Plant water relations of *Elytropappus Rhinocerotis* with specific reference to soil restrictions on growth.

by

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DECLARATION

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ABSTRACT

The Renosterveld of the Western Cape region is often seen as a natural occurring veld type that will very easily re-establish itself wherever land is left unattended. In this study it was firstly noted that where wheatlands of the Berg River catchment (BRC) is left bare for a number of years, the renosterbos as a pioneer is slow in its re-growth response and when it does, certain patches in the landscape are preferred. This study therefore firstly focussed on the soil restrictions that widely determined the positions in the Berg River landscape where the renosterbos will re-establish itself.

Secondly we needed to know whether some of the soil restrictions encountered could be alleviated and was possibly due to cultivation of this land. Through aerial observation it was found that a general patchiness does exist in the naturally occurring Renosterveld of the Voëlvlei area and hill tops of the region and was described by others as the true nature of this veld type. Closer investigation of the soils in the Voëlvlei reserve however showed that soil type played a major role in the patchiness found here.

When re-growth of the renosterbos in previously cultivated areas was investigated, it was found that the soil type played the major role in the patchiness that occurred. The most commonly found soil restriction was soil density of the lower horizons. Any soil form that prevented the renosterbos to access the perched water table, to about 15m depth could not support the renosterbos. It is however our belief that soil could be prepared for the re-growth of renosterbos and through this action; renosterbos could also be used to alleviate the salinity problems found in this region.

Additionally we investigated the impact of land-use change on the soil water balance and soil salinity by comparing a mature re-established stand of Renosterveld with an adjacent wheatfield. From the results, large differences in salinity and soil water behaviour were detected between the Renosterveld and wheatfield. Modelling of soil and plant water relations was done and the results were correlated well with field observations.

This research also confirmed that the renosterbos through its deep rootedness is crucial in the conservation of other species found in the Renosterveld resulting from its ability to keep the water table down and with that the salts that is so often a problem in this area.

OPSOMMING

In die Wes-Kaap word Renosterveld gesien as ‘n veld tipe wat natuurlik voorkom en maklik sal hervestig in areas waar land sonder toesig gelaat word. In hierdie studie is dit eerstens opgemerk dat waar koringlande in die Berg Rivier opvanggebied kaal gelaat word vir ‘n aantal jare, is die renosterbos as pionier stadig in sy hervestiging en wanneer terug groei wel plaasvind is dit selektief. Die studie fokus dus eerstens op grondbeperkinge wat die areas bepaal waar Renosterveld sal hervestig.

Tweedens wou ons vasstel of die grondbeperkings wat voorkom in die grond en wat heel moontlik die oorsaak is van landbewerking opgehef kan word. Deur lugfoto-waarneming is dit gevind dat algemene leë kolle wel opgemerk is in die natuurlik plantegroei van die Renosterveld, in die Voëlvlei area, asook teen die berg hange. Dit word beskryf as ‘n algemene kenmerk van die Renosterveld. Nadere ondersoek in die verskillende grondtipes van die area het egter gewys dat die grond tipe ‘n belangrike rol speel in die voorkoms en groei van die renosterbos en uiteindelik die (her-)vestiging van Renosterveld.

Die terug groei van die renosterbos is ondersoek in voorheen bewerkte lande. Dit is gevind dat die grond tipe ‘n belangrike rol speel in die voorkoms van die leë kolle in die Renosterveld. Die mees algemene grond beperking wat opgemerk is, was die verdigte sub-horisonte. Enige grondvorm wat toegang van die renosterboswortels tot by die grondwatertafel (tot by ‘n diepte van 15m) beperk, is nie voldoende om die groei van ‘n volwasse renosterbos te onderhou nie. Dit is egter ons oortuiging dat die grond voorberei kan word vir die hervestinging van die renosterbos and deur dit te bewerkstellig sal grondversouting beheer kan word.

Die impak van landgebruikverandering op die grondwaterbalans en grondversouting is ook ondersoek, deur ‘n volwasse stand van Renosterveld the vergelyk met ‘n nabygeleë koringveld. Die resultate het getoon dat daar groot verskille in die grondwatervlakke, asook die soutinhoud tussen die Renosterveld en die koringland voorkom. Modellering van die grond-en plantwaterverhouding is uitgevoer en data het goed gekorreleer met veld waarnemings.

Die studie het bevestig dat die natuurlike bewaring van die diep gewortelde renosterbos noodsaaklik is vir die voortbestaan van blom- en skilpadspesies wat slegs in die Renosterveld voorkom asook die vermoë van die renosterbos om stygende watertafels en versouting te beheer waar dit dikwels ‘n probleem in hierdie area is.

DEDICATION

I dedicate this work to my Creator, Lord God Almighty, without whom I would not have been able to complete this study. For your word is faithful and true:

"For I know the plans I have for you," declares the Lord, "plans to prosper you, not to harm you, plans to give you hope and a future."

-Jeremiah 29:11-

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'If I have seen further, it was by standing on the shoulders of giants.'
-Sir Isaac Newton-

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List of Abbreviations

AED: Atmospheric Evaporative Demand

AAS: Atomic Absorption Spectroscopy

BRC: Berg River Catchment

CEC: Cation Exchange Capacity

EC: Electrical Conductivity

ECaP: Exchangeable Calcium Percentage

EMgP: Exchangeable Magnesium Percentage

ESP: Exchangeable Sodium Percentage

ET: Evapotranspiration

ET_0: Reference Evapotranspiration

FAO: Food and Agricultural Organisation of the United Nations

IUCN: Union for Conservation of Nature and Natural Resources

SAR: Sodium Absorption Ratio

SEM: Scanning Electron Microscope

PET: Potential Evapotranspiration

PT: Potential Transpiration

PE: Potential Evaporation

RV: Renosterveld

WF: Wheatfield

CHAPTER 1. GENERAL INTRODUCTION

Elytropappus Rhinocerotis is an indigenous vegetation type in the Western Cape Province (WP) of South Africa. No records of this genus occurring in another country have been noted (Levyns, 1926).

Renosterveld is a seriously threatened vegetation type, acknowledged as having irreplaceable value (von Hase *et al.*, 2003). Of the once very prominent Swartland Shale Renosterveld, less than 3 per cent still remains along the West Coast (Krug *et al*., 2004, Rebelo, 1998). The demise of Renosterveld vegetation has not occurred without warning; recommendations for formal protection have been advised with very little results up to date (Tansley, 1982; McDowell, 1988).

In the Western Cape, Renosterveld is largely associated with shale- and cape granite derived soils which are relatively fertile, suitable for cereal cultivation such as wheat (Hoffman, 1997). Due to extensive cultivation, the remaining fragments of Renosterveld are subjected to severe alteration of ecosystem processes. Remaining patches of Renosterveld hold a great specie composition and diversity. But these small patches are not able to contain other plant species, thereby affecting the biodiversity surrounding Renosterveld (Cowling & Richardson, 1995).

The area surrounding the Berg River catchment can be described as a semi-arid coastal region with an abundance of salts, of marine origin, having accumulated over time (de Clercq *et al*., 2010). Changes in land use from pastoral to intensive cropping have caused groundwater tables to rise to the root zone, mobilizing salts stored in the regolith; leading to crops being cultivated under water tables with increasing salinity (Nishida *et al*, 2009).

Shallow water tables, along with increased surface runoff during winter, have caused the leaching of saltine water into surrounding river catchments and ultimately the Berg River; this has led to the rapid deterioration of water quality of the BRC (Jovanovic *et al.*, 2010). Cape Town as well as other neighbouring towns is dependent on the BRC for drinking water and it also supplies farmers with water for irrigational purposes.

Saltine irrigation water together with the weathering of rock minerals, rising groundwater tables and salt transported from the ocean by wind and rain has caused an increase in the continuing process of dryland salinity. Soil salinity is seen as a threat for agricultural activity (Nishida *et al*., 2009) as it causes a decline in productivity, farm income and land value.

Therefore, it is important to investigate the effect extensive land-use change has on the soil water balance, as well as methods to manage dryland salinity. It has been proposed that to prevent groundwater tables from rising, the establishment of native perennial plant (shrubs and trees) is most effective (Pannell & Ewing, 2004, De Clercq *et al*., 2010).

Renosterveld was chosen as indigenous vegetation type. Very little, to no work has been conducted on the water use pattern of this native plant. As this vegetation type has been subjected to high levels of obliteration, the conservation therefore is crucial for the survival and existence of certain bulb and tortoise species. If Renosterveld can be used as tool to control groundwater tables and soil salinity; it would be of great advantage for land owners as well as giving the property a conservation status.

1.1 Hypothesis

The plant water relations of *Elytropappus Rhinocerotis*, with specific emphasis on water availability, are strongly affected by soil restrictions on growth and water infiltrability.

1.2 Aims of the study

The aims of this study can be summarized as follows:

1. To establish to what extent certain soil variables (physical and chemical) contribute to root distribution, penetration and ultimately the re-establishment of Renosterveld.
2. To better understand the physiological aspects and growth pattern of the renosterbos and its adaption to environmental conditions.
3. To obtain a thorough understanding of the soil, plant-water dynamics of the renosterbos and how changes in land-use affect salt mobilisation.
4. To be able to conclude to what degree Renosterveld can manage soil salinity in arid and semi-arid areas.
5. To compare changes in the water balance of wheat with Renosterveld using HYDRUS-1D
6. To compare the water use pattern of renosterbos with wheat.

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CHAPTER 2. LITERATURE REVIEW

2.1 Introduction

The Cape Floristic Region (CFR) constitutes the fynbos of the South-western part of Africa and falls mainly within the Western Cape region. The flora of this area is very distinct from the lands surrounding it and has lured naturalist from all over the world with its rich botanical diversity.

One of the most threatened habitat types in the Cape Floristic Region (CFR) is Renosterveld (Krug, 2004), with less than 10% of this natural vegetation type still remaining. Renosterveld is a very distinct vegetation type. It is mostly restricted to richer, fine-grained clayey soil types derived from shales or granites. In the Western Cape region, Renosterveld is restricted to winter rainfall areas with a Mediterranean climate (Walton, 2005). Since the early 1900's, a large extent of Renosterveld has been transformed to agricultural land, mainly used for wheat production and grazing. Today, most of Renosterveld that still remain is confined to steep, rocky areas that cannot be ploughed and areas dedicated to the conservation of Renosterveld.

2.2 The Term Renosterveld

A controversy exists around the term Renosterveld. Many people believe that the term Renosterveld must not be identified with the renosterbos as it is not the true origin of the Renosterveld.

In 1685 Simon van der Stel found the Olifants River "...*bewassen met Rhenosters bosch..., so called because these animals are usually found in it..."* (Waterhouse, 1932). In contrast to this, Levyns (1972) suggested that grey-green colour of the renosterbos is reflected in the hide of the rhinoceros. Since then the term Renosterveld has not been clearly defined. In 1980 Boucher suggested that the term Renosterveld be used, rather than 'Renosterbosveld', 'Rhenosterveld' or 'Rhenosterbosveld' and clarified that Renosterveld referred to the vegetation in which rhinoceros previously occurred.

2.3 The Concept of Renosterveld

Vegetation in the CFR is predominantly composed of Renosterveld, Fynbos and Strandveld (Boucher, 1982; Moll and Bossi, 1984). In the Western Cape the lowland areas are dominated by Fynbos and Renosterveld (Rebelo *et al*., 2006). Unlike Fynbos, the description and definition for Renosterveld is very often complex (Walton, 2005) due to different specie types and geophytes that inhabit the Renosterveld. Both, fynbos and Renosterveld, are shrub dominated plant communities growing in winter rainfall areas in the Western Cape.

Renosterveld can be described as a shrub land that is being dominated by the *Elytropappus rhinocerotis* (Renosterbos), although it is not floristically attractive it is an important component of our indigenous flora. All available evidence proves that South Africa is home to the renosterbos and up to date there have been no records that this specie has been found in any other country (Levyns, 1926). Usually these shrub lands have a high specie richness that consists of geophytic plants: *Iridaceae* (Iris family), *Liliaceae* (Lily family) and the *Orichidaceae* (Orchid family) (Mdiko, 2004). Although Fynbos and Renosterveld share very few species, almost one-third of the species endemic to the Cape Floral Kingdom can be identified in Renosterveld (Boucher, 1995).

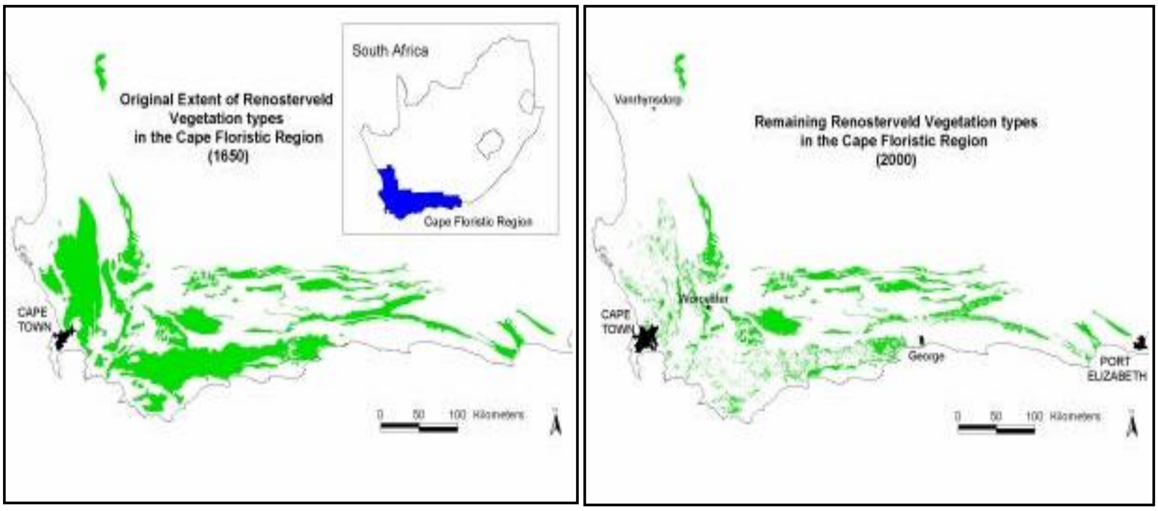
2.4 The Transformation of Renosterveld

According to Mucina and Rutherford (2006) earlier studies suggested that Renosterveld contained more grass (mainly the specie *Themeda)* than is currently the case.

The Khoi-Khoi was travelling pastoralists in search of good grazing sites for their animals. They found the grassy component in the Renosterveld of great value as pastures for their stock. It is believed that the Khoi used the plants in the Renosterveld for food and medicinal purposes (von Hase, 2003).

Khoi inhabitants of the CFR attracted European settlers with their cattle and sheep farming practices. By combining the farming practices of the Khoi with their own techniques, the Europeans found prosperity in this method of farming. As more and more Europeans migrated to the CFR, bartering and trading of livestock and other necessities (e.g. water) increased (Deacon 1992; Hoffman 1997). Because of an increase in trading the Khoi-Khoi needed to be near the trading areas (established in 1652 by The Dutch East India Company), they left their nomadic lifestyle and began burning vegetation areas in the lowland to increase grassland feeding areas for livestock (Boucher, 1982; Deacon, 1992). These developments as well as an increase of people, caused resources in the CFR to become depleted and exploited (Boucher, 1982; Deacon, 1992; Hoffman, 1997).

In the next 50 years after European colonisation it was noted that the amount of grass available for grazing was rapidly declining, causing an increase in the abundance of *Elytropappus rhinocerotis* (Mucina and Rutherford, 2006), and converting what was once grassland to shrubland. By 1760, most of the Renosterveld and Fynbos vegetation in the West Coast has been removed to make place for agricultural fields and for livestock farming (Hoffman 1997; Boucher, 1981; Deacon, 1992).



(a) (b)

Figure 2.01 Two maps illustrating the variation in the (a) original (1850) and (b) remaining (2000) extent of Renosterveld in the Cape Floristic Region (von Hase, 2003; Parker and Lomba, 2009).

2.5 Current Distribution of Renosterveld

For the last 150 years large areas of the coastal foreland has been subjected to high levels of transformation and fragmentation all along the South- and West Coast. This, along with the loss of mammal fauna, has caused large amounts of changes in the ecological patterns and processes (Krug *et al*., 2004). Since the 1920's an estimated 160 000 ha of natural vegetation has been transformed to agricultural land, mainly used for wheat production and artificial pastures (Cowling *et al.*, 1986; Hoffman, 1997). Approximately 14.7% of the coastal foreland vegetation remains today (Boucher, 1981) of which the Renosterveld is by far the most threatened (Figure 2.02).

Figure 2.02 Remaining natural vegetation in the Western Cape foreland south of the Berg River in 1972 (Boucher, 1981).

Veld Type	Original area (ha)	Remaining area (ha)	Persentage left
West Coast Strandveld	177 266	74 195	41%
Coastal Fynbos	295 860	41 239	14%
Coastal Renosterveld	512 266	29 502	6%

Today, only 1% of Renosterveld is formally conserved (Von Hase *et al.*, 2003). Most of the Renosterveld that is not formally conserved is subjected to grazing, trampling, burning, crop spraying (Kemper, 1997) and most of these areas are vulnerable to clearance (McDowell and Moll, 1992).

There are mainly four distinct Renosterveld areas that still remain in South Africa: West Coast Renosterveld, South West Coast Renosterveld, South Coast Renosterveld and the Mountain Renosterveld. Each of these areas have their own characteristic features by which they can be identified (Mdiko, 2004).

2.5.2 West Coast Renosterveld

West Coast Renosterveld use to cover an area of 512 266 ha and is one of South Africa's scarcest vegetation types (Boucher, 1995; Boucher, 1981). Only 5% of the original vegetation type still remains and the remnants of this natural vegetation type is scattered among agricultural fields (Von Hase *et al*., 2003). The return of Renosterveld to abandoned fields is limited and very slow (Krug *et al.,* 2004).

The West Coast Renosterveld climate is typically Mediterranean (semi-arid region) with a rainfall of 250mm to 600mm per year, with most of the rain falling in winter. Summers are mostly hot, dry and windy (Boucher and Moll, 1981) with sporadic rain showers. In areas where the climate is hotter and drier, Renosterveld is replaced with Karoo vegetation. In high rainfall areas (>650mm) this vegetation type is replaced with coastal Fynbos (Boucher and Moll, 1981, Rebelo, 1998). Fynbos mainly occur on leached sands which accumulate from the in situ weathering of granites and sandstones or the accumulation of sand blown in from rivers (Boucher, 1981), whereas Renosterveld occur on more fertile soils. Therefore, the rainfall regime and soil type determine the dominant vegetation type of an area (Krug *et al.,* 2004).

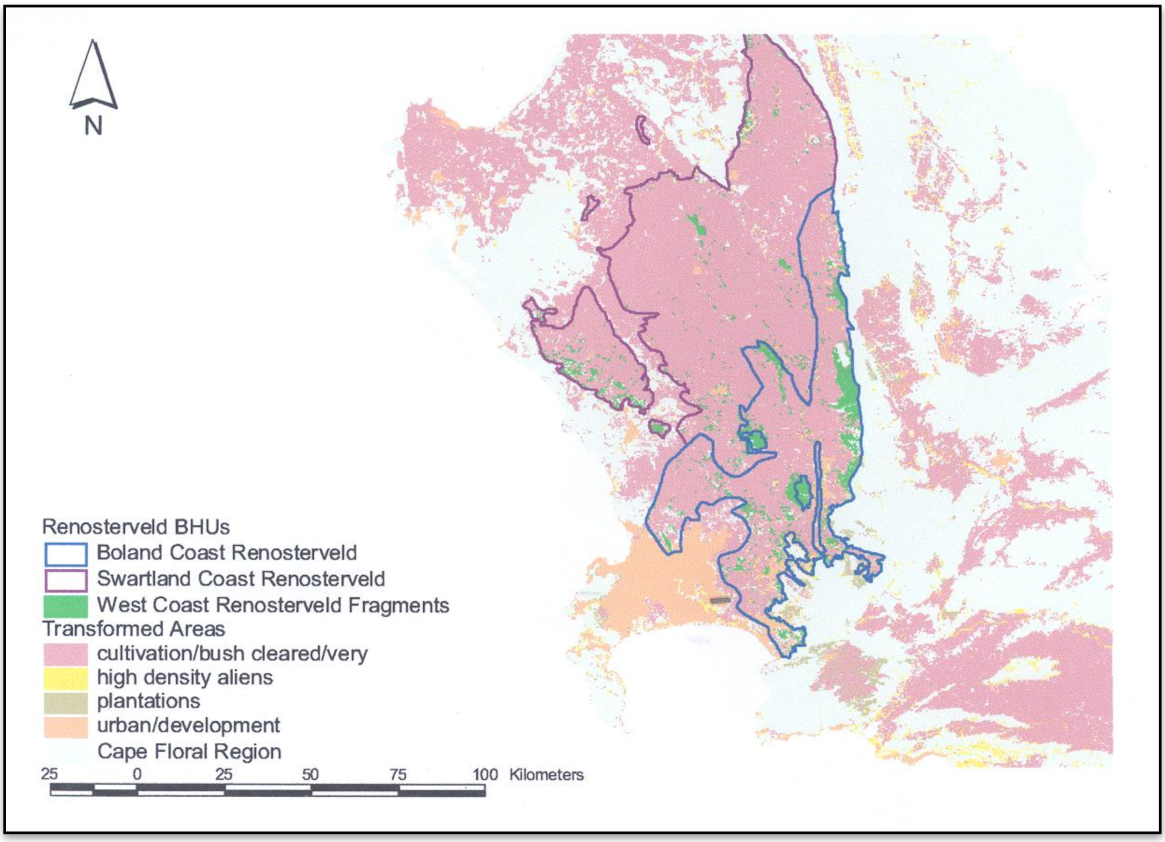


Figure 2.03 Renosterveld fragmentation in the West Coast (From Krug *et al*., 2004).

Renosterveld in the West Coast is predominantly associated with fertile soils, with naturally high salt levels in the regolith (Boucher and Moll, 1981). Renosterveld in these areas have been confined to Cape granite and Klipheuwel shale derived soils and through weathering form soils that have high clay content (Boucher, 1981). Soils in the West Coast region are subjected to soil salinity due to the semi-arid climate, which have caused the leaching of salts into the Berg River (Flügel, 1995). The Berg River is known for its important role in rural and industrial development in the Western Cape. The leaching of salts into river catchments is a serious land degradation issue threatening the health and productivity of many catchments. A continuous increase in the salt content of the Berg River could adversely affect its use for domestic, agricultural, environmental and industrial purposes (Fey and de Clercq, 2004). Sources contributing to the salinity in these arid and semi-arid areas include rainfall and mineral weathering (Bresler *et al*., 1982). Rainfall can transport salts and deposit them on the land, while through mineral weathering salts are slowly released and over time salts become soluble and leaches into the river catchments.

A very prominent local feature in the West Coast Renosterveld landscape are the clumps of taller, woody, re-sprouting shrubs, that mainly occur on “heuweltjies” (termitaria) or mounds that are the result of underground termite action.

