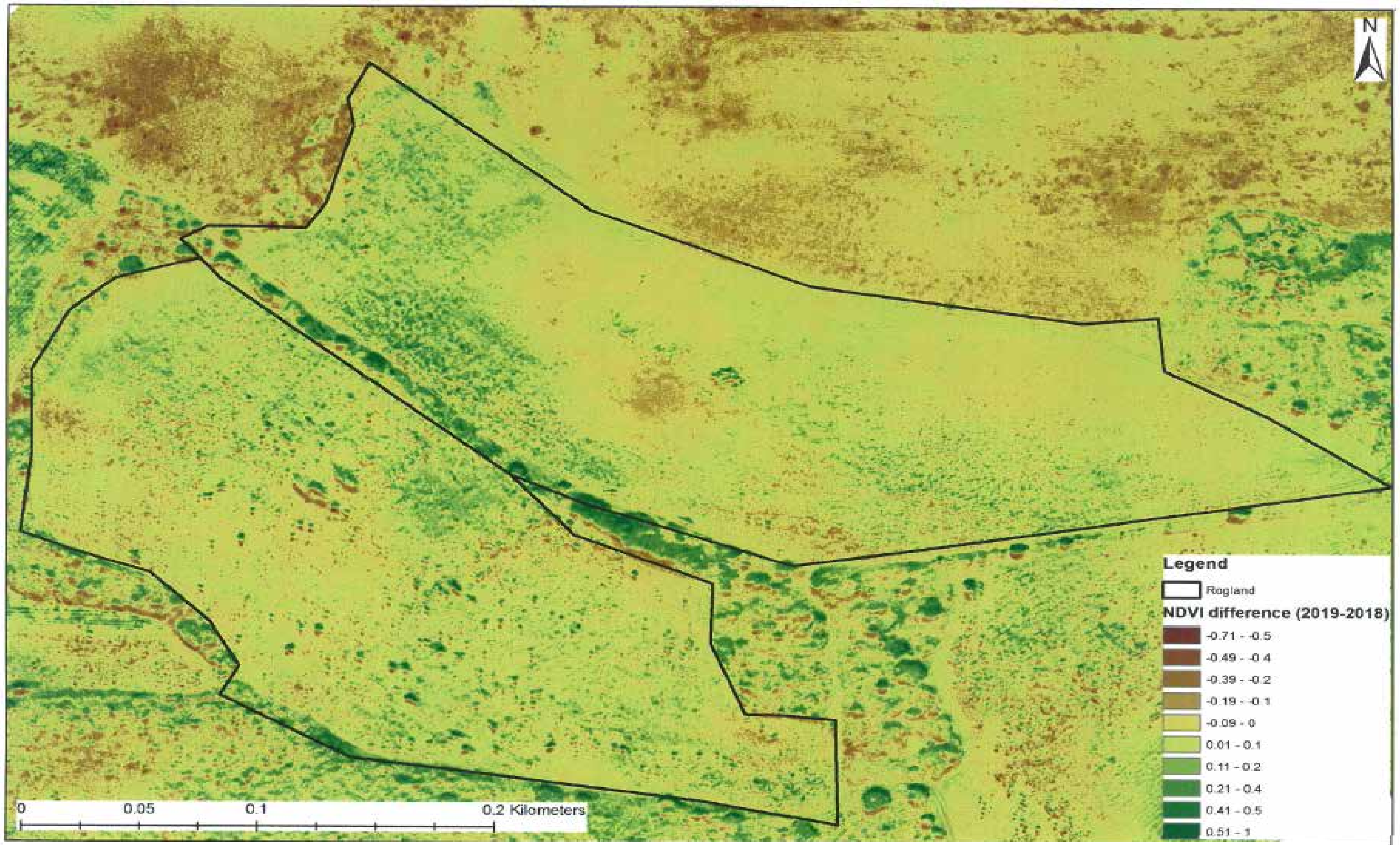

Figure 4.11: NDVI map of the Rogland study site showing the difference in vegetation between 10th February 2018 and 22nd January 2019.

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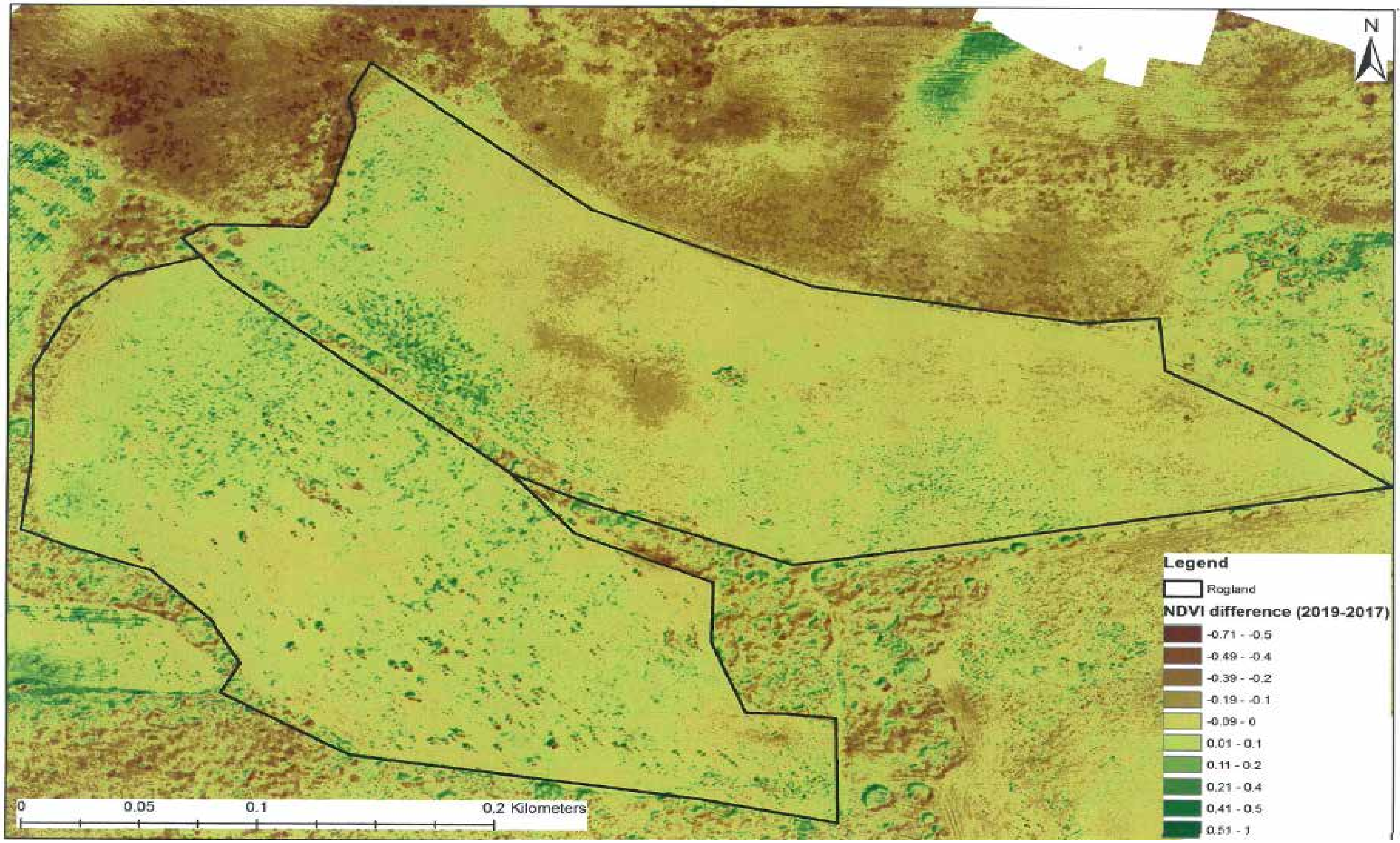

Figure 4.12: NDVI map of Rogland study site showing the difference in vegetation between 4th April 2017 and 22nd January 2019.

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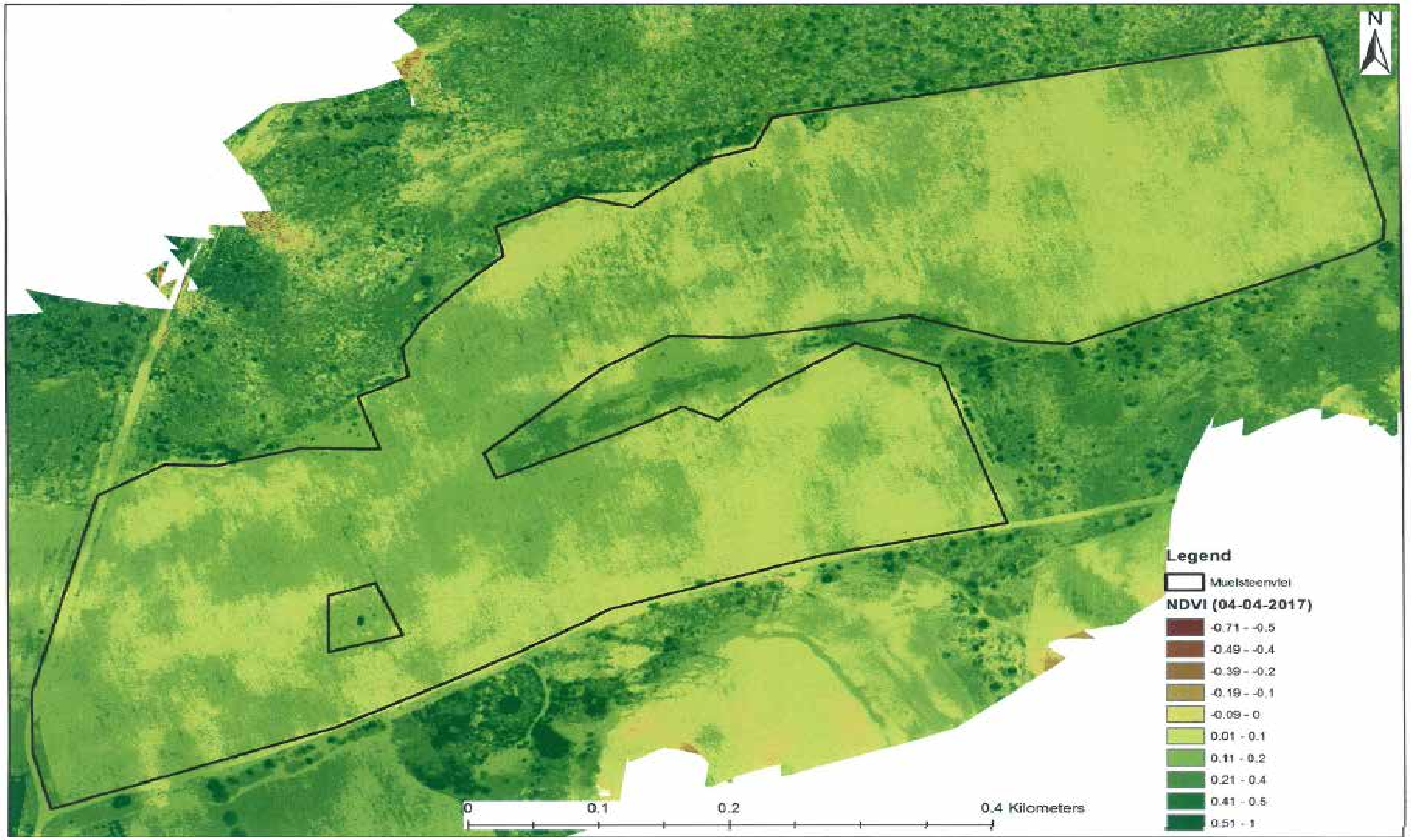

Figure 4.13: NDVI map of the Meulsteenvlei study site on the 4th April 2017.

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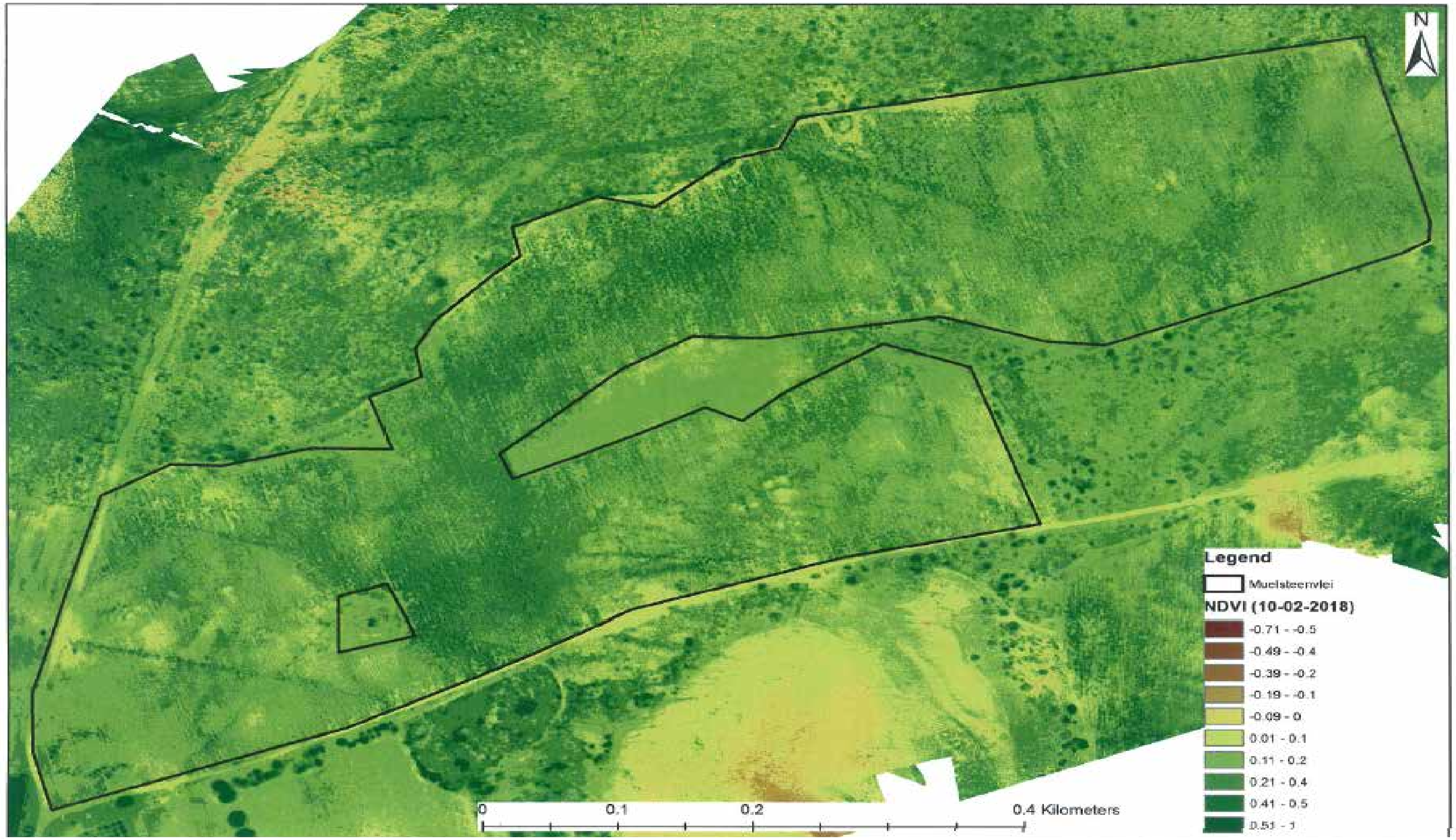

Figure 4.14: NDVI map of the Meulsteenvlei study site on the 10th February 2018.

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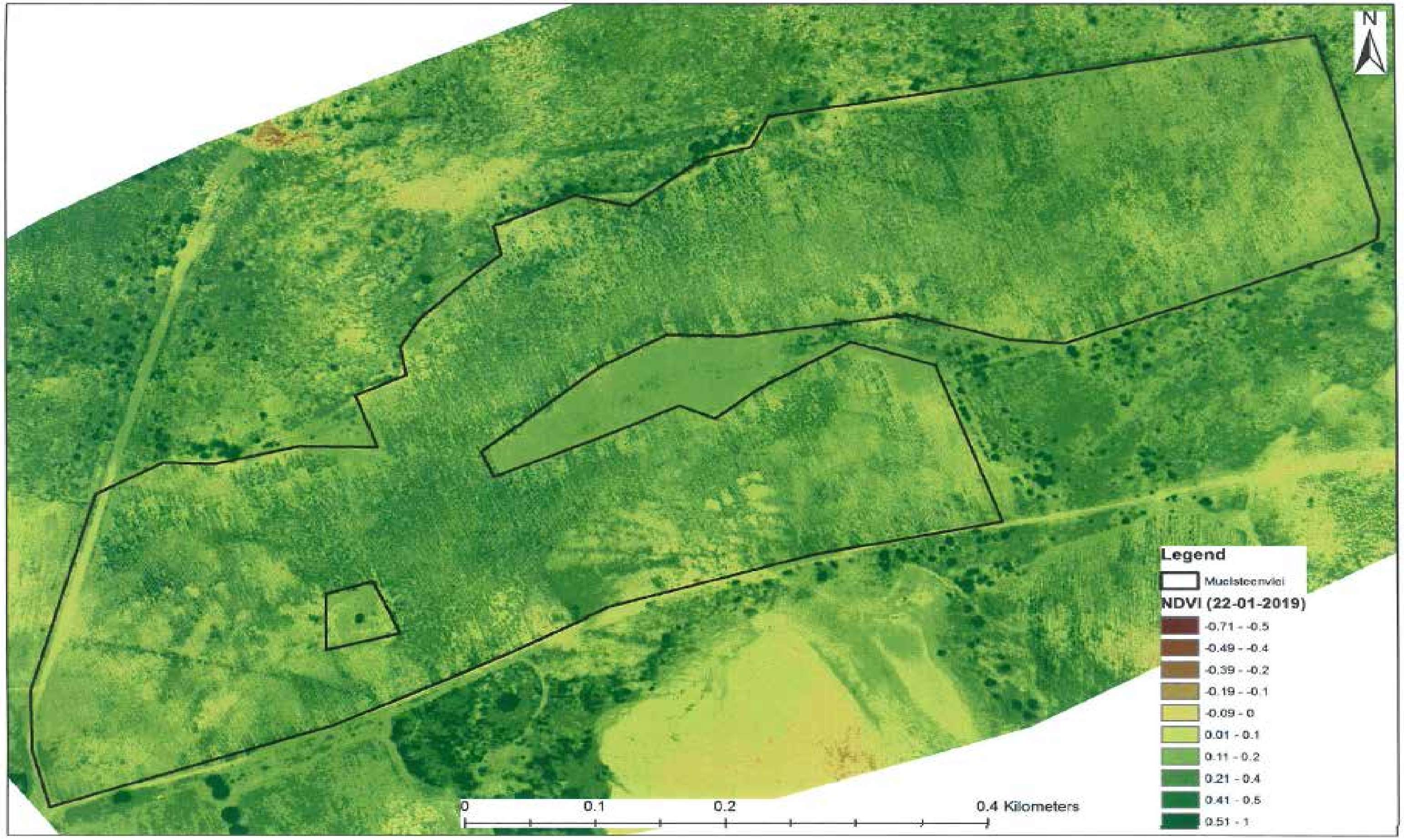

Figure 4.15: NDVI map of the Meulsteenvlei study site on the 22nd January 2019.

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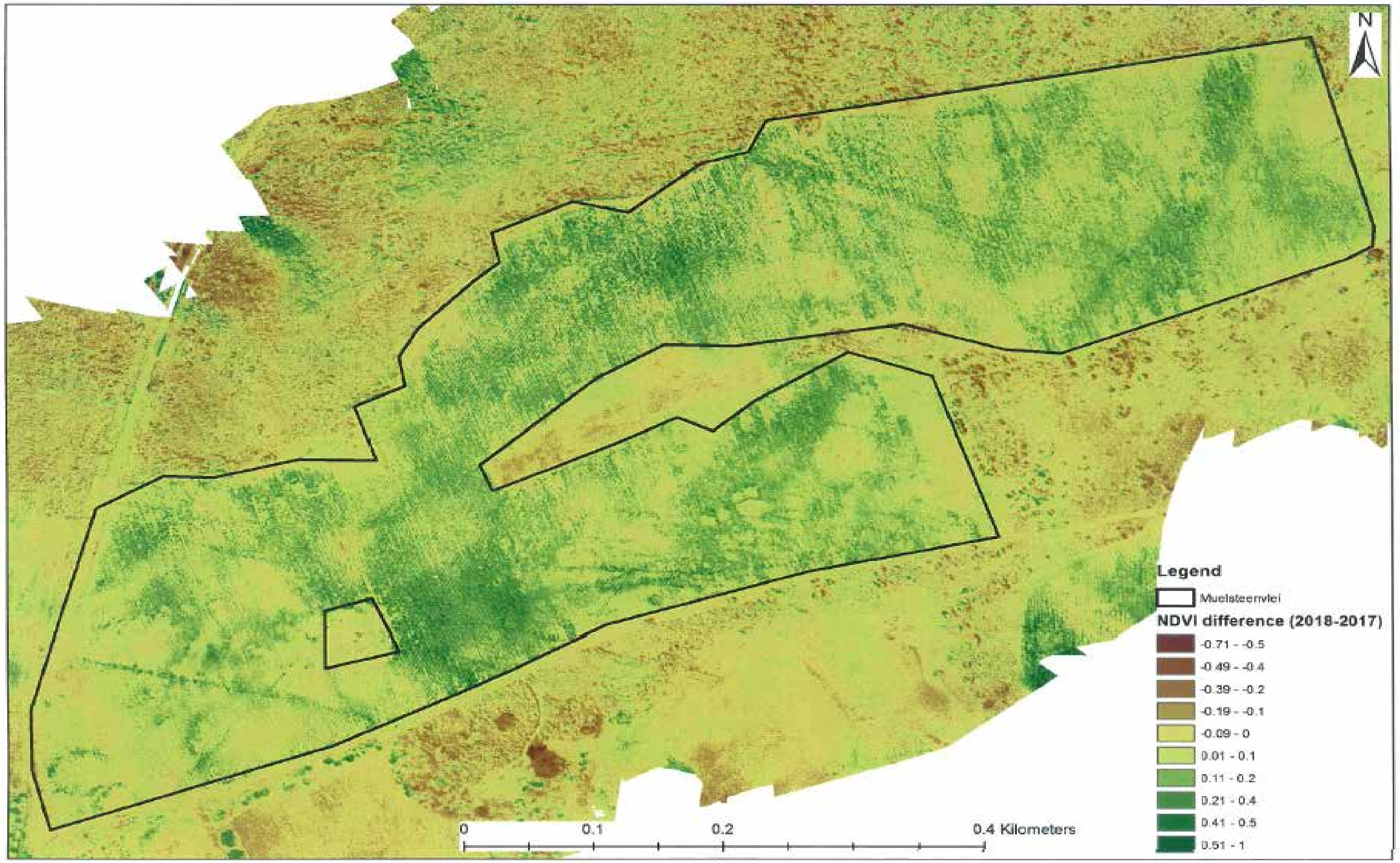

Figure 4.16: NDVI map of the Meulsteenvlei study site showing the difference in vegetation between 4th April 2017 and 10th February 2018.

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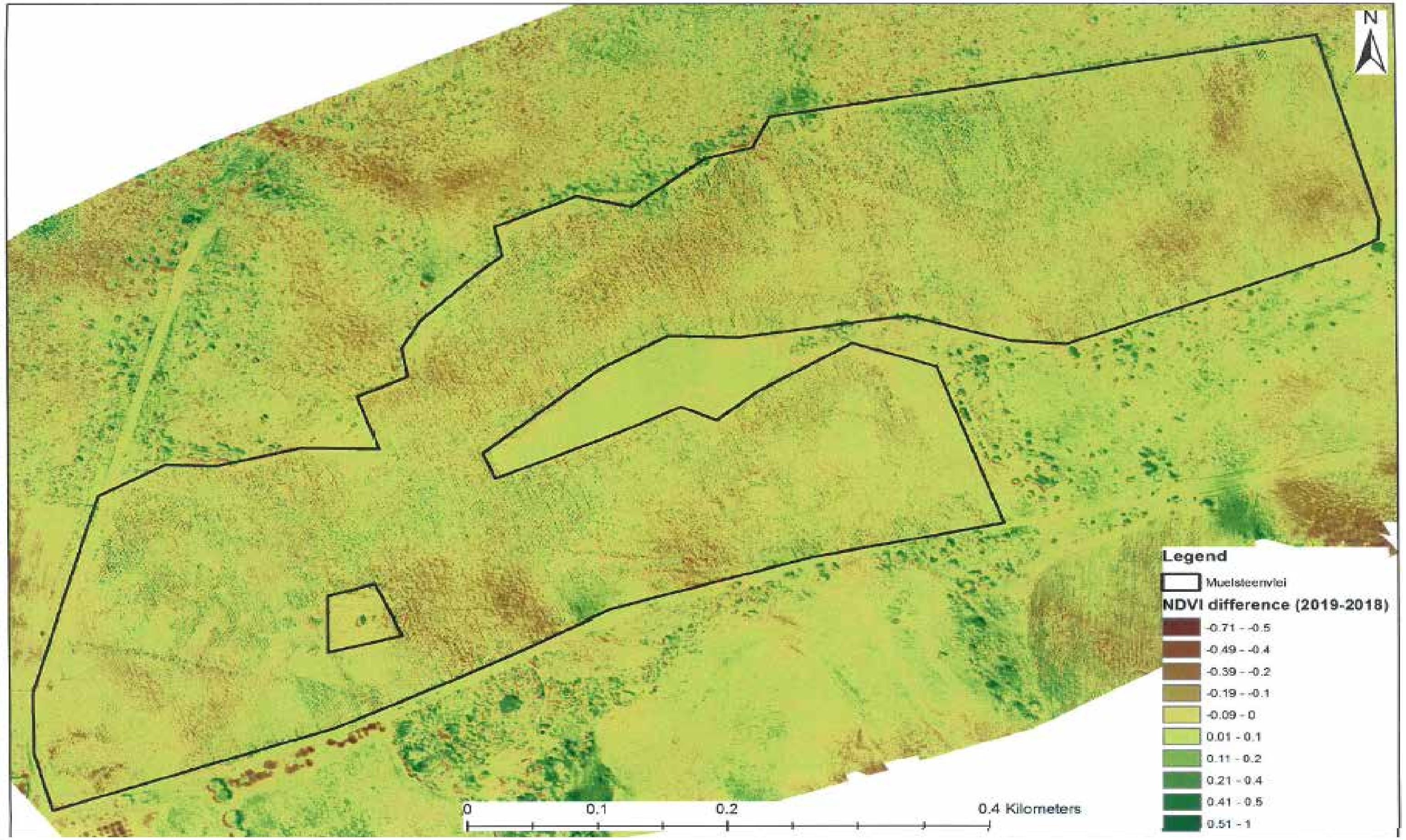

Figure 4.17: NDVI map of the Meulsteenvlei study site showing the difference in vegetation between 10th February 2018 and 22nd January 2019.

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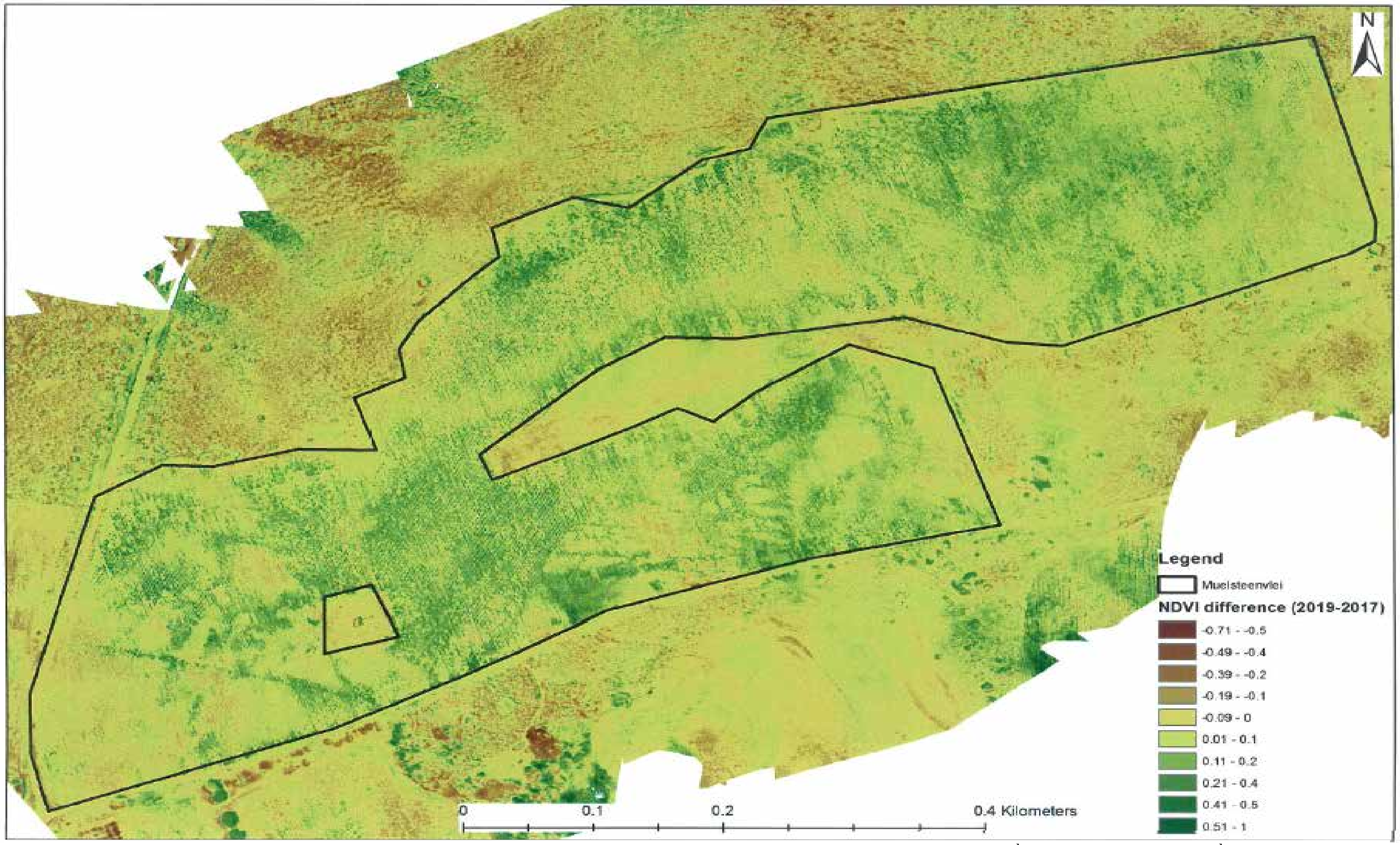

Figure 4.18: NDVI map of the Meulsteenvlei study site showing the difference in vegetation between 4th April 2017 and 22nd January 2019.

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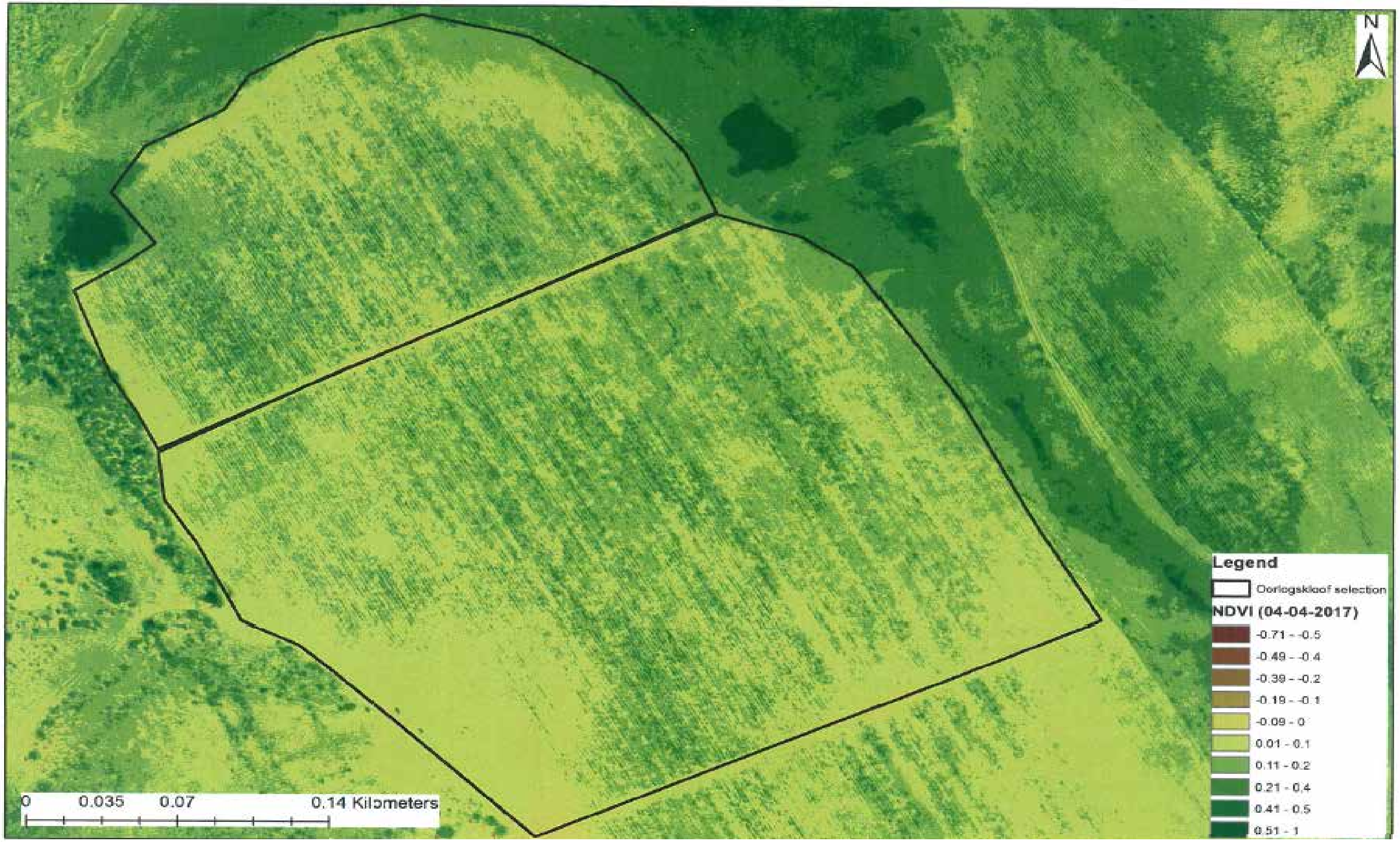

Figure 4.19: NDVI map of the Oorlogskloof study site on the 4th April 2017.

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Figure 4.20: NDVI map of the Oorlogskloof study site on the 10th February 2018.

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Figure 4.21: NDVI map of the Oorlogskloof study site on the 22nd January 2019.

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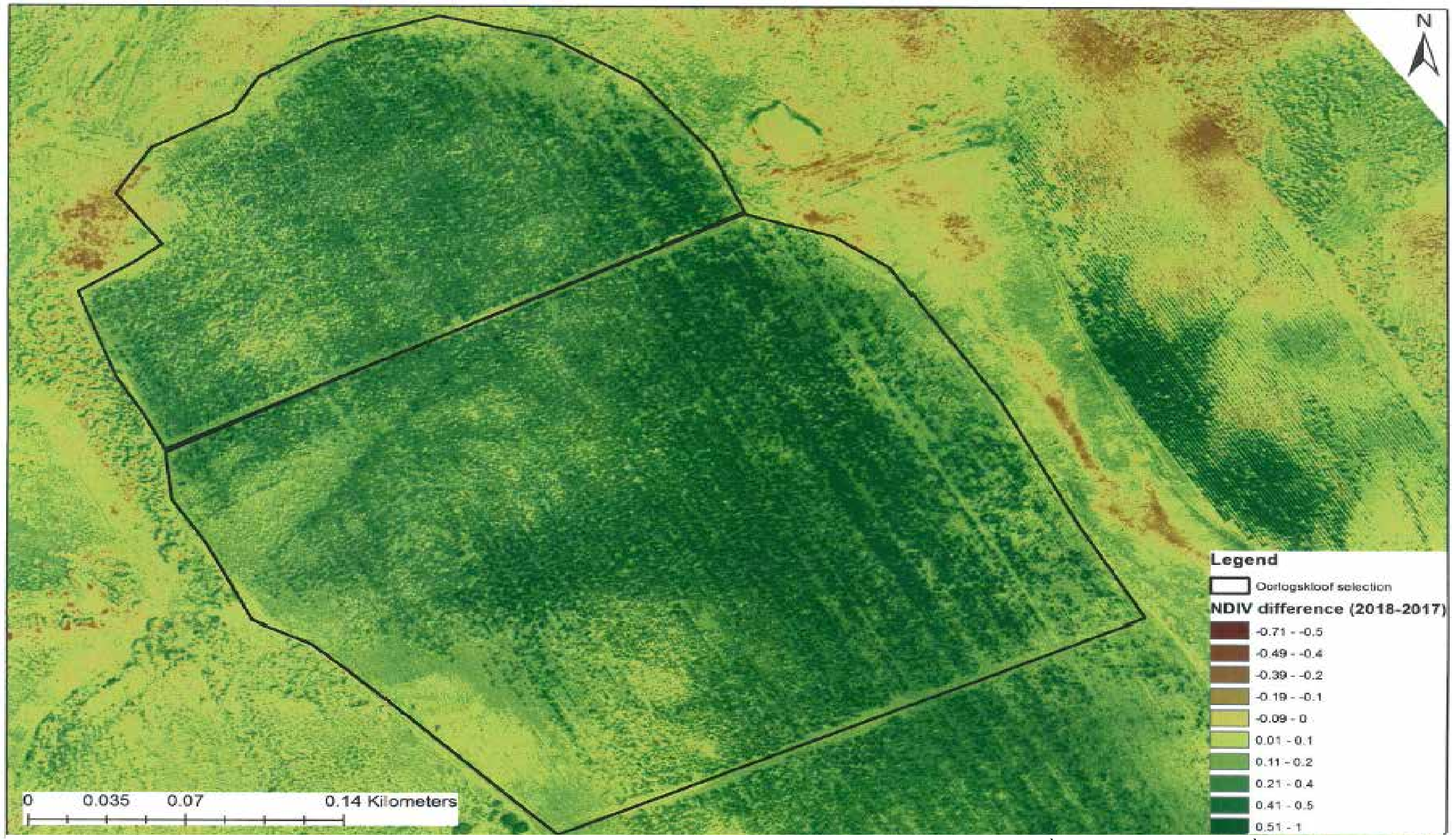

Figure 4.22: NDVI map of the Oorlogskloof study site showing the difference in vegetation between 4th April 2017 and 10th February 2018.

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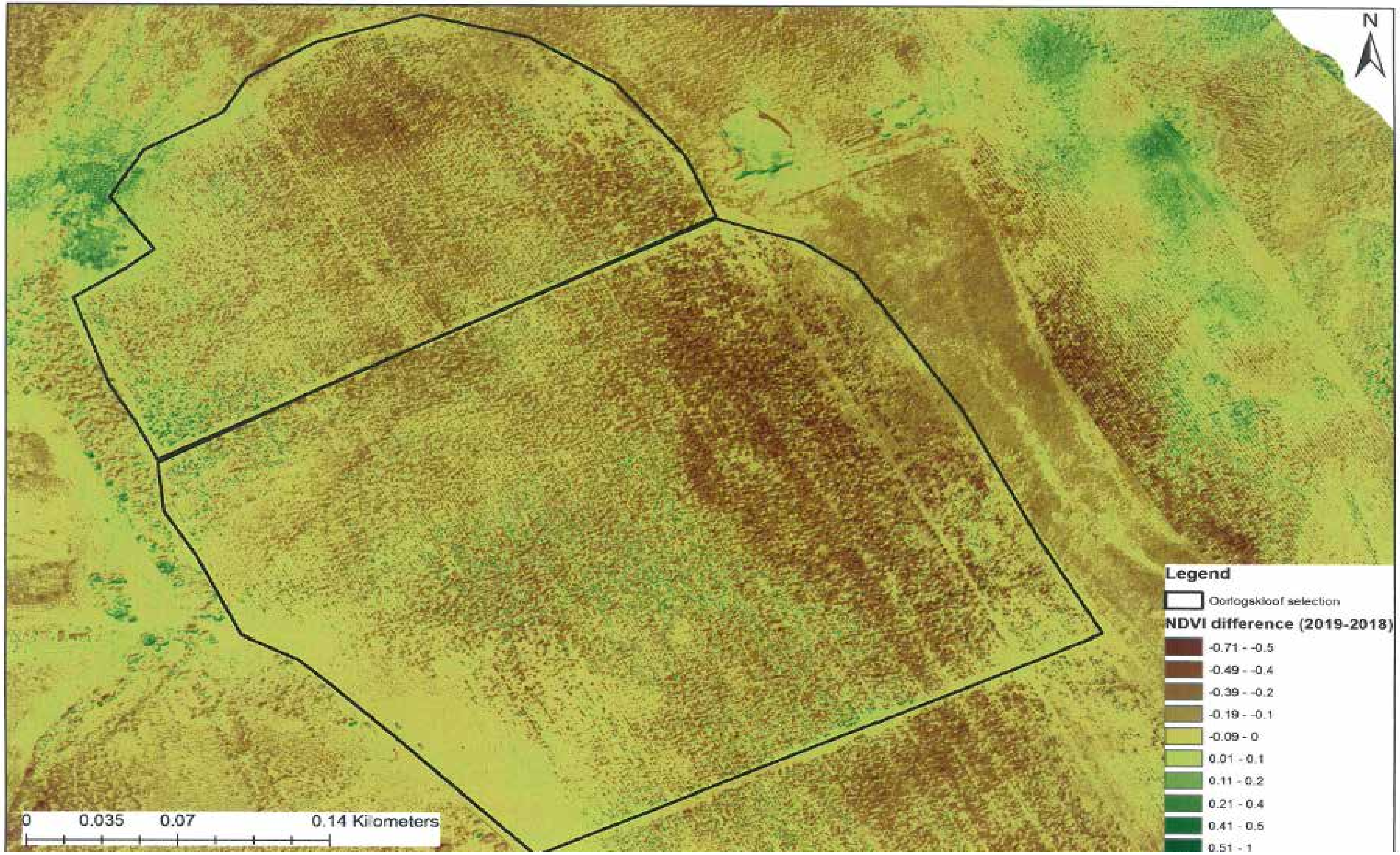

Figure 4.23: NDVI map of the Oorlogskloof study site showing the difference in vegetation between 10th February 2018 and 22nd January 2019.

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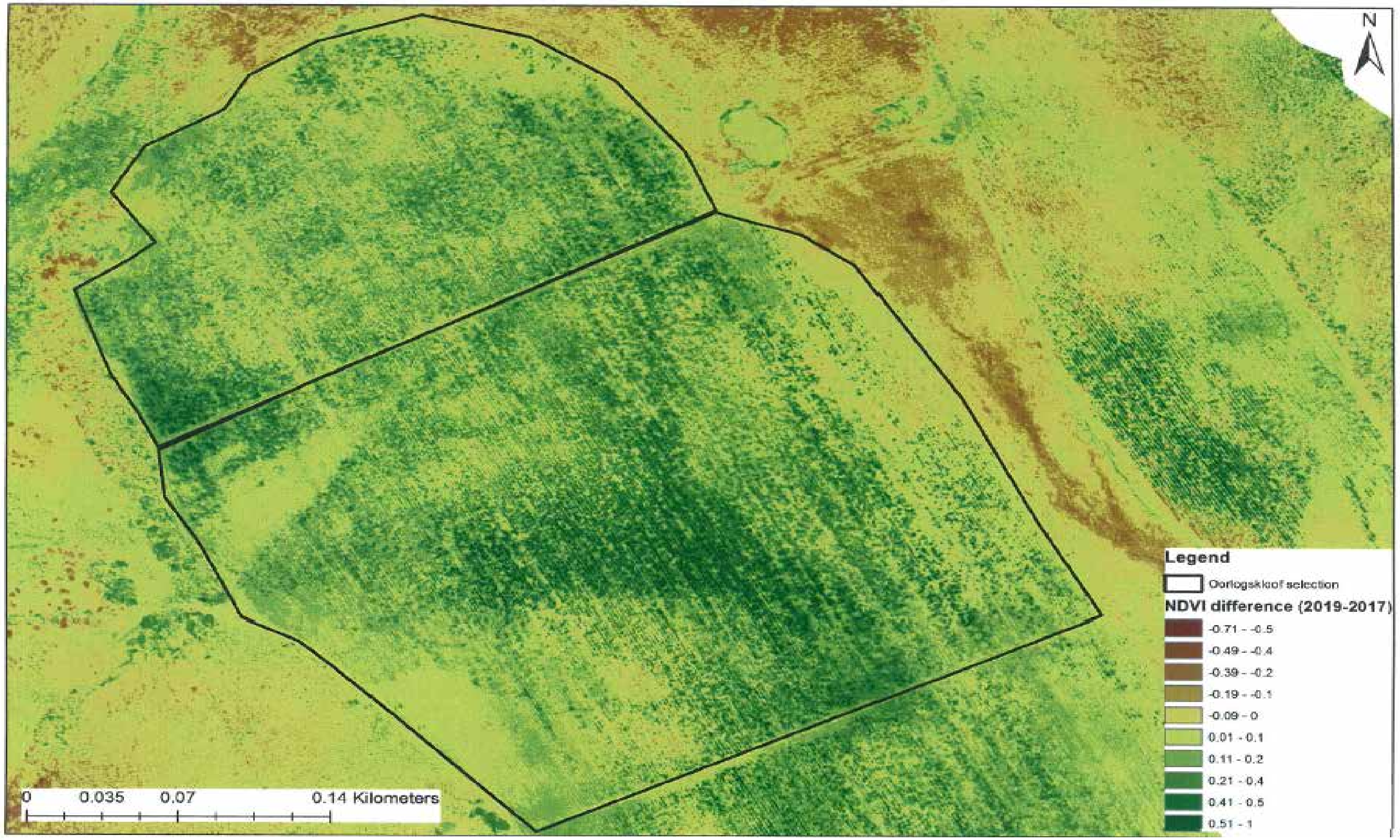

Figure 4.24: NDVI map of the Oorlogskloof study site showing the difference in vegetation between 4th April 2017 and 22nd January 2019.