These "heuweltjies" are rich in nutrients and have higher moisture levels than surrounding areas and can be dominated by different Biome species, such as Wild Olive (*Olea europaea* subsp. *Africana*), Dune Taaibos (*Rhus laevigata*) and Bush Guarri (*Euclea racemosa*) (Rebelo, 1992). It is because of these termite mounds that the mountains in the Western Cape look like spotted Tigers, from there the name Tyger Hills.

Figure 2.04 Fynbos vegetation growing exuberantly on very prominent "huweltjies".

2.5.3 South Coast Renosterveld

South Coast Renosterveld is confined to semi-arid and sub humid coastal forelands of the Southern Cape of South Africa (Kemper *et al.*, 2000). Rainfall for this region varies between 350 mm to 600 mm per year, but because of the high levels of evapotranspiration, the summer months are always dry.

West Coast Renosterveld appears to be more fragmented than South Coast Renosterveld, although there is no quantitative data to support this (Cowling *et al.*, 1986; Rebelo, 1995). South Coast Renosterveld is a small-leaved grassy shrub that occurs on moderately fertile, fine-grained soils, this vegetation type is restricted to soil forms with poorly developed B-horizons, with high clay content (Boucher and Moll, 1980; Cowling, 1984), which can cause soils to become waterlogged in areas where the topography is level.

Due to the relatively high agricultural potential of these soils, Renosterveld areas are becoming more and more fragmented (Bigalke, 1979; Moll and Bossi; 1984). Renosterveld is being replaced with cultivated crops. The situation is not yet as bad as in the West Coast, where only 6% of the original Renosterveld is still undisturbed (Boucher, 1982).

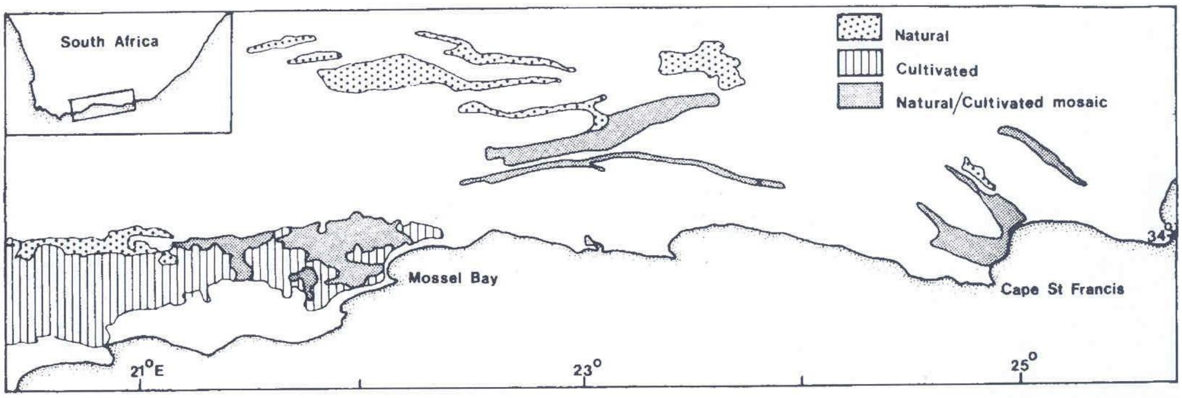


Figure 2.05 Map illustration of the distribution of Renosterveld in the South Coast (Cowling *et al*., 1986).

Just like in the West Coast Renosterveld, "heuweltjies" (termitaria) are a common feature. Due to termite activity thick patches of large-leaved evergreen shrubs can be found on deep well drained soils. Certain growth-forms of Renosterveld dominate on these termite mounds (Cowling *et al.*, 1986).

2.5.4 Mountain Renosterveld

Vegetation types of Mountain Renosterveld are not well known and are restricted to the areas in which they occur. Mountain Renosterveld is mostly confined to the Kamiesberg highlands, where the topography ensures sufficient rainfall to support this vegetation type (Low and Rebelo, 1996). Most Mountain Renostelveld areas are dominated by the Renosterbos (*Elytropapus rhinocerotis*) and the Gombos (*Relhania genisfolia*) species (Boucher, 1995).

Of all the Renosterveld types, Mountain Renosterveld is less transformed and almost entirely intact (Reyers *et al*., 2001). This could be due to the fact that Mountain Renosterveld is confined to steep, rocky areas that cannot be ploughed and therefore cannot be used for cultivation. The remaining fragments of Mountain Renosterveld (Escarpment Mountain, North-West Mountain and Central Mountain) have an irreplaceable conservation value (Ferrier *et al.*, 2000).

2.6 The root system of the renosterbos (*E. Rhinocerotis)*

Although a lot of ecological work has been carried on the renosterbos specie (Scott and van Breda, 1937), very little research has been done on the root distribution and the effective root depth of the renosterbos under different natural conditions.

In 1937 J.D Scott conducted a preliminary study on the root system of the renosterbos at the Worcester Veld Reserve. Scott and van Breda (1937) studied the effective depth to which the roots of the renosterbos could penetrate the soil. They found the root depth of a mature, well established, renosterbos can go beyond 7 meters.

However, they did not draw a parallel between the root distribution of the plant and the different soil forms in which they occur. The downward movement of roots may, however, be limited by a variety of factors, such as bulk density or shallow bedrock. The environmental conditions may have an effect on roots structure, architecture and depth (Canadell *et al.*, 1996).

The physical and chemical attributes of a soil may prove to have a severe effect on root depth and growth and may affect the re-establishment and longevity of the plant. Soil crusts are thin soil surface layers more compact and hard, when dry, than the material beneath surface layer. The formation of soil crusts can influence the rate of water infiltration as it reduces the macro-porosity of the soil layer. Crusting is the result of raindrop impact on the soil surface, causing clay to disperse and to wash into soil pores and seal them (Mills and Fey, 2004; McIntyre, 1959b). The natural biota (i.e. bacteria, lichens, mosses, earthworms and fungi) activity of the pedoderm facilitates infiltration and the supply of nutrients to the plants. The destruction of the pedoderm can reduce infiltration and lead to crust formation (Mills and Fey, 2003) and prevent seed germination.

Plants that have a low oxygen tolerance may develop morphological and anatomical characteristics that can facilitate the plant in utilizing oxygen in poorly aerated soils (Huang and Scott NeSmith, 1999) making roots more tolerant to poorly aerated soils. Soils with an excessive amount of winter water in the top horizons are subjected to an oxygen deficiency and can cause newly established plants to develop a shallow root system. The plant will then confine its main water uptake to the top soil layer taking advantage of rain or other surface water, such as dew drops that form during cold evenings. Younger renosterbos plants that are subjected to continual wet soils develop shallow root systems (Scott and van Breda, 1937).

In the present study a root study has been conducted in the Voëlvlei Conservation Reserve and emphasis has been placed on the natural occurring limiting soil properties that might affect root penetration and growth. This will be discussed in greater detail in Chapter 3.

2.7 The effect of the removal of deep rooted vegetation on soil salinity.

Dryland salinisation is caused by extensive changes in land-use in a catchment area; this coincides with the clearing of native vegetation (Greiner, 1998). Secondary dryland salinity refers to human induced salinity in non-irrigated areas (Pannell and Ewing, 2004).

River salination due to dryland agriculture is a world-wide known process responding to land clearing. The clearing of deep rooted natural vegetation causes the groundwater tables to rise (Flügel, 1995), mobilizing salts, causing soil and stream salinity by redistributing salts into the soil root zone and surface water (Greiner, 1997). In the wheatbelt of Australia, the removal of deep rooted natural vegetation has lead to an increase in soil salinity levels on cultivated fields (Cramer and Hobbs, 2002; Cramer, Hobbs and Atkins, 2004; Cramer *et al*., 2007).

In South Africa, the Berg River is suffering from increasing salinity due to dryland salinity (Flügel, 1995). Large parts of the catchment consist of semi-arid wheat lands, which is non-irrigated and receive most of their rain in the winter months (Jevanovic *et.al*, 2010). Contributors of salt in the area include; salt being transported by rain and deposited on the soil surface, salts being gradually released into the catchment through groundwater and interflow from weathered material. Groundwater flow is mainly lateral and downslope (Figure 2.05); as water travels, salts are dissolved and leached into the catchment (Yadav and Massaud, 1988).

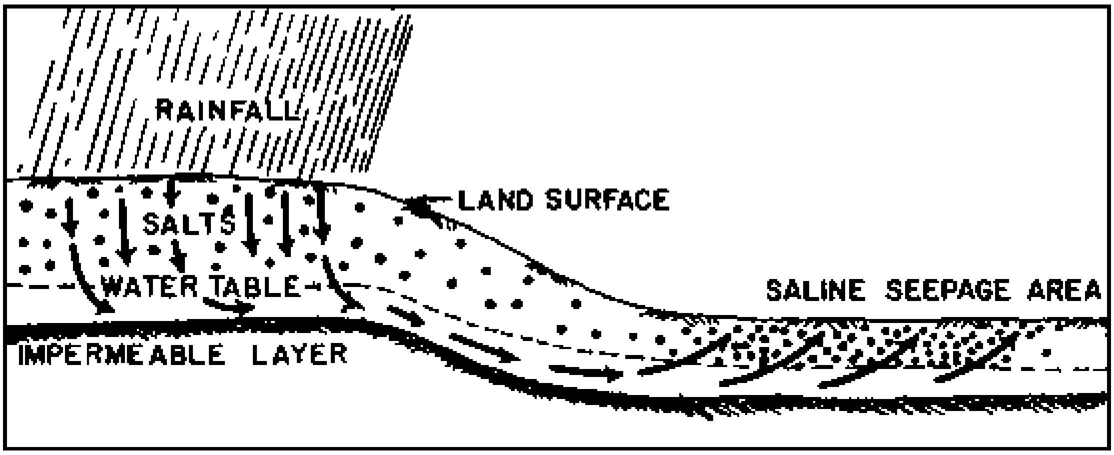


Figure 2.06 Schematic diagram illustrating salt movement and accumulation (Yadav and Massaud, 1988).

There has been large increase in the use of Renosterveld for agricultural purposes over the last 125 years in South Africa (Krug *et al.*, 2004). Ploughing of the Swartland (Western Cape) occurred rapidly when European settlers discovered the fertility of the region. By the clearing of this indigenous, endemic vegetation type to make space for dryland farming it may have caused the acceleration of salt mobilization and deterioration of the Berg River (Jovanovic *et.al*, 2010).

2.8 The Restoration of Renosterveld

In a number of areas where Renosterveld has been previously used for agricultural purposes or that has been subjected to fire, there has now been a re-establishment of Renosterveld. Renosterveld re-establishes easily after fire because most species of this vegetation type have wind dispersed seeds (Shiponeni 2003; Cowling *et al*., 1994). Only recently have re-establishment projects begun to include aspects of different soil properties of a specified area. García *et al*. (2007) found that pH varied between abandoned areas, with the pH value being highest in areas which were dominantly covered with grass species. The pH plays an important role in nutrient availability. Paschke *et al*. (2000) found that pH influenced the levels of nitrogen that are available for root uptake. The electrical conductivity (EC) measures the salt concentration in a soil and also influences pH and water availability for plant uptake. Mills (2003) studied the EC in West Coast Renosterveld and found that EC of re-established natural vegetation fields were similar when compared to nearby wheat fields. He suggested that the similarity can be caused by previous fertilizer application to vegetation areas.

When a Renosterveld is ploughed, resprouters and most of the geophytes are removed, re-vegetation of old fields is therefore slow and *Elytropappus rhinocerotis* is mostly the dominant specie in these areas (Shiponeni, 2003). Fish (1988) compared ploughed and unploughed Renosterveld areas in the Elandsberg region, but he found no significant difference in specie richness between these two treatments.

In some areas *Elytropappus rhinocerotis* or *Athanasia trifurcata* dominate, but this change can also be related to factors such as the season of ploughing, soil type or due to burning. Older Renosterveld areas such as the Voëlvlei Conservation Reserve near Riebeeck West are more sensitive to the grazing of mammals than unploughed Renosterveld areas (Walton, 2006). Selective grazing can strongly affect the shaping of vegetation in arid and semi-arid regions (Eccard *et al.,* 2000) and is contributing to the evolution and maintenance of species diversity in any area (Cowling, 1984).

Restoration of Renosterveld is deemed crucial for conservation due to its high specie richness and rich biodiversity (Walton, 2005)

2.9 Conservation of Renosterveld

Of all the vegetation types in South Africa, Renosterveld has shown the greatest decline in the Western Cape (Mcdowell and Moll, 1992) (Figure 2.06). Conservation of Renosterveld is compromised by their close proximity to nearby abandoned agricultural fields (Krug *et al.,* 2004; Low and Rebelo, 1996; McDowell and Moll, 1992), which are the source of alien plant species that are invading the natural vegetation (Krug *et al.,* 2004, Rebelo *et al.,* 2006; Kemper *et al*., 1999, von Hase *et al*., 2003). Thus the understanding and the correct interpretation of ecosystems in Renosterveld at a local and landscape scale are important for the conservation of Renosterveld and other endangered plant and animal species (Walton, 2006).

One such endangered specie is the *Psammobates geometricus* (geometric tortoise). Its presence is limited to the extreme south-western Cape Province of South Africa (Baard, 1993) and as far as is currently known the geometric tortoise is confined to Renosterveld. The clearing of Renosterveld for cultivation has led to the destruction of the geometric tortoise's habitat and has caused a significant depletion in numbers (Baard, 1993). Fire, naturally ignited or uncontrolled, also threaten the populations of the geometric tortoise (Baard, 1993).

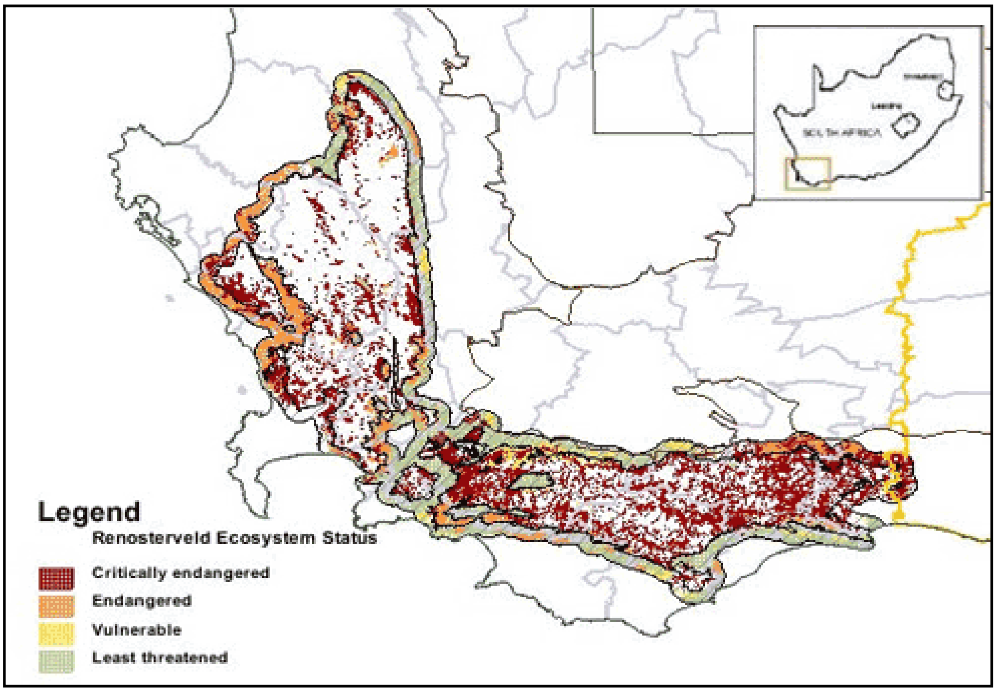


Figure 2.07 Endangered Renosterveld areas along the coastline (map from http://www.botanicalsociety.org.za/cu/downloads.php).

Conservation Managers and Ecologists are finding ways in which farmers can benefit from putting a part of their land aside for Renosterveld conservation. Many farmers are starting to realize the importance of biodiversity and have started managing their farms in a more conservation-friendly way (Curtis, 2007).

2.10 Conclusion

Various studies over the last few years (Walton, 2006; Mdiko-Iponga, 2004; Shiponeni, 2003 etc.) have focussed on Renosterveld. Although the ecological and conservational aspects of Renosterveld are well understood, there is a gap in knowledge of the role soil play. Not much research has been done on the effect of different soil types and soil properties on Renosterveld, natural vegetation as well as re-established Renosterveld. As to date there have been very little noteworthy studies into root penetration, root depth, water uptake through the root system in correlation with transpiration of the Renosterveld.

As Renosterveld is an endangered vegetation type, it is important to investigate techniques to best restore Renosterveld in degraded areas which can in turn be used for the conservation. Renosterveld can thus be seen as a specific land use that can also decrease soil salinity in areas such as Sandspruit and ultimately the Berg River catchment.

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CHAPTER 3. SITE DESCRIPTION AND ANALYSIS OF SOIL PROPERTIES CONTRIBUTING TO SOIL SALINITY AND AFFECTING PLANT GROWTH OF THE *ELYTROPAPPUS RHINOCEROTIS*

3.1 Introduction

Although the interaction between soil properties and their effects on plant growth has been relatively well studied, it is known that these properties can influence each other differently in changing climatic conditions and different locations. Root penetration and distribution may be limited by various natural occurring soil factors (Canadell *et al.*, 1996)

As very little work has been done on renosterbos itself, as well as soil properties affecting plant growth, the aim of this Chapter is to identify the physical and chemical soil properties in the study site, which determine the soils ability to change root structure and influence rooting depth.

3.2 The Study Area

The location of the two study sites and the Berg River catchment is indicated in Figure 3.01. The Berg River has its origin in the Franschoek Mountains and its outlet is in the Atlantic Ocean near Laaiplek. The area in which the study sites are situated is commonly known as the Swartland district and almost all of the arable land is under cultivation. The major part of the cultivated land is cropped to a wheat-lupin-fallowland rotation. The wheat and lupin stubble are either grazed by sheep or in some instances burned by controlled fire.

3.2.1 The Study Site

The study site is located in the Berg River Catchment (BRC) and is a contiguous part of the Agter-Groeneberg Conservancy (AGC) in the Western Cape, South Africa. The AGC contains the Elandsberg Private Nature Reserve and the Voëlvlei Provincial Nature Reserve. Previously Voëlvlei was used for wheat cultivation. Currently Voëlvlei is managed by Cape Nature (formerly Western Cape Nature Conservation Board). This site was selected for research as it contains one of the last portions of the Swartland Shale Renosterveld. Voëlvlei was afforded protection status in ± 45 years ago and since then Renosterveld has re-established itself in this area and has been a source of knowledge for many years. Opposite the Renosterveld is the adjoining wheat farm, Schoongezicht, which in addition with the Renosterveld makes part of this study site and will here forth be referred to as Voëlvlei.

The second study site, Malansdam, is located 16 kilometres to the North-West of the town Riebeeck-Wes. This site was selected, as it contains a mountainous area that is home to the Mountain Renosterveld. As this area is to steep to be cultivated, this site is of great value as it contains an area of Renosterveld that is undisturbed and has a rich renosterbos specie diversity.

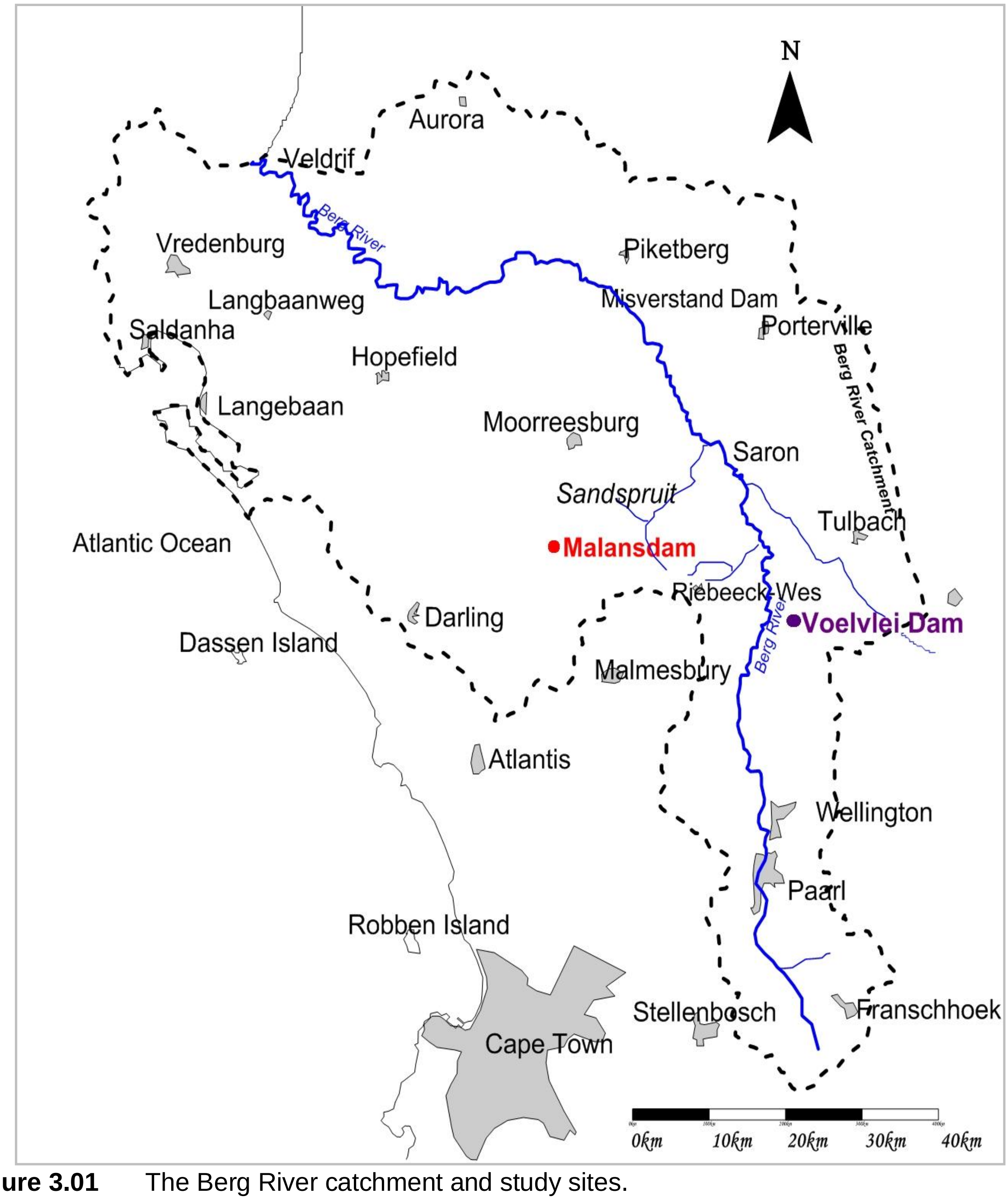

Figure 3.01 The Berg River catchment and study sites.