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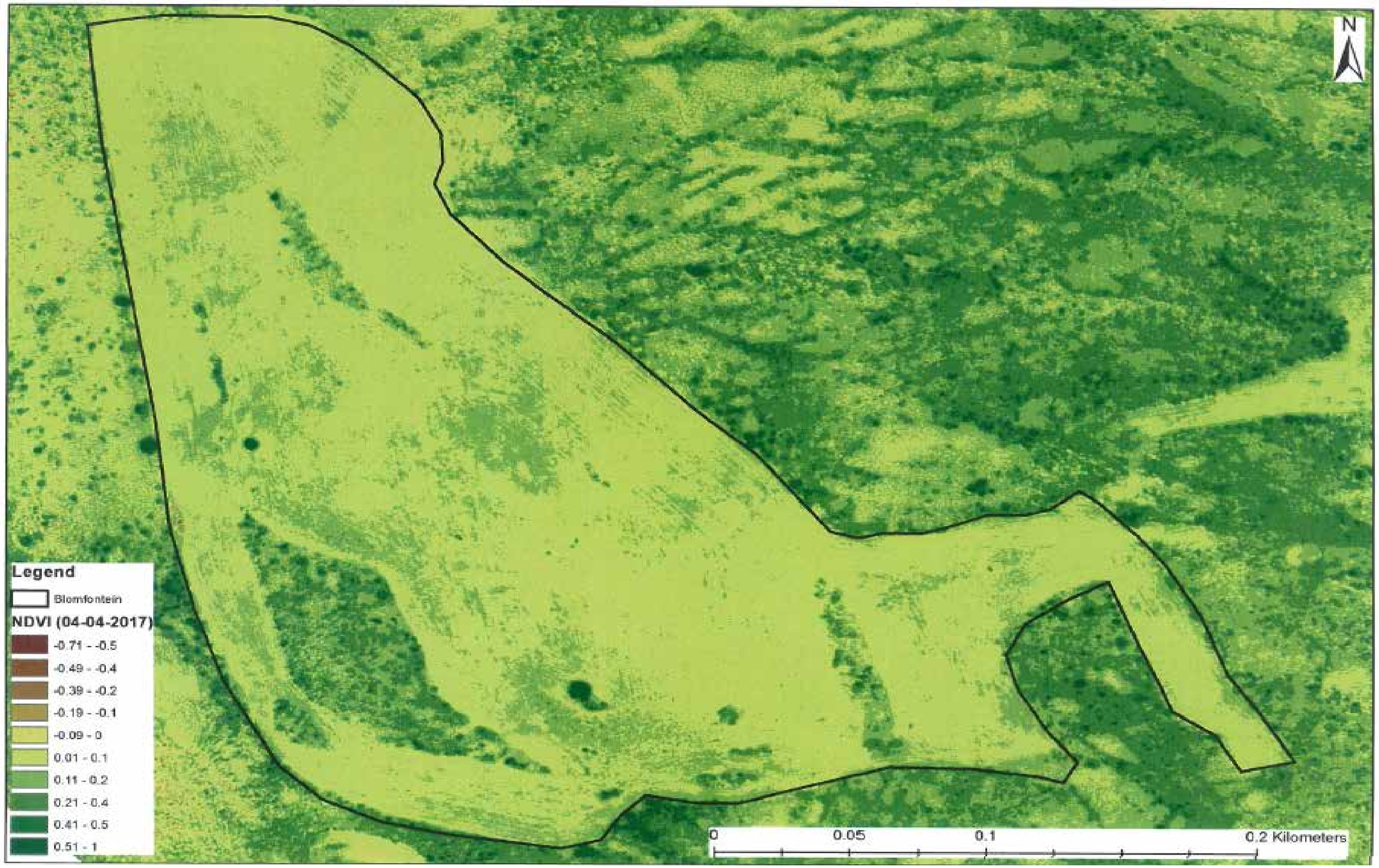

Figure 4.25: NDVI map of the Klein Blomfontein study site on the 4th April 2017.

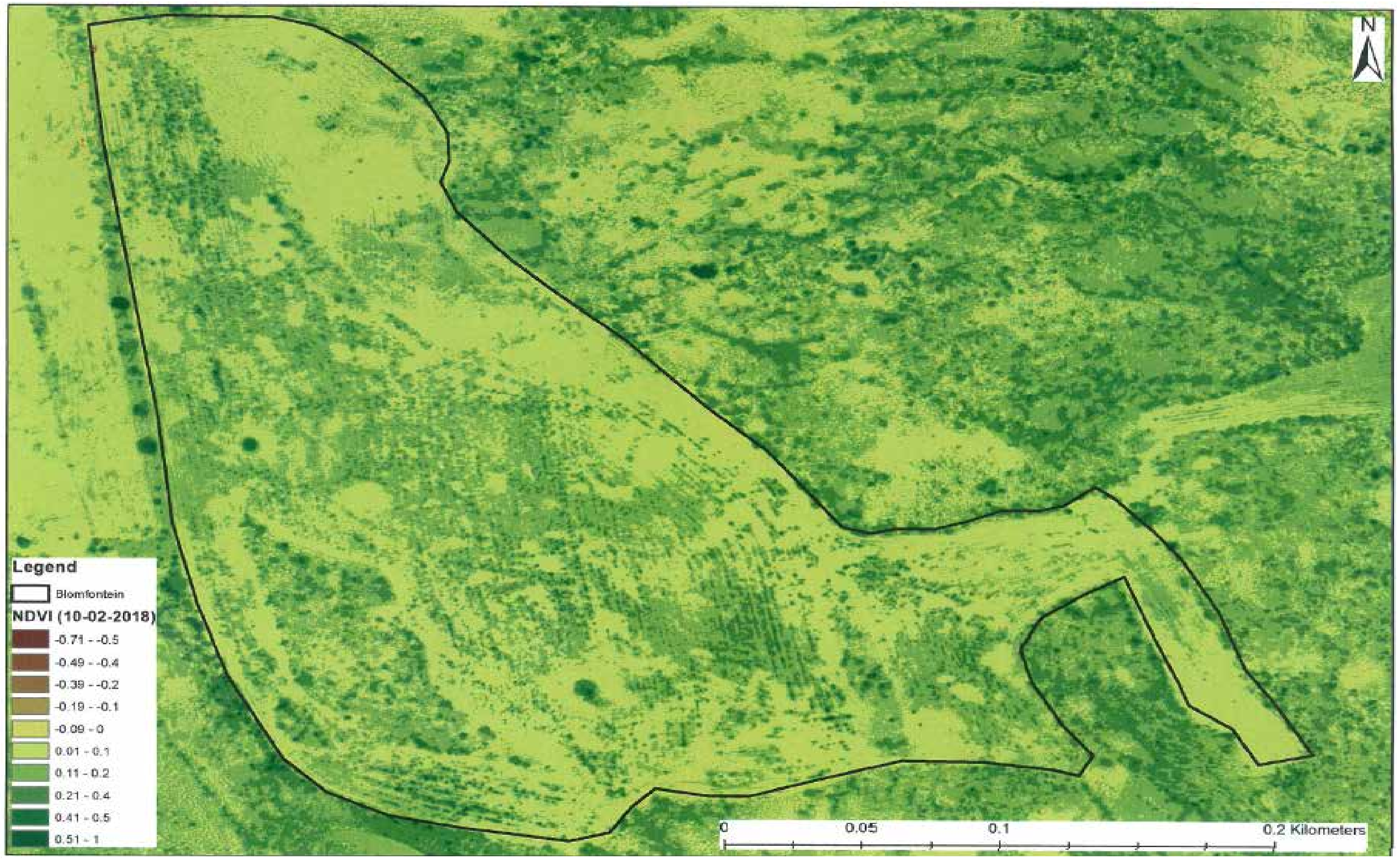

Figure 4.26: NDVI map of the Klein Blomfontein study site on the 10th February 2018.

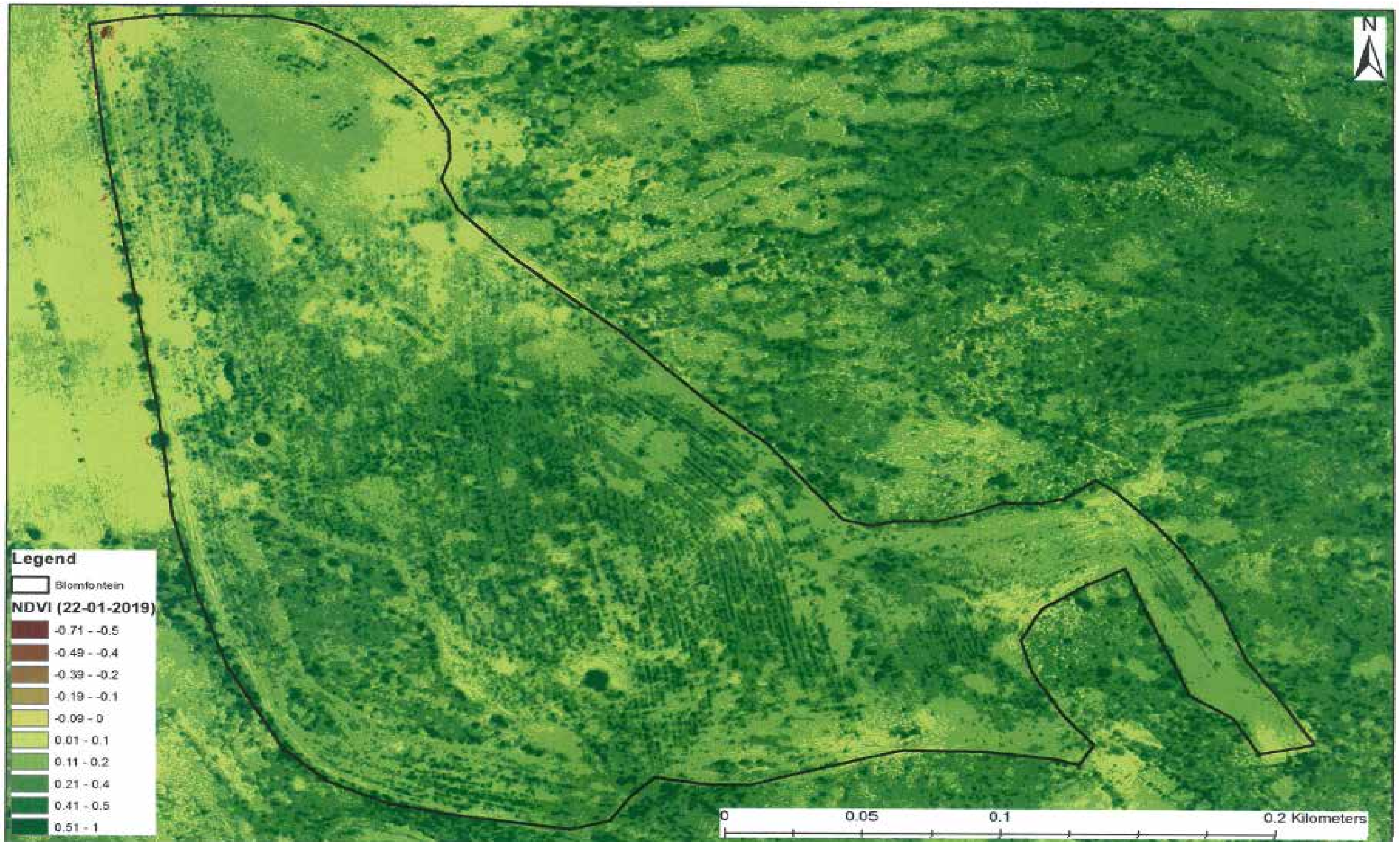

Figure 4.27: NDVI map of the Klein Blomfontein study site on the 22nd January 2019.

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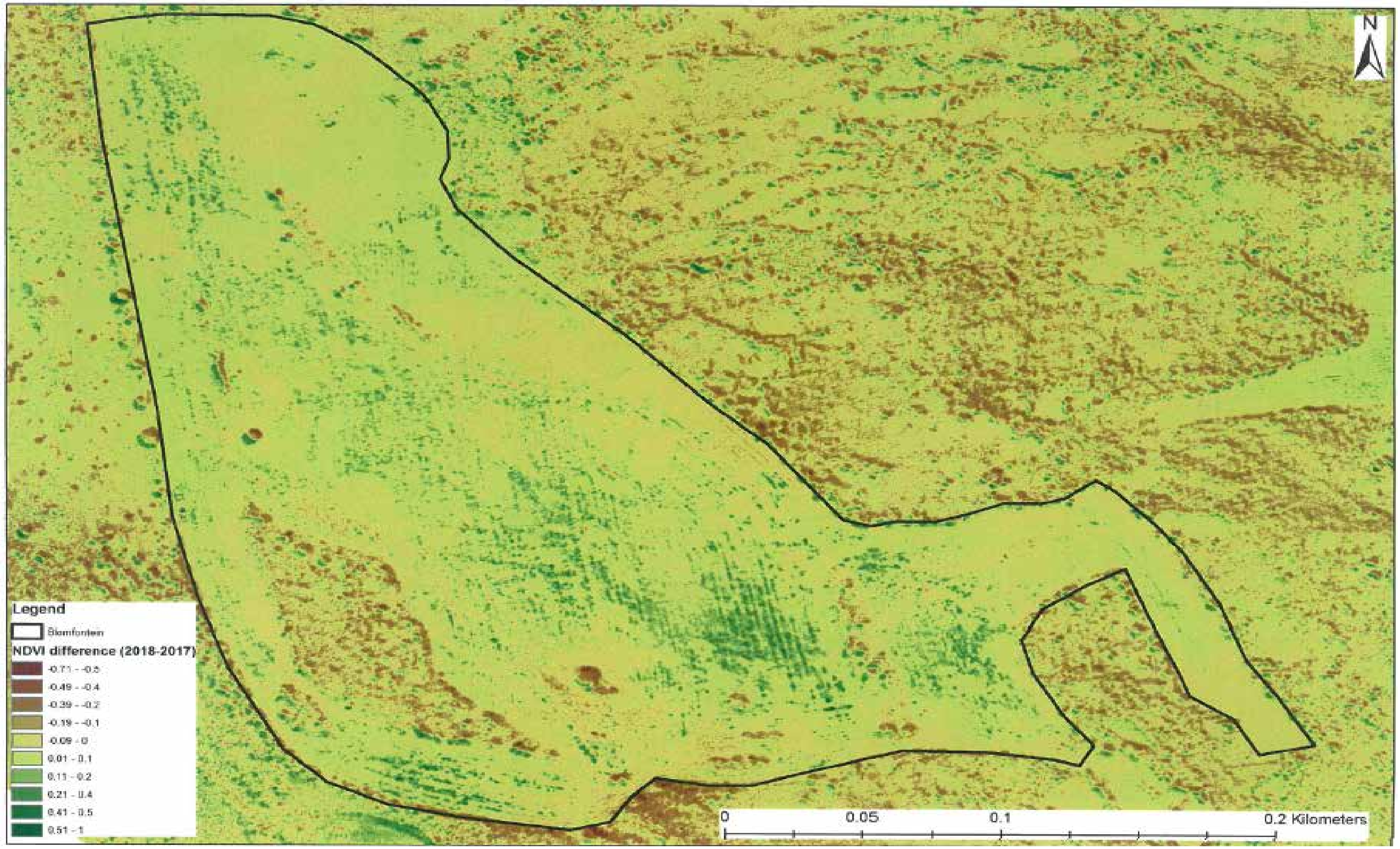

Figure 4.28: NDVI map of the Klein Blomfontein study site showing the difference in vegetation between 4th April 2017 and 10th February 2018.

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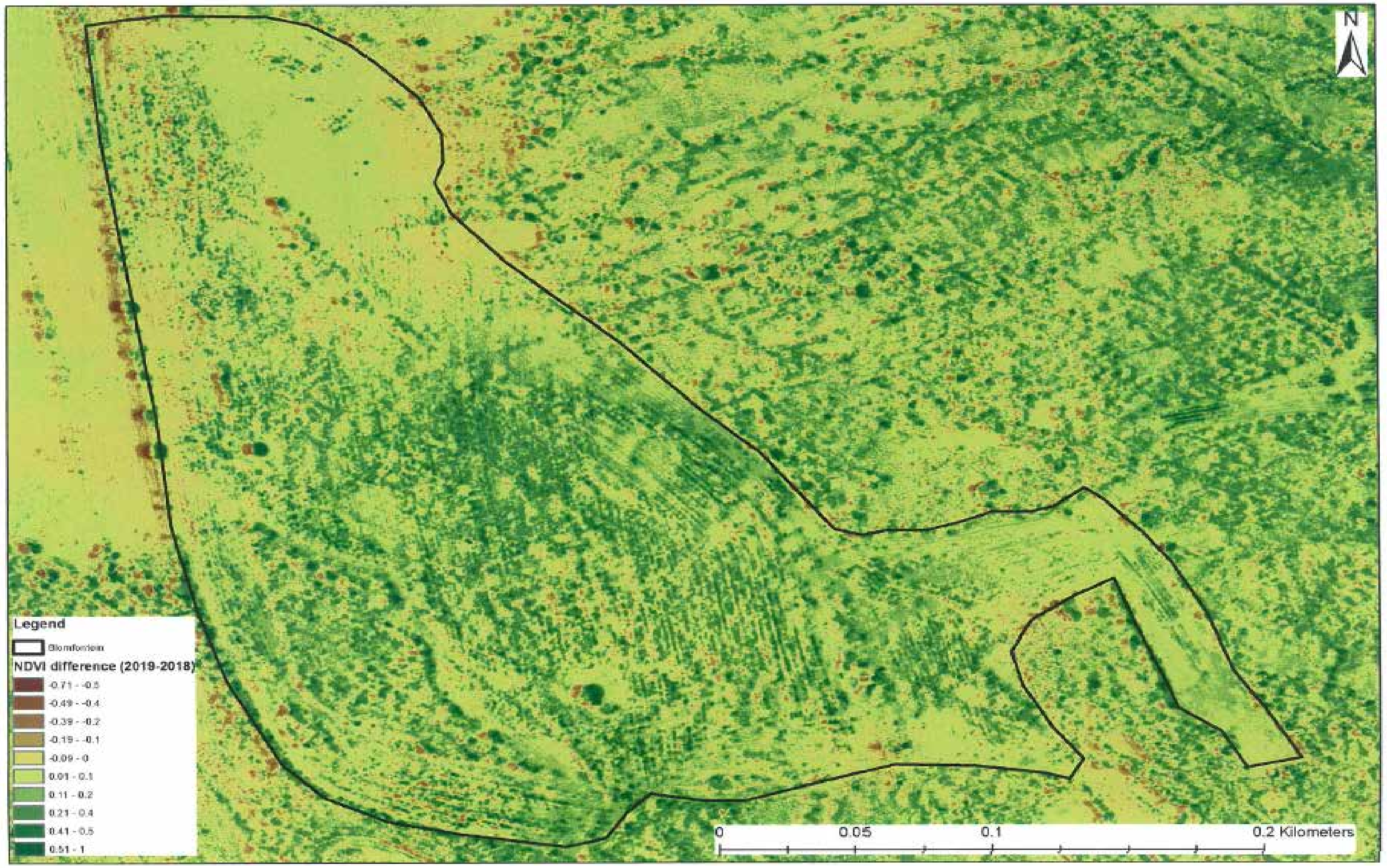

Figure 4.29: NDVI map of Klein Blomfontein study site showing the difference in vegetation between 10th February 2018 and 22nd January 2019.

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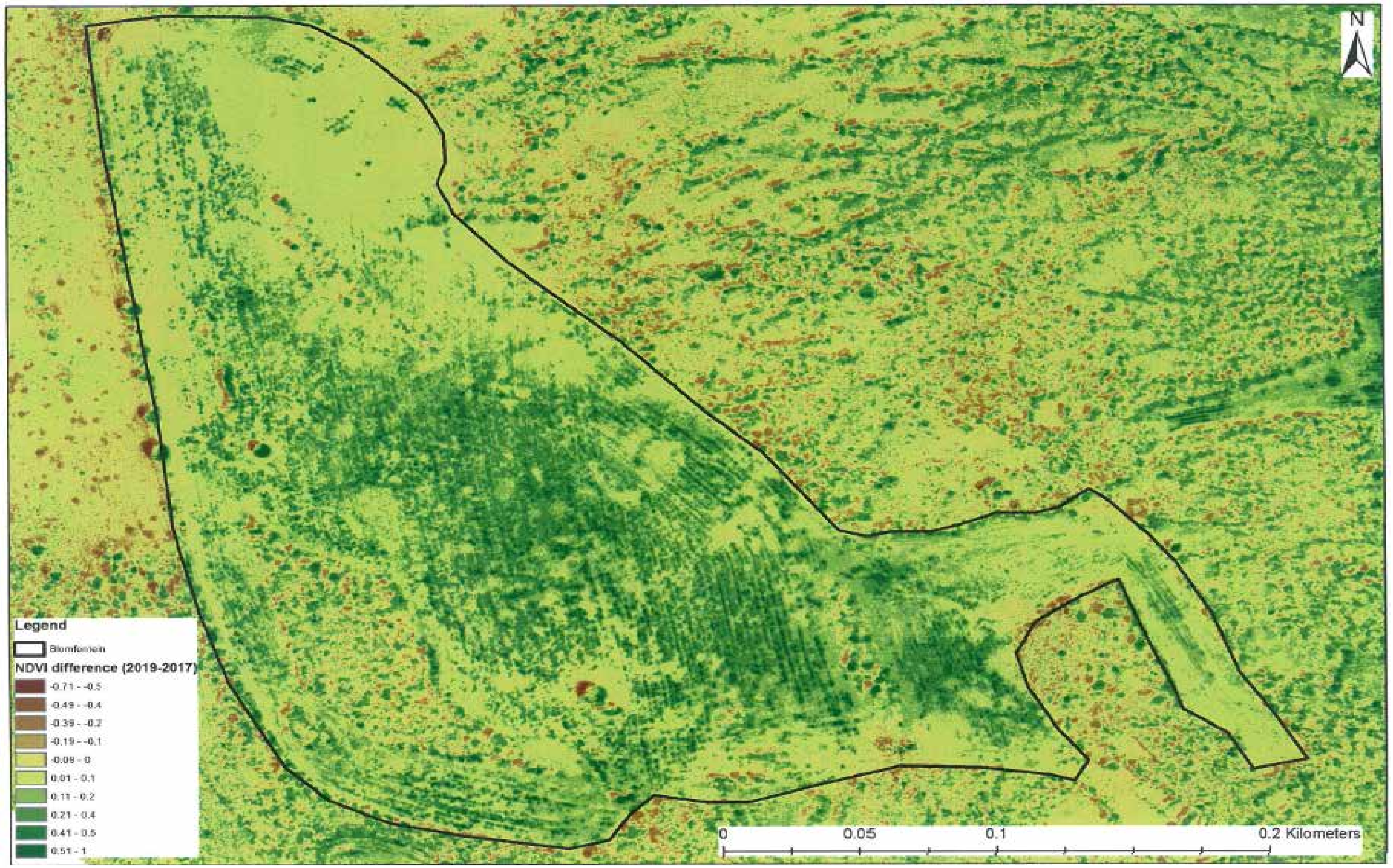

Figure 4.30: NDVI map of the Klein Blomfontein study site showing the difference in vegetation between 4th April 2017 and 22nd January 2019.

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4.5 Conclusion

There were no difference in total number weeds per square meter between study sites. However, there were difference observed in terms of types of weeds. Results showed that only *Arctotheca calendula, Chysocoma oblongifolia, Othonna coronofolia* and *Raphanus raphanistrum* produced PA's. These PA's were dominated by PANO. There were no correlation between the numbers of weeds producing PA's and PA's concentration found in the Rooibos plant. A pot study revealed that Rooibos on its own cannot produce PA's rather than obtaining PA's from the contaminated soil through absorption.

A decrease in vegetation growth from the study sites was due to plant stunting caused by shallow soil effects and slow growth caused by plant stress (frost). However, an increase in vegetation growth was observed on deeper soils across the study sites. Prominent vegetative increase was on the deeper soils at Oorlogskloof (refer to section 3.3.1) with the soil depth greater than 500 mm. Higher rainfall received in 2018 led to more water storage which formed a water table on the plinthics at Rogland and Klein Blomfontein (refer to section 3.3.3.2) had a positive influence towards the vegetative growth by providing water during the critical stage were water was needed during the growth season.

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CHAPTER 5: CONCLUSIONS, RECOMMENDATIONS AND FUTURE RESEARCH

5.1 Conclusions

The soil water content (SWC) was low in summer due to low rainfall and high evapotranspiration (ET). However, in winter the SWC was high because most of the rain occurred during this period. Soils with plinthic layers stored more water during the rainy season which tend to be beneficial to Rooibos during the critical growth stages where rainfall was low. Moreover, total SWC of the deeper soils remained high compared to the shallow soil during the course of the study. The low SWC on the shallow soil was due to low soil was storage capacity.

The cumulative evapotranspiration (ET) of the north Bokkeveld was high compared to both shallow and deep soils of the south Bokkeveld. The high ET was triggered by high rainfall and high SWC. Furthermore, cumulative upward capillary flow (U) was high on soils with shallow plinthic layers. In winter, upward capillary flow and drainage occurred to be at peak as compared to summer. The high upward capillary flow was induced by high rainfall which led to high SWC and soil water table.

Soil water loss and gain in the soil profile was mostly influenced by external factors. The loss of water was high in the 0 – 200 mm soil depth compared to 600 to 1 000 mm soil depth. The high loss of water in the 0 – 200 mm soil depth was due to the exposure of the layer to sunlight and wind which stimulated ET. Furthermore, high bulk density on the surface layer impacted soil water redistribution which led to most of water being loss in the 0 – 200 mm soil layer.

Rooibos from the study sites contained pyrrolizidine alkaloids (PA's) and *Arctotheca calendula*, *Chysocoma oblogifolia*, *Othonna coronofolia* and *Raphanus raphanistrum* were the most dominant weeds that produced these PA's. The PA's concentration in Rooibos was high at Oorlogskloof compared to Klein Blomfontein. However, there was no correlation between the dominant weeds containing PA's and PA's concentration measured in Rooibos. A pot study revealed that Rooibos absorbed PA's from decayed weeds containing PA's in the soil.

5.2 Recommendations

Rooibos prefer deep soils with high soil water storage and high soil water content, hence most of Rooibos was stunted on shallow soils. It is therefore suggested that farmers should

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utilize deep soils as much as possible compared to shallow soils in order to optimize Rooibos production.

Since weeds are source of PA's, it is important that the current code of practice for weeds control to prevent and reduce PA's contamination in food and feeds (Codex Alimentarius Commission, 2014) be adhered to.

5.3 Future research

Future research is recommended on investigating the effects of tillage practice on cultivation of Rooibos for biomass production and water management. Since best tillage practice is unknown for Rooibos, it is believed that deep tinny tillage improves water infiltration, storage, SWC and roots penetration which eventually leads to the improved biomass production. Therefore, investigating different tillage techniques over the life span of Rooibos will provide a better understanding of water usage throughout its growing period. Looking at the dryness forecast, it is suggested that the irrigation research on Rooibos including timing of irrigation be considered.

A study on PA's contamination in the soil, the correlation between the soil PA's and PA's concentration and a pot study on different soil type in Rooibos is suggested in order to provide better understanding towards Rooibos PA's absorption.

In addition, a research that would investigate the seasonal accumulation of PA's concentration in Rooibos is recommended.

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APPENDICES

Appendix 1 – Comprehensive description of profile pits

Profile number:	Rogland 1	Slope form:	Straight
Latitude and longitude:	31 13' 29,154'' S/ 19 01'08,655''E	Aspect:	West
Soil form:	Wasbank	Terrain unit:	Midslope
Soil family:	Lynedoch (2000)	Altitude:	848.3 m
Parent material:	Sandstone	Surface coarse fraction: None	
Slope:	2.8%		

HORIZON	DEPTH (mm)	DESCRIPTION	DIAGNOSTIC HORIZON
A	250	Dry colour: Light grey 5YR 5/1; moist colour: very dark brown 10YR 2/2; structure: apedal single grained; consistency: lose in dry state, lime: none; gravel: none; few plants roots observed; clear transition.	Orthic
E	650	Dry colour: White 5YR 8/1; moist colour: yellowish brown 10YR 5/4; structure: apedal granular; consistency: slightly hard in dry state and friable in moist state; lime: none; gravel: none; very few plants roots observed; abrupt transition.	E
B	650+	Dry colour: Pinkish grey 7.5YR 6/2; moist colour: dark brown 10YR 3/3; structure: apedal massive; consistency: hard in dry state and slightly hard in moist state; lime: none; gravel: none; no plants roots observe; mottle: Common (2-20%), medium (5mm – 15 mm), clear and red in colour.	Hard plinthic

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Profile number:	Rogland 2	Slope form:	Straight
Latitude and longitude:	31 13' 32,052'' S/ 19 01'10,256''E	Aspect:	South West
Soil form:	Wasbank	Terrain unit:	Midslope
Soil family:	Lynedoch (2000)	Altitude:	848.1 m
Parent material:	Sandstone	Surface coarse fraction: None	
Slope:	3.3%		

HORIZON	DEPTH (mm)	DESCRIPTION	DIAGNOSTIC HORIZON
A	300	Dry colour: Light grey 5YR 5/1; moist colour: very dark brown 10YR 2/2; structure: apedal single grained; consistency: lose in dry state, lime: none; gravel: none; few plants roots observed; clear transition.	Orthic
E	540	Dry colour: White 5YR 8/1; moist colour: yellowish brown 10YR 5/4; structure: apedal granular; consistency: slightly hard in dry state and friable in moist state; lime: none; gravel: none; very few plants roots observed; abrupt transition.	E
B	540+	Dry colour: Pinkish grey 7.5YR 6/2; moist colour: dark brown 10YR 3/3; structure: apedal massive; consistency: hard in dry state and slightly hard in moist state; lime: none; gravel: none; no plants roots observe; mottle: Common (2-20%), medium (5mm – 15 mm), clear and red in colour.	Hard plinthic

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Profile number:	Rogland 3	Slope form:	Concave
Latitude and longitude:	31 13' 34,116'' S/ 19 01'14,020''E	Aspect:	South West
Soil form:	Wasbank	Terrain unit:	Midslope
Soil family:	Lynedoch (2000)	Altitude:	849.2 m
Parent material:	Sandstone	Surface coarse fraction: None	
Slope:	3.2%		

HORIZON	DEPTH (mm)	DESCRIPTION	DIAGNOSTIC HORIZON
A	300	Dry colour: Light grey 5YR 5/1; moist colour: very dark brown 10YR 3/3; structure: apedal single grained; consistency: lose in dry state, lime: none; gravel: none; few plants roots observed; clear transition.	Orthic
E	500	Dry colour: Pink 5YR 8/4; moist colour: reddish yellow 5YR 7/6; structure: apedal granular; consistency: slightly hard in dry state and friable in moist state; lime: none; gravel: none; very few plants roots observed; abrupt transition.	E
B	500+	Dry colour: Pinkish grey 7.5YR 6/2; moist colour: dark brown 10YR 3/3; structure: apedal massive; consistency: hard in dry state and slightly hard in moist state; lime: none; gravel: none; no plants roots observe; mottle: Few (< 2%), medium (5mm – 15 mm), clear and red in colour.	Hard plinthic

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Profile number:	Rogland 4	Slope form:	Straight
Latitude and longitude:	31 13’ 35,031’’ S/ 19 01'18,032’’E	Aspect:	South West
Soil form:	Wasbank	Terrain unit:	Midslope
Soil family:	Lynedoch (2000)	Altitude:	849.9 m
Parent material:	Sandstone	Surface coarse fraction:	None
Slope:	4.2%		

HORIZON	DEPTH (mm)	DESCRIPTION	DIAGNOSTIC HORIZON
A	200	Dry colour: Light grey 5YR 5/1; moist colour: very dark brown 10YR 3/3; structure: apedal single grained; consistency: lose in dry state, lime: none; gravel: none; few plants roots observed; clear transition.	Orthic
E	500	Dry colour: Pinkish grey 7.5YR 7/2; moist colour: reddish yellow 5YR 7/6; structure: apedal granular; consistency: slightly hard in dry state and friable in moist state; lime: none; gravel: none; very few plants roots observed; abrupt transition.	E
B	500+	Dry colour: Pinkish grey 7.5YR 6/2; moist colour: dark brown 10YR 3/3; structure: apedal massive; consistency: hard in dry state and slightly in moist state; lime: none; gravel: none; no plants roots observe; mottle: Few (< 2%), medium (5mm – 15 mm), clear and red in colour.	Hard plinthic

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Profile number:	Rogland 5	Slope form:	Straight
Latitude and longitude:	31 13' 37,096'' S/ 19 01'09,340''E	Aspect:	South West
Soil form:	Wasbank	Terrain unit:	Midslope
Soil family:	Lynedoch (2000)	Altitude:	854.1 m
Parent material:	Sandstone	Surface coarse fraction: None	
Slope:	3.8%		

HORIZON	DEPTH (mm)	DESCRIPTION	DIAGNOSTIC HORIZON
A	120	Dry colour: Light grey 7.5YR 5/2; moist colour: brown 10YR 3/3; structure: apedal single grained; consistency: lose in dry state, lime: none; gravel: none; few plants roots observed; clear transition.	Orthic
E	520	Dry colour: Pinkish grey 7.5YR 7/2; moist colour: dark yellowish brown 10YR 4/4; structure: apedal granular; consistency: slightly hard in dry state and friable in moist state; lime: none; gravel: none; very few plants roots observed; abrupt transition.	E
B	520+	Dry colour: Pinkish grey 7.5YR 6/2; moist colour: dark brown 10YR 3/3; structure: apedal massive; consistency: hard in dry state and slightly hard in moist state; lime: none; gravel: none; no plants roots observe; mottle: Few (< 2%), medium (5mm – 15 mm), clear and red in colour.	Hard plinthic

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Profile number:	Meulsteenvlei 1	Slope form:	Straight
Latitude and longitude:	31 21' 38,255'' S/ 19 02'01,153''E	Aspect:	South West
Soil form:	Wasbank	Terrain unit:	Midslope
Soil family:	Lynedoch (2000)	Altitude:	807 m
Parent material:	Sandstone	Surface coarse fraction:	None
Slope:	3.7%		

HORIZON	DEPTH (mm)	DESCRIPTION	DIAGNOSTIC HORIZON
A	160	Dry colour: Brownish yellow 10YR 6/6; moist colour: yellowish brown 10YR 5/4; structure: apedal single grained; consistency: lose in dry state, lime: none; gravel: none; few plants roots observed; clear transition.	Orthic
E	560	Dry colour: Brownish yellow 10YR 6/6; moist colour: yellowish brown 10YR 5/8; structure: apedal granular; consistency: lose in dry state; lime: none; gravel: none; very few plants roots observed; clear transition.	E
B	560+	Dry colour: yellowish brown 10YR 5/8; moist colour: yellowish brown 10YR 5/8; structure: apedal massive; consistency: hard in dry state and slightly hard in moist state; lime: none; gravel: few (<2%), size (2-25 mm); no plants roots observe; mottle: Few (< 2%), medium (5mm – 15 mm), clear and red in colour.	Hard plinthic

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Profile number:	Meulsteenvlei 2	Slope form:	Straight
Latitude and longitude:	31 21' 38,325'' S/ 19 01'58,388''E	Aspect:	South West
Soil form:	Wasbank	Terrain unit:	Midslope
Soil family:	Lynedoch (2000)	Altitude:	808 m
Parent material:	Sandstone	Surface coarse fraction: None	
Slope:	2.0%		

HORIZON	DEPTH (mm)	DESCRIPTION	DIAGNOSTIC HORIZON
A	300	Dry colour: Brownish yellow 10YR 5/4; moist colour: yellowish brown 10YR 4/4; structure: apedal single grained; consistency: lose in dry state, lime: none; gravel: none; few plants roots observed; clear transition.	Orthic
E	700	Dry colour: Brownish yellow 10YR 6/6; moist colour: yellowish brown 10YR 5/8; structure: apedal granular; consistency: lose in dry state; lime: none; gravel: none; very few plants roots observed; clear transition.	E
B	700+	Dry colour: light yellowish brown 10YR 6/4; moist colour: yellowish brown 10YR 5/8; structure: apedal massive; consistency: hard in dry state and slightly hard in moist state; lime: none; gravel: few (<2%), size (2-25 mm); no plants roots observe; mottle: Few (< 2%), medium (5mm – 15 mm), clear and red in colour.	Hard plinthic

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Profile number:	Meulsteenvlei 3	Slope form:	Straight
Latitude and longitude:	31 21' 39,093'' S/ 19 01'53,291''E	Aspect:	South West
Soil form:	Wasbank	Terrain unit:	Midslope
Soil family:	Lynedoch (2000)	Altitude:	810 m
Parent material:	Sandstone	Surface coarse fraction: None	
Slope:	2.1%		

HORIZON	DEPTH (mm)	DESCRIPTION	DIAGNOSTIC HORIZON
A	180	Dry colour: Brownish yellow 10YR 5/4; moist colour: yellowish brown 10YR 4/4; structure: apedal single grained; consistency: lose in dry state, lime: none; gravel: none; few plants roots observed; clear transition.	Orthic
E	300	Dry colour: Brownish yellow 10YR 6/6; moist colour: yellowish brown 10YR 5/8; structure: apedal granular; consistency: lose in dry state; lime: none; gravel: none; very few plants roots observed; clear transition.	E
B	300+	Dry colour: light yellowish brown 10YR 6/4; moist colour: yellowish brown 10YR 5/8; structure: apedal massive; consistency: hard in dry state and slightly hard in moist state; lime: none; gravel: few (<2%), size (2-25 mm); no plants roots observe; mottle: Few (< 2%), medium (5mm – 15 mm), clear and red in colour.	Hard plinthic

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Profile number:	Meulsteenvlei 4	Slope form:	Straight
Latitude and longitude:	31 21' 39,074'' S/ 19 01'50,556''E	Aspect:	South West
Soil form:	Wasbank	Terrain unit:	Midslope
Soil family:	Lynedoch (2000)	Altitude:	811.5 m
Parent material:	Sandstone	Surface coarse fraction:	None
Slope:	2.1%		

HORIZON	DEPTH (mm)	DESCRIPTION	DIAGNOSTIC HORIZON
A	130	Dry colour: Brownish yellow 10YR 5/4; moist colour: yellowish brown 10YR 4/4; structure: apedal single grained; consistency: lose in dry state, lime: none; gravel: none; few plants roots observed; clear transition.	Orthic
E	330	Dry colour: Brownish yellow 10YR 6/6; moist colour: yellowish brown 10YR 5/8; structure: apedal granular; consistency: lose in dry state; lime: none; gravel: none; very few plants roots observed; clear transition.	E
B	330+	Dry colour: light yellowish brown 10YR 6/4; moist colour: yellowish brown 10YR 5/8; structure: apedal massive; consistency: hard in dry state and slightly hard in moist state; lime: none; gravel: few (<2%), size (2-25 mm); no plants roots observe; mottle: Few (< 2%), medium (5mm – 15 mm), clear and red in colour.	Hard plinthic

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Profile number:	Meulsteenvlei 5	Slope form:	Straight
Latitude and longitude:	31 21' 40,067'' S/ 19 01'47,063''E	Aspect:	South
Soil form:	Wasbank	Terrain unit:	Midslope
Soil family:	Lynedoch (2000)	Altitude:	812.5 m
Parent material:	Sandstone	Surface coarse fraction: None	
Slope:	2.8%		

HORIZON	DEPTH (mm)	DESCRIPTION	DIAGNOSTIC HORIZON
A	150	Dry colour: Brownish yellow 10YR 5/4; moist colour: yellowish brown 10YR 4/4; structure: apedal single grained; consistency: lose in dry state, lime: none; gravel: none; few plants roots observed; clear transition.	Orthic
E	300	Dry colour: Brownish yellow 10YR 6/6; moist colour: yellowish brown 10YR 5/8; structure: apedal granular; consistency: lose in dry state; lime: none; gravel: none; very few plants roots observed; clear transition.	E
B	300+	Dry colour: light yellowish brown 10YR 6/4; moist colour: yellowish brown 10YR 5/8; structure: apedal massive; consistency: hard in dry state and slightly hard in moist state; lime: none; gravel: few (<2%), size (2-25 mm); no plants roots observe; mottle: Few (< 2%), medium (5mm – 15 mm), clear and red in colour.	Hard plinthic

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Profile number:	Meulsteenvlei 6	Slope form:	Straight
Latitude and longitude:	31 21' 43,021'' S/ 19 01''44,096''E	Aspect:	South West
Soil form:	Mispah	Terrain unit:	Midslope
Soil family:	Gulu (2100)	Altitude:	814.4 m
Parent material:	Sandstone	Surface coarse fraction :< 20%	
Slope:	1.6%		

HORIZON	DEPTH (mm)	DESCRIPTION	DIAGNOSTIC HORIZON
A	150	Dry colour: Brown 7.5YR 4/4; moist colour: dark yellowish brown 10YR 4/6; structure: apedal single grained; consistency: lose in dry state, lime: none; gravel: < 20% with the size ranging between 2 mm and 25 mm; plants roots observed; abrupt transition.	Orthic
R	150+	Hard sandstone rock	Rock

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Profile number:	Meulsteenvlei 7	Slope form:	Straight
Latitude and longitude:	31 21' 46,054'' S/ 19 01''41,022''E	Aspect:	South West
Soil form:	Mispah	Terrain unit:	Midslope
Soil family:	Gulu (2100)	Altitude:	817.1 m
Parent material:	Sandstone	Surface coarse fraction: <20%	
Slope:	3.0%		

HORIZON	DEPTH (mm)	DESCRIPTION	DIAGNOSTIC HORIZON
A	200	Dry colour: Strong brown 7.5YR 4/6; moist colour: brown 7.5YR 4/3; structure: apedal single grained; consistency: lose in dry state, lime: none; gravel: < 20% with the size ranging between 2 mm and 25 mm; plants roots observed; abrupt transition.	Orthic
R	200+	Hard sandstone rock	Rock

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Profile number:	Meulsteenvlei 8	Slope form:	Concave
Latitude and longitude:	31 21' 36,022'' S/ 19 01''49,057''E	Aspect:	South East
Soil form:	Dresden	Terrain unit:	Midslope
Soil family:	Hilldrop (2000)	Altitude:	810.2 m
Parent material:	Sandstone	Surface coarse fraction: <20%	
Slope:	2.4%		

HORIZON	DEPTH (mm)	DESCRIPTION	DIAGNOSTIC HORIZON
A	200	Dry colour: Brown 7.5YR 5/3; moist colour: brown 7.5YR 4/4; structure: apedal single grained; consistency: lose in dry state, lime: none; gravel: <20% with the size ranging between 2 mm and 25 mm; few plants roots observed; smooth transition.	Orthic
B	200+	Dry colour: Brown 7.5YR 5/3; moist colour: brown 7.5YR 4/3; structure: apedal massive; consistency: hard in dry state and slightly hard in moist state; lime: none; gravel: common (20-50%), size (2-25 mm); no plants roots observe; mottle: common (2 – 20%), medium (5mm – 15 mm), clear and red in colour.	Hard plinthic

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Profile number:	Meulsteenvlei 9	Slope form:	Concave
Latitude and longitude:	31 21' 34,089'' S/ 19 01''51,011''E	Aspect:	South East
Soil form:	Dresden	Terrain unit:	Midslope
Soil family:	Hilldrop (2000)	Altitude:	809.2 m
Parent material:	Sandstone	Surface coarse fraction:	<20%
Slope:	2.3%		

HORIZON	DEPTH (mm)	DESCRIPTION	DIAGNOSTIC HORIZON
A	200	Dry colour: Yellowish brown 10YR 5/4; moist colour: brown 7.5YR 4/3; structure: apedal single grained; consistency: lose in dry state, lime: none; gravel: <20% with the size ranging between 2 mm and 25 mm; few plants roots observed; clear transition.	Orthic
B	200+	Dry colour: Brown 7.5YR 5/3; moist colour: brown 7.5YR 4/3; structure: apedal massive; consistency: hard in dry state and slightly hard in moist state; lime: none; gravel: common (20-50%), size (2-25 mm); no plants roots observe; mottle: common (2 – 20%), medium (5mm – 15 mm), clear and red in colour.	Hard plinthic

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Profile number:	Meulsteenvlei 10	Slope form:	Concave
Latitude and longitude:	31 21' 31,977'' S/ 19 01''54,070''E	Aspect:	South East
Soil form:	Dresden	Terrain unit:	Midslope
Soil family:	Hilldrop (2000)	Altitude:	809.5 m
Parent material:	Sandstone	Surface coarse fraction: <20%	
Slope:	0.1%		

HORIZON	DEPTH (mm)	DESCRIPTION	DIAGNOSTIC HORIZON
A	240	Dry colour: Brown 7.5YR 5/4; moist colour: brown 7.5YR 4/4; structure: apedal single grained; consistency: lose in dry state, lime: none; gravel: <20% with the size ranging between 2 mm and 25 mm; few plants roots observed; smooth transition.	Orthic
B	240+	Dry colour: Brown 7.5YR 5/3; moist colour: brown 7.5YR 4/3; structure: apedal massive; consistency: hard in dry state and slightly hard in moist state; lime: none; gravel: common (20-50%), size (2-25 mm); no plants roots observe; mottle: common (2 – 20%), medium (5mm – 15 mm), clear and red in colour.	Hard plinthic

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Profile number: Meulsteenvlei 11

Latitude and longitude: 31 21’ 30,945’’ S/ 19 01’’57,966’’E

Soil form: Dresden

Soil family: Hilldrop (2000)

Parent material: Sandstone

Slope: 1.3%

Slope form: Concave

Aspect: North West

Terrain unit: Midslope

Altitude: 809 m

Surface coarse fraction: <20%

HORIZON	DEPTH (mm)	DESCRIPTION	DIAGNOSTIC HORIZON
A	270	Dry colour: Brown 7.5YR 5/4; moist colour: brown 7.5YR 4/4; structure: apedal single grained; consistency: lose in dry state, lime: none; gravel: <20% with the size ranging between 2 mm and 25 mm; few plants roots observed; clear transition.	Orthic
B	270+	Dry colour: Yellowish Brown 10YR 5/8; moist colour: dark brown 7.5YR 3/4; structure: apedal massive; consistency: hard in dry state and slightly hard in moist state; lime: none; gravel: common (20-50%), size (2-25 mm); no plants roots observe; mottle: common (2 – 20%), medium (5mm – 15 mm), clear and red in colour.	Hard plinthic

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Profile number:	Meulsteenvlei 12	Slope form:	Concave
Latitude and longitude:	31 21' 30,106'' S/ 19 02''00,418''E	Aspect:	North West
Soil form:	Dresden	Terrain unit:	Midslope
Soil family:	Hilldrop (2000)	Altitude:	808 m
Parent material:	Sandstone	Surface coarse fraction: <20%	
Slope:	2.4%		

HORIZON	DEPTH (mm)	DESCRIPTION	DIAGNOSTIC HORIZON
A	300	Dry colour: Yellowish brown 10YR 5/4; moist colour: dark brown 7.5YR 3/4; structure: apedal single grained; consistency: lose in dry state, lime: none; gravel: <20% with the size ranging between 2 mm and 25 mm; few plants roots observed; clear transition.	Orthic
B	300+	Dry colour: Yellowish Brown 10YR 5/8; moist colour: dark brown 7.5YR 3/4; structure: apedal massive; consistency: hard in dry state and slightly hard in moist state; lime: none; gravel: common (20-50%), size (2-25 mm); no plants roots observe; mottle: common (2 – 20%), medium (5mm – 15 mm), clear and red in colour.	Hard plinthic

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Profile number:	Meulsteenvlei 13	Slope form:	Concave
Latitude and longitude:	31 21’ 29,993’’ S/ 19 02’’04,023’’E	Aspect:	North West
Soil form:	Dresden	Terrain unit:	Midslope
Soil family:	Hilldrop (2000)	Altitude:	807.4 m
Parent material:	Sandstone	Surface coarse fraction: <20%	
Slope:	2.9%		

HORIZON	DEPTH (mm)	DESCRIPTION	DIAGNOSTIC HORIZON
A	300	Dry colour: Yellowish brown 10YR 5/4; moist colour: dark yellowish brown 10YR 4/4; structure: apedal single grained; consistency: lose in dry state, lime: none; gravel: <20% with the size ranging between 2 mm and 25 mm; few plants roots observed; clear transition.	Orthic
B	300+	Dry colour: Yellowish Brown 10YR 5/8; moist colour: dark brown 7.5YR 3/4; structure: apedal massive; consistency: hard in dry state and slightly hard in moist state; lime: none; gravel: common (20-50%), size (2-25 mm); no plants roots observe; mottle: Common (2 – 20%), medium (5mm – 15 mm), clear and red in colour.	Hard plinthic