3.2.2 Climate

Both sites are situated in the winter rainfall district of the Western Cape. Climate in this area can be described as typically Mediterranean (semi-arid region) with an annual rainfall that ranges from 250mm-600mm (Boucher and Moll, 1981) (Figure 3.02)

Summers are dry and windy with sporadic showers. The long-term climate data for Voëlvlei and Langgewens is summarized in Table 3.01 and Table 3.02 respectively. The weather station at Voëlvlei was only established in 2009; therefore the long term climate data for Langgewens is of great importance to understanding the climate of the study area.

Table 3.01 Long-term average climate data for Langgewens

Months	Presipitation (mm)	Relative Humidity (%)		Temperature (ºC)		Wind Speed (m/s)
		Max	Min	Max	Min	
January	11.3	71.6	24.5	30.7	18.2	2.4
February	10.8	70.4	27.0	31.0	18.6	2.3
March	6.4	71.6	22.4	30.0	16.2	2.3
April	34.6	84.0	26.0	27.8	13.7	2.3
May	55.9	88.9	25.9	23.9	11.2	2.5
June	60.9	90.6	34.8	19.7	9.6	2.8
July	71.4	89.9	36.6	18.4	9.0	2.5
August	68.8	88.8	43.6	18.7	8.9	2.2
September	42.7	84.7	33.8	20.9	10.1	2.0
October	18.6	76.8	25.8	25.3	12.0	2.2
November	23.4	76.1	24.8	28.3	14.1	2.2
December	11.3	72.3	28.1	28.7	17.3	2.3
Total	416.0					
Average	34.7	80.5	29.4	25.3	13.3	2.3

Table 3.02 Long-term average climate data for Voëlvlei

Months	Presipitation (mm)	Relative Humidity (%)		Temperature (ºC)		Wind Speed (m/s)
		Max	Min	Max	Min	
January	0.0					3.7
February	74.0	100.1		24.8	4.5	2.9
March	61.4	103.3	28.3	26.7	2.6	0.6
April	31.2	103.5	25.4	28.0	2.7	0.6
May	14.0	101.6	11.3	36.9	4.4	0.7
June	81.8	100.8	13.5	38.2	8.7	0.8
July	1.0	96.9	11.6	38.1	10.9	0.7
August	0.0	97.4	10.4	43.4	14.0	0.8
September	13.8	98.3	11.9	44.2	11.1	0.7
Total	277.2					
Average	30.8	89.1	12.5	31.1	6.5	1.3

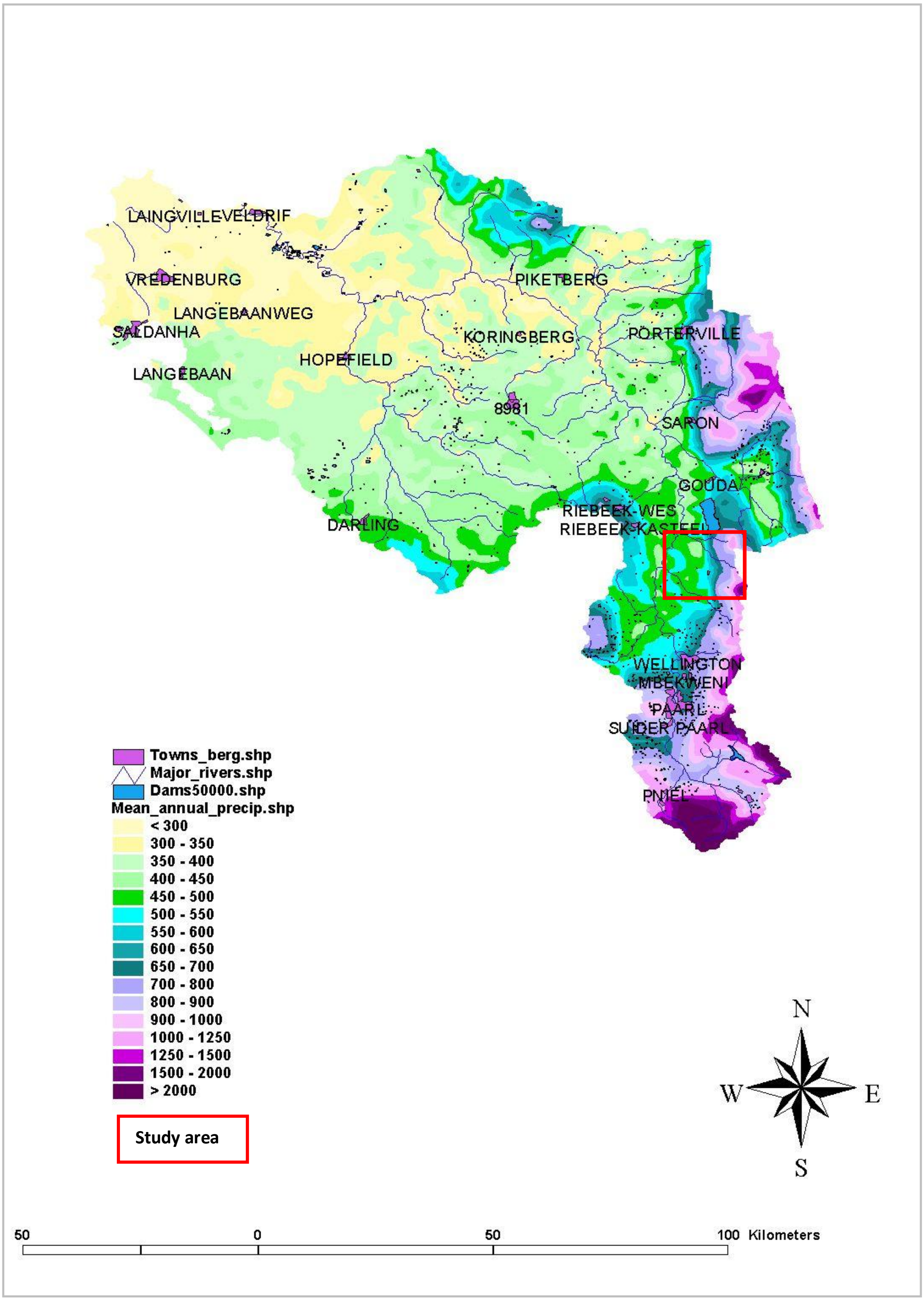

Figure 3.02 Mean annual precipitation for the BRC area (de Clercq *et al.*, 2010). Location of study area indicated in the red block.

3.2.3 Vegetation

In a study conducted in 2006 by Mucina and Rutherford; Renosterveld have been split into 29 vegetation units based on their distribution, landscape features, geology and climate (Figure 3.03). For the purpose of this study we will focus on the Western Cape.

In the remaining fragments of vegetation the *Elytropappus rhinocerotis,* the renosterbos, is most dominant. In unison with the renosterbos other scelerphyllous shrubs such as the *Ecomis axyrioides* and the *Eriocepalus umbellatus* also occur.

When observed from far away, Renosterveld seems dull and faded, especially in summer when very few plants are in bloom and surrounding croplands are barren and dry. A closer look, preferably in springtime, reveals an interesting variation in bulb plant species such as the *Ixia maculate, Serriuria scorparia, Babiana rubrocyancaea* and the *Moraea villosa.*

The remaining fragments of the Swartland Alluvium Fynbos and Swartland Shale Renosterveld are deemed crucial for conservation due its high species richness (Walton, 2005). In Figure 3.04 the main vegetation types that are found in the BRC is indicated.

3.2.4 The effect of Land use change

The structure and composition of natural vegetation is affected by various human activities which include the clearing of land for agricultural purposes as well as an increase in population growth. There is, however, a danger in linking population growth directly to land degradation. An increase in the human population does not automatically mean that there is an increase in land degradation (Cowling *et al*., 1997). Other factors that also play an important role in degrading natural vegetation include the use of fire, grazing by domestic animals, cultivation and alien species intrusion.

Although Voëlvlei is not intentionally stocked with large herbivores a few wild Grey Rhebok, Grysbok and Duikers was cited, this area serves as a control site for grazing. Fires in the Western Cape are often the result of lightning strikes (Kruger, 1979c) in the mountains or human induced. Voëlvlei have been subjected to wild fires in the past, descending from the mountain to the foothills and foreland of plains below (Walton, 2005). From an aerial view the difference in Renosterveld density can be seen clearly, creating a montage of varying sizes and ages al through the conservation area. Alien species such as Mediterranean grasses comprise most of the alien component in the Swartland region. Alien species are defined as species that are not native to the Cape Flora and have entered Africa via the transport of oat and wheat from Europe (Walton, 2005).

One of the greatest impacts on this natural vegetation type has been the removal of Renosterveld for cultivation. Since the arrival of the colonist in the 17th century, the Swartland has been subjected to transformation for agricultural purposes that have intensified during the 20th century (Walton, 2005). In Renosterveld alone, nearly 96% of the original vegetation has been transformed causing an alarming decrease in bulb plant species, many of which are now listed as rare and endangered as well as certain herbivore species such as the geometric tortoise (*Psammobates geometricus*) which is now critically endangered specie.

3.2.5 Geology

Renosterveld in the Western Cape occurs mainly on soils derived from the Malmesbury and Cape granite sediments. The West Coast foreland supporting Renosterveld is predominantly built by metamorphosed shales of the Malmesbury Group (Walton, 2005) which was flooded by the sea till the late tertiary period (Flügel, 1995). The West Coast, bordered by the Olifants River and Elandskloof Mountains in the east, is made-up of sandstone of the Table Mountain group. In the west the shales are overlain by aeolian deposits (Walton, 2005). The Swartland terrain is composed of the Berg River, Klipplaat, and Moorreesburg formations (Rozendaal *et al*., 1999) (Figure 3.05).

The lithology of the Berg River formation are mainly fine-grained greywacke, phyllite (Merryweather, 1965), chlorite schist, cherty limestone lenses and quartz schist on top, overlain by the Klipplaat formation which mainly consist out of quartz sericite chlorites schist with phyllite and limestone between layers (Walton, 2005) . The Cape granite occurs below the Malmesbury shales.

Small areas of the Klipheuwel formation also occur in this area. Klipheuwel beds consist mainly of sandstones and conglomerates with minor shale bands. The Klipheuwel formation is harder and has a lower salt content than the Malmesbury formation (Merryweather, 1965). Rocks of the Malmesbury shale group give rise to sandy brown soils that under this climate are subjected to erosion and sheet wash after heavy rainfall (Talbot, 1974).

Soils derived from granite and shale is base-saturated, with relatively high pH values and can be described as fertile (Ellis, 1973). Shale derived soils are fine-grained clayey. These soils may affect the infiltration and drainage properties (Kruger, 1979a).

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Fires in the Western Cape are often the result of lightning strikes (Kruger, 1979c) in the mountains or human induced. Voëlvlei have been subjected to wild fires in the past, descending from the mountain to the foothills and foreland of plains below (Walton, 2005). From a aerial view the difference in Renosterveld density can be seen clearly, creating a montage of varying sizes and ages al through the conservation area.

Alien species such as Mediterranean grasses comprise most of the alien component in the Swartland region. Alien species are defined as species that are not native to the Cape Flora and have entered Africa via the transport of oat and wheat from Europe (Walton, 2005).

One of the greatest impacts on this natural vegetation type has been the removal of Renosterveld for cultivation. Since the arrival of the colonist in the 17th century, the Swartland has been subjected to transformation for agricultural purposes that have intensified during the 20th century (Walton, 2005). In Renosterveld alone, nearly 96% of the original vegetation has been transformed causing an alarming decrease in bulb plant species, many of which are now listed as rare and endangered as well as certain herbivore species such as the geometric tortoise (*Psammobates geometricus*) which is now critically endangered specie

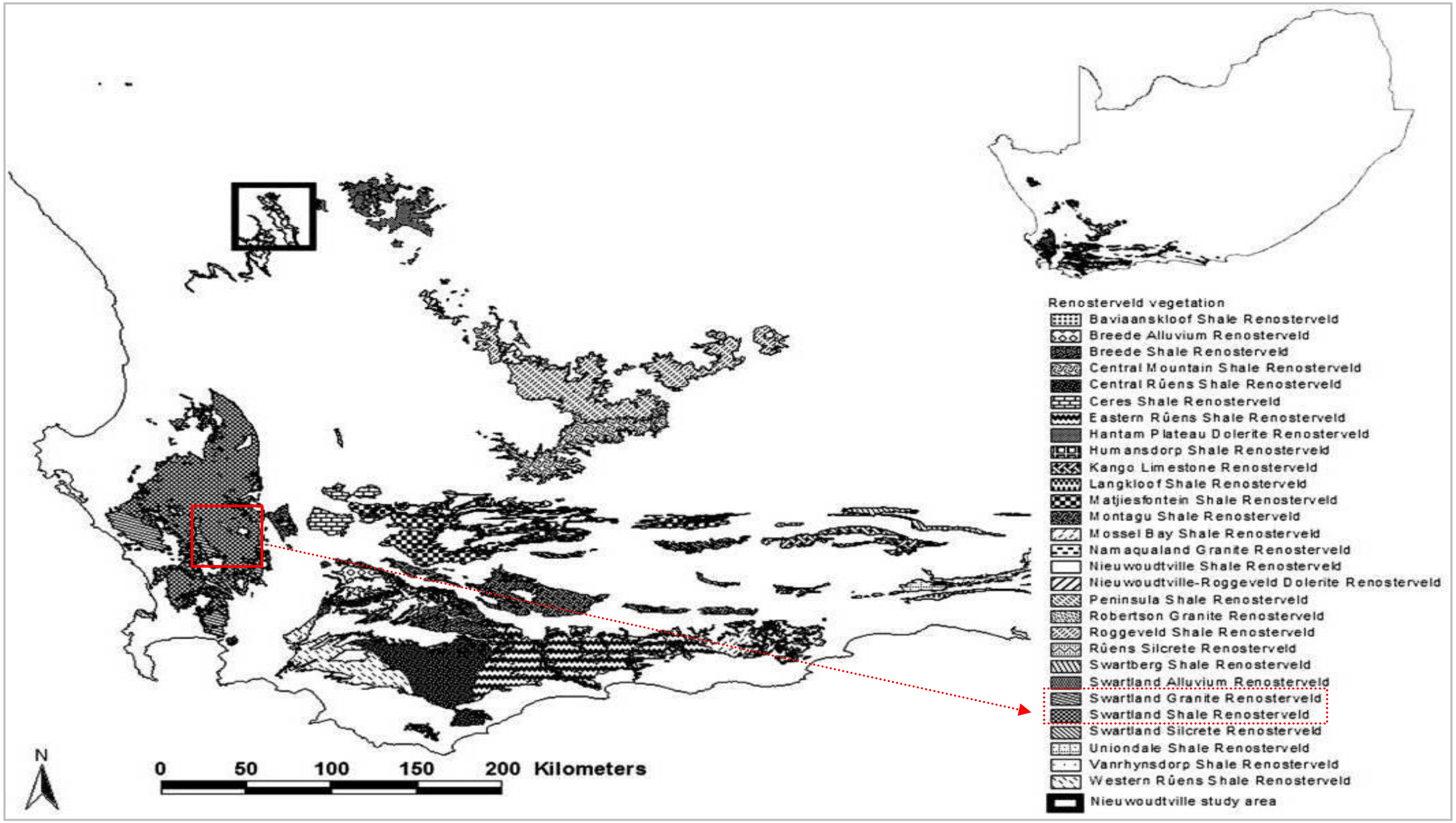


Figure 3.03 The variety of Renosterveld units and their location in South Africa (as defined by Mucina and Rutherford, 2006). Location of study area indicated in the red block.

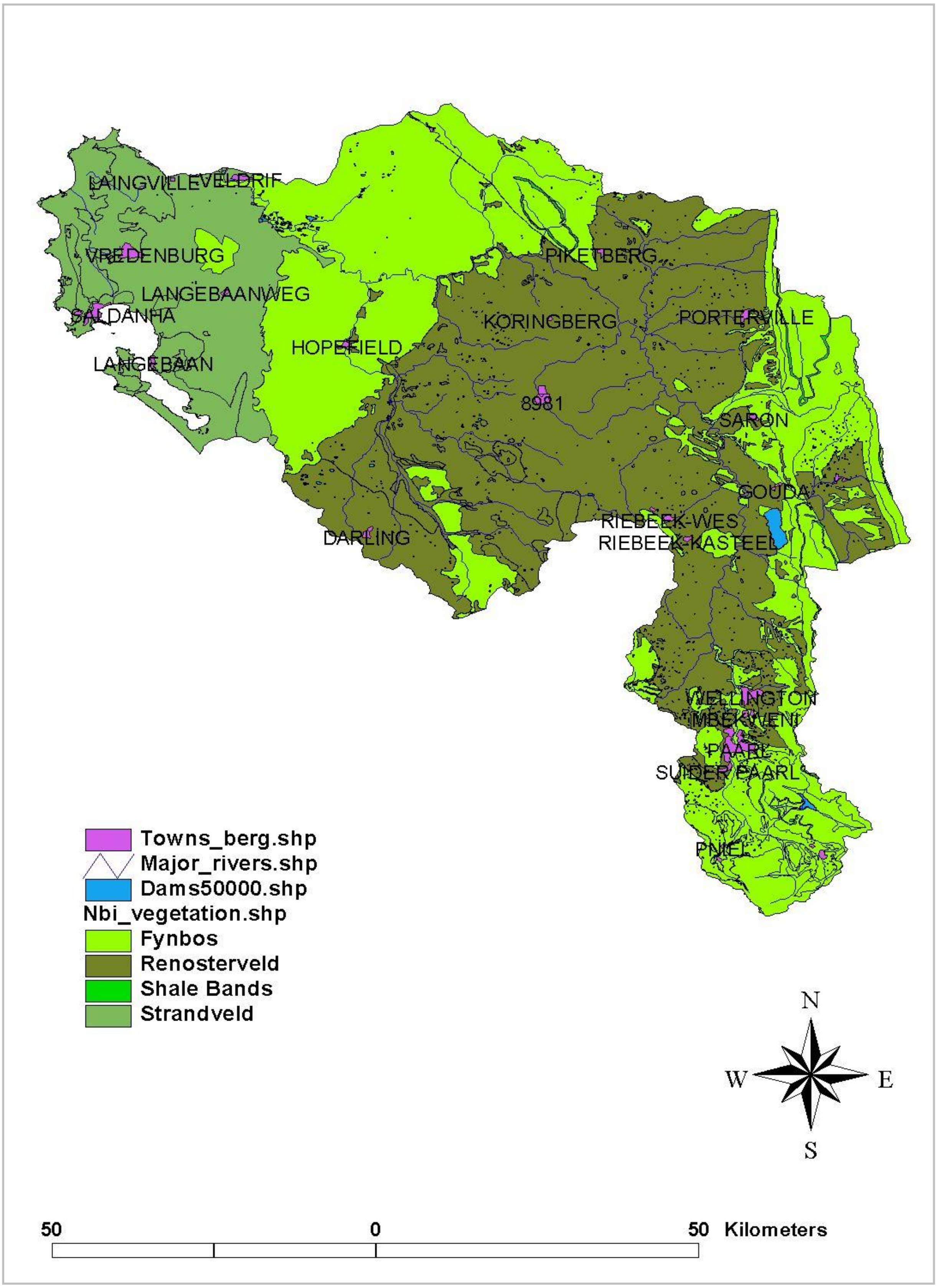


Figure 3.04 Main vegetation types in the Berg River Catchment area as classified by de Clercq *et al.* (2010).

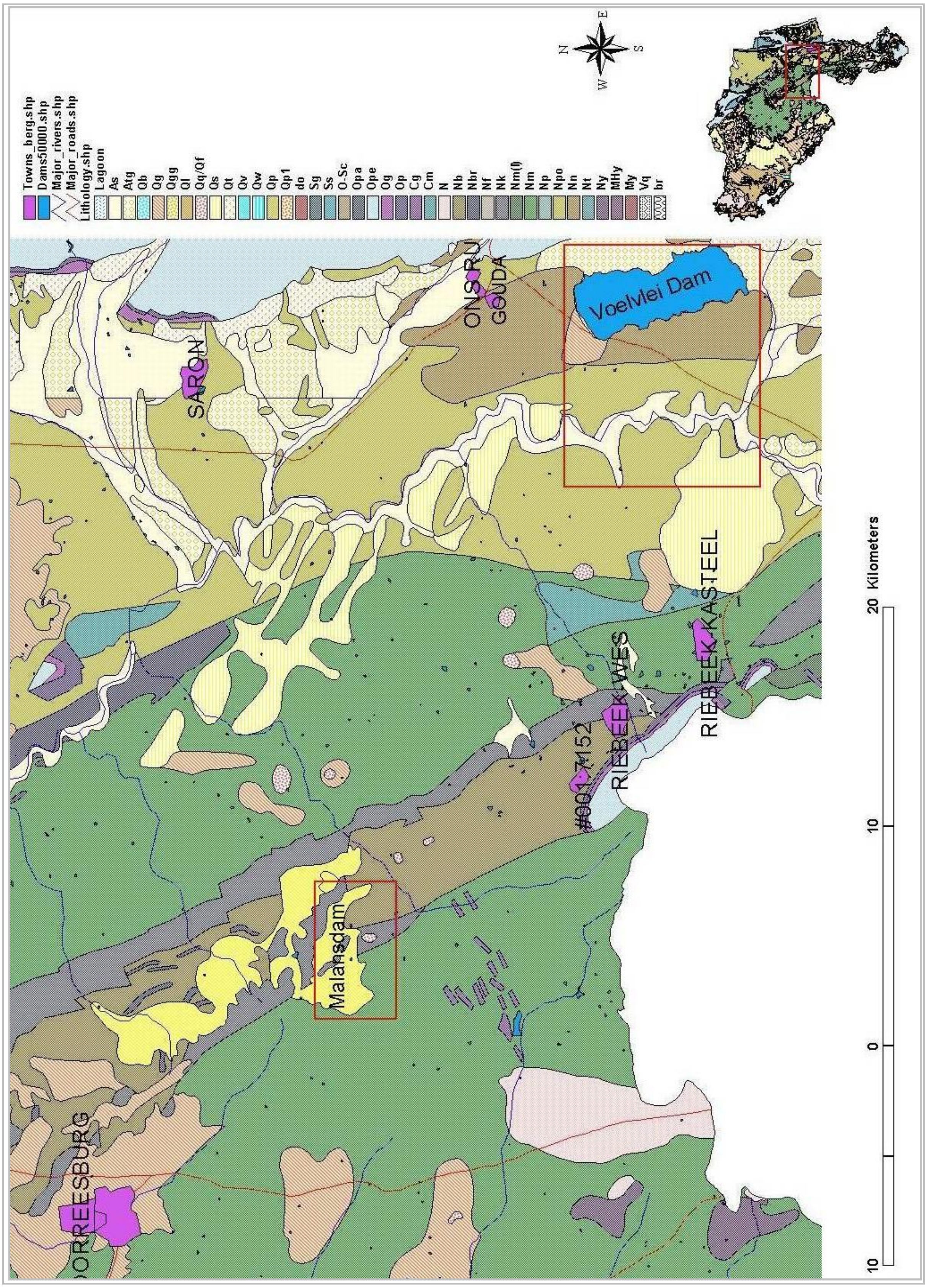


Figure 3.05 Geological Map identifying main rock formations at site localities. Legend description in Appendix 1 (de Grys, 1980; de Clercq *et al.,* 2010).