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Profile number:	Meulsteenvlei 14	Slope form:	Straight
Latitude and longitude:	31 21' 27,969'' S/ 19 02'07,035''E	Aspect:	West
Soil form:	Wasbank	Terrain unit:	Midslope
Soil family:	Lynedoch (2000)	Altitude:	804 m
Parent material:	Sandstone	Surface coarse fraction: None	
Slope:	4.4%		

HORIZON	DEPTH (mm)	DESCRIPTION	DIAGNOSTIC HORIZON
A	200	Dry colour: Brownish yellow 10YR 5/4; moist colour: yellowish brown 10YR 4/4; structure: apedal single grained; consistency: lose in dry state, lime: none; gravel: none; few plants roots observed; clear transition.	Orthic
E	500	Dry colour: Yellowish brown 10YR 5/6; moist colour: dark yellowish brown 10YR 4/6; structure: apedal granular; consistency: lose in dry state; lime: none; gravel: none; very few plants roots observed; clear transition.	E
B	500+	Dry colour: light yellowish brown 10YR 6/4; moist colour: yellowish brown 10YR 5/8; structure: apedal massive; consistency: hard in dry state and slightly hard in moist state; lime: none; gravel: few (<2%), size (2-25 mm); no plants roots observe; mottle: few (< 2%), medium (5mm – 15 mm), clear and red in colour.	Hard plinthic

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Profile number:	Meulsteenvlei 15	Slope form:	Straight
Latitude and longitude:	31 21' 28,052'' S/ 19 02'10,141''E	Aspect:	West
Soil form:	Wasbank	Terrain unit:	Midslope
Soil family:	Lynedoch (2000)	Altitude:	799 m
Parent material:	Sandstone	Surface coarse fraction:	None
Slope:	5.0%		

HORIZON	DEPTH (mm)	DESCRIPTION	DIAGNOSTIC HORIZON
A	200	Dry colour: Brownish yellow 10YR 5/4; moist colour: yellowish brown 10YR 4/4; structure: apedal single grained; consistency: lose in dry state, lime: none; gravel: none; few plants roots observed; smooth transition.	Orthic
E	500	Dry colour: Brownish yellow 10YR 5/4; moist colour: yellowish brown 10YR 4/4; structure: apedal granular; consistency: lose in dry state; lime: none; gravel: none; very few plants roots observed; clear transition.	E
B	500+	Dry colour: light yellowish brown 10YR 6/4; moist colour: yellowish brown 10YR 5/8; structure: apedal massive; consistency: hard in dry state and slightly hard in moist state; lime: none; gravel: few (<2%), size (2-25 mm); no plants roots observe; mottle: few (< 2%), medium (5mm – 15 mm), clear and red in colour.	Hard plinthic

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Profile number:	Oorlogskloof 1	Slope form:	Straight
Latitude and longitude:	31 27’ 25,099’’ S/ 19 05’’37,006’’E	Aspect:	South East
Soil form:	Wasbank	Terrain unit:	Midslope
Soil family:	Lynedoch (2000)	Altitude:	741.3 m
Parent material:	Sandstone	Surface coarse fraction: None	
Slope:	4.1 %		

HORIZON	DEPTH (mm)	DESCRIPTION	DIAGNOSTIC HORIZON
A	170	Dry colour: grey 10YR 6/1; moist colour: dark grey 10YR 6/4; structure: apedal single grained; consistency: lose in dry state, lime: none; gravel: none; few plants roots observed; gradual smooth transition.	Orthic
E	600	Dry colour: very pale brown 10YR 7/4; moist colour: yellow 10YR 7/6; structure: apedal granular; consistency: slightly hard in dry state and friable in moist state; lime: none; gravel: none; very few plants roots observed; abrupt transition.	E
B	600+	Dry colour: yellow 10YR 8/6; moist colour: yellow 10YR 8/8; structure: apedal massive; consistency: hard in dry state and slightly hard in moist condition; lime: none; gravel: none; no plants roots observed; mottles: common (2-20%), medium size (5-15 mm), clear and red in colour.	Hard plinthic

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Profile number:	Oorlogskloof 2	Slope form:	Straight
Latitude and longitude:	31 27' 23,010'' S/ 19 05''39,076''E	Aspect:	South East
Soil form:	Longlands	Terrain unit:	Midslope
Soil family:	Ermelo (2000)	Altitude:	740.2 m
Parent material:	Sandstone	Surface coarse fraction:	None
Slope:	3.3%		

HORIZON	DEPTH (mm)	DESCRIPTION	DIAGNOSTIC HORIZON
A	300	Dry colour: Light grey 10YR 7/1; moist colour: brown 7.5YR 4/2; structure: apedal single grained; consistency: lose in dry state, lime: none; gravel: none; few plants roots observed; gradual smooth transition.	Orthic
E	900	Dry colour: light grey 10YR 7/1; moist colour: yellowish brown 10YR 5/6; structure: apedal granular; consistency: slightly hard in dry state and friable in moist state; lime: none; gravel: none; very few plants roots observed; clear transition.	E
B	900+	Dry colour: very pale brown 10YR 8/3; moist colour: reddish yellow 7.5YR 8/6; structure: apedal massive; consistency: slightly hard in dry state and friable in moist state; lime: none; gravel: none; no plants roots observe; mottle: few (< 2%), medium (5mm – 15 mm), clear and red in colour.	Soft plinthic

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Profile number:	Oorlogskloof 3	Slope form:	Straight
Latitude and longitude:	31 27’ 23,022’’ S/ 19 05’’43,005’’E	Aspect:	South
Soil form:	Longlands	Terrain unit:	Footslope
Soil family:	Ermelo (2000)	Altitude:	739.6 m
Parent material:	Sandstone	Surface coarse fraction:	None
Slope:	3.1%		

HORIZON	DEPTH (mm)	DESCRIPTION	DIAGNOSTIC HORIZON
A	300	Dry colour: grey 7.5YR 6/1; moist colour: very dark grey 7.5YR 3/1; structure: apedal single grained; consistency: lose in dry state, lime: none; gravel: none; few plants roots observed; gradual smooth transition.	Orthic
E	900	Dry colour: very pale brown 10YR 7/3; moist colour: brownish yellow 10YR 6/6; structure: apedal granular; consistency: slightly hard in dry state and loose in moist state; lime: none; gravel: none; very few plants roots observed; clear transition.	E
B	900+	Dry colour: pink 7.5YR 8/3; moist colour: reddish yellow 7.5YR 8/6; structure: apedal massive; consistency: slightly hard in dry state and friable in moist state; lime: none; gravel: none; no plants roots observe; mottle: few (< 2%), medium (5mm – 15 mm), clear and red in colour.	Soft plinthic

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Profile number:	Oorlogskloof 4	Slope form:	Straight
Latitude and longitude:	31 27' 27,197'' S/ 19 05''42,025''E	Aspect:	South
Soil form:	Wasbank	Terrain unit:	Midslope
Soil family:	Lynedoch (2000)	Altitude:	743.8 m
Parent material:	Sandstone	Surface coarse fraction: None	
Slope:	3.8%		

HORIZON	DEPTH (mm)	DESCRIPTION	DIAGNOSTIC HORIZON
A	300	Dry colour: light grey 7.5YR 7/1; moist colour: very dark grey 10YR 3/1; structure: apedal single grained; consistency: lose in dry state, lime: none; gravel: none; few plants roots observed; gradual smooth transition.	Orthic
E	700	Dry colour: pink 7.5YR 7/3; moist colour: reddish yellow 7.5YR 6/6; structure: apedal granular; consistency: slightly hard in dry state and loose in moist state; lime: none; gravel: none; very few plants roots observed; clear transition.	E
B	700+	Dry colour: pink 7.5YR 8/3; moist colour: reddish yellow 7.5YR 8/6; structure: apedal massive; consistency: hard in dry state and slightly hard in moist state; lime: none; gravel: none; no plants roots observe; mottle: Common (2 – 20%), medium (5mm – 15 mm), clear and red in colour.	Hard plinthic

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Profile number:	Oorlogskloof 5	Slope form:	Straight
Latitude and longitude:	31 27’ 31,091’’ S/ 19 05’’49,149’’E	Aspect:	South West
Soil form:	Longlands	Terrain unit:	Footslope
Soil family:	Ermelo (2000)	Altitude:	746.3 m
Parent material:	Sandstone	Surface coarse fraction:	None
Slope:	3.5%		

HORIZON	DEPTH (mm)	DESCRIPTION	DIAGNOSTIC HORIZON
A	170	Dry colour: light grey 7.5YR 7/1; moist colour: brown 7.5YR 5/2; structure: apedal single grained; consistency: lose in dry state, lime: none; gravel: none; few plants roots observed; gradual smooth transition.	Orthic
E	720	Dry colour: pink 7.5YR 7/3; moist colour: reddish yellow 7.5YR 6/6; structure: apedal granular; consistency: slightly hard in dry state and friable in moist state; lime: none; gravel: none; very few plants roots observed; clear transition.	E
B	720+	Dry colour: pink 7.5YR 7/3; moist colour: reddish yellow 7.5YR 6/6; structure: apedal massive; consistency: slightly hard in dry state and friable in moist state; lime: none; gravel: none; no plants roots observe; mottle: Few (< 2%), medium (5mm – 15 mm), clear and red in colour.	Soft plinthic

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Profile number:	Oorlogskloof 6	Slope form:	Straight
Latitude and longitude:	31 27' 33,064'' S/ 19 05''46,060''E	Aspect:	South West
Soil form:	Longlands	Terrain unit:	Midslope
Soil family:	Ermelo (2000)	Altitude:	749.1 m
Parent material:	Sandstone	Surface coarse fraction: None	
Slope:	3.6%		

HORIZON	DEPTH (mm)	DESCRIPTION	DIAGNOSTIC HORIZON
A	150	Dry colour: grey 7.5YR 6/1; moist colour: brown 7.5YR 5/3; structure: apedal single grained; consistency: lose in dry state, lime: none; gravel: none; few plants roots observed; gradual smooth transition.	Orthic
E	650	Dry colour: Pink 7.5YR 7/3; moist colour: reddish yellow 7.5YR 6/6; structure: apedal granular; consistency: slightly hard in dry state and friable in moist state; lime: none; gravel: none; very few plants roots observed; clear transition.	E
B	650+	Dry colour: Pink 7.5YR 7/3; moist colour: reddish yellow 7.5YR 6/6; structure: apedal massive; consistency: slightly hard in dry state and friable in moist state; lime: none; gravel: none; no plants roots observe; mottle: Few (< 2%), medium (5mm – 15 mm), clear and red in colour.	Soft plinthic

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Profile number:	Oorlogskloof 7	Slope form:	Straight
Latitude and longitude:	31 27' 33,105'' S/ 19 05''42,108''E	Aspect:	South West
Soil form:	Mispah	Terrain unit:	Midslope
Soil family:	Gulu (2100)	Altitude:	750.7 m
Parent material:	Sandstone	Surface coarse fraction: None	
Slope:	3.6%		

HORIZON	DEPTH (mm)	DESCRIPTION	DIAGNOSTIC HORIZON
A	200	Dry colour: light brown 7.5YR 6/3; moist colour: dark brown 7.5YR 3/2; structure: apedal single grained; consistency: lose in dry state, lime: none; gravel: none; few plants roots observed; abrupt transition.	Orthic
R	200+	Hard sandstone rock	Rock

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Profile number:	Klein Blomfontein 1	Slope form:	Concave
Latitude and longitude:	31 42’ 21,979’’ S/ 19 07’’10,133’’E	Aspect:	West
Soil form:	Wasbank	Terrain unit:	Midslope
Soil family:	Lynedoch (2000)	Altitude:	838 m
Parent material:	Sandstone	Surface coarse fraction: None	
Slope:	5.6%		

HORIZON	DEPTH (mm)	DESCRIPTION	DIAGNOSTIC HORIZON
A	130	Dry colour: grey 10YR 5/1; moist colour: very dark grey 10YR 3/1; structure: apedal single grained; consistency: lose in dry state, lime: none; gravel: none; few plants roots observed; clear transition.	Orthic
E	400	Dry colour: light yellowish brown 10YR 6/4; moist colour: yellowish brown 10YR 5/6; structure: apedal granular; consistency: slightly hard in dry state and friable in moist state; lime: none; gravel: none; very few plants roots observed; clear transition.	E
B	400+	Dry colour: light yellowish brown 10YR 6/4; moist colour: yellowish brown 10YR 5/6; structure: apedal massive; consistency: slightly hard in dry state and friable in moist state; lime: none; gravel: none; no plants roots observe; mottle: Common (2 – 20 %), medium (5mm – 15 mm), clear and red in colour.	Hard plinthic

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Profile number:	Klein Blomfontein 2	Slope form:	Concave
Latitude and longitude:	31 42’ 22,966’’ S/ 19 07’’11,016’’E	Aspect:	West
Soil form:	Wasbank	Terrain unit:	Midslope
Soil family:	Lynedoch (2000)	Altitude:	836.8 m
Parent material:	Sandstone	Surface coarse fraction: None	
Slope:	5.1%		

HORIZON	DEPTH (mm)	DESCRIPTION	DIAGNOSTIC HORIZON
A	130	Dry colour: grey 10YR 5/1; moist colour: very dark grey 10YR 3/1; structure: apedal single grained; consistency: lose in dry state, lime: none; gravel: none; few plants roots observed; clear transition.	Orthic
E	650	Dry colour: light yellowish brown 10YR 6/4; moist colour: yellowish brown 10YR 5/6; structure: apedal granular; consistency: slightly hard in dry state and friable in moist state; lime: none; gravel: none; very few plants roots observed; clear transition.	E
B	650+	Dry colour: light yellowish brown 10YR 6/4; moist colour: yellowish brown 10YR 5/6; structure: apedal massive; consistency: slightly hard in dry state and friable in moist state; lime: none; gravel: none; no plants roots observe; mottle: Common (2 – 20 %), medium (5mm – 15 mm), clear and red in colour.	Hard plinthic

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Profile number:	Klein Blomfontein 3	Slope form:	Straight
Latitude and longitude:	31 42' 22,966'' S/ 19 07''11,016''E	Aspect:	West
Soil form:	Dresden	Terrain unit:	Midslope
Soil family:	Hilldrop (2000)	Altitude:	833.8 m
Parent material:	Sandstone	Surface coarse fraction:	None
Slope:	4.3%		

HORIZON	DEPTH (mm)	DESCRIPTION	DIAGNOSTIC HORIZON
A	200	Dry colour: greyish brown 10YR 5/2; moist colour: very dark greyish brown 10YR 3/2; structure: apedal single grained; consistency: lose in dry state, lime: none; gravel: none; few plants roots observed; clear transition.	Orthic
B	200+	Dry colour: pale brown 10YR 6/3; moist colour: brown 10YR 5/3; structure: apedal massive; consistency: hard in dry state and slightly hard in moist state; lime: none; gravel: common (20-50%), size (2-25 mm); no plants roots observe; mottle: Common (2 – 20%), medium (5mm – 15 mm), clear and red in colour.	Hard plinthic

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Profile number:	Klein Blomfontein 4	Slope form:	Straight
Latitude and longitude:	31 42’ 25,879’’ S/ 19 07’’15,093’’E	Aspect:	West
Soil form:	Dresden	Terrain unit:	Midslope
Soil family:	Hilldrop (2000)	Altitude:	832.4 m
Parent material:	Sandstone	Surface coarse fraction:	None
Slope:	5.6%		

HORIZON	DEPTH (mm)	DESCRIPTION	DIAGNOSTIC HORIZON
A	170	Dry colour: greyish brown 10YR 5/2; moist colour: very dark greyish brown 10YR 3/2; structure: apedal single grained; consistency: lose in dry state, lime: none; gravel: none; few plants roots observed; clear transition.	Orthic
B	170+	Dry colour: brown 10YR 4/3; moist colour: very dark brown 10YR 3/2; structure: apedal massive; consistency: hard in dry state and slightly hard in moist state; lime: none; gravel: common (20-50%), size (2-25 mm); no plants roots observe; mottle: Common (2 – 20%), medium (5mm – 15 mm), clear and red in colour.	Hard plinthic

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Profile number:	Klein Blomfontein 5	Slope form:	Straight
Latitude and longitude:	31 42' 29,096'' S/ 19 07''17,086''E	Aspect:	West
Soil form:	Dresden	Terrain unit:	Midslope
Soil family:	Hilldrop (2000)	Altitude:	829.9 m
Parent material:	Sandstone	Surface coarse fraction: None	
Slope:	5.2%		

HORIZON	DEPTH (mm)	DESCRIPTION	DIAGNOSTIC HORIZON
A	200	Dry colour: reddish brown 2.5YR 5/3; moist colour: brown 10YR 4/3; structure: apedal single grained; consistency: lose in dry state, lime: none; gravel: none; few plants roots observed; clear transition.	Orthic
B	200+	Dry colour: pale brown 10YR 6/3; moist colour: brown 10YR 5/3; structure: apedal massive; consistency: hard in dry state and slightly hard in moist state; lime: none; gravel: common (20-50%), size (2-25 mm); no plants roots observe; mottle: Common (2 – 20%), medium (5mm – 15 mm), clear and red in colour.	Hard plinthic

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Profile number:	Klein Blomfontein 6	Slope form:	Straight
Latitude and longitude:	31 42' 29,076'' S/ 19 07''20,047''E	Aspect:	West
Soil form:	Dresden	Terrain unit:	Midslope
Soil family:	Hilldrop (2000)	Altitude:	827.3 m
Parent material:	Sandstone	Surface coarse fraction: None	
Slope:	3.2%		

HORIZON	DEPTH (mm)	DESCRIPTION	DIAGNOSTIC HORIZON
A	200	Dry colour: pale red 2.5YR 6/2; moist colour: brown 10YR 4/3; structure: apedal single grained; consistency: lose in dry state, lime: none; gravel: none; few plants roots observed; clear transition.	Orthic
B	200+	Dry colour: Light yellowish brown 10YR 6/4; moist colour: yellowish brown 10YR 5/6; structure: apedal massive; consistency: hard in dry state and slightly hard in moist state; lime: none; gravel: common (20-50%), size (2-25 mm); no plants roots observe; mottle: Common (2 – 20%), medium (5mm – 15 mm), clear and red in colour.	Hard plinthic

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Appendix 2 – Detailed graphs presenting linear regression of five depths of four selected sites

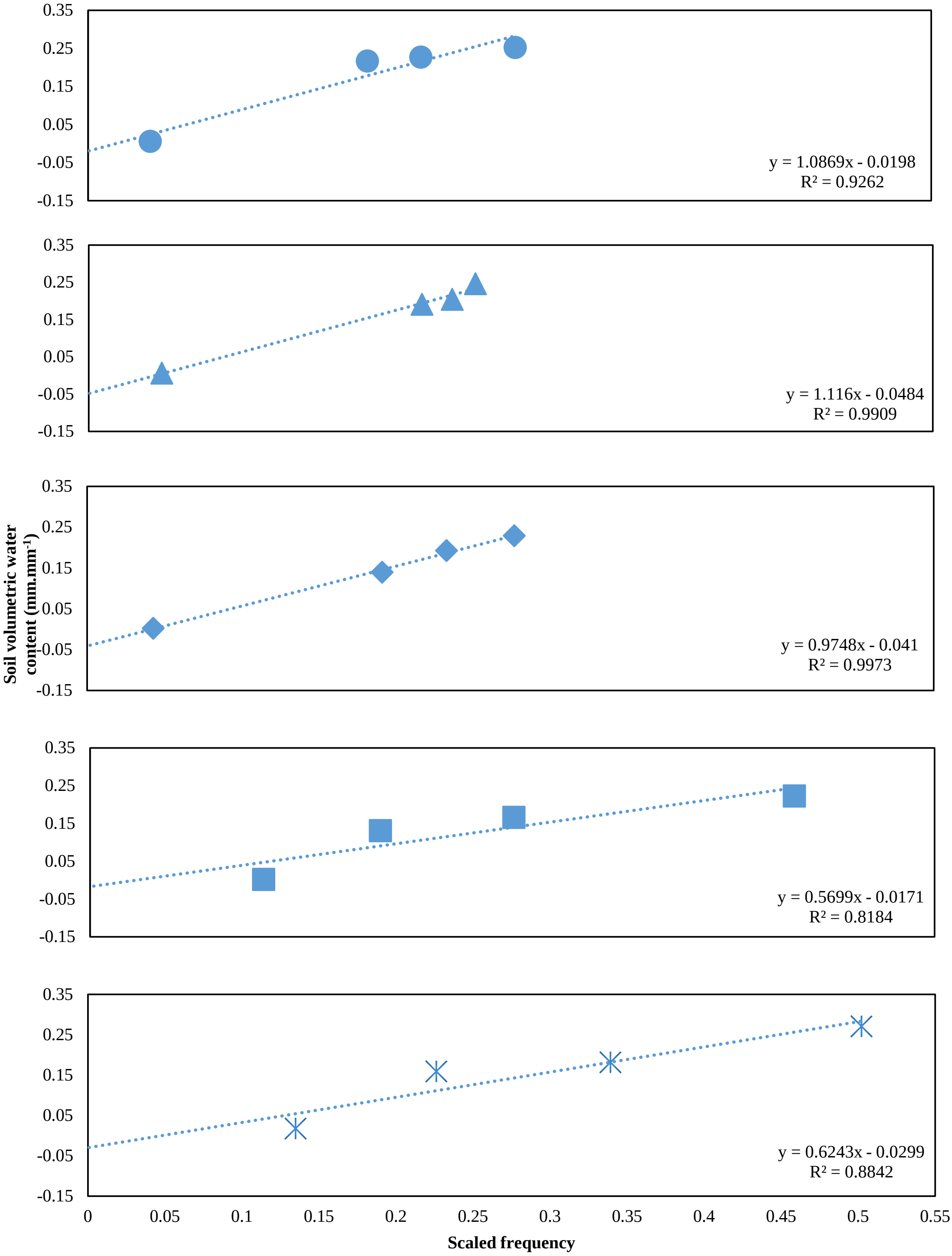

Figure A2-1: Soil volumetric water content calibration curves of the Rogland study site (A: 50 mm depth; B: 150 mm depth; C: 250 mm; D: 550 mm depth; E: 850 mm depth).

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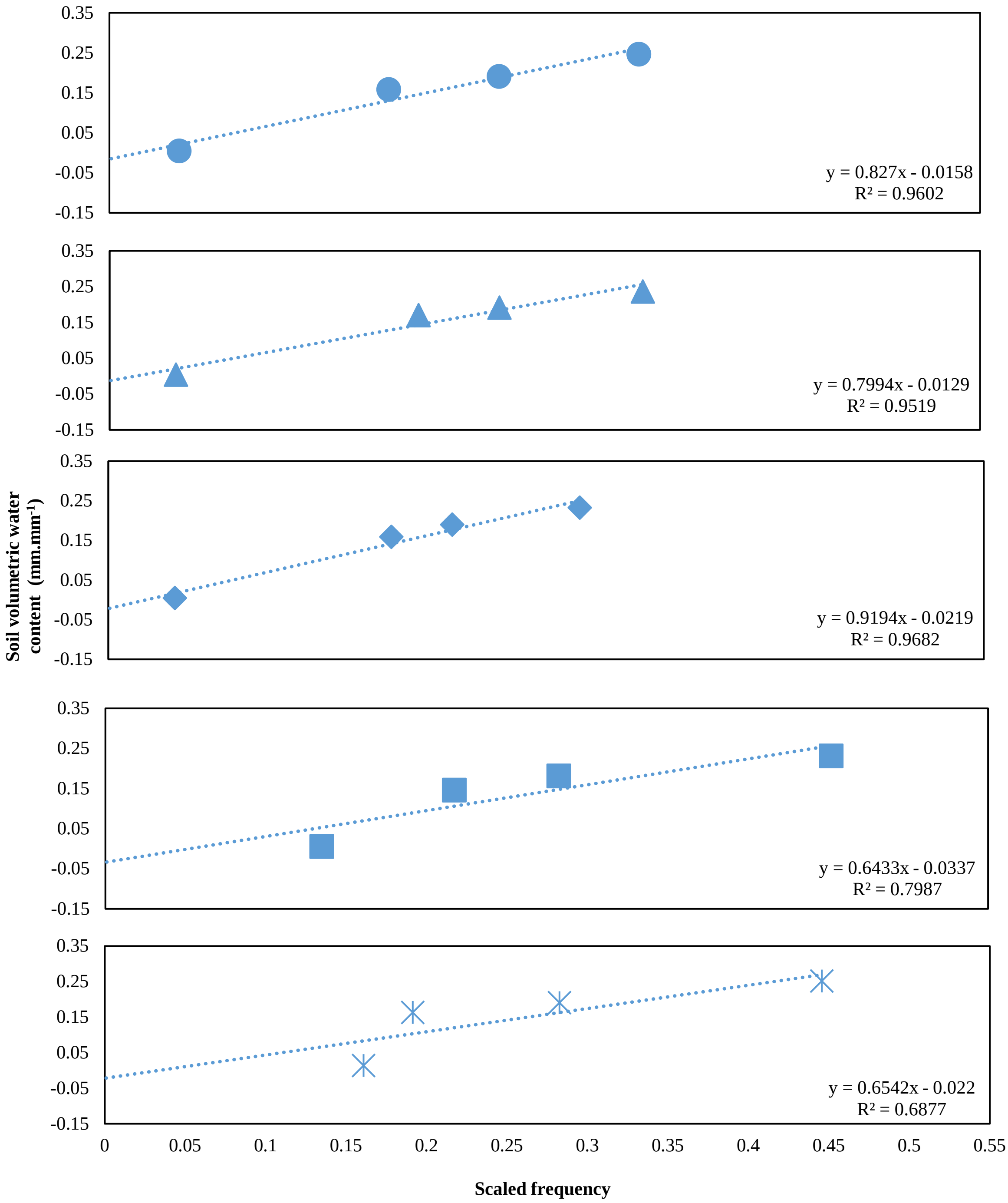

Figure A2-2: Soil volumetric water content calibration curves of Meulsteenvlei site (A: 50 mm depth; B: 150 mm depth; C: 250 mm; D: 550 mm depth; E: 850 mm depth).

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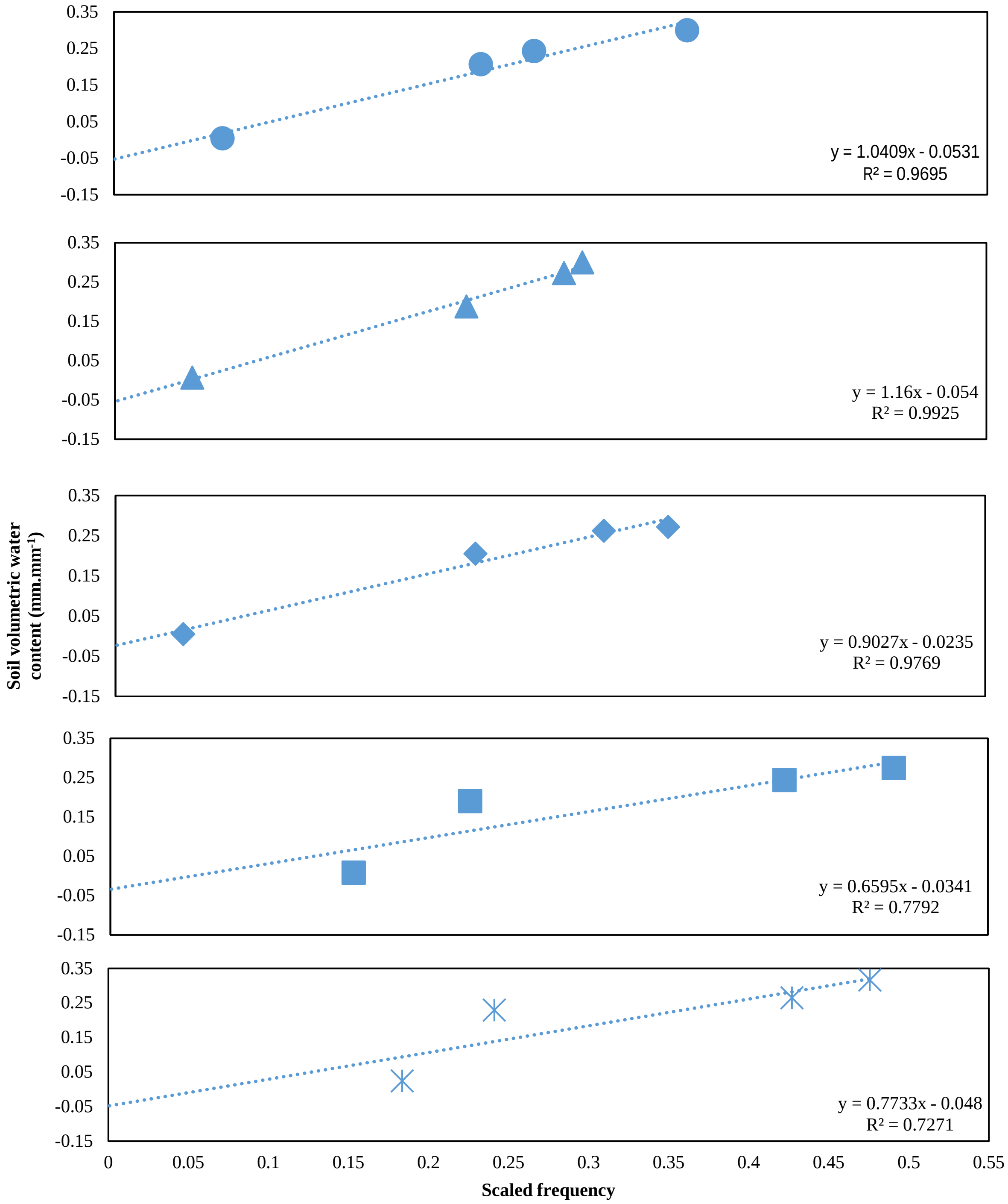

Figure A2-3: Soil volumetric water content calibration curves of Oorlogskloof site (A: 50 mm depth; B: 150 mm depth; C: 250 mm; D: 550 mm depth; E: 850 mm depth).

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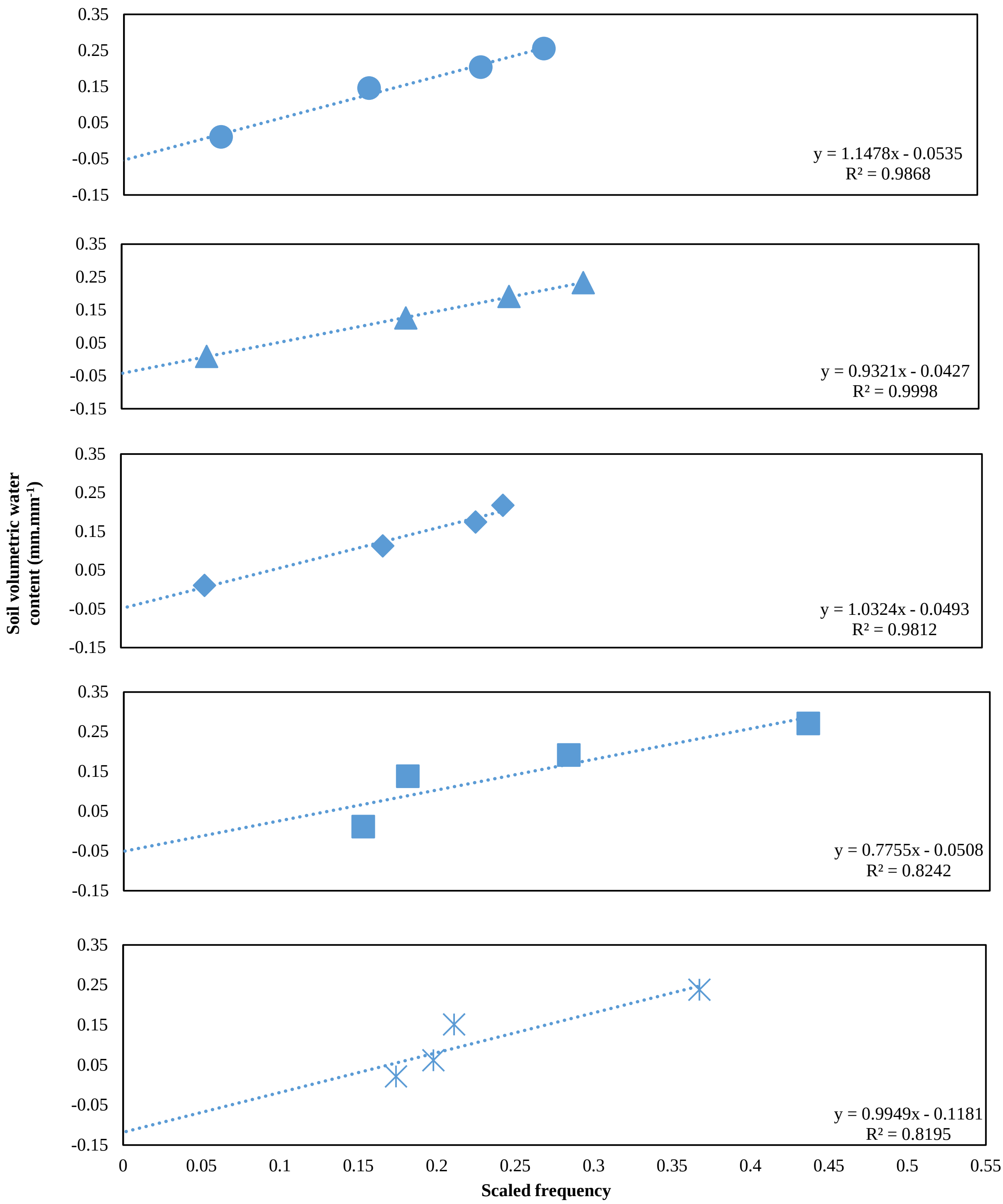

Figure A2-4: Soil volumetric water content calibration curves of Klein Blomfontein site (A: 50 mm depth; B: 150 mm depth; C: 250 mm; 350 mm depth; 450 mm depth).

Appendix 3 - Graphical representation of the daily soil water content and rainfall of the study sites

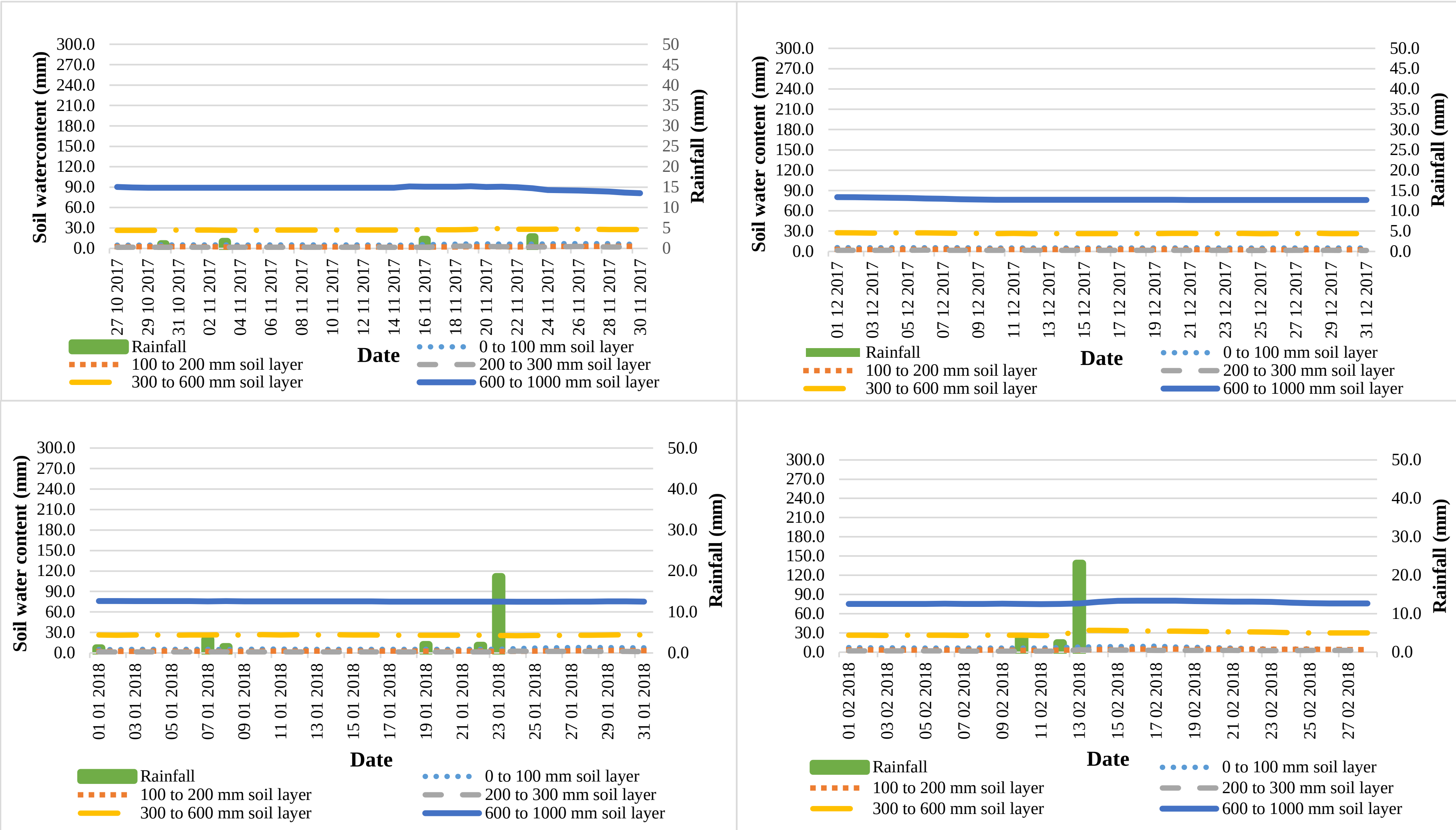

Figure A3-1: Soil water content and rainfall of Rogland (from October 2017 to February 2018).

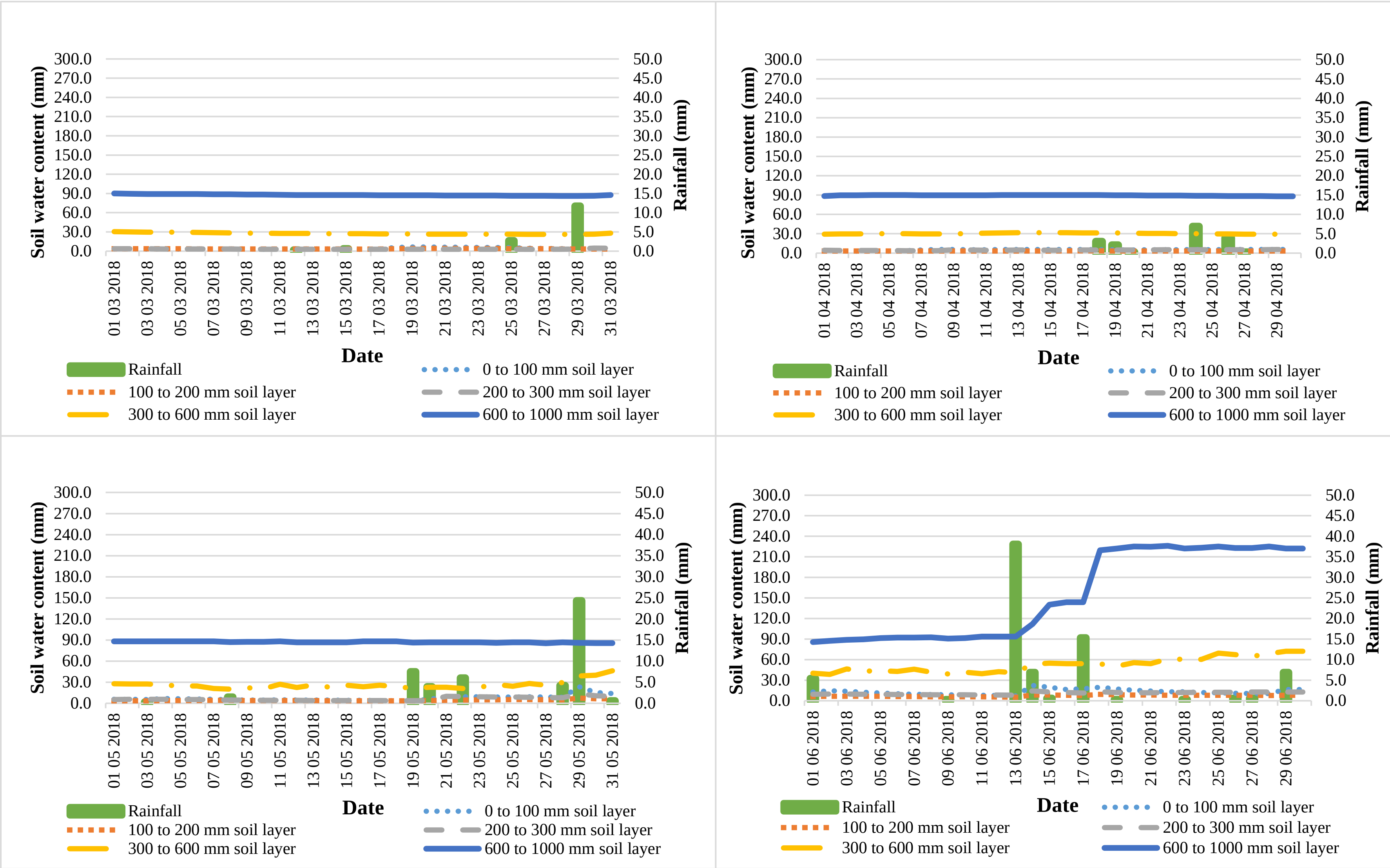

Figure A3-2: Soil water content and rainfall of Rogland (from March 2018 to June 2018)

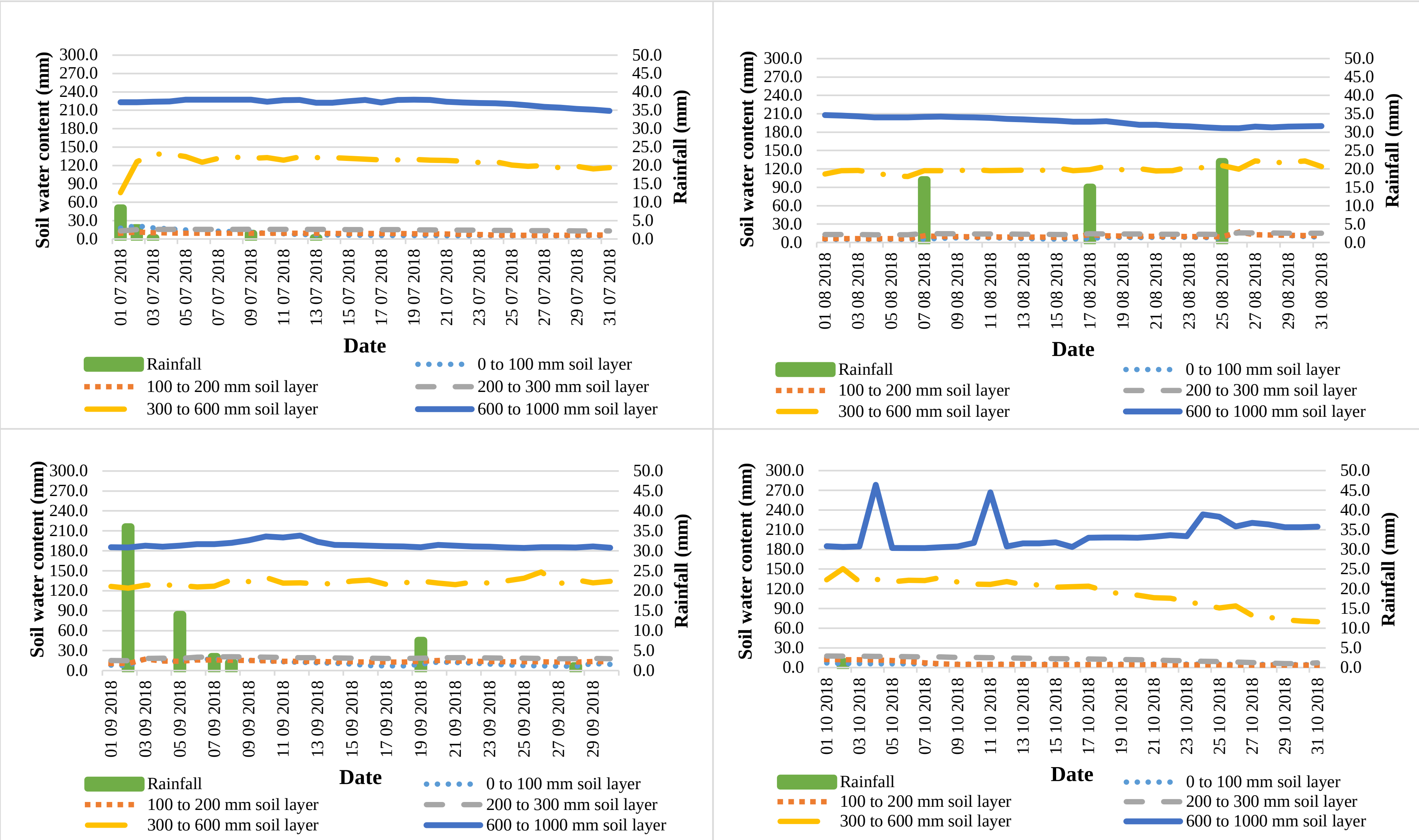

Figure A3-3: Soil water content and rainfall of Rogland (from July 2018 to October 2018).

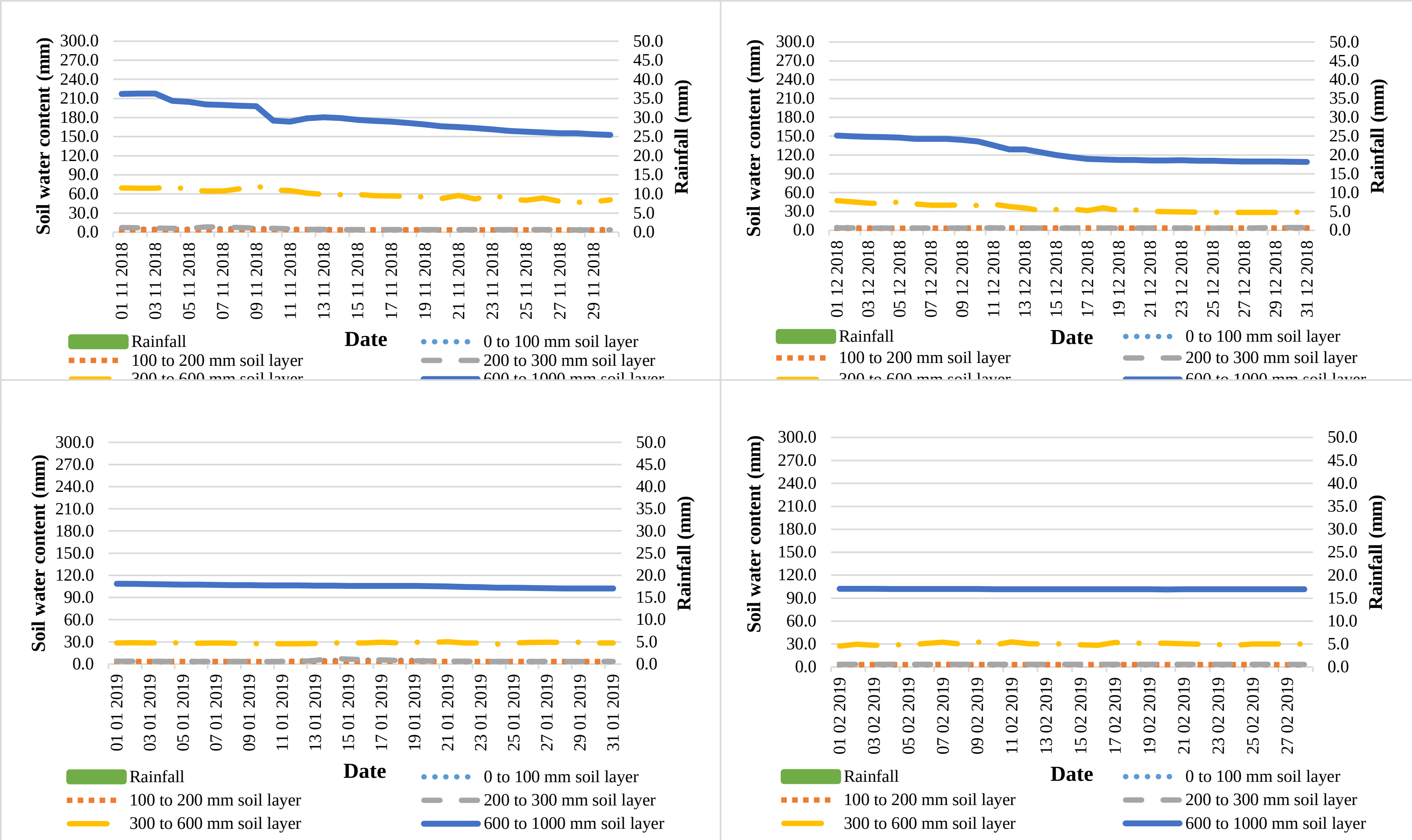

Figure A3-4: Soil water content and rainfall of Rogland (from November 2018 to February 2019).