3.2.6 Soils

3.2.6.1 Soil distribution pattern

Dominant soil types below the Berg River Catchment was chosen to focus the study on and can be classified as followed:

Shallow residual developed soils with underlying shale – These soils are most dominant with Malmesbury shale as parent material, which are in different stages of weathering (Merrywheather, 1965; Bester, 1966). Soil preparation tear up the shale layers and transport it to the sub-soil layers which cause an increase in the amount of coarse fragments in the root zone. Associated soils include Swartland, Glenrosa and Klapmuts (Soil Classification Workgroup, 1991).

Deep red soils are less dominant than the above mentioned soil types but still of great significance because of its development potential. These deep red soil types develop out of transported material (Merrywheather, 1965; Bester, 1966). Coarse fragments that occur are mainly quartz fragments. Oakleaf is one of the soil types that can be associated with this soil group.

One of the main purposes of this study was to compare different soil patterns to determine how Renosterveld would interact with different soil types.

Table 3.03 A brief description of the dominant soil forms in the Malmesbury-, Riebeeck-Wes-, and Tulbagh district (F.Ellis, 2001).

Soil Form	Desciption
Oakleaf	Deeply developed soils (0-120cm) with very few obstructions, bleached orthic A horizon on a neocutanic B with a moderately developed structure
Swartland	Bleached A orthic horizon on a pedocutanic B horizon, Swartland soil form is mostly shallow (0-70cm) with a moderate to strongly developed blocky structure and a grey-brown gravelly sandy loam texture
Glenrosa	Grey coloured orthic A horizon on lithocutanic B horizon with underlying hard/soft shale, mostly shallow (0-70cm) with gravelly sandy-clay-loam texture
Klapmuts	Dominantly shallow (0-70cm) soil form with coarse fragments in the top- and sub-soil layers, orthic A horizon on a E horizon on a pedocutanic B with a clay to clay-loam texture on hard/soft shale
Sepane	Mostly shallow (0-60cm),moderately to poorly developed structure. Bleached orthic A horizon on a pedocutanic B horizon on unspesified material with signs of wetness

Several different factors can contribute to the variation in soil patterns. The parent material, from which different soil forms develop being the most distinctive, contributing factor (Merryweather, 1965; Bester, 1966; Flügel, 1986). An additional factor contributing to the natural variation in soil types is the occurrence of 'heuweltjies'. Termite activity causes the localisation of lime in certain areas. The depth of silica deposition and thus the depth at which the hardpan will form is dependent on soil texture and the rate of infiltration after rains (Ellis, 2002).

3.2.6.2 Soil Salinity

In this area the occurrence of soil salinity can be the result of various climate factors such as; temperature, humidity and rainfall, with temperature being most crucial. With an increase in temperature the water stress level of the plant rises and influences the salt tolerance of the plant. Rainfall can transport salts and deposit it on the soil surface. An additional factor is the ET (evapo-transpiration), which causes an increase in the salt concentration in the soil and the surface water (de Clercq, 2008).

A sub-catchment study was done by Flügel (1995) in the BRC indicating the distribution of salts in the same areas that has been selected for this study. He also indicated that the topography had a great influence on the occurrence of salt in the landscape. On hilltops or mountainous areas the salinity was relatively low, with an increase in soil salinity downhill. The result found in this study is similar to studies done in the wheat belt of Australia.

Contributing factors that are affecting soil salinity is the quality of the water that is being used by farmers to irrigate their fields as well as salinity recharge from dryland agriculture. High levels of soluble salts and trace elements can have a serious effect on plant growth (Ayers and Westcot, 1985; Gorgens and de Clercq, 2006). The process of leaching and draining is important to prevent an increase in the salt concentration in irrigated agriculture. Yet it is through the process of leaching and draining that excessive amounts of salts are being released into rivers and groundwater (Rhoades *et al.*, 1990). The effect of salt accumulation on plant growth will be discussed later in the chapter.

3.3 Profile Description

3.3.1 Material and Methods

Three profile pits were made at different elevations on Malansdam. Two profile pits were made in the wheatfield as well as in the adjoining Renosterveld. The conservation value of the Renosterveld limited the soil profiles to two. Additional soil pits were made with an auger throughout the Renosterveld to validate dominant soil types found in this area. The depth of profile pits was limited by various factors, which included the excavator's mechanical ability, topography, underlying parent material and the limitation that was set at Voëlvlei. Depth of the profile pits was restricted to ±1100mm.

For each horizon the depth, wet and dry Munsell colours (Munsell, 2000) and soil structure were noted (Appendix 2.2). Texture class, clay percentage, coarse fragments and sand grade were subjectively determined according to the FAO guidelines (2006). Soil samples were taken, with a geological hammer from each horizon to determine the physical and chemical attributes. All the samples were air dried and passed through a 2mm sieve.

Bulk density for each horizon was determined with the core method (Blake and Hartge, 1986). Undisturbed core samples were taken (Hoffman, 1997). The pH (water and 1M KCl) and electrical conductivity (EC) were measured (White, 1997). Since the results of this method cannot be compared to the saturated paste extract method, the results were converted to EC_e values based on the estimated water holding capacity of the soil based on the texture of the soil (Hazelton and Murphy, 2007). A Multiplier factor (Table 3.04) was used to convert the EC 1:5 (dS m^{-1}) values to appropriate EC_e (dS m^{-1}) values. The multiplier factor is dependent on the moisture holding capacity of the soil. Additionally, saturated pastes were made to determine the conversion factors.

Table 3.04 Multiplier factors for converting EC 1:5 (dS m^{-1}) to EC_e (dS m^{-1}) values (Hazelton and Murphy, 2007).

Soil Texture	*Multiplier Factor
Loamy sand, clayey sand	23
Sandy loam, fine sandy loam	14
Loam	9.5
Clay Loam	8.6
Light medium clay	8.6
Medium clay	7.5
Heavy clay	5.8

EC_e (dS m^{-1}) = EC 1:5 (dS m^{-1}) x *Multiplier factor

Samples from EC measurements were filtered and used to determine the soluble anions and cations in a 1:5 soil:water ratio (Page, Miller & Keeney, 1982). In comparison with $EC_{1:5}$ method, the EC was also determined with the saturated paste extract (EC_e). Ca^{2+}, Mg^{2+}, K^{2+} and Na^+ were determined by AAS (atomic absorption spectroscopy) from a filtered supernatant of a 1:10 NH_4OAc extract, (White, 2006), thereby giving an indication of the soils nutrient status. As the pH indicated relatively high values, it was prescribed (Hardie, 2010) that pH of the ammonium acetate extract be increased to a pH of 8.0 by adding ammonia.

Effective cation exchange capacity (ECEC) was calculated by the summation of all the exchangeable cations (Ca^{2+}, Mg^{2+}, K^+, Na^+ and exchangeable acidity). ESP, EMgP, ECaP and ECEC/Clay% were among the soil chemical parameters calculated. All the data for the different soil samples are shown in Appendix 2.1 and the formulas used for the calculations are shown in Appendix 5.

Textural analysis of the soils was done for all horizons. Sand fractions were separated through the method described by Gee *et al.* (1986) and silt- and clay fractions were determined with a LASER particle size analyzer (Micrometrics Instrument Corporation, Faculty of Process Engineering, Stellenbosch University). Data was analysed with Saturn Digisizer 5200 software. The method of laser diffraction particle size analysis is dependent on a particle's ability to scatter light at an angle directly related to their size, when passing through a laser beam (Webb, 2000). A particle-size instrument based on light scattering can distinguish the scattering patterns of large particles from small particles because large particles scatter strongly and principally to small angles away from the incident light beam while small particles scatter weakly and too much larger angles (Wedd, 2003).The fraction of sand, silt and clay in the soil determines its textural characteristics. Once the percentage of the sand, silt and clay in the soil is known, the texture class can be determined.

Table 3.05 Particle size classes (Soil classification working group, 1991) and method of separation.

Fraction	Diameter (mm)	Separation method
Coarse sand	2 - 0.5	Sieve
Medium sand	0.5 - 0.25	Sieve
Fine sand	0.25 - 0.1	Sieve
Very fine sand	0.1 - 0.05	Sieve
Coarse silt	0.05 - 0.02	Laser diffraction
Fine silt	0.02 - 0.002	Laser diffraction
Clay	< 0.002	Laser diffraction

A root study was conducted with the help of the profile wall method (Böhm, 1979). A list of soil factors that may limit plant growth or affect root distribution was compiled.

3.4 Results and Discussion

The physical attributes of a soil type play an important role in the hydraulic conductivity, water holding capacity and the root distribution of a soil profile.

3.4.1 Morphological characteristics

Profile pits were classified using the South African soil classification system (Soil Classification Working Group, 1991). Figure 3.06 shows the dominant soil types that are found at Voëlvlei and Malansdam as briefly described in Table 3.03. Before classification the slope, aspect, main landform and the plant growth were noted according to the FAO guidelines (2006). Appendix 2.2 contains a detailed profile description for each profile pit from the different site localities.

At Voëlvlei the dominant soil forms found in the Renosterveld included Swartland, Glenrosa and Klapmuts. In the wheatfield, Swartland and Glenrosa were the dominant soil forms. At Malansdam the Oakleaf soil form was the dominant soil form on the slope with the Sepane soil form dominating at the foot of the slope. These soil forms are characteristically found in the drier convex landscape of the Berg River area (F. Ellis, 2001).

The Swartland, Klapmuts and Sepane soil forms are classified as duplex soils. These soils can be identified by accumulation of clay by illuviation in the B-horizon. Clay enrichment in the B-horizon results in strong, blocky or prismatic soil structure. The B-horizon is often very hard and dense and is commonly an obstruction to root growth, water movement and deep cultivation. Clay dispersibility results in soils that are prone to surface crusting and susceptible to severe erosion if not managed carefully. Therefore, intensive cropping should be avoided. The Oakleaf soil form is defined as a young, immature soil that is weakly altered with an increase in clay content with depth, but inadequate to be classified as a duplex soil. Oakleaf soil types are usually deeply developed soils with very few restrictions relating to root growth and permeability. The Glenrosa is defined as lithic soil that develops through rock weathering and is commonly found in the wheat belt of the Western Cape where the Malmesbury shale and Cape granite rock formations dominate. The lithocutanic B horizon of the Glenrosa soil form is defined as not hard due to softening of weathering shale.

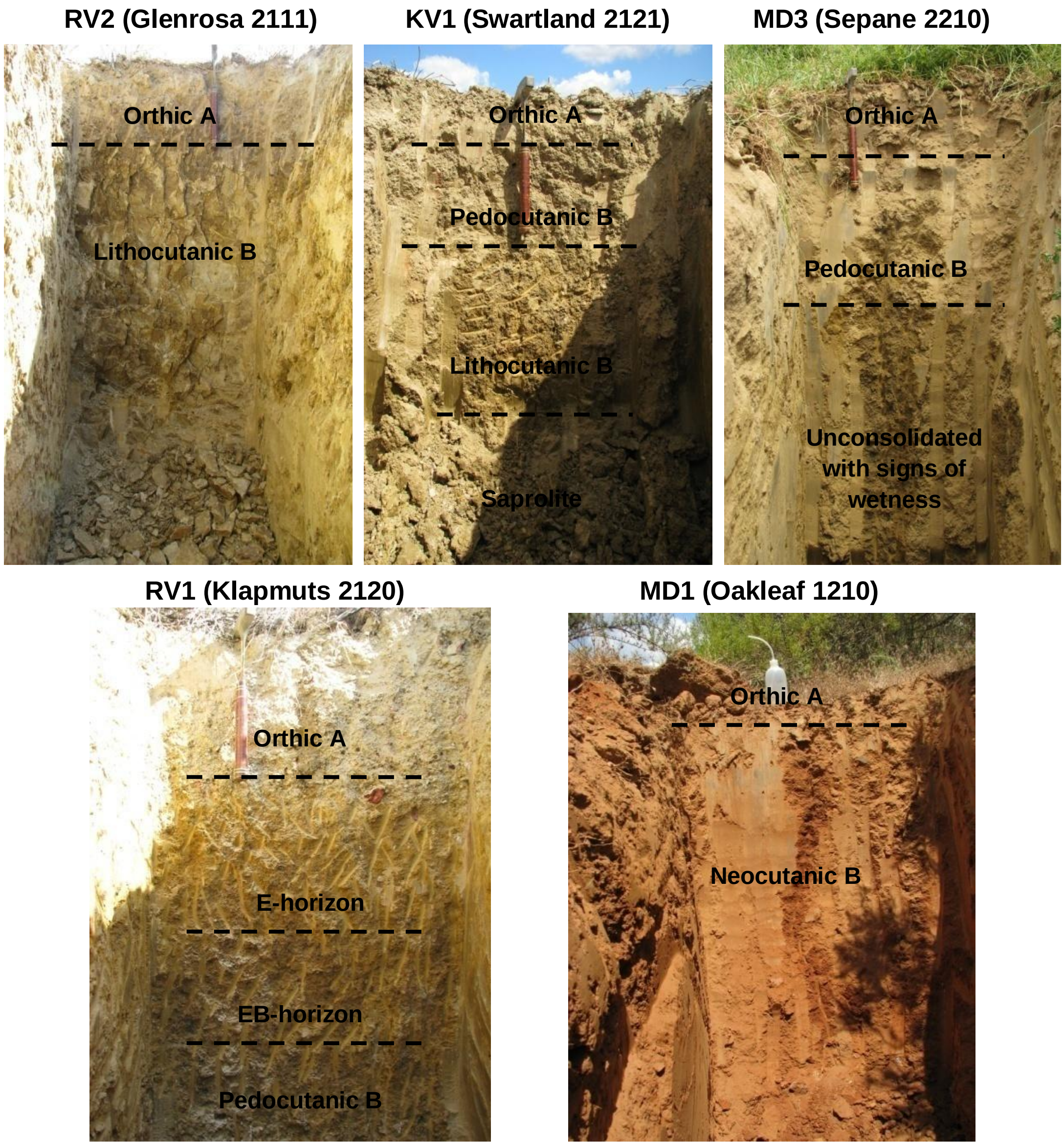


Figure 3.06 Photo illustrations of the dominant soil types on research sites.

3.4.2 Bulk Density

Bulk density (BD) values were determined for soil profiles at Voëlvlei and Malansdam (Appendix 2.3.2). At Voëlvlei the dominant soil forms were mainly Glenrosa, Swartland and Klapmuts, with bulk density values that varied between, 1.54-1.63 g.cm^{-3}, 1.53-1.58 g.cm^{-3} and 1.55-1.65 g.cm^{-3} respectively.

At Malansdam, Oakleaf and Sepane were the dominant soil forms with bulk density values varying between 1.52-1.61 g.cm^{-3} for Oakleaf and 1.54-1.58 g.cm^{-3} for Sepane. In most instances bulk density values were relatively uniform throughout the profiles.

Limiting values of bulk density for plant growth depend on the soil texture. For clayey and clay loam textured soil types critical bulk density values vary between 1.4 – 1.6 g.cm^{-3}.

At these bulk-density values root penetration and plant growth may be restricted, however, the effect of soil density on plant growth will be discussed later on in the chapter.

3.4.3 Root Study

Very little work has been done in connection to the root development of renosterbos. Previous studies have shown that a knowledge of root distribution, root penetration and root competition between plants is not only of great scientific value, but also of great practical value in understanding the interaction of plants with different soil types and what effect different soil forms has on root growth.

Figures 3.07 – 3.09 contains photo illustrations as well as line sketches of the root system of a single renosterbos at the two main study site localities. Three root studies were done on three different soil types in the study area. Different symbols were used in the line sketches to indicate different root sizes. Table 3.06 contains the collected root study data according to the profile wall method (Böhm, 1976). There was a significant decrease in root density from the top (0-20cm) to the bottom (80-100cm) horizon.

Table 3.06 Root distribution of selected soil profiles at Malansdam (MD1) and Voëlvlei (RV1 and RV2) (see Figures 3.08 to 3.10).

Study Site	Depth	Soil Form	Root density/m.m^{-2} profile wall/root diameter				Total root density/m.m^{-2} for profile wall
	(cm)		<2	2 -5	5 - 10	>10	
MD1	20	Oakleaf	94	9	1	5	109
	40		16	0	0	0	16
	60		8	0	0	0	8
	80		7	0	0	0	7
	100		4	0	0	0	4
	Total		25.8	1.8	0.2	1	144
RV1	20	Klapmuts	16	4	2	0	22
	40		24	3	2	0	29
	60		17	1	1	1	20
	80		5	0	0	0	5
	100		0	0	0	0	0
	Total		12.4	1.6	1	0.2	76
RV2	20	Glenrosa	28	17	3	0	48
	40		34	9	0	0	43
	60		26	0	0	0	26
	80		19	1	0	0	20
	100		2	1	0	0	3
	Total		21.8	5.6	0.6	0	140

In the Oakleaf soil form, roots were more evenly distributed and root penetration was much deeper (Figure 3.08 & 3.07), when compared to the Klapmuts and Glenrosa soil forms.

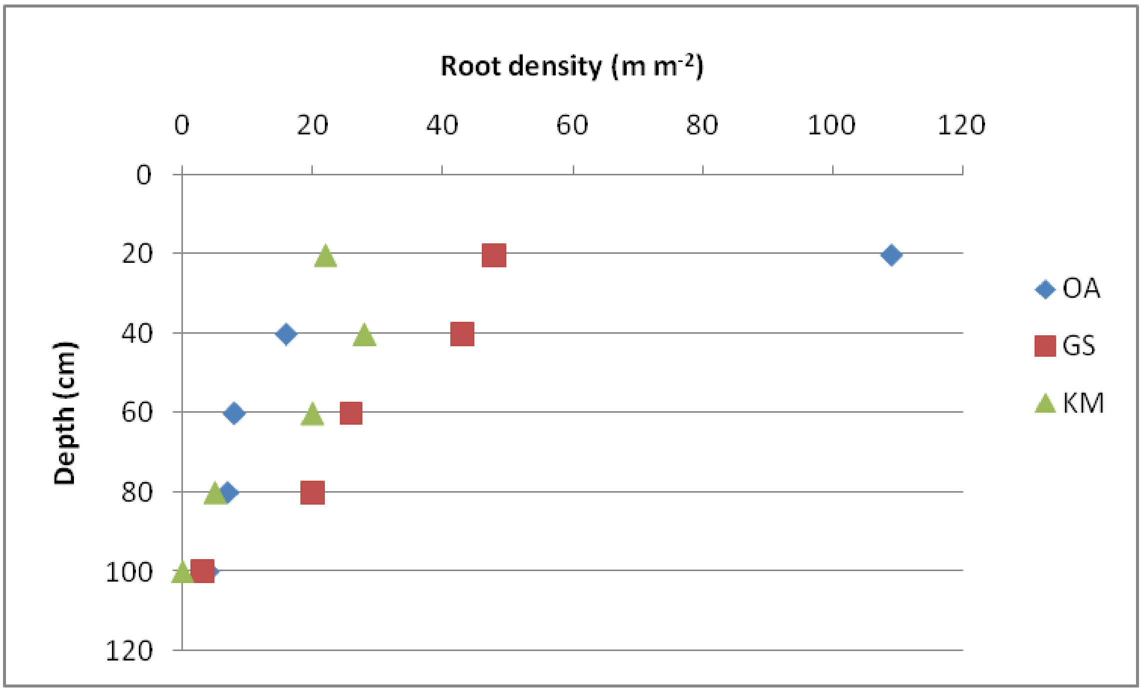


Figure 3.07 A comparison in the root distribution with depth of the different soils found at Malansdam and Voëlvlei.

Resulting from the strongly structured B-horizon of the Klapmuts soil form, root growth is non-uniform (Figure 3.09 & 3.07). In the Glenrosa soil form root distribution is uneven (Figure 3.10 & 3.07). Penetration of roots and water is restricted to spaces between fragments of shale. The vertical positioning of the shale enhanced the root penetration.

3.4.4 pH

The pH (H_2O & KCl) values (Table 3.07) for the wheatfield are greater when compared to the Renosterveld at Voëlvlei or the mountain Renosterveld at Malansdam. The higher pH values in the wheatfield can be ascribed to fertilizer amendment. The pH values in the Renosterveld vary between 6 and 8 (in H_2O), which generally indicates optimum soil conditions for growth with very few negative consequences. Conditions like these increase the availability of Al, Mn, Zn and B for plant uptake. In the Glenrosa soil form, pH values increase dramatically with depth. This can be ascribed to the weathering shale bed that is clearly visible from a depth of 500mm. Soils with higher pH values (>7) usually have an excess amount of $CaCO_3$, which may influence the availability of micronutrients (Donahue, 1977).

At Malansdam the pH in the Oakleaf soil form is lower than in the Sepane soil form. We hereby came to the conclusion that since the Oakleaf soil form is positioned higher up the slope, nutrients and basic cations move down the slope with water movement to accumulate at the bottom of the slope causing the higher pH values in the Sepane soil form. Higher pH values may also be attributed to higher clay content and sub-soil wetness.

3.4.5 Particle size distribution

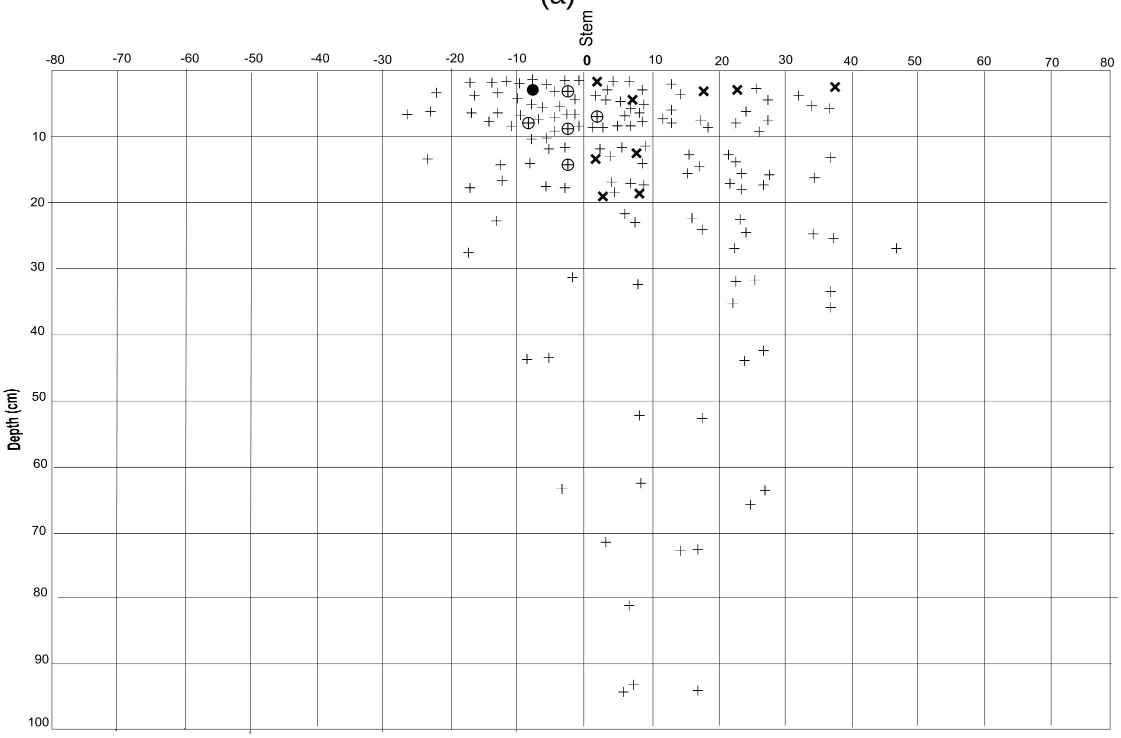
Particle size distribution analysis was selectively done on dominant soil forms representative of both sites (Appendix 2.3.2). Glenrosa soil forms at Voëlvlei (Wheatfield and Renosterveld) were predominantly of a clay-loam to sandy-clay-loam texture. Underlying the B-horizon is the weathered soft shale with a clay-loam texture. The Klapmuts soil forms at Voëlvlei have a clay-loam texture with a noticeable increase in clay from top- to sub horizons. Oakleaf soil forms indicated changes in texture from clay-loam to sandy-clay-loam. The texture of the Swartland soil form is primarily sandy-clay-loam with an increase in clay content in the sub-horizon. The texture of the Sepane soil form varied between coarse sandy-clay-loam and fine sandy-clay-loam with an increase in clay content with depth.