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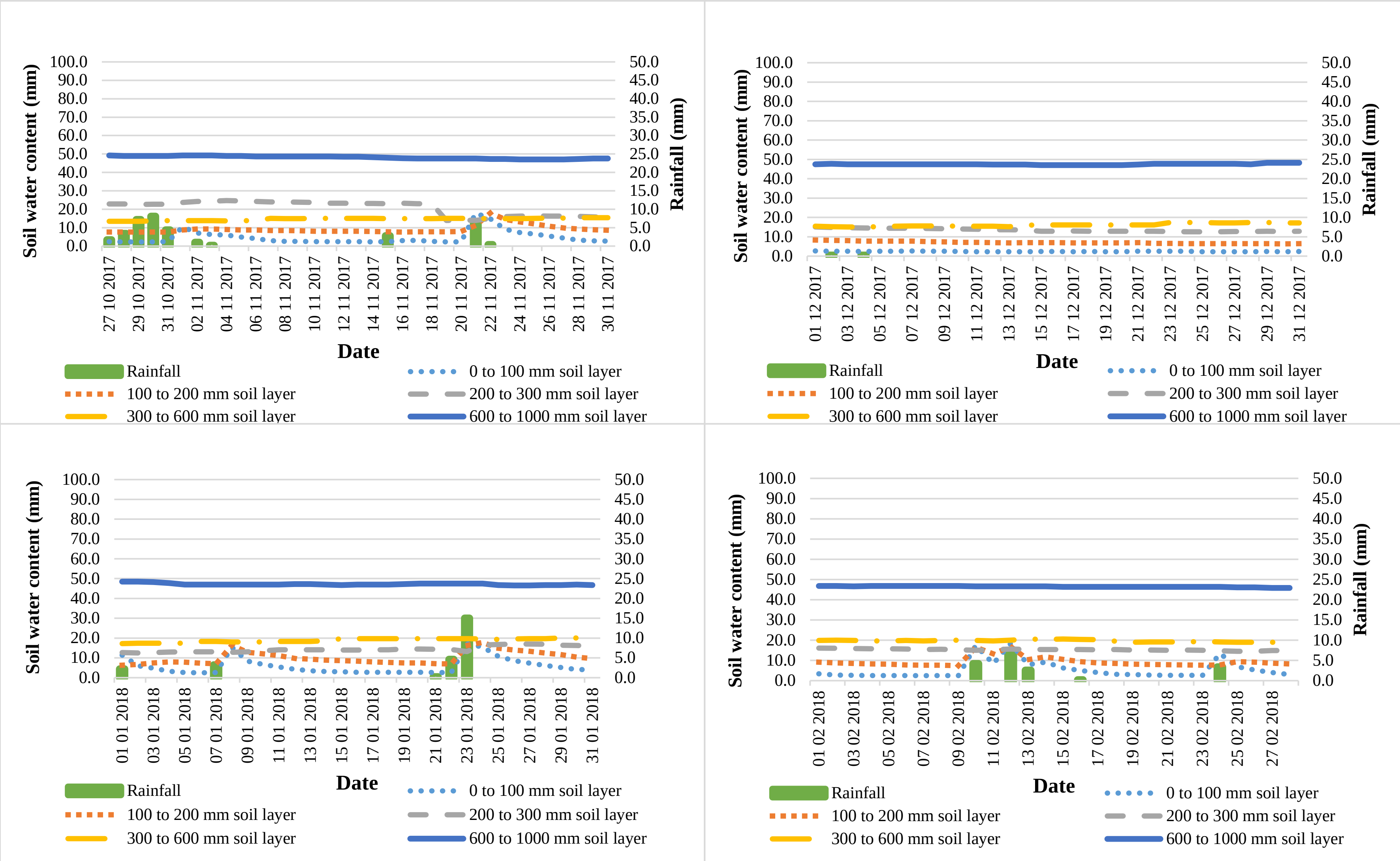

Figure A3-5: Soil water content and rainfall of Meulsteenvlei (from October 2017 to February 2018).

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Figure A3-6: Soil water content and rainfall of Meulsteenvlei (from March 2018 to June 2018).

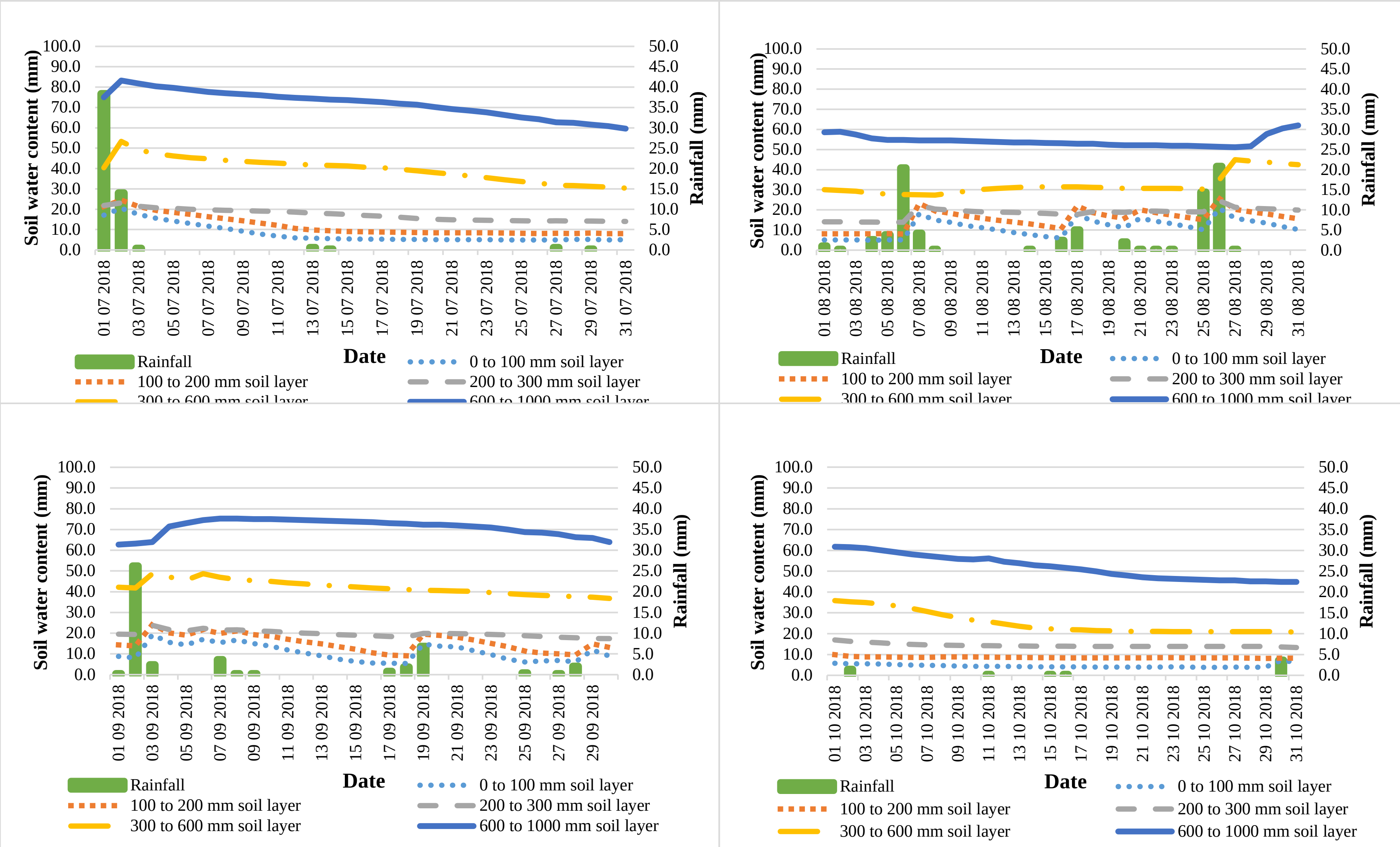

Figure A3-7: Soil water content and rainfall of Meulsteenvlei (from July 2018 to October 2018).

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Figure A3-8: Soil water content and rainfall of Meulsteenvlei (from November 2018 to February 2018).

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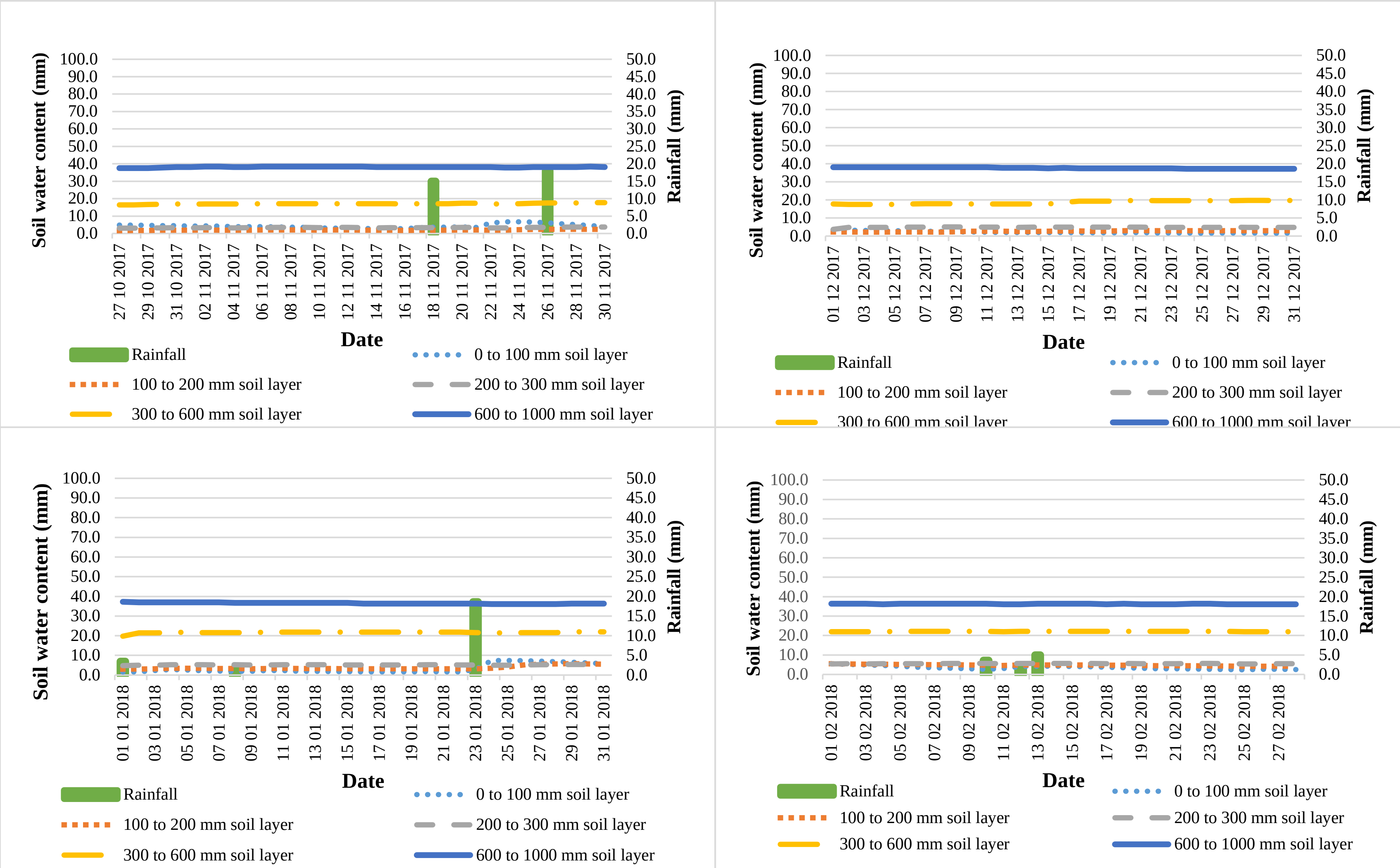

Figure A3-9: Soil water content and rainfall of Oorlogskloof (from October 2017 to February 2018).

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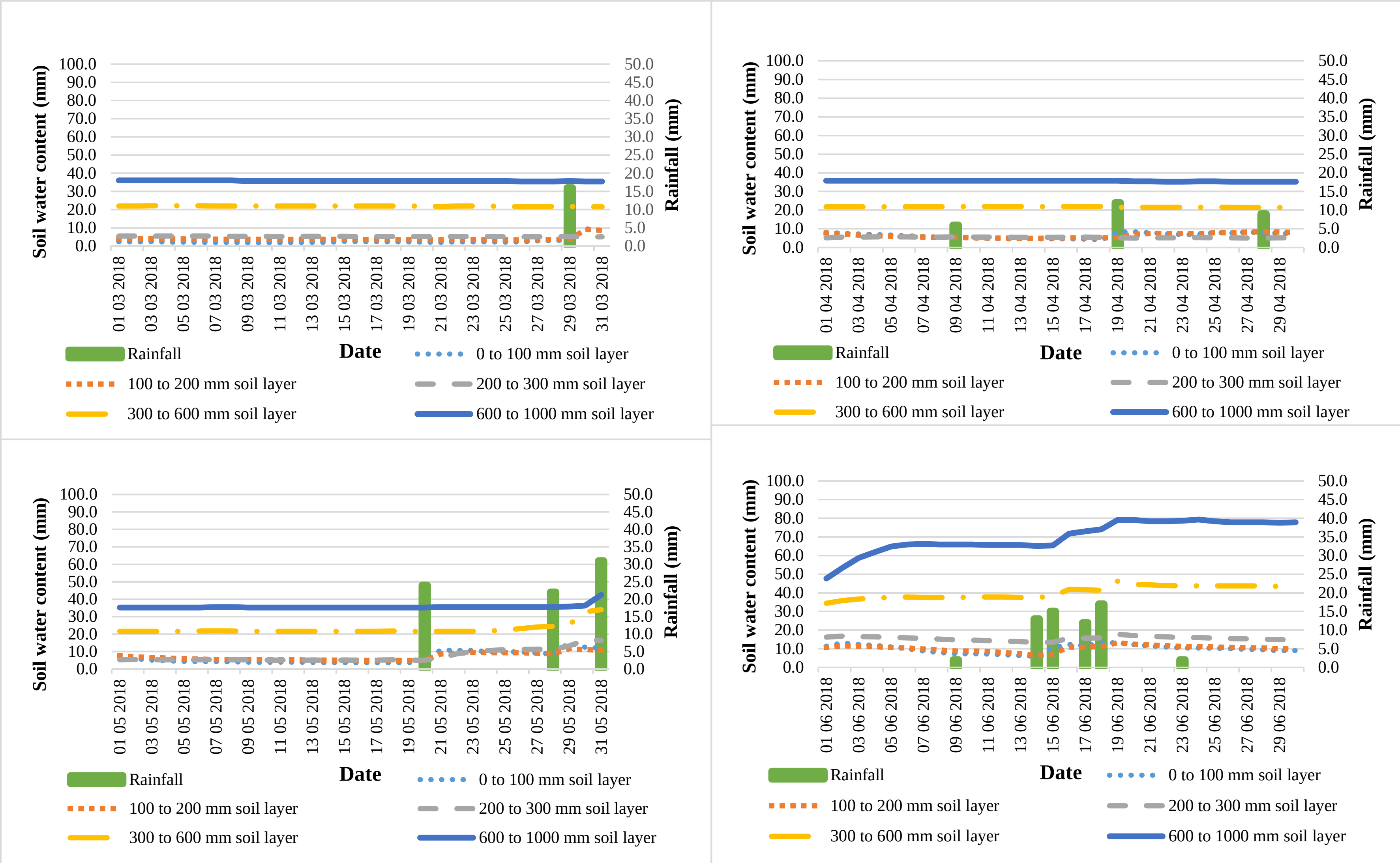

Figure A3-10: Soil water content and rainfall of Oorlogskloof (from March 2018 to June 2018).

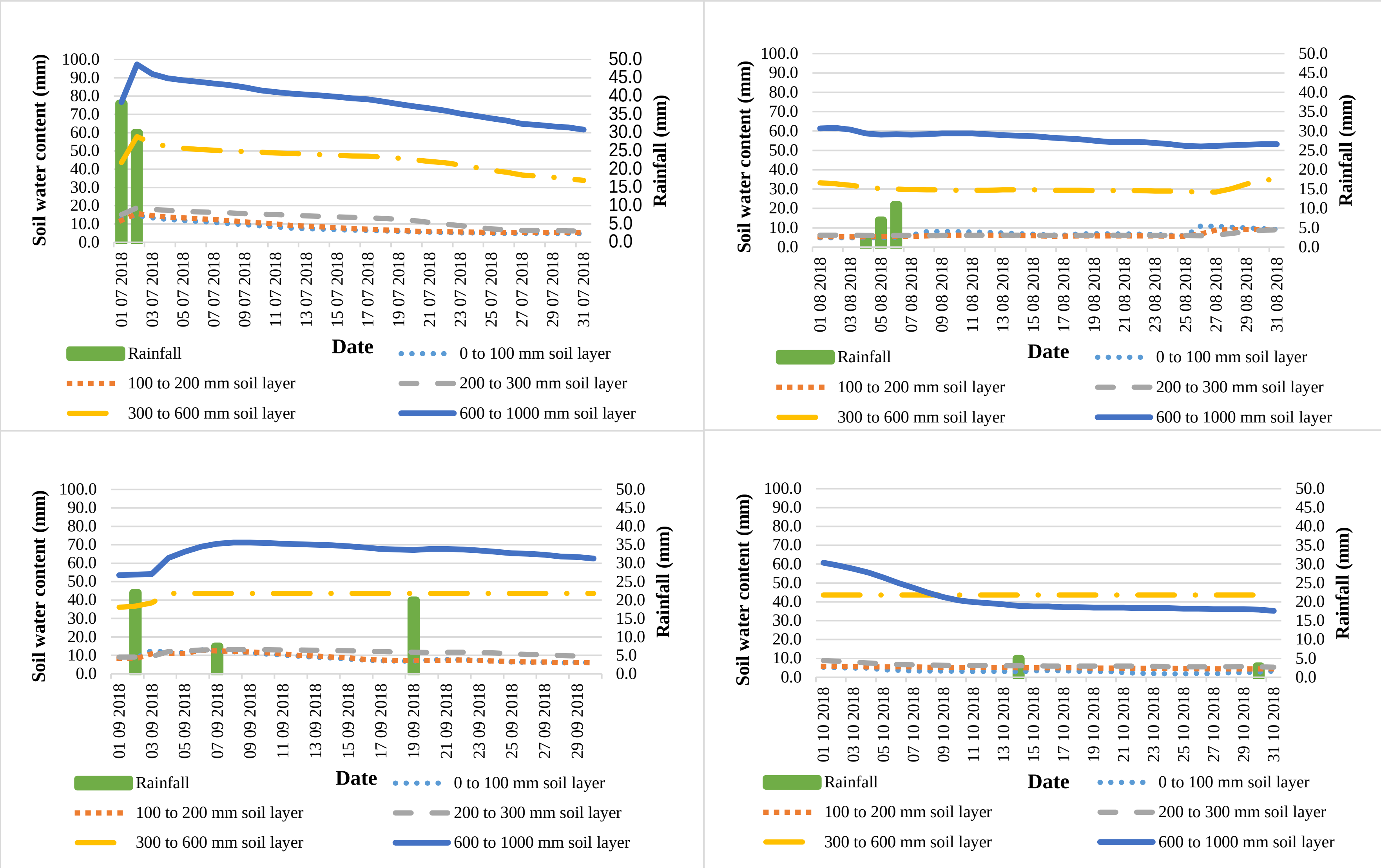

Figure A3-11: Soil water content and rainfall of Oorlogskloof (from July 2018 to October 2018).

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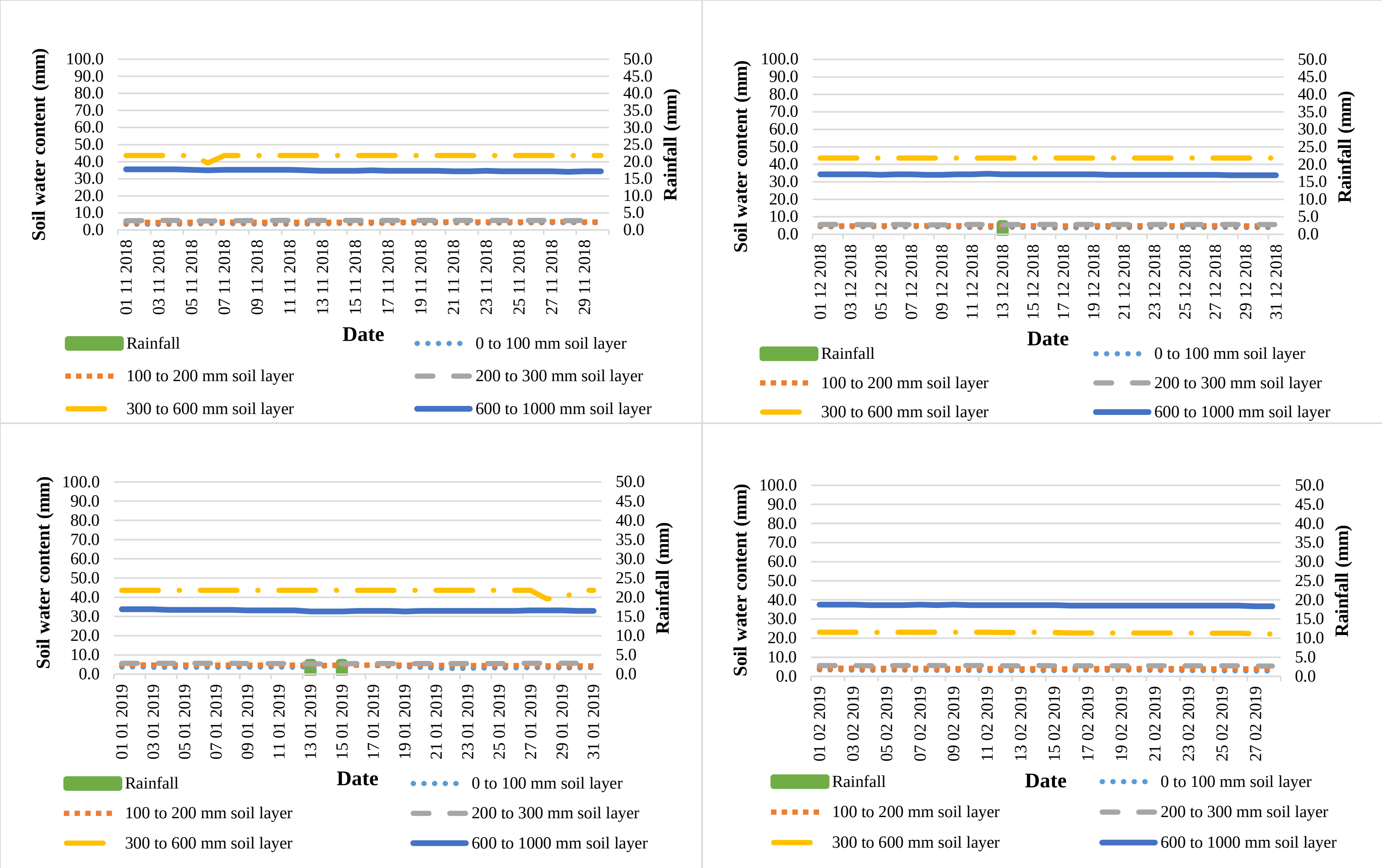

Figure A3-12: Soil water content and rainfall (from November 2018 to February 2019).

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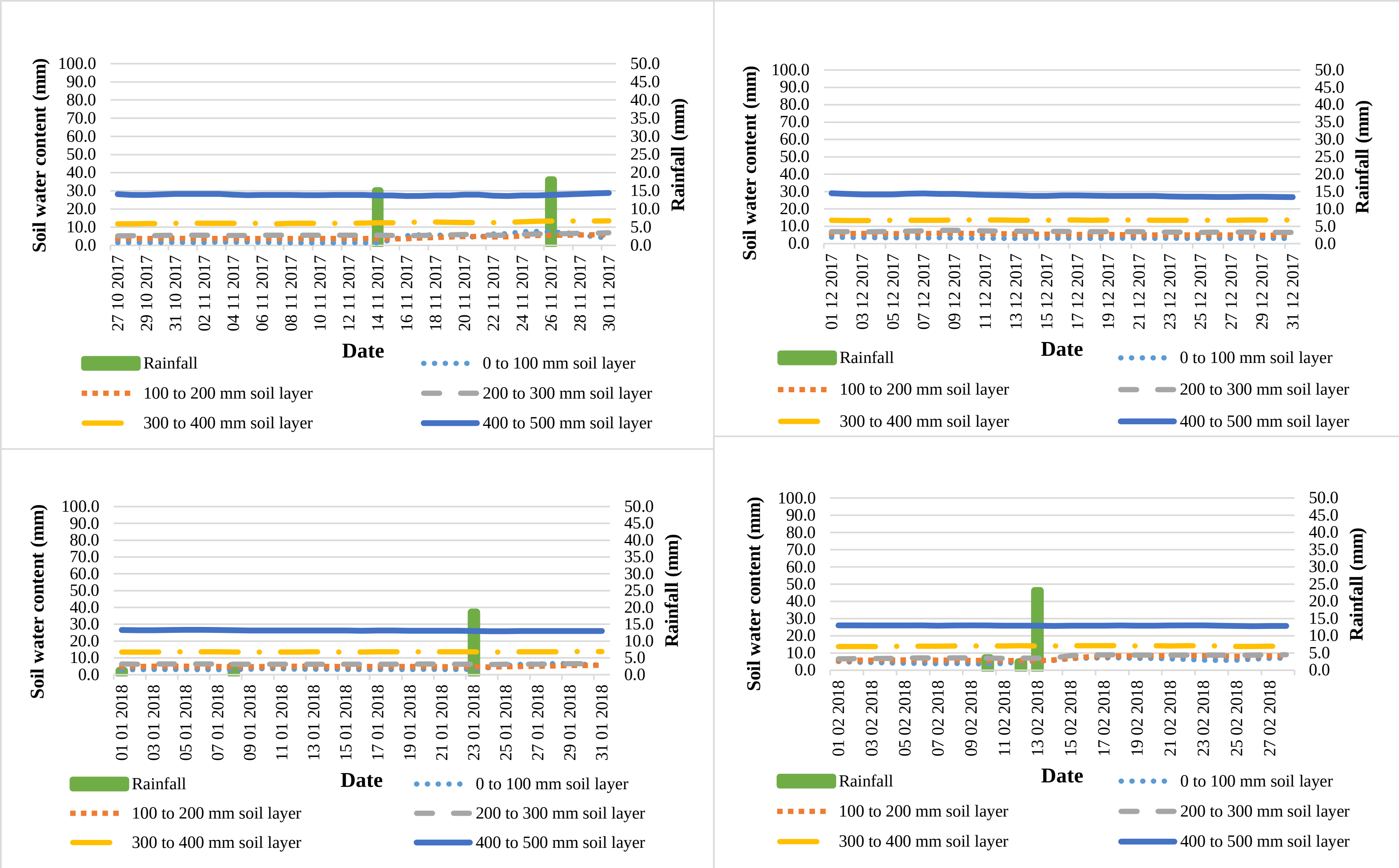

Figure A3-13: Soil water content and rainfall of Klein Blomfontein (from October 2017 to February 2018).

Figure A3-14: Soil water content and rainfall of Klein Blomfontein (from March 2018 to June 2018).

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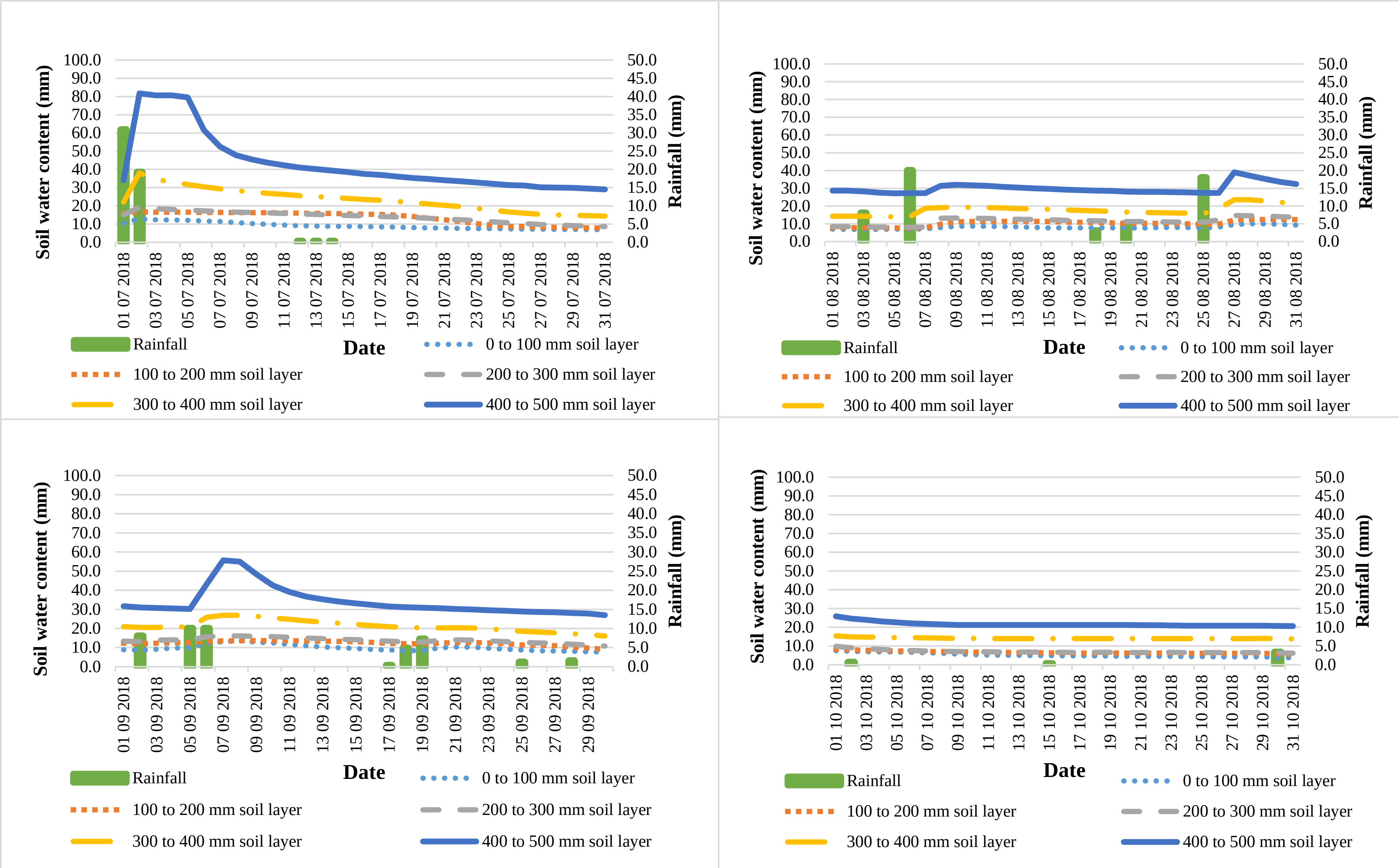

Figure A3-15: Soil water content and rainfall of Klein Blomfontein (from July 2018 to October 2018).

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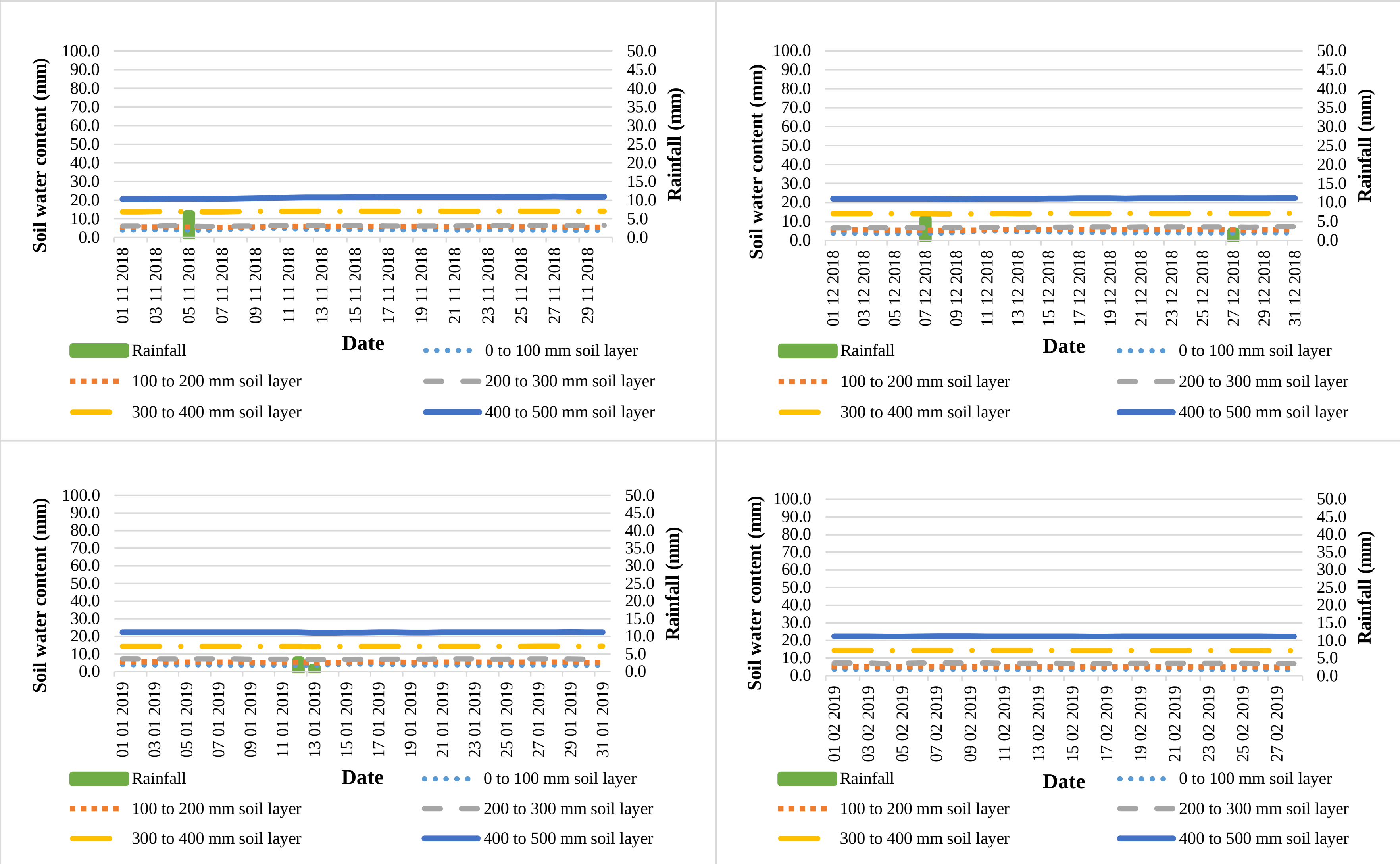

Figure A3-16: Soil water content and rainfall of Klein Blomfontein (from November 2018 to February 2019).

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Appendix 4 – Detailed weed population density of the study sites

Table A4-1: Weed population density measured at the Rogland site.

Plot ID	R-1	R-2	R-3	R-4	R-5	R-6	R-7	R-8	R-9	R-10	**Total**
Date	**04-09-18**	**04-09-18**	**04-09-18**	**04-09-18**	**04-09-18**	**04-09-18**	**04-09-18**	**04-09-18**	**04-09-18**	**04-09-18**	
GPS S	-31.22444	-31.22472	-31.22472	-31.22472	-31.225	-31.225	-31.225	-31.225	-31.2252	-31.22527	
GPS E	19.01889	19.01889	19.01889	19.01888	19.0186	19.0191	19.0194	19.0194	19.0191	19.01889	
Species											**Average.m^{-2}**
Arctotheca calendula	0	0	0	0	0	0	0	0	0	0	**0.0**
Bulbinella caudafelis	0	0	0	0	0	0	0	0	0	0	**0.0**
Chaetobromus involueratus	0	0	0	0	0	0	0	0	0	0	**0.0**
Chrysocoma oblongifolia	0	2	0	0	0	0	0	0	0	3	**0.5**
Cleretum papulosum	0	0	0	0	0	0	0	0	0	0	**0.0**
Cynodon dactylon	0	0	6	5	0	0	0	0	3	5	**1.9**
Ehrharta longiflora	5	15	8	4	2	5	3	1	0	2	**4.5**
Grielum humifusum	0	0	0	0	0	0	7	1	1	0	**0.9**
Heliophilia africana	0	2	0	0	0	0	0	0	0	0	**0.2**
Juncus capensis	0	0	0	0	2	1	0	0	1	1	**0.5**
Othonna coronopifolia	0	0	0	0	0	0	0	0	0	0	**0.0**
Oxalis oculifera	0	0	0	0	0	0	0	0	0	0	**0.0**
Oxalis pes-capre	0	0	0	0	0	1	0	0	0	0	**0.1**
Psammotropha spicata	0	0	6	11	1	0	2	0	1	0	**2.1**
Raphanus raphanistrum	0	0	0	0	0	0	0	0	0	0	**0.0**
Rumex cordatus	2	0	0	0	0	0	0	0	0	0	**0.2**
Selago inaequifolia	1	0	0	0	0	0	0	0	0	0	**0.1**
Senecio angustifolia	2	0	0	0	2	0	0	1	0	0	**0.5**
Senecio arenarius	0	0	0	0	0	0	0	0	0	0	**0.0**
Senecio erosus	0	0	0	0	0	0	0	0	0	0	**0.0**
Spergula arvensis	0	0	0	0	0	0	0	0	0	0	**0.0**
Ursinia anthemoides	41	27	24	24	2	0	0	3	4	17	**14.2**
Total species.m^{-2}	**51**	**46**	**44**	**44**	**9**	**7**	**12**	**6**	**10**	**28**	**25.7**

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Table A4-2: Weed population density measured at the Meulsteenvlei site.

Replicates	M-1	M-2	M-3	M-4	M-5	M-6	M-7	M-8	M-9	M-10	**Total**
Date	**04-09-18**	**04-09-18**	**04-09-18**	**04-09-18**	**04-09-18**	**04-09-18**	**04-09-18**	**04-09-18**	**04-09-18**	**04-09-18**	
GPS S	-31.3608	-31.3602	-31.3605	-31.3602	-31.3605	-31.3602	-31.3605	-31.3605	-31.3608	-31.3611	
GPS E	19.03306	19.03306	19.03306	19.03278	19.03250	19.03250	19.03222	19.03194	19.03194	19.03222	
Species											**Average.m^{-2}**
Arctotheca calendula	9	5	5	1	0	6	8	7	2	4	**4.7**
Bulbinella caudafelis	0	0	0	0	0	0	0	0	0	0	**0.0**
Chaetobromus involueratus	0	0	0	0	0	0	0	0	0	0	**0.0**
Chrysocoma oblongifolia	0	0	0	0	0	0	0	0	0	0	**0.0**
Cleretum papulosum	7	5	1	8	12	9	9	14	6	4	**7.5**
Cynodon dactylon	0	0	0	0	0	0	0	0	0	0	**0.0**
Ehrharta longiflora	0	0	1	0	0	0	1	0	0	2	**0.4**
Grielum humifusum	0	0	0	0	0	0	1	0	0	0	**0.1**
Heliophilia africana	0	0	0	0	0	0	0	0	0	0	**0.0**
Juncus capensis	0	0	0	0	0	0	0	0	0	0	**0.0**
Othonna coronopifolia	0	0	0	0	0	0	0	0	0	0	**0.0**
Oxalis oculifera	0	0	0	0	0	0	0	0	0	0	**0.0**
Oxalis pes-capre	0	0	0	0	0	0	0	0	0	0	**0.0**
Psammotropha spicata	0	0	0	0	0	0	0	0	0	0	**0.0**
Raphanus raphanistrum	1	0	1	2	0	0	3	0	0	4	**1.1**
Rumex cordatus	1	1	0	0	0	0	0	0	0	1	**0.3**
Selago inaequifolia	0	1	0	0	0	0	0	0	0	0	**0.1**
Senecio angustifolia	0	0	0	0	0	0	0	0	0	0	**0.0**
Senecio arenarius	0	0	0	0	0	0	0	0	0	0	**0.0**
Senecio erosus	0	0	0	0	0	0	0	0	0	0	**0.0**
Spergula arvensis	0	0	0	0	2	0	0	0	0	0	**0.2**
Ursinia anthemoides	0	3	16	7	19	16	1	13	23	2	**10.0**
Total.m^{-2}	**18**	**15**	**24**	**18**	**33**	**31**	**23**	**34**	**31**	**17**	**24.4**

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Table A4-3: Weed population density measured at the Oorlogskloof site.

Replicates	O-1	O-2	O-3	O-4	O-5	O-6	O-7	O-8	O-9	O-10	**Total**
Date	**04-09-18**	**04-09-18**	**04-09-18**	**04-09-18**	**04-09-18**	**04-09-18**	**04-09-18**	**04-09-18**	**04-09-18**	**04-09-18**	
GPS S	-31.4572	-31.4575	-31.4578	-31.4578	-31.4578	-31.4578	-31.4572	-31.4569	-31.4569	-31.4572	
GPS E	19.0947	19.0950	19.0950	19.0947	19.0947	19.0947	19.0942	19.0942	19.0944	19.0947	
Species											**Average.m^{-2}**
Arctotheca calendula	0	4	0	0	0	1	0	7	0	2	**1.4**
Bulbinella caudafelis	0	0	0	0	0	0	0	1	4	0	**0.5**
Chaetobromus involueratus	0	0	0	0	0	0	0	0	0	0	**0.0**
Chrysocoma oblongifolia	5	0	0	0	3	4	1	0	3	12	**2.8**
Cleretum papulosum	0	0	0	0	0	0	0	0	0	0	**0.0**
Cynodon dactylon	0	1	0	0	0	0	5	0	1	0	**0.7**
Ehrharta longiflora	3	0	0	0	1	3	3	0	2	0	**1.2**
Grielum humifusum	6	4	3	0	1	2	1	6	4	8	**3.5**
Heliophilia africana	0	0	0	0	0	0	0	0	0	0	**0.0**
Juncus capensis	0	0	0	0	0	0	0	0	0	0	**0.0**
Othonna coronopifolia	0	0	0	0	0	0	0	0	0	0	**0.0**
Oxalis oculifera	0	0	0	0	0	1	0	0	1	0	**0.2**
Oxalis pes-capre	0	0	0	0	0	0	0	0	0	0	**0.0**
Psammotropha spicata	1	0	0	0	0	1	0	0	0	1	**0.3**
Raphanus raphanistrum	0	5	1	2	0	1	0	2	1	0	**1.2**
Rumex cordatus	0	0	0	0	0	0	0	0	0	0	**0.0**
Selago inaequifolia	0	0	3	3	0	0	0	0	0	0	**0.6**
Senecio angustifolia	2	0	0	0	0	1	2	1	0	0	**0.6**
Senecio arenarius	0	0	0	0	1	0	1	0	0	0	**0.2**
Senecio erosus	0	0	2	0	0	0	0	0	0	0	**0.2**
Spergula arvensis	0	0	0	0	0	0	0	0	0	0	**0.0**
Ursinia anthemoides	1	4	0	0	0	1	0	12	0	0	**1.8**
Total.m^{-2}	**18**	**18**	**9**	**5**	**6**	**15**	**13**	**29**	**16**	**23**	**15.2**

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Table A4- 4: Weed population density measured at the Klein Blomfontein site.

Replicates	KB-1	KB-2	KB-3	KB-4	KB-5	KB-6	KB-7	KB-8	KB-9	KB-10	**Total**
Date	**04-09-18**	**04-09-18**	**04-09-18**	**04-09-18**	**04-09-18**	**04-09 18**	**04-09-18**	**04-09-18**	**04-09-18**	**04-09-18**	
GPS S	-31.7067	-31.7067	-31.7064	-31.7064	-31.7061	-31.7061	-31.6894	-31.7058	-31.7061	-31.7064	
GPS E	19.1194	19.1197	19.1197	19.1194	19.1194	19.1197	19.1197	19.1194	19.1194	19.1194	
Species											**Average.m^{-2}**
Arctotheca calendula	0	0	0	0	0	0	0	0	0	0	**0.0**
Bulbinella caudafelis	0	0	0	0	0	2	0	0	0	0	**0.2**
Chaetobromus involueratus	0	0	0	0	0	2	0	0	0	0	**0.2**
Chrysocoma oblongifolia	0	0	0	0	0	0	0	0	0	0	**0.0**
Cleretum papulosum	6	0	0	0	0	0	0	0	0	0	**0.6**
Cynodon dactylon	0	0	0	0	0	0	0	0	0	0	**0.0**
Ehrharta longiflora	3	11	5	2	2	7	0	0	4	5	**3.9**
Grielum humifusum	1	0	0	0	0	2	0	5	0	20	**2.8**
Heliophilia africana	0	0	1	0	0	0	0	0	0	0	**0.1**
Juncus capensis	0	0	0	0	0	0	0	0	0	0	**0.0**
Othonna coronopifolia	0	0	0	7	0	0	0	0	0	0	**0.7**
Oxalis oculifera	0	0	0	0	0	0	0	0	0	0	**0.0**
Oxalis pes-capre	0	0	0	0	0	0	0	0	0	0	**0.0**
Psammotropha spicata	0	0	0	0	0	0	1	0	0	0	**0.1**
Raphanus raphanistrum	6	1	1	0	3	0	0	0	0	1	**1.2**
Rumex cordatus	0	0	0	0	0	0	0	0	0	0	**0.0**
Selago inaequifolia	0	4	0	0	0	0	0	0	0	0	**0.4**
Senecio angustifolia	0	0	0	0	0	0	0	0	1	0	**0.1**
Senecio arenarius	0	0	0	3	4	2	2	1	6	4	**2.2**
Senecio erosus	0	0	0	11	4	0	0	1	4	0	**2.9**
Spergula arvensis	0	0	0	0	0	0	0	8	0	0	**0.8**
Ursinia anthemoides	0	4	12	0	12	0	2	9	11	4	**5.4**
Total.m^{-2}	**16**	**20**	**19**	**23**	**25**	**15**	**5**	**24**	**26**	**34**	**20.7**

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