3.4.6 Exchangeable Cations

Although the exchangeable magnesium is exceptionally high for all the above mentioned soil forms, the soil profiles in the Renosterveld at Voëlvlei exhibited significantly higher values of exchangeable magnesium than the wheatfield or the mountain Renosterveld (Appendix 2.1). From results obtained it can be deduced that a soil, derived from the ever continuing weathering of the Malmesbury shale formation, will have a higher clay content and higher silt content. Chemically, these soil forms contained more exchangeable Mg, which will lead to a higher EMgP and lower ECaP. Ultimately this will lead to a lower Ca:Mg ratio, which may cause the positive effect of Ca to be suppressed as also indicated by Hazelton and Murphy (2007). The higher Mg content of the wheatfield also indicated poor water infiltration.

Sodium levels are moderate to low. As sodium is a very soluble and mobile cation, it is easily transported by surface runoff or underground water flow to rivers such as the Berg River, contributing to its salinization.

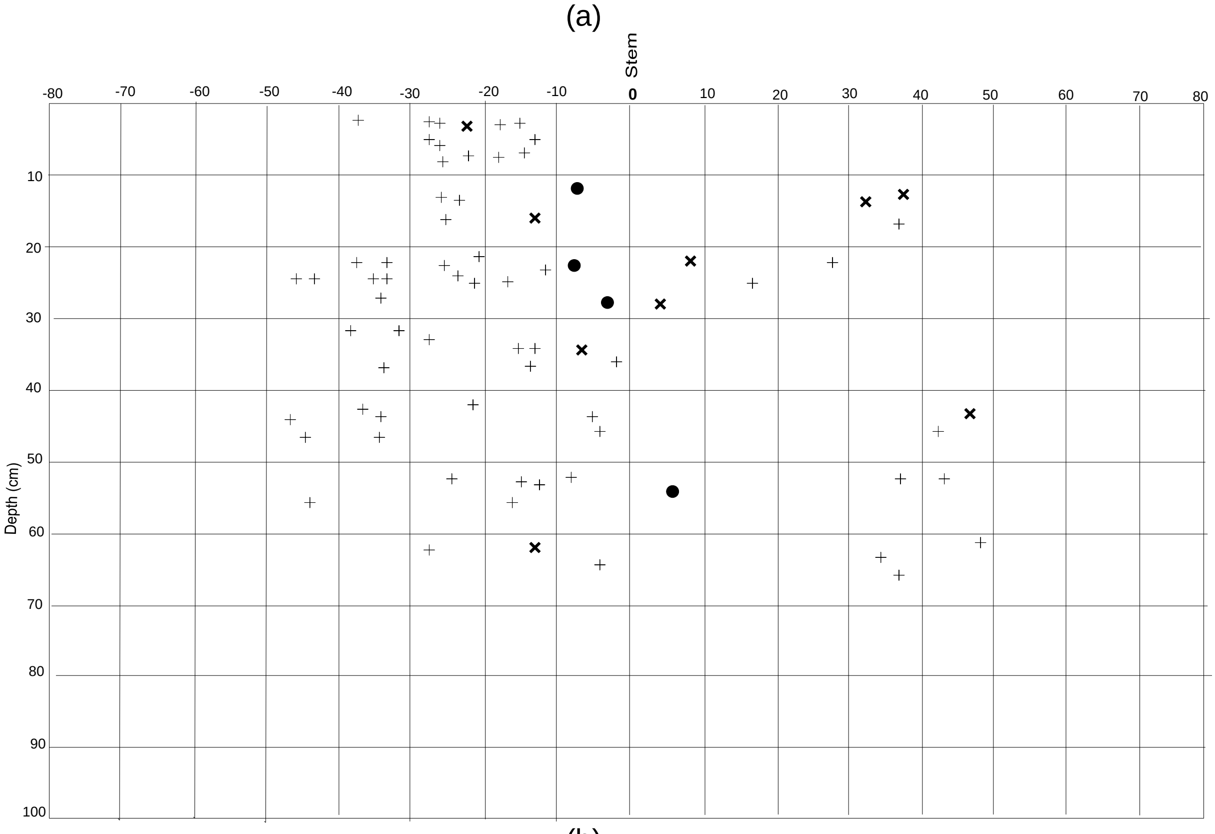
(a)



(b)

Figure 3.08 (a) Photo illustration (b) Line sketch of the root distribution at Malansdam (MD1) (Mountain Renosterveld); **+** = <2mm, **x** =2mm – 5mm, **•** **=** 5mm – 10mm, ⊕ = >10mm in the Oakleaf soil form.

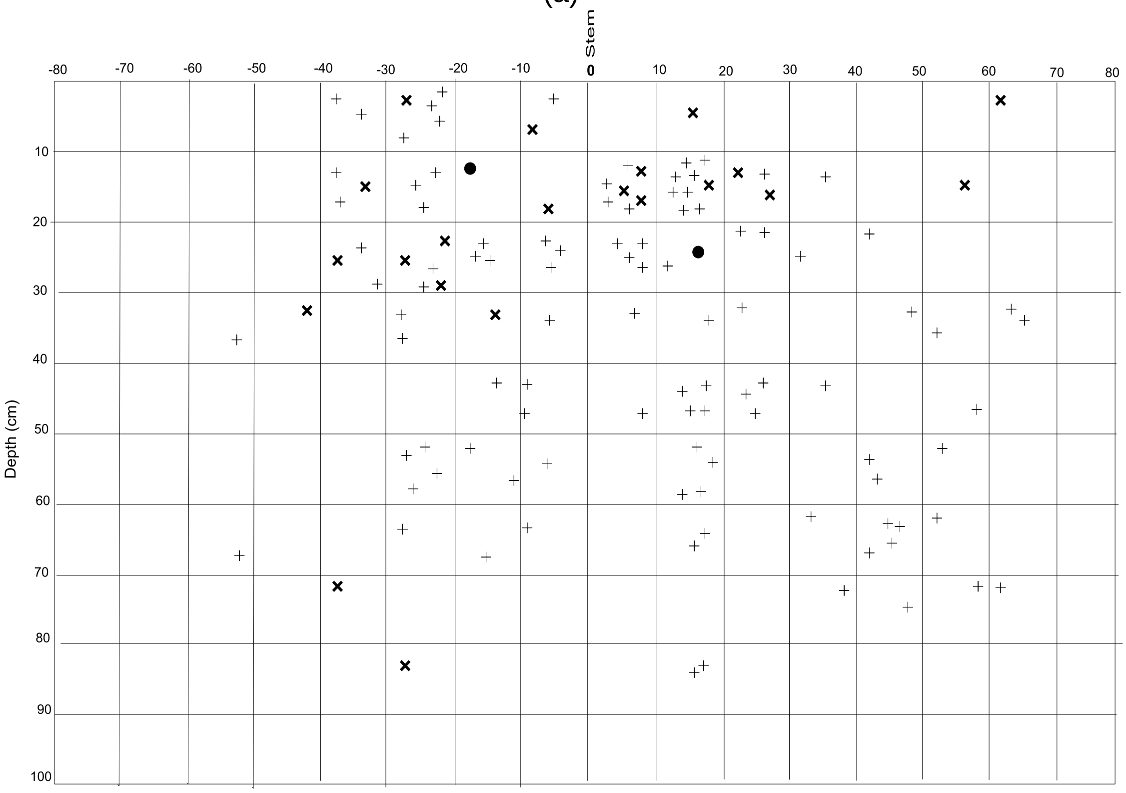
(a)



(b)

Figure 3.09 (a) Photo illustration (b) Line sketch of the root distribution at Voëlvlei (RV1) (Re-established Renosterveld); **+** = <2mm, **x** =2mm – 5mm, **• =** 5mm – 10mm, ⊕ = >10mm in the Klapmuts soil form.

(a)



(b)

Figure 3.10 (a) Photo illustration (b) Line sketch of the root distribution at Voëlvlei (RV2) (Re-established Renosterveld); **+** = <2mm, **x** =2mm – 5mm, • = 5mm – 10mm, ⊕ = >10mm in the Glenrosa soil form.

3.5 Limiting soil factors affecting root growth of Renosterveld

In the Berg River basin the ability of plant roots to develop and absorb water and nutrients is restricted by a variety of natural occurring soil properties. Several soil types are affected by chemical and physical restrictions or inadequate rainfall (Rosemary and Kirkegaard, 2010).

3.5.1 Physical and Morphological factors

3.5.1.1 Surface crusting

During field assessment the soil under Renosterveld vegetation seems to be in a better condition than the soil under wheat production (Figure 3.11a). More crusting is observed on the wheatfield due to the fact that the soil is left bare for parts of the year (Figure 3.11b). The heat that the soil is exposed to during periods that it is bare also lead to faster breakdown of organic matter rendering the soil more vulnerable to structural degradation and thus more prone to crust formation.

In the Renosterveld barren patches occur in the dry summer months between the Renosterveld bushes, causing a cracked hard layer made to form on the surface (Figure 3.12). Water infiltration on these barren patches is poor, resulting in water accumulating on the soil surface promoting greater surface run-off. The effect of soil crusting is not always damaging. Depending on the strength of the soil crust, it may give some protection against wind and water erosion.

(a) (b)

Figure 3.11 Contrasting soil surface conditions in (a) the Renosterveld and (b) the wheatfield (de Clercq *et al*., 2010).

At Malansdam the Munsell colour indicated more available free iron. Iron compounds can act as stabilizing constituents and can reduce the tendency of the soil to crust, thereby improving soil water infiltration.

Figure 3.12 Photo illustration of crust formation in the Renosterveld that occur on barren patches during dry summer months.

Reduced water infiltration in crusted soils can reduce plant available water and may cause plants to stress. The hard consistency of soil crusts can prevent seed germination (Mills and Fey, 2003 & 2004). We consequently predict that crusted soils in combination with an increase in runoff can cause seeds to be distributed to areas were crusting is less pronounced.

3.5.1.2 Low clay content in the topsoil

In the first view years of the plant's life cycle, the renosterbos is dependent on the topsoil for nutrients and water. This forces the younger plant to take immediate advantage of rain and any available surface water (Scott and Van Breda, 1937).

Older, more mature plants, with more deeply developed root systems are dependent on the subsoil for nutrients and water and have their greatest absorbing activity in the deeper soil layers (Scott and Van Breda, 1937).

During field assessment bleached topsoils (A-horizon) was noted at Voëlvlei and Malansdam, respectively (Figures 3.8a and 3.9a). The illuvial accumulation of clay in the B-horizon is caused by larger rainfall events that can lead to rapid water infiltration or increased runoff. In the case of the Renosterveld were rapid water infiltration occurs, nutrients and fine particles is washed down to the sub-soil. In the wheatfield water build-up is slower, therefore, increased runoff occurs.

Soils with low clay content in the topsoil have reduced moisture retention and very little plant available water. As clay moves downwards, it often carries plant nutrients with it limiting availability for plant uptake. The A-horizon is often weakly structured and when it contains sufficient sand, silt with some clay, soils can become very hard (Fey, 2010). Younger plants, and plants in the seedling stage, may show signs of reduced growth as they rely on the top soils for much of their absorbing activity.

3.5.1.3 Dense and/or strongly structured sub-soils.

Soil structure and soil water content are influential in modifying the root system. The distinction between available plant water and accessible water may be affected by variations in soil structure, even within the same soil-type (White and Kirkegaard, 2010).

Many soil physical properties are affected by the clay content of a soil. The downward movement of clay (lessivage) and the in situ weathering of parent material (shale) can cause sub-soils to develop into more densely structured soil layers. Plant roots follow an intricate course when encountering a more densely structured soil layer, becoming distorted and kinked. Penetrating roots of the renosterbos get thinner when coming in contact with a more densely structured sub-soil (Scott and van Breda, 1937).

During field assessment the soil profile pits in the Renosterveld revealed a densely structured B-horizon (Figure 3.13a) in the Klapmuts soil form. From the root study data collected (Figure 3.09), roots appeared to grow relatively freely through the first 300 mm of the soil (A-horizon). When encountering the B-horizon root density decreased significantly. Roots with diameter of <2mm appeared frayed and flat. In some instances it was noted that roots were subjected to pruning due to the swell and shrink action of the sub-soil layer.

The Glenrosa soil form revealed a more uniform distribution of roots in the top- and sub soil (Figure 3.10). Similar to the Klapmuts soil form a decrease in root density was noted at a depth of 0.35m. The decline in the root quantity can be the result of the weathering shale band that occurs at a depth of 0.4m. The shale is positioned vertically (Figure 3.13b) allowing root penetration and enhanced water infiltration.

Root penetration in the Glenrosa soil type was much deeper compared with the Klapmuts soil form. Deeper root penetration in the Glenrosa soil can be the result of a drier soil climate due to higher elevation (Ellis, personal communication). The Klapmuts soil form stays wet for longer periods after rainfall, increasing in situ weathering of shale causing a dire increase in the clay content and allowing sub-soils to become densely structured.

(a)

(b)

Figure 3.13 (a) Densely structured E-horizon of the Klapmuts soil form. (b) Photo illustration of root growth between the shale layers of the Glenrosa soil form.

The profiles at Malansdam exposed deeply developed red Oakleaf soils with very little restrictions. Root distribution and penetration is deeper and more uniform (Figure 3.08) when compared to Voëlvlei. There was a notable decrease in root density from top to bottom. Aforementioned the Munsell colour (5YR4/4) indicated available free iron that can act as stabilizing agent.

This feature together with coarse fragment content can lessen soils inclination to compact. Deeper root growth suggests that roots are buffered against the negative effects (pH, EC) that the soil might have on root growth.

Even though a root study was not conducted for the wheatfield, the soil structure of the profile pits in the wheatfield was examined to determine limiting soil factors that may affect the root growth of wheat. Open profile pits revealed well structured Swartland and Glenrosa soil types with noticeably harder sub-soils, representing bulk density values greater than $1.5g.cm^{-3}$, with an underlying layer of shale in the Glenrosa soil form. Clay content increases with depth and can act as cementing agent, generating high soil strength (Mullins *et al*., 1990). Soil pits indicated similar characteristics to the profile pits made in the Renosterveld.

3.5.1.4 Weathered parent material

Field assessment indicated that the dominant source of parent material in the study area is of the Malmesbury shale origin. As aforementioned the position in which the shale layers are arranged affects root growth as well as water infiltration. Shale that is horizontally bedded can restrict root growth to the top soil layer and can decrease water infiltration causing water to pond on the soil surface, thereby blocking micro pores and causing soil to become more densely structured. Through profile classification it was concluded that the shale bands, such as found in the Glenrosa soil form, is highly weathered and has a vertical dip which allow roots to penetrate between the shale layers and enhance water infiltration.

3.5.1.5 Soil Wetness/Aeration

Soil aeration and structure play a key role in determining the depth of root penetration. Oxygen deficiency in soils is a major factor limiting root growth and plant establishment, especially in the early stages of the plant's life cycle. Oxygen deprived soils can be the result of poor soil quality, such as heavy fine-textured soils, layered soils with inadequate drainage or excessive rainfall during the winter.

Most of the soils in the study area have relatively high clay content, increasing with depth. Soils with high clay content have poor water infiltration rate, causing water to puddle on the soil surface. With barren patches in the Renosterveld, standing water on the soil surface can cause an increase in water runoff, soil erosion and have a major effect on seedling establishment.

Shallow root systems of younger plants can be problematic during the warm summer months or during windy periods, since the plant is weakly anchored and the only water available is deep in sub-soil layers. Older mature plants have deeply developed root systems and have their main water absorption activity in deeper soil layers. Thicker woody roots act as carriers and anchors and are not so much affected by poorly aerated soils.

3.5.1.6 Coarse fragments in top- and upper sub soils

During field observation it was noted that soils had a relatively high coarse fragment (>2mm) content in the first 35cm of soil profiles. Although this cannot be described as severe limiting factor, the amount of coarse fragments in the top soil may have an effect on plant growth. Coarse fragments dilute the soil causing a more rapid infiltration of water and nutrients. For younger Renosterbos plants this factor may play a critical role in the survival of the plant since the younger plant is dependent on the top soil for its water absorption and solutes. Coarse fragments also restrict evaporation from the soil as it restricts capillary rise.

3.5.2 Chemical factors

3.5.2.1 Salt affected soils and soil water

Primary sources of salt in the study area include the weathering of parent material, climate (i.e. temperature), rainfall, landscape effects, inadequate leaching and drainage of soil moisture.

Mineral weathering can be defined as a spontaneous process that transforms primary minerals, to other minerals that are more stable at the earth's surface (Jurinak, 1990). In the Renosterveld it was found that the primary factor contributing to salts in soil and water is the ever-continuing weathering of the shale bands found at a depth of >60cm, predominantly visible in the Glenrosa soil form (Table 3.07).

High SAR values adversely affect permeability and tilth of the soil. The SAR values are relatively low for all soil forms in the first metre. It is hypothesized that with an increase in soil depth the bulk EC will increase, as the shale band can be found up to a depth of >15m.

Although mineral weathering is a continuing process, the extent of weathering may be strongly influenced by the climate. Climate is a major factor affecting salt tolerance. In a cool and humid climate, plants tend to have a higher salt tolerance than in an arid to semi-arid climate with hot, dry and windy summers (Jurinak, 1990).

The EC values and water depths of boreholes in the Renosterveld and wheatfield were monitored on a regular interval. The EC measurements showed there was a visible variation in EC values between the Renosterveld and the wheatfield (Table 3.6). As the water table continues to rise in the wheatfield, the water table in the Renosterveld seems stay at a seemingly unvarying depth. As the wheatfield dries out during summer months, the quantity of salts increased uniformly by an average of 10% before declining to their original levels with winter rainfall.

From the results obtained through chemical analysis of borehole samples (Table 3.08) it was found that water samples contained a considerable amount of NaCl (Appendix 3.1 and 3.2). Sodium plays an important role in influencing the EC value and is very mobile. The leaching of NaCl into the Berg River is one of the major sources of salt contributing to the salinization and deterioration of the BRC (Jovanovic *et al*., 2010).

Table 3.07 Chemical analysis for dominant soil forms – pH (H2O and KCl), Water Soluble Cations1:5, EC1:5[1], EC_e[2] and SAR[3]

	Depth	pH		$EC_{1:5}$	Ec_e	Resistance	Ca	Mg	K	Na	SAR	
		H_2O	KCl	(mS/m)		(Ω)		mmol/dm^3			mmol/dm^3	
KV Swartland	10cm	6.09	5.17	11.30	67.50	1221.00	0.18	0.11	0.10	0.37	0.98	wheat field
KV Swartland	30cm	8.99	7.34	22.90	112.40	412.20	0.17	0.22	0.07	2.63	5.97	
KV Swartland	60cm	7.45	6.05	13.60	55.90	627.40	0.07	0.18	0.13	0.87	2.46	
KV Swartland	90cm	7.09	5.36	8.20	38.00	909.30	0.10	0.15	0.13	0.53	1.50	
RV Klapmuts	20cm(1)	5.86	4.16	3.10	72.30	2575.00	0.03	0.11	0.14	0.34	1.29	Renosterveld
RV Klapmuts	20cm(2)	5.78	4.1	3.20	30.50	3105.00	0.03	0.08	0.10	0.36	1.55	
RV Klapmuts	60cm	5.95	4.65	10.80	46.10	922.40	0.02	0.04	0.03	0.77	4.35	
RV Klapmuts	90cm	6.94	5.41	14.30	38.80	599.00	0.08	0.24	0.13	0.88	2.20	
RV Glenrosa	30cm(1)	6.42	4.84	10.60	52.50	691.40	0.07	0.23	0.42	0.93	2.38	
RV Glenrosa	30cm(2)	6.52	4.7	7.40	47.50	836.60	0.07	0.21	0.43	0.70	1.88	
RV Glenrosa	60cm	8.62	7.13	22.70	138.70	432.50	0.11	0.38	0.28	1.89	3.84	
RV Glenrosa	90cm	9.53	7.84	38.80	173.30	347.00	0.07	0.16	0.09	3.16	9.35	
MD Oakleaf	15cm	5.7	4.03	2.80	45.50	4426.00	0.03	0.03	0.06	0.28	1.67	Mountain Renosterveld
MD Oakleaf	30cm	6.91	4.91	2.50	24.40	3037.00	0.03	0.03	0.04	0.33	1.83	
MD Oakleaf	60cm	6.68	4.86	4.20	27.80	2190.00	0.03	0.05	0.03	0.41	2.05	
MD Oakleaf	100cm	6.14	5.02	12.80	153.30	683.40	0.05	0.12	0.06	0.76	2.61	
MD Sepane	30cm	7.33	6.26	4.80	49.30	1957.00	0.12	0.06	0.09	0.31	1.05	
MD Sepane	60cm	7.8	6.23	6.20	31.90	1719.00	0.11	0.18	0.16	0.37	0.98	

Water movement through the soil, is to a great extent influenced by the soil texture and structure as previously discussed. Soil water content during the dry summer is a critical factor for the survival of the renosterbos as their water sources is limited.

As previously discussed the water content of a specific soil is influenced by the capacity of a soil to store water, which in turn is influenced by soil texture and structure. Changes in soil structure and infiltration may have an effect on surface runoff and rain interception.

Soil moisture content is shown in Figure 3.14 (a) and (b) for the June, August, November, March and April samplings for the wheatfield and the Renosterveld respectively. The data presented, cover the extremes of the wetting and drying cycle of the soil. Normally during November soil would start drying out, but November 2009 was an exceptionally wet month with high summer rainfall.

[1] $EC_{1:5}$: Electrical conductivity of the 1:5 soil solution

[2] EC_e: Electrical conductivity of saturated paste extract

[3] SAR: Sodium Adsorption Ration

Table 3.08 EC and water depth measurements of shallow boreholes in the Renosterveld and Wheatfield respectively.

Renosterveld				Wheatfield		
Date	Depth (m)	EC (mS/m)		Date	Depth (m)	EC (mS/m)
2010/02/17	15.60	107.0		2010/02/17	7.57	147.0
2010/03/10	15.40	108.5		2010/03/10	8.20	155.2
2010/03/17	15.50	110.5		2010/03/17	8.80	158.4
2010/03/25	15.10	110.0		2010/03/25	8.12	156.0
2010/03/31	15.40	114.2		2010/03/31	8.14	161.2
2010/04/06	15.08	111.4		2010/04/06	8.86	158.4
2010/04/13	15.12	104.0		2010/04/13	8.27	148.0
2010/04/20	15.22	107.6		2010/04/20	6.90	150.6
2010/04/29	15.15	110.3		2010/04/29	7.43	156.8
2010/05/04	14.88	105.0		2010/05/04	7.42	148.0
2010/05/12	15.15	115.0		2010/05/12	8.11	161.6
2010/05/19	14.18	108.7		2010/05/19	6.97	153.7
2010/05/27	15.02	106.0		2010/05/27	6.73	144.0
2010/06/01	12.26	111.1		2010/06/01	6.30	149.5
2010/06/10	15.20	105.4		2010/06/10	6.40	135.0
2010/06/17	15.15	104.0		2010/06/17	5.87	140.0
2010/06/23	15.26	106.2		2010/06/23	4.13	138.8
2010/07/05	15.12	102.8		2010/07/20	5.48	137.6
2010/07/20	15.27	101.0		2010/07/06	5.16	135.0

It was noted that the water content for the Renosterveld was generally higher than for the wheatfield. This may be ascribed to the fact that the younger renosterbos, not yet with a fully developed root system, is dependent on the top soil for its water supply, thereby keeping the water in the top and upper subsoil layers. The clay content for the dominant soil types in the Renosterveld tend to be higher than for the soil types in the wheatfield (Appendix 2.3.2), indicating a higher water holding capacity with poor infiltration.

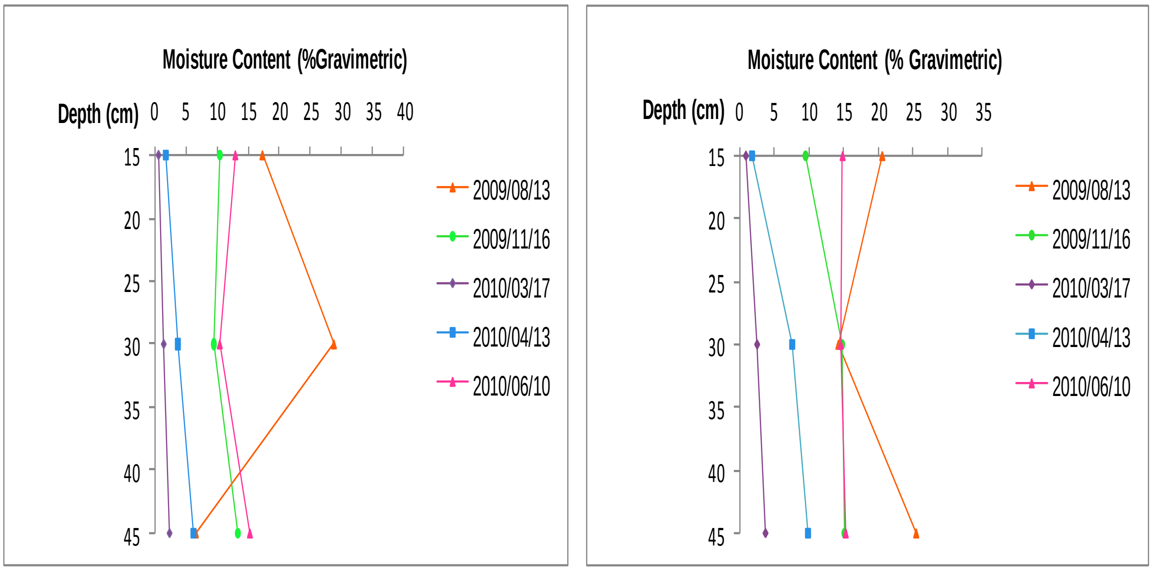
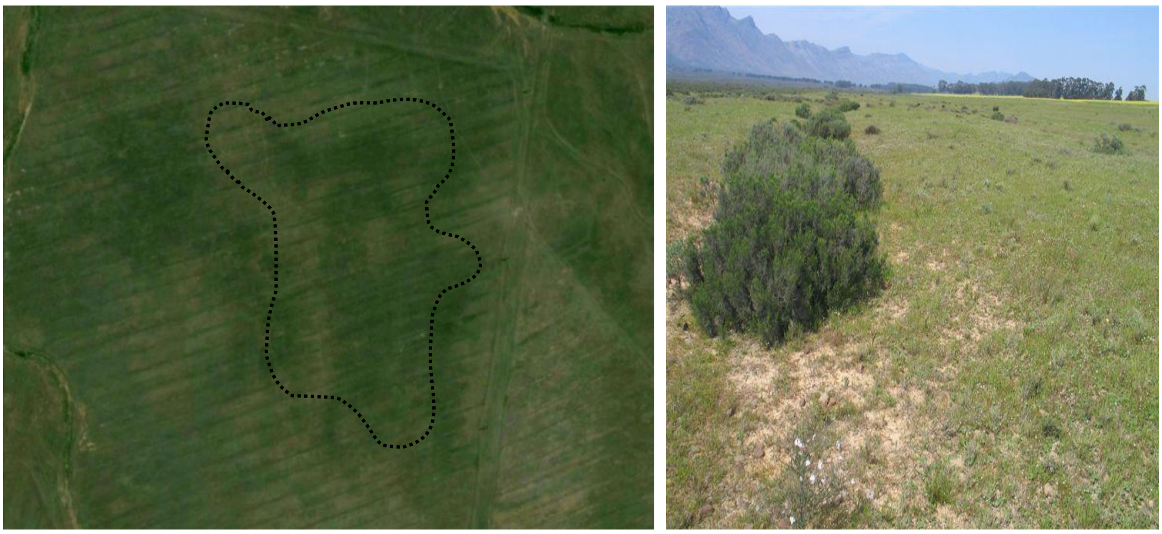


Figure 3.14 Seasonal changes in moisture content (% Gravimetric) at three different soil depths for (a) the wheatfield and (b) the Renosterveld.

3.5.3 The influence of plough layers on the re-establishment of Renosterveld

The re-establishment of Renosterveld might be vulnerable to both soil limiting factors and human activity. Research has indicated that the re-growth of Renosterveld is very subjected to soil conditions in areas where the ridge and furrow system has previously been implemented (Figure 3.15 a & b). From the images it is clear that the re-growth is denser in some areas than others and plough layers are clearly visible.



(a) (b)

Figure 3.15 **(a)** Google image indicating a rehabilitated area of Renosterveld near the research site and **(b)** renosterbos growing on the sides of ridges on a rehabilitated ridge and furrow system.

In areas where the restoration of Renosterveld has been allowed, it is clear that the re-growth of the renosterbos tends to be on the side of the ridge. In the wheatfield adjacent to the Renosterveld, a profile pit was dug, which exposed a trench across the ridge and furrow system. Along the side of the ridge, the B-horizon had been scraped away. We consequently predict that by the removal of the B-horizon, conditions were more favourable for re-growth. Therefore, as soil conditions are more favourable along the side of the ridge, the renosterbos is inclined to establish itself here first before establishing itself in the furrow or on the ridge.

3.6 Conclusion

From the discussion above it can be concluded that various soil properties can influence the growth as well as the re-establishment of Renosterveld.

Very little is known about the underground part of this vegetation type and these preliminary studies on the soil properties affecting growth and establishment of the renosterbos indicated to what extent these deep rooted plants can adapt and benefit from the surrounding soil conditions.

Physical soil limitations along with the root distribution pattern gave an accurate indication of the effective profile depth. It is exceedingly important that we understand the effect of soil limitations on deep root development and as plant occurrence, if we are to maintain our indigenous flora and also prevent a decline in the bio-diversity. Therefore it is vital to the researcher to be familiar with the soil-plant-water status as availability contributes to the sensitivity of this system. The effect of salinity on plant growth will be discussed in to a greater extent in Chapter 4.

This validates the hypothesis that a mature renosterbos with a well anchored root system can utilize winter water, keeping water tables at bay. Thereby, immobilizing salts and decreasing seepage into the BRC. This chapter showed and proved to what extent deep rooted plants can adapt to different soil conditions as well as benefit from soil water that is locked away in deeper soil layers and therefore able to survive the dry summer months.

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CHAPTER 4. PLANT PHYSIOLOGY AND GROWTH PATTERN OF THE RENOSTERBOS (*ELYTROPPUS RHINOCEROTIS)*.

4.1 Introduction

Renosterveld has an exceptional specie rich ecosystem (Walton, 2005; Levyns, 1929) and occurs throughout the area of the Cape Floral Kingdom. Although Renosterveld is a very distinct vegetation type, its definition and description is often complicated. This can be ascribed to the fact that Renosterveld is one of the first vegetation types to be changed by grazing (Milton, 2007). The decline of the Renosterveld is mostly due to the transformation of this vegetation type to agricultural land used for crop production, mainly wheat.

Due to the variation in the composition of Renosterveld, which is affected by seasonality, gradient and rainfall it is difficult to define the ideal structure of Renosterveld (Milton, 2007). Thus classification, identification and description are often very difficult. Limited research has been done in South Africa on specie classification, description and mapping of Renosterveld (Walton, 2005).

Voëlvlei conservancy under the management of Cape Nature has devoted itself to the re-establishment of Renosterveld and to the biodiversity surrounding it. It is here that an extensive field of mature Renosterveld is situated. Wild fires have caused this area to have a mosaic appearance (Walton, 2005), with the ages of plants varying from >35 years to 11 years. This site has been selected as it is ideal in understanding the effect of land-use changes on the re-establishment of Renosterveld as well as the effect of land-use change on the soil water balance and it can be directly compared to the adjoining wheatfield as these two sites have similar dominant soil forms, underlying parent material and climate conditions.

To better understand the effect of land-use changes on the soil water balance we need to compare the water use pattern of wheat/fallow land with Renosterveld. We hypothesize that by the clearing of deep-rooted, perennial native vegetation, i.e. Renosterveld a different water balance will be produced and in turn lead to the acceleration process of salt mobilization and ultimately the deterioration of water quality in the Berg River (Jovanovic, 2010).

Very little, to no research has been done on the water use pattern of this vegetation type. Therefore it was of great importance understanding the dynamics of the renosterbos and how it is affected by soil, climate and seasonal changes. It is also of great importance to determine how these elements will influence the re-establishment of Renosterveld.

The Renosterveld at Voëlvlei is dominated by *Elytropappus rhinocerotis*, which is a small leaved evergreen asteracious shrub with an understory of grasses and geophytes. The renosterbos varies in habit, size and height and to fully understand the water use pattern of the renosterbos it is important to distinguish between different species of the *E.rhinocerotis*.

4.2 Material and Methods

To better explain the plant physiology of the renosterbos, a microscope study was conducted by using a Spencer microscope with a high resolution camera attached to microscope. The different components of the plant were dissected and studied under the microscope. Images were magnified by 100X, 150X and 200X. Photos were then taken of magnified images.

Imaging of leaf samples was done with a Leo®1430VP Scanning Electron Microscope (SEM) at the Geology Department, Stellenbosch University. Prior to imaging samples were mounted on a stub with double sided carbon tape. The sample was then coated with a thin layer of gold in order to make the sample surface electrically conducting. The Scanning electron (SE) images show the surface structure of the leaf. Beam conditions during surface analysis were 7 KV and approximately 1.5 nA, with a working distance of 13 mm and a spot size of 150. The SEM micrographs are used to give a more accurate description of the leaf phenology of the renosterbos.

Stomatal conductance of a single mature renosterbos was monitored throughout the season. Porometer measurements were taken on a weekly interval with a PP Systems, EMG-1 porometer according to the method described by Pearcy *et al*. (1989). The bush was divided into four quadrants; measurements were taken randomly in those quadrants. The bush was also divided into four equal segments according to height, 0-30cm, 30-60cm, 60-90cm and 90-120cm respectively; measurements were randomly taken within those segments. Leaf branches with a minimum length of 15mm were used as it could fit easily into the cuvette of the porometer. In this Chapter only stomatal measurements for two single time periods are given to illustrate the decline in stomatal conductance as water resources become depleted and the plant adapts itself to limit water loss.

Leaves were sampled at Voëlvlei and analysed for nutrient composition on the same bush used for measuring the stomata conductance. Branches were randomly selected at four different heights, 30cm, 60cm, 90cm and 120cm respectively. Plant material was dried in the oven at 80°C for 48 hours. After drying the leaves were removed from the stems and ground to a fine powdery substance. Carbon and Nitrogen Elemental Combustion analysis was determined with a EurovectorEA3000 instrument.

Soil standards from the Eurovector were used to calibrate the instrument, detection limits are typically in the range of 0.01wt%. Macro- and micro element analysis was determined with a VarianAA240FS Fast Sequential Atomic Absorption Spectrometer (SAF Labourites, Stellenbosch University).

4.3 Results and Discussion

4.3.1 Differentiation of the *E. rhinocertis* types identified at the study site.

According to M.R Levyns (1929) there are three clearly distinct forms within the *E. rhinocertis* specie. The first type is more erect, standing unusually tall (2-3 meters), and is mainly confined to sheltered areas and prefers moist areas such as Seven Weeks Poort and the Roggeveld. This is an interesting occurrence since the renosterbos is known to avoid moist areas (Levyns, 1959). This preference can also be ascribed to the surrounding soil conditions, moist conditions does not necessarily indicate that soils have an excess of water. As this type of renosterbos does not appear at any of the two study sites, its appearance does not concern us for this particular research study.

At Voëlvlei in the Renosterveld two distinct forms of the renosterbos occur, hence forth known as type A and type B. Type A has contracted internodes (Figure 4.01), whereas type B has longer internodes (Figure 4.02).

Figure 4.01 Photo illustrations of the renosterbos with the contracted internodes (Type A).

This type (A) of Renosterveld makes out a large part of the Renosterveld population at Voëlvlei and is a common form in the West Coast region. In this type of Renosterveld groups of capitula[4] grow near the tips of the slender branches (Levyns, 1929).

Figure 4.02 Photo illustration of the renosterbos with longer internodes (Type B).

As observed in Figure 4.02 this type of Renosterveld is greener than type A and is known to bear its capitula closer to the woody portion of the branch (Levyns, 1929). Although these two types of Renosterveld are very similar in habit and behaviour they can be easily identified when in flower. In their vegetative stadium they resemble one another closely, with the only exception being the colour difference (Figure 4.03).

Figure 4.03 Image indicating the colour difference between two renosterbos types.

[4] Capitula – A dense grouping of flower buds.

Very little research have been carried out on the breeding pattern of *E.rhinocerotis*, only in recent years have researchers begun to notice the irreplaceable value of Renosterveld to biodiversity and therefore started identifying and characterizing renosterbos species, hereby referring to research done by C.Boucher (1987) and more recently B.A Walton (2005).

Numerous studies have however been conducted into the genus of other species such as *E.gnaphaloides* and *E.scaber* which revealed that parallel forms do occur within specie. This can be attributed to a single genetic difference in the plant composition (Levyns, 1956). This occurrence has been phrased as *homologous series in variation* which is defined as two similar plant forms can grow in the same locality, but usually the one plant type is more dominant than the other (Vavilov, 1949; Levyns, 1956).

Even though it was established that different forms of renosterbos do occur in the Renosterveld at Voëlvlei it was concluded that both plant forms are very similar in habitat, flowering and seed germination. Therefore it was not considered necessary to continue using both plant forms. We decided on the more dominant of the two plant forms, type A.

4.3.2 Flowering

Flowering season stretches from November to March (Levyns, 1926; personal observation). Flowers are borne in large numbers near edges of the top branches, they are small and inconspicuous. Before flowering the flowers are small dark pink-red buds (personal observation) that accumulate on the tips of the branches (Figure 4.04a). The capitulum has chaffy[5] bracts[6] surrounding three tubular shaped flowers, called florets (Figure 4.04b). There is a well developed feathery pappus[7], with the bristles lightly attached to the base of the flower seeds (Levyns, 1929; Bergh, 2006).

4.3.3 Seed Germination and Seedling Growth

Large numbers of seeds are produced by each plant (>300 seeds per flowering shoot) but of these seeds a fair amount (>50%) is said to be sterile (Levyns, 1929). The first seed is shed between May and June, just after the first rainfall, but seed is still immature and the percentage of seed germination is very low (Levyns, 1935; Levyns, 1956). Seeds are stored in the soil and after a year of rest the ability of seeds to germinate is much greater. Seed germination continues well into the third year after being shed, thereafter seed germination deteriorates, we presume that after this extended period seeds are no longer viable.

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[5] Chaffy - The scales or bracts borne on the receptacle among the small individual flowers.
[6] Bracts - A modified leaf growing just below a flower or flower stalk.
[7] Pappus – A structure made of scales, bristles or featherlike hairs attached to the seeds of plant of the composite family and that aids in dispersal by the wind.

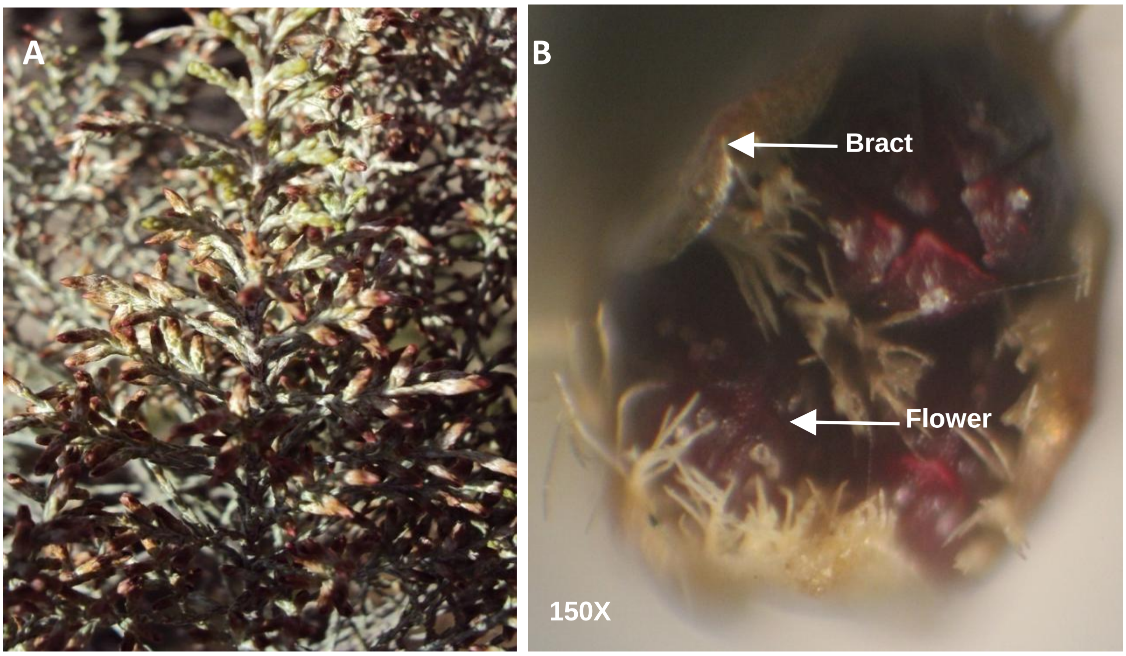


Figure 4.04 (a) Photo illustration of the accumulation of flowers at edges of branches and (b) a microscope photo illustration taken from the top of a single renosterbos flower.

Seeds are well adapted for wind dispersal (Figure 4.05b). With its light fruit and yellowish, brown feathery pappus (Figure 4.5a), seeds are expected to travel quite a distance even though exact distances are not known (Cowling *et.al*). Genetic studies indicate that the renosterbos does not self-fertilize and it has been suggested that these plants propagate by wind-pollination (Bergh, 2006).

Figure 4.05 Microscope photo illustration of (a) the pappus with seed attached (b) the pappus without the seed and **(c)** a photo illustration of the renosterbos in flower.

Various hypotheses have been formed about the germination process and why the germination period is so prolonged. Various factors may influence the germination of seedlings. Very little research has been done on this subject. Levyns (1956) found that temperature plays a significant role in seed germination. Seeds stored at a moderate and uniform temperature showed lower germination capacity than seed stored under fluctuating temperatures. Thus heating, i.e. burning or wild fires can act as a stimulus for seed germination.

We suggest that the soil conditions under which seeds germinate may affect the germination as well as the initial growth period of the renosterbos. Under harsh environmental soil conditions seeds may be affected by soil crusts, seeds may not be able to penetrate the soil surface and may be subjected to surface runoff. Since seeds are so light weighted they may be transported by water to lower lying positions where the soil might be more penetrable and seeds will be able to germinate.

During dry summer months soils become cracked and seeds can move in between cracks. After the first rain, soil start to swell, covering the seed and in so doing creating ideal conditions for seed to germinate.

Research (Levyns, 1956) has shown that seedlings are shade intolerant in closed communities and have very little probability of reproducing; even the shade from mature bushes will have an effect on plant growth. The Renosterveld at Voëlvlei is more openly spaced and shade can no longer act as an inhibiting factor, therefore seedlings can establish themselves between mature bushes.

Even though the mature renosterbos is seemingly resistant to the onslaught from both predators as well as climate variation, seedling growth is greatly affected by environmental conditions such as drought (Levyns, 1956). Seedlings with newly developed tap roots are susceptible to draught no matter how temporary. In semi-arid areas, such as Voëlvlei, which is dependent on winter rainfall this trait may affect the seedling growth to a great extent. As the plant matures and become more established the taproot and laterals becomes woodier and penetrates the soil great depths. After five to seven years the plant is no longer dependant on the upper roots for water absorption, and has moved its absorbing activity to the lower regions which make the plant less susceptible to draught (Scott and van Breda, 1937).

4.3.4 Plant Phenology

The renosterbos has a great tolerance for draught and high temperatures. To fully understand the water use pattern of the renosterbos it is imperative to understand how this plant is acclimatised to its surrounding environment and how the plant reacts to limited plant available water and high summer temperatures.

As previously discussed in Chapter 3 the mature renosterbos has a well developed root system, with a taproot that can penetrate soil to well over 7 meters. This enables the plant to utilise water that is stored in deeper sub soil layers. In addition to having a deeply developed rooting system the plant phenology is also of great importance as it affects the transpiration of the plant. The leaves of the renosterbos are oval shaped, minuscule and blanketed by white fibrous hairs as illustrated in Figure 4.06 (a) and (b).

We suggest that the leaves are shaped this way to limit water loss during warm summer months and the fibrous hair enable the plant to utilise atmospheric water such as dew-drops or rain and furthermore protect stomata from excessive water loss.

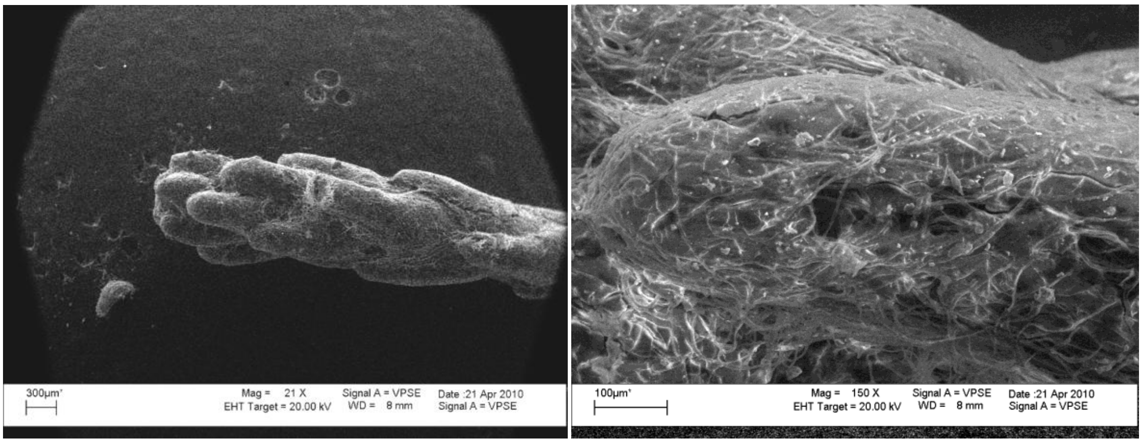


Figure 4.06 SEM photo illustration of (a) a twig and (Magnification = 21X) (b) a leaf (Magnification = 150X) of the renosterbos covered with fibrous hair.

Similar to xerophytes we predict that the moisture intercepted from the atmosphere is stored in the leaves of the renosterbos. Through electron microscopy we were able to analyse the leaves of the renosterbos. We observed that the leaves of the renosterbos have very few stomata which are sunken below the plane of the epidermis and not clearly visible (Figure 4.07). This allows the plant to regulate water loss through transpiration and evaporation.

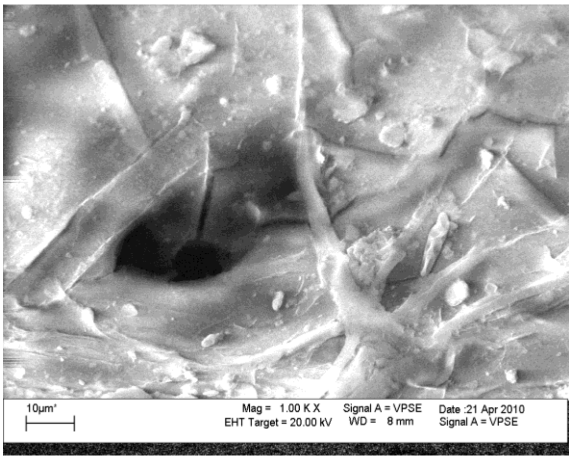
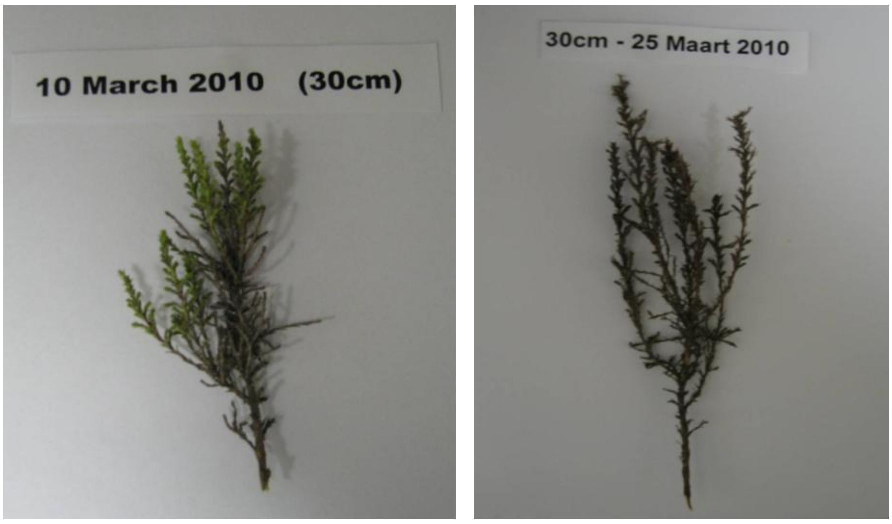


Figure 4.07 SEM photo illustration of the sunken stomata on the leaf of a renosterbos (Magnification = 1.00 K X).

During field observation we observed that the renosterbos sheds its leaves from the bottom to top during the period before flowering. We suggest that, since there are limited water resources from February to May and the plant is enduring a lot of stress, it may shed its leaves to prevent further water loss through transpiration and channelling all its nutrients and water resources to the top of the plant where flowering occurs. In a short time period leaves change colour and become dry before falling off (Figure 4.08 a and b).



(a) (b)

Figure 4.08 Photo illustration of the deterioration of the leaves of the renosterbos in a short period of time.

During this period the plant is entirely dependent on soil water content and on the moisture it intercepts from the atmosphere. When soil water supply becomes limiting; transpiration declines as a result of stomatal closure.

Even though the transpiration tempo decreases, the renosterbos does not stop transpiring during summer months as exemplified in Table 4.8(a) and (b). Consequently, we suggest that the plant limits its loss of water through transpiration by shedding its leaves and the partial closure of the sunken stomata.

From the stomatal conductance results obtained (Figure 4.11) there was a general decline in the stomatal conductance from February till May. This period indicates the phonological stage just after flowering, when plant is under great water stress and soil water is depleted. After the first effective rainfall in at the end of May; there was a slow, but noticeable increase in the stomatal conductance. It was during the period from May to August that new vegetative growth was perceived at a 30cm height from the base (Figure 4.09a) of the plant and at the very top of the plant (Figure 4.09b); a colour change was also apparent in the plant, from a dull grey-brown colour to its more distinct green colour.

The measurement of stomatal conductance (Gs) for the respective heights and quadrants gave a good indication of the effect of seasonal changes transpiration (Figure 4.10 and 4.11).

Figure 4.09 Data collected illustrating the decline in the stomatal conductance (Gs)[8] of a renosterbos from February to March.

Date	Height	G*
2010/02/17	90-120cm	12
2010/02/17	90-120cm	6
2010/02/17	90-120cm	14
2010/02/17	90-120cm	12
2010/02/17	90-120cm	12
2010/02/17	90-120cm	12
2010/02/17	90-120cm	14
2010/02/17	90-120cm	22
2010/02/17	90-120cm	8
2010/02/17	90-120cm	6
2010/02/17	60-90cm	6
2010/02/17	60-90cm	6
2010/02/17	60-90cm	6
2010/02/17	60-90cm	14
2010/02/17	60-90cm	10
2010/02/17	30-60cm	14
2010/02/17	30-60cm	12
2010/02/17	30-60cm	12
2010/02/17	30-60cm	14
2010/02/17	30-60cm	6
2010/02/17	0-30cm	10
2010/02/17	0-30cm	14
2010/02/17	0-30cm	38
2010/02/17	0-30cm	12
2010/02/17	0-30cm	6

Date	Height	G*
2010/04/13	90-120cm	10
2010/04/13	90-120cm	6
2010/04/13	90-120cm	6
2010/04/13	90-120cm	4
2010/04/13	90-120cm	6
2010/04/13	90-120cm	6
2010/04/13	90-120cm	8
2010/04/13	90-120cm	6
2010/04/13	90-120cm	6
2010/04/13	90-120cm	8
2010/04/13	60-90cm	2
2010/04/13	60-90cm	4
2010/04/13	60-90cm	4
2010/04/13	60-90cm	4
2010/04/13	60-90cm	6
2010/04/13	30-60cm	4
2010/04/13	30-60cm	4
2010/04/13	30-60cm	4
2010/04/13	30-60cm	6
2010/04/13	30-60cm	7
2010/04/13	0-30cm	No Leaves
2010/04/13	0-30cm	
2010/04/13	0-30cm	
2010/04/13	0-30cm	
2010/04/13	0-30cm	

[8] Stomatal Conductance (mmol $m^2.s^{-1}$)

Figure 4.10 Photo illustration (a) new vegetative growth at the base of the renosterbos and (b) at the top of the renosterbos.

The stomatal conductance measurements presented give clear indication of the decline in stomatal conductance at every height for the time period February to May (Figure 4.10). Only at a height of 120cm the renosterbos seemed to transpire at an unusually high rate. This can be ascribed to the fact that is during this time period, the plant is in flower and the plant is channelling all its nutrients and water resources to top of the plant. After flowering, when seeds are being shed there is a decrease in the transpiration rate at the top (120cm) of the, but a significant increase in transpiration at a height of 30cm, 60cm and 90cm respectively. It was during this time period, from May to June that water resources were replenished and new vegetative growth was observed at het base of the renosterbos (30cm). New vegetative growth showed the greatest increase in stomatal conductance. Leaves at the base (30cm) of the plant are less exposed to sunlight and wind flow than at the top (120cm), open stomata allow for a higher transpiration rate.

During summer periods, measured stomatal conductance was lower than during winter periods. As previously highlighted in the chapter, the renosterbos has adapted itself to its surrounding climate conditions. Therefore, lower Gs during summer periods suggest that the plant has the ability to prevent excess water loss through transpiration. The Gs measured for the quadrants (Figure 4.11) showed morning sun had a definite effect on the transpiration rate of the plant.

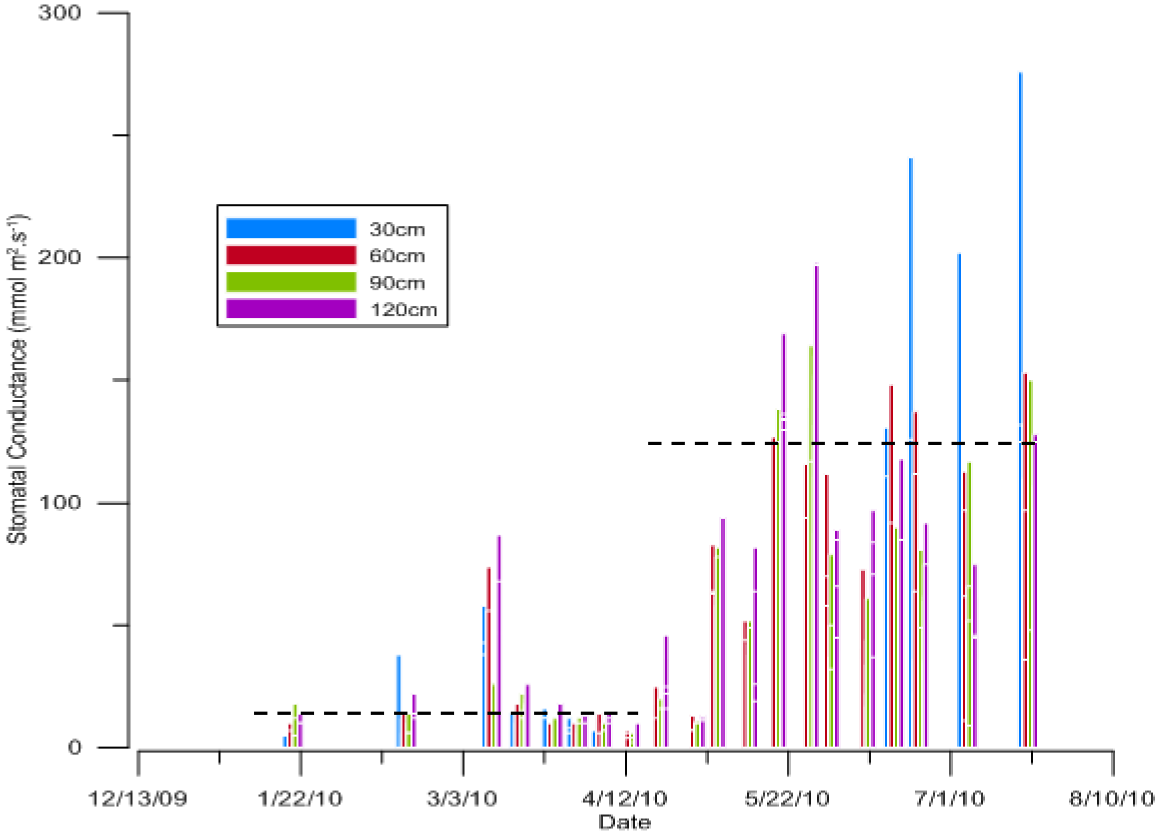


Figure 4.11 Graph illustrating stomatal conductance measurements at respective heights over time.

In this study the average Gs values collected with the porometer was compared to the average crop coefficient generated with data collected from the Scintillator study conducted in 2008 by de Clercq *et al*. (2010) (Figure 4.12). The Scintellator was used to measure ET in the same area as the study site. The average Gs values were synonym to the crop coefficient values. We consequently suggest that when the average Gs value, measured in the field, is related to the same time period an average crop factor can be estimated.

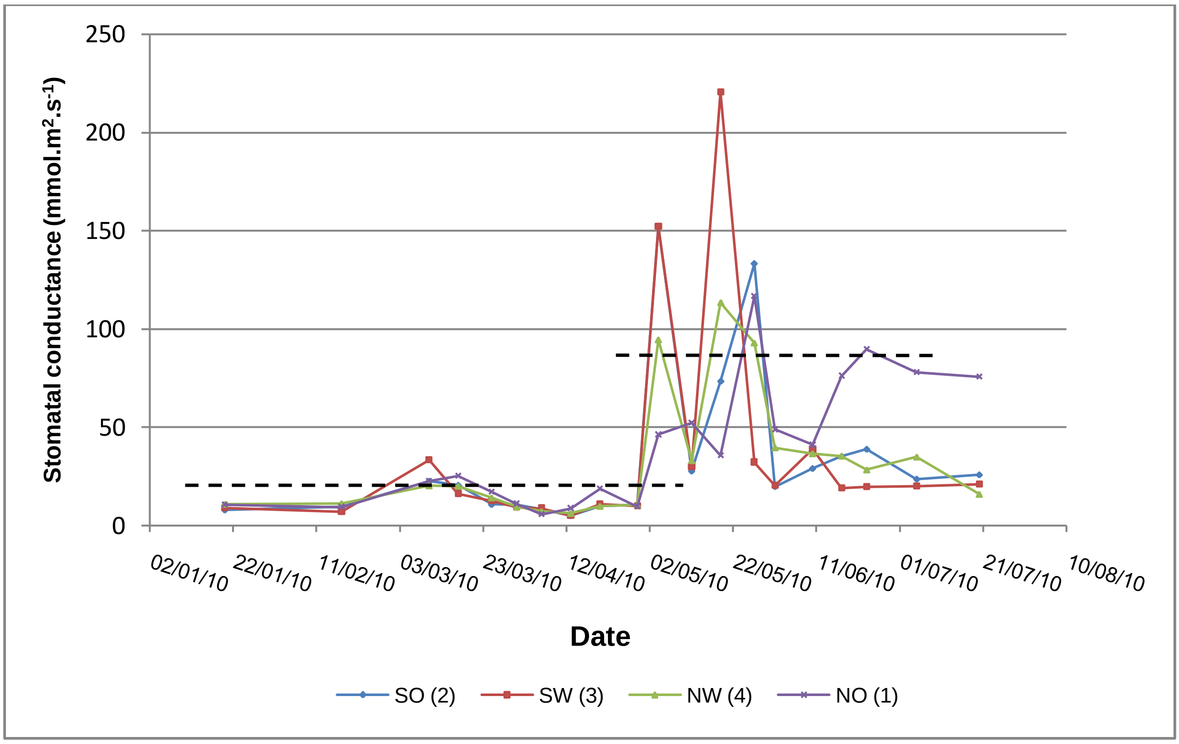


Figure 4.12 Graph illustrating stomatal conductance measurements at respective quadrants over time.

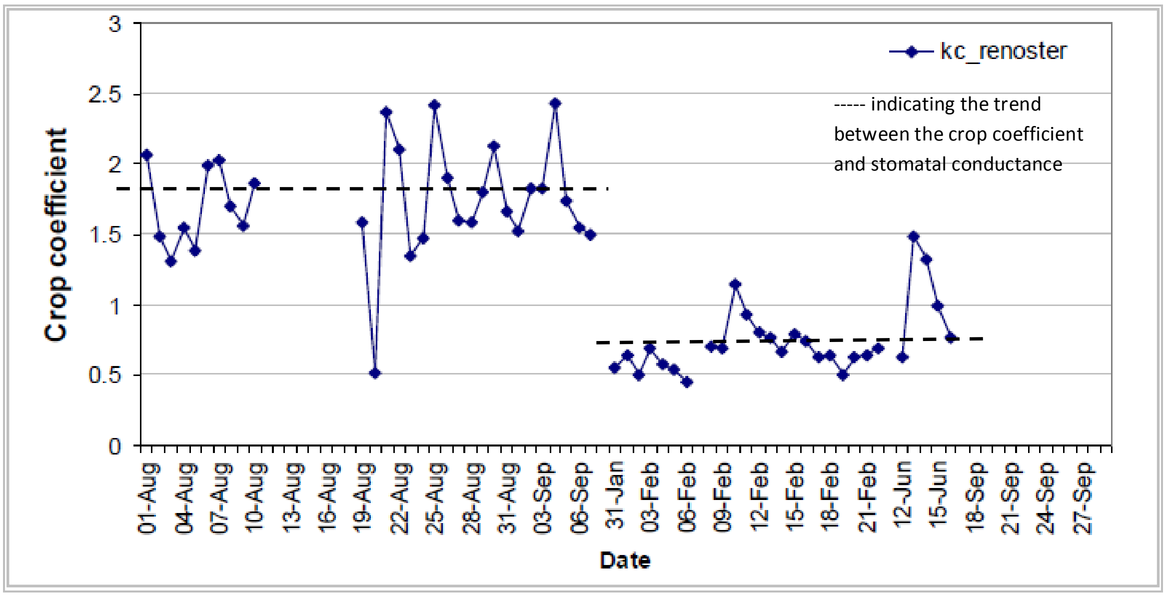


Figure 4.13 Graph illustrating the crop coefficients for the Renosterveld site (from de Clercq *et al.*, 2010).

4.3.5 Leaf distribution of the *E. rhinocertis*.

As the leaves of the renosterbos are so small, it is very hard to determine the leaf area index and thus very hard to predict the transpiration of a single renosterbos leaf. An average branch length is ±155mm (Figure 4.13a) and the length of 'n twig on the branch varies between 55mm and 12mm (Figure 4.13b).

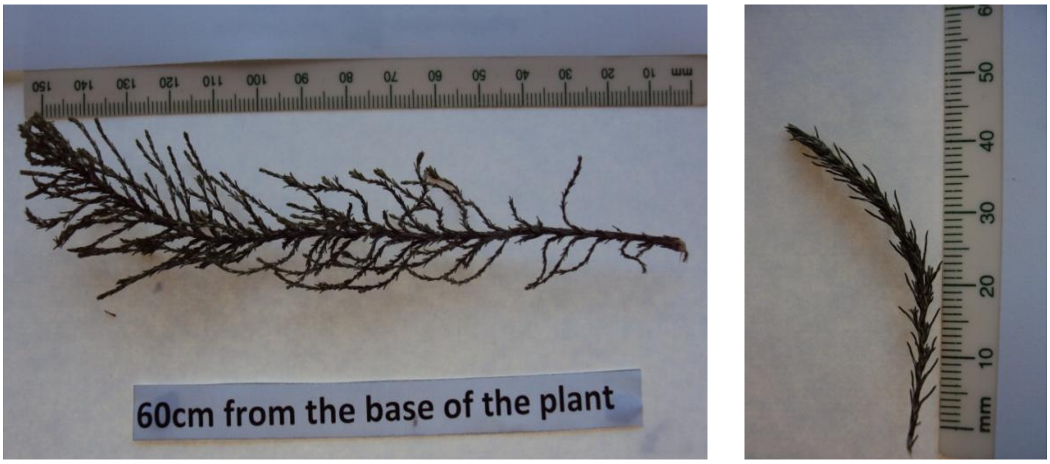


Figure 4.14 Photo illustration of (a) the average branch length and (b) the average twig length on the branch.

The leaves on the twigs of the branches, with varying lengths, were counted and the results are illustrated in Figure 4.14. The average length of the twigs at a height of 30cm was shorter than at a 100cm, leading to a lesser leaf count. With an increase in height there was an increase in the length of the twig and thus the amount of leaves per stem.

It was necessary to to describe the architecture of the plant as Gs values needed to be related to stomatal resistance values per plant or total leaf area. Since it is extremely difficult to determine the leaf area of these plants, it was decided to work with a leaf count. Therefore the total amount of leaves per plant was estimated using the information given in figure 4.14 and table 4.01. One could therefore estimate the total leaf count per plant by counting the number of branches. A typical leaf count per mature plant at end of summer amounted to 350000 while an average leaf count per mid winter amounted to 780000. These values should be seen in relation to the information presented in Figure 4.10 to 4.12

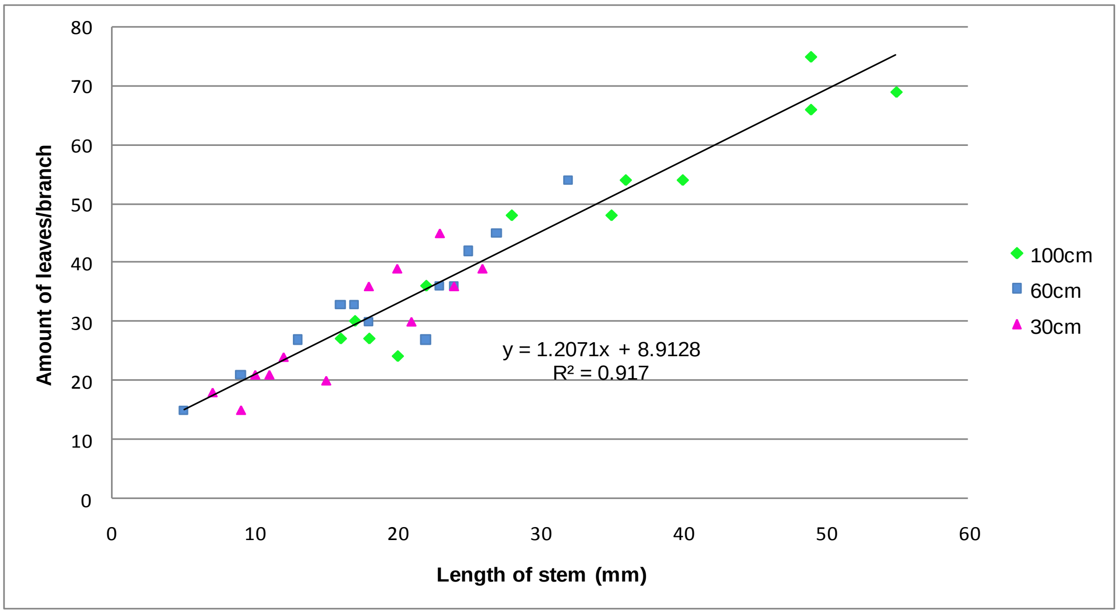


Figure 4.15 Graph illustration of the increase in the amount of leaver per stem, with an increase in the length of the twig.

4.3.6 Nutrient composition of *E. rhinocertis* leaves and stems

Although sampling throughout the season would be preferable to determine seasonal trends in nutrient concentration and translocation in plant components, this was not possible due to time limitations and funds. Even though it is important that the date of sampling should coincide with the phonological stage and not be a categorical calendar date, we decided to sample during April when the plant is in flower and under a great deal of stress due to water shortage. The second sampling date was at the beginning of August, after seed dispersal and after water resources have been replenished.

Nutrient content of plant components are generally low and is possibly due to the plant not storing any nutrients but taking them up as needed, just enough to satisfy the need of this slow growing specie. Table 4.2 gives the nutrient concentration content for the leaves and stems of a mature renosterbos in April and August.

Element concentrations (N, K, Ca, Zn, Fe and Cu) increased from April to August. Lower nitrogen levels in April may be ascribed to all nitrogen being translocated to reproductive organs. One must also keep in mind that during April, the N level of the deep groundwater (only source of water for the plant) is quite low. N is mostly trapped in the upper aerated soil. The increase in N levels was quite significant, especially in the leaves. The probable cause may be an increase in the mineralized soil N after rain.

Very little is known about the contribution of deep soil nutrients to the plants nutritional demand (Canadell *et al.,* 1996). Biological processes within the soil are strongly associated with root activity (Richter and Markewitz, 1995). Schachtschabel *et al*., (1992) also showed the importance of deep root development for nutrient cycling for tropical soils with seasonal drought. During the rainy season, deep rooted vegetation plants are not able to utilize nitrate salts mineralized by organic matter. These salts are the washed out of the top soil to deep soil horizons. In the deeper soil layers nitrate is immobilized by the positive charge balance of Al^{3+} and Fe^{3+}. Therefore deep rooted plants will be able to access nitrate later in the season, when needed for growth.

Potassium levels also showed an increase in the analysed plant material, between winter and summer samples. A cursory look at the data suggested that this occurrence may be ascribed to high potassium levels found in the weathered rock material which mainly consist out of weathered shale with a potassium content of 7.2 $mg.L^{-1}$ (de Clercq *et al.*, 2010). Through the uptake of winter water, roots have the ability to absorb potassium, which is then translocated to stems and leaves causing an increase in K.

Plant sodium levels decreased from April to August. During dry spells the plant is tapped in on groundwater resources. As discussed in Chapter 3 the weathering parent material (Malmesbury shale formation) leads to the mineralization of the groundwater and ultimately the Berg River. Sodium is also taken up by deep rooted plants and translocated to the leaves and stems. During winter months, after the first effective rainfall, salts are leached down to the water table and the plants utilize easily accessible plant water higher up in the profile..

Similar to fynbos species such as *Protea Repens L*. (Stock and Lewis, 1984) the *E.rhinocertis* has the ability to adapt to surrounding conditions and can continue to grow by using internal reserves after depletion of soil nutrients.

Table 4.01 Nutrient composition of components of *E.rhinocertis* sampled at two dates in the Renosterveld at Voëlvlei Nature Conservation
.

Sampling Date	Plant Component	Height (cm)	N	C	H	Ca	Mg	K	Na	Fe	Cu	Zn	Mn
			%			%				mg kg^{-1}			
April	Leaves	30	0.70	46.47	5.99	0.47	0.18	0.25	0.71	486	18	47	498
		60	0.46	46.56	5.23	0.42	0.17	0.25	1.00	261	17	41	439
		90	0.45	45.83	5.13	0.37	0.18	0.21	0.88	201	13	36	288
		120	0.39	46.77	5.91	0.38	0.17	0.22	0.82	328	13	41	301
August	Leaves	30	1.81	46.73	4.82	0.35	0.12	0.85	0.17	525	37	85	295
		60	1.65	46.99	4.95	0.41	0.21	0.61	0.21	430	15	60	265
		90	1.87	48.69	4.91	0.39	0.20	0.59	0.20	455	18	65	235
		120	1.64	50.33	5.46	0.41	0.19	0.44	0.20	505	16	70	215
Sampling Date	**Plant Component**	**Height (cm)**	**N**	**C**	**H**	**Ca**	**Mg**	**K**	**Na**	**Fe**	**Cu**	**Zn**	**Mn**
			%			**%**				**mg kg^{-1}**			
April	Stems	30	0.53	44.00	4.99	0.32	0.10	0.15	0.73	403	14	33	367
		60	0.36	44.25	5.75	0.42	0.12	0.09	0.45	182	19	35	404
		90	0.43	40.34	5.20	0.40	0.12	0.09	0.32	218	12	44	386
		120	0.42	46.22	6.05	0.37	0.12	0.11	0.31	267	27	37	433
August	Stems	30	0.86	45.77	4.92	0.39	0.11	0.63	0.13	485	15	50	200
		60	0.88	45.18	4.97	0.60	0.09	0.39	0.10	395	11	40	200
		90	0.83	45.89	5.12	0.68	0.09	0.36	0.11	385	14	45	170
		120	0.87	47.33	4.55	0.69	0.10	0.33	0.11	380	15	50	160

4.4 Conclusion

Since the early work of M.R Levyns, very little research on the physiological aspects of the renosterbos has been done.

The renosterbos is a true member of the Cape floristic kingdom (CFK), but data has shown that this plant has an exceptional capability of adapting itself to drought and cold, unlike many other members of the CFR.

Renosterveld, in spite of its apparent uniformity varies in its floristic composition in different localities (Levyns, 1929). Therefore, further research is needed into the acclimatisation of the renosterbos in various environments. Soil and climate play an important role in the survival of the renosterbos and ultimately the Renosterveld. Specific attention must be given to areas intended for Renosterveld rehabilitation.

A number of key components were explored in this section and the findings are summarized as follows.

1. There was a remarkable change in the plants leaf cover through the season.
2. The measured stomatal conductance responses over the season related to the Scintillator study done in the same region.
3. The plants make extensive use of their fibrous cover during the year to not only limit evaporation but also channel water down the stems.
4. The seeds of these plants are adapted to be windblown and distributed.
5. Very little stomata could be found on leaves and the estimate is that no leaf has more than three sunken stomata.
6. The fact that more sodium (K) was found in the plant than in the surrounding soils indicate that these plants could be crucial bioturbation, as these elements are also much needed by other plants and animals.

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CHAPTER 5. PLANT- AND SOIL WATER OF RENOSTERVELD AND WHEATFIELD

5.1 Introduction

In South Africa, with specific reference to the Western Cape, the clearing of endemic vegetation i.e. Renosterveld to make place for wheat farming, is a continuing process. The process of land clearing, resulting in an increase in dryland salinity, has been identified as one of the contributing factors leading to the deterioration of the water quality of the Berg River (Fey and de Clercq, 2004). Changes in land-use, from pastoral use to intensive cropping, may cause changes in the water balance, different runoff responses and the mobilization of salts, leading to the same process of salt decantation that occurs in Australia (Flügel, 1995). The removal of deep rooted perennial vegetation has caused water tables to rise and may have accelerated the process of salt mobilization (Jovanovic *et al.*, 2010). The spatial distribution and depth, to which roots penetrate the soil, may exert a large degree of control on the water fluxes to the atmosphere and the groundwater (Canadell *et al*., 1996). Root-soil interactions in the rhizosphere influence the quantity of water being transported to and from the vadose[9] zone. Root water uptake is not only influenced by root distribution but also by soil water availability and soil salinity (Vrugt *et al.*, 2001). Homaee (1999) suggested that root water uptake may be reduced when the concentration of soluble salts in the soil exceed plant-specific threshold.

It is therefore crucial that the negative effect of the removal of deep rooted native vegetation on soil water resources is understood so that long term sustainability and productivity can be maintained.

Continued transpiration of the renosterbos led us to investigate the influence of deep rooted vegetation on water resources even after soil moisture depletion. This could be better understood by using soil water simulation models.

This study forms part of a project that was set out to determined the impact of land-use changes on the soil water balance and soil salinity. The aim of this Chapter was to assess changes in water fluxes by comparing a mature re-established Renosterveld stand with an

[9] Vadose zone – Unsaturated zone

adjacent wheat field. Water content determined through field measurement methods were compared to predicted HYDRUS-1D values.

5.2 Material and Methods

The experiment was initiated at the end of 2009 in an extensive stand of 45 year old *E.rhinocertis* (Renosterveld) at Voëlvlei Nature Conservancy with an adjoining wheatfield on the farm Schoongezicht.

A weather station was installed in an open area of the Renosterveld near the fence bordering the wheatfield. The weather station hourly recorded rainfall, temperature, relative humidity, net radiation, wind speed and wind direction. An additional rain gauge was installed in the Renosterveld. Since the weather station in the Renosterveld has only recently been established (June 2009), additional climate data was retrieved from a nearby weather station at the Langgewens experimental farm with adequate 20 year record of weather data. The data was stored in the DrysalRbis (a database for Berg River hydrological data with an added data manipulation toolbox), from where daily maximum and minimum values could be derived (Appendix 4.1).

During the winter of 2008, two ECH2O soil water/salinity/temperature logging sensors were installed, one in the Renosterveld and one in the wheatfield at depths of 15cm and 30cm respectively.

Gravimetric soil water content samples were taken over a 12 month period on a monthly basis from June 2009 to June 2010, in the wheat and Renosterveld at a depth of 15cm and 30cm respectively. Volumetric water content was calculated using soil bulk density values. Field measured volumetric values were used at periodic intervals to correlate with the volumetric soil water content measured with ECH2O sensors. The aim was to compare water content at 15cm and 30cm depth for the wheatfield and the Renosterveld respectively and to correlate data sets of different measurement methods.

In 2006, six boreholes were drilled at the Voëlvlei site, two in the Renosterveld reserve, two in the adjacent wheatfield and two that are located at the bottom of the catchment (Figure 5.1).

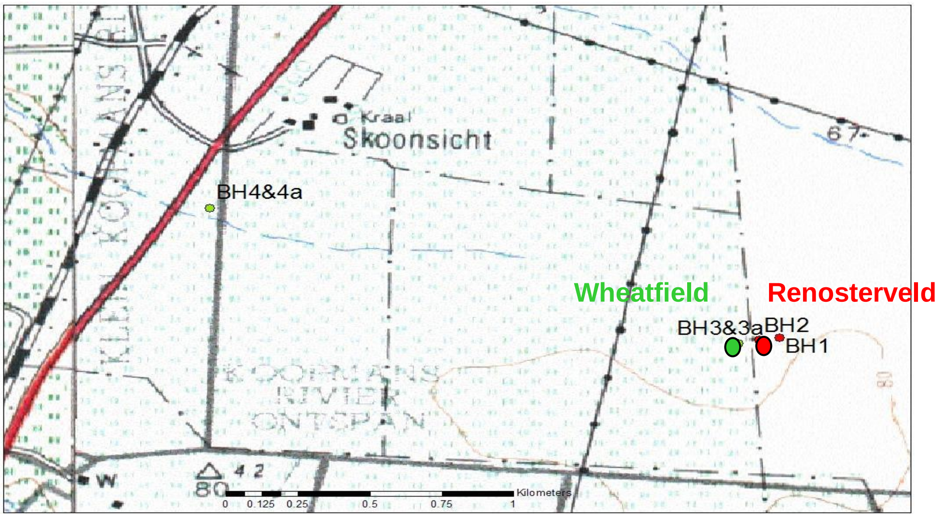


Figure 5.01 Topographic map (1:50 000) of the borehole positions (de Clercq *et.al*, 2010).

For the purpose of this study only two boreholes, one in the Renosterveld and one directly across in the adjacent wheatfield were chosen to monitor the water table depth and EC. The depth of the water tables was measured on a weekly interval and 50ml water samples were taken for EC measurements. From these selected samples were analysed, soluble cations were determined by AAS (Atomic Absorption Spectroscopy) and the Ion Chromatography method was used to determine soluble anions (SAF Labarotories, Stellenbosch University). The Sodium Absorption Ratio (SAR) was calculated for the borehole water samples of the wheat- and Renosterveld.

The vadose zone plays a key role in many aspects of the hydrological cycle including infiltration, evaporation, plant water uptake, runoff, groundwater recharge and erosion (Simunek *et al*., 2005). The impact of changes in land use and the influence of plant root systems on water movement can be better understood by using water simulation models. The one dimensional Hydrus model, version 4.0 (Šimunek *et al*., 2005) was parameterised for the study site and used to predict daily soil water content and root water uptake. Richards equation (5.1):

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x}\left[K\left(\frac{\partial h}{\partial x} + \cos\alpha\right)\right] - s \quad \text{.......... (5.1)}$$

is used for simulating water movement in a partially saturated porous medium, where h is the water pressure head, θ is the volumetric water content, t is time, x is the spatial coordinate (positive upward), S is the sink term, α is the angle between the flow direction and the vertical axis and K is the unsaturated hydraulic conductivity (Šimunek *et al*., 2005).

The water flow equation incorporates a sink term (*S*) to account for root water uptake. *S* is defined as the volume of water removed from a unit volume of soil (Šimunek *et al*., 2005). A root water uptake model after Feddes *et al*. (1978) in the HYDRUS-1D model was used to simulate root water uptake on a daily time step (Jovanovic, 2010).

An rooting depth of 1.2m was estimated for Renosterveld by means of a root study. The root study indicated that Renosterveld roots were able to penetrate soils much deeper than the profile depth allowed, therefore rooting depth of Renosterveld was assumed to be >10m. This corresponds to the measured groundwater table depth of 15m, with root density declining with depth and taproots tapping into the deep groundwater source. A rooting depth of 65cm was estimated for wheat, with a linear root distribution from top to bottom.

Allen *et al*. (1998) defines ET_0 as the 'evaporation from a reference surface, not short of water'. The only factors affecting ET_0 are climatic parameters; therefore ET_0 can be calculated from meteorological data

The FAO Penman-Monteith (FAO-PM) method (FAO-ET_0 calculator) was used to calculate the daily ET_0 values by using the long term meteorological data collected from the Langgewens weather station. The FAO-PM equation (5.2) was used for daily ET_0 estimation.

$$ET_o = \frac{\Delta(R_n - G) + \rho_a c_p \frac{(e_s - e_a)}{r_a}}{\Delta + \gamma\left(1 + \frac{r_s}{r_a}\right)} \quad \text{.......... (5.2)}$$

where R_n is the net radiation, G is the soil heat flux, (e_s - e_a) represents the vapour pressure deficit of the air, ρ_a is the mean air density at constant pressure, c_p is the specific heat of the air, Δ represents the slope of the saturation vapour pressure temperature relationship, γ is the psychrometric constant, and r_s and r_a are the (bulk) surface and aerodynamic resistances (Allen *et al*., 1998).

To calculate PET from ET_0 the following equation was used:

$$PET = ET_0 * Kc_{max} \quad \text{.......... (5.3)}$$

where Kc_{max} is calculated as a function of weather data and vegetation height (Allen *et al*., 1998, Jovanovic *et al*., 2010). Crop coefficient data for wheat was received from Langgewens experimental farm (Hardy, 2010) and was correlated with data from various databases (Allen *et al*., 1998). Crop coefficient (Kc) values for Renosterveld may vary between 0.3 – 1.5, depending on seasonal and climate changes (de Clercq *et al*., 2010; Jarmain,).

ET_0 values determined with FAO-PM method was used to determine Kcb values (5.4) (Jovanovic *et al*, 2010). The Kcb (basal crop coefficient) can be used to divide PET into potential transpiration (PT) and potential evaporation (PE) from the soil surface (Jovanovic *et al*., 2010; Jovanovic and Annandale, 1999; Jovanovic, 2010)

$$Kcb = Kc_{max}*C \quad \text{.......} \quad (5.4)$$

where C is the estimated crop cover for wheat and renosteveld respectively. Vegetation height for the renosterbos was chosen at a constant 1.2m, as this is the average length of a renosterbos in the Voëlvlei area and very little growth occurs during a two year time period (personal observation). For wheat, the length stages were estimated on data received from the Langgewens experimental farm (Hardy, 2010). The planting date for wheat is in May and harvesting in November, the rest of the year the field is left uncultivated and therefore bare. Wheat length was only determined for the growth period until harvesting.

The van Genuchten-Mualem hydraulic model was chosen, with no dual porosity or hysteresis taken into consideration (Jovanovic, 2010). Hydraulic parameters from soil data (i.e. soil texture, structure, bulk density) collected throughout the study was also imported into the model to predict water flow and root water uptake.

Two-year simulations were run from August 2008 to August 2010 to compare soil water balance between wheat as land use type and Renosterveld as natural vegetation type.

5.3 Results

5.3.1 Data collected from Borehole water samples

Data for water collected samples from the boreholes in the wheat- and Renosterveld are given in Appendix 3.1 and 3.2. Figure 5.02(a) and (b) gives the measured depth and EC values of the boreholes in the wheat en Renosterveld respectively. From the results obtained, large differences in salinity and soil-water behaviour were detected between wheat and the adjoining Renosterveld.

5.3.1.1 Groundwater table depth

During the period of measurement the groundwater table in the Renosterveld was at a constant depth of 15 meters (Figure 5.02 b). Effective rainfall events did not result in a noticeable increase. This is worthy evidence that the renosterbos has the ability to adapt itself to its surrounding environment and send its roots very deep into the soil. Most of the root biomass occurs in the first 70cm of the soil profile, there is however a few roots (tap roots) that are able to reach below and have the ability to access and transport water from deeper soil horizons to the top soil horizons (Candell *et al*., 1996). During winter periods, water is extracted from shallow soil layers where root density is highest (Scott and Van Breda, 1937), but as these layers dry out, roots rely on deeper water resources allowing these plants to keep transpiring and growing. Nepstad *et al*. (1994) found that during the dry season, evapotranspiration may be greatly underestimated when roots deeper than 2 meters are not taken into account.

For the wheatfield the results obtained were quite different from that of the Renosterveld. The groundwater table continued to rise during the period of measurement from 7.5m to 4.9m soil depth (Figure 5.02 b). Wheat roots can reach depths of more than 2 meters in deep sandy soils, if no physical or chemical constraints exist. Where roots are subjected to soil limitations, such as high bulk density, relatively high clay content and low permeability, the root distribution of wheat is generally restricted to the topsoil, the first 50cm and could be as low as 30cm (Kirkegaard and Lilley, 2007).

Changes in the water balance between the wheat and Renosterveld is not only caused by water extraction. Differences were found in soil surface roughness, compaction, structure and infiltrability as a result of biological activity and vegetation cover (Chapter 3). Soil texture, the tendency of the soil to crust and the soil water content during a rainfall event may influence the infiltrability of a soil. Water infiltrates quickly into coarse textured soils, but only a little water can be retained in the soil. When the soil has reached saturation, the rest of the water will run off. Fine textured (clayey) soils can hold much more water, but the infiltration rate is lower. De Clercq *et al.* (2010) found that larger rainfall events caused faster runoff in wheat than in Renosterveld. In the wheatfield water build-up in the soil profile is slower from the surface downward. Therefore, when overland flow occurs in the Renosterveld, it is mostly after soil saturation, whereas in the wheat lands it results directly from slow infiltration of water.

Another contributing factor to the rising winter groundwater level in the wheatfield may be the contour banks. As the slope of the contour banks are <1%, water flow is very slow causing water to dam behind the contour banks, with slow infiltration. De Clercq *et al*. (2010) indicated that the EC of the water behind the contour banks is generally high with relatively low SAR. This causes higher infiltration in these zones.

Figure 5.02 (a) EC (mS.m^{-1}) values and (b) depth measured from boreholes in the wheat and Renosterveld respectively.

5.3.1.2 Electrical conductivity (EC)

The groundwater salinity levels mirrors the water table depth of the boreholes, with the EC values of the wheatfield being higher than those of the Renosterveld (Figure 5.02a). Changes in EC values cannot be attributed to a change in geology or elevation, as weathering depth and geology would be the same because of the distance between boreholes (de Clercq *et al*., 2010).

The higher salinity in the wheatfield levels may be attributed to the higher saline water being transported along the contact zone with the Malmesbury shale, with the capillary rise of the groundwater table during winter months, salts are mobilized and transported to the surface.

The wheatfield is left bare for parts of the year and every second year; the salinity recharge may greater for the wheatfield than for the permanently covered Renosterveld. Because of the high clay content of weathered Malmesbury Shale, recharge occurs via preferred pathways and fault zones within the shale. Without any wheat coverage, the recharge due to infiltration is higher in the wheatfield, resulting in a perched water table once this infiltration reaches an impermeable clay layer.

5.3.1.3 Chemical analysis

As we were able to monitor groundwater levels on frequent intervals, it allowed us to observe the effect of seasonal changes on the pH as well as chemical composition contributing to groundwater salinity (Figure 5.03). Data for chemical analysis is given in Appendix 4.1 and 4.2.

The pH values for the wheatfield increased dramatically after the first effective rainfall in May, increasing from 7.3 to 8.5 (Appendix 3.2). The increase in pH for Renosterveld was less (Figure 5.03). This may be attributed to the sodium and potassium content. The initial increase in pH is caused by an increase in the cations (Na^{2+} and K^{+}) that is released after the first effective rainfall. After the first initial rise, pH values decreased for both the wheatfield and Renosterveld respectively. After rainfall salts are diluted by water causing a decrease in the divalent to monovalent ratio and ultimately leading to a decline in pH. The increase in potassium and chloride levels may be attributed to the weathering rock material and groundwater flow, as both these cations are highly soluble and may leach easily into surface water. The leaching of these salts, mainly NaCl, into river catchments is one of the sources contributing to the deterioration of the water quality (Day and King, 1995).

The SAR values were higher for the wheatfield than for the Renosterveld (Table 5.01). Statistical analysis showed a high F-value (3.765) and small P-value (0.001); which indicates a strong linear relationship between the two data sets. Salinity and SAR must be considered together to determine the ultimate effect that these factors may have on the water infiltration rate. As a result of the increased salt concentration, higher SAR values and a difference in soil texture and structure in the wheat field. Soil infiltration for the wheatfield is slower and water may accumulate on the soil surface which can lead to increased runoff to the contour bank. In the Renosterveld water infiltration rate is faster as a result of the preferential flow path caused by bioactivity (earthworms and termites), Renosterveld roots as well as decreased surface crusting due to the restoration of Renosterveld. This means the infiltration of rainwater through the A-horizon is faster and salts are more easily diluted and leached away, therefore salt concentrations and SAR values for the Renosterveld are lower.

Table 5.01 Calculated Sodium Absorption Ratio (SAR) for selected borehole water samples for the Renosterveld and wheatfield respectively.

	Renosterveld	Wheatfield
Date	**SAR**	
2010/02/17	6.01	8.62
2010/03/25	6.27	8.84
2010/04/13	5.58	7.66
2010/05/04	5.54	7.62
2010/05/27	5.68	5.10
2010/06/17	5.40	6.59
2010/07/20	5.20	6.34
***P*-Value**		0.001
***F*-Value**		3.765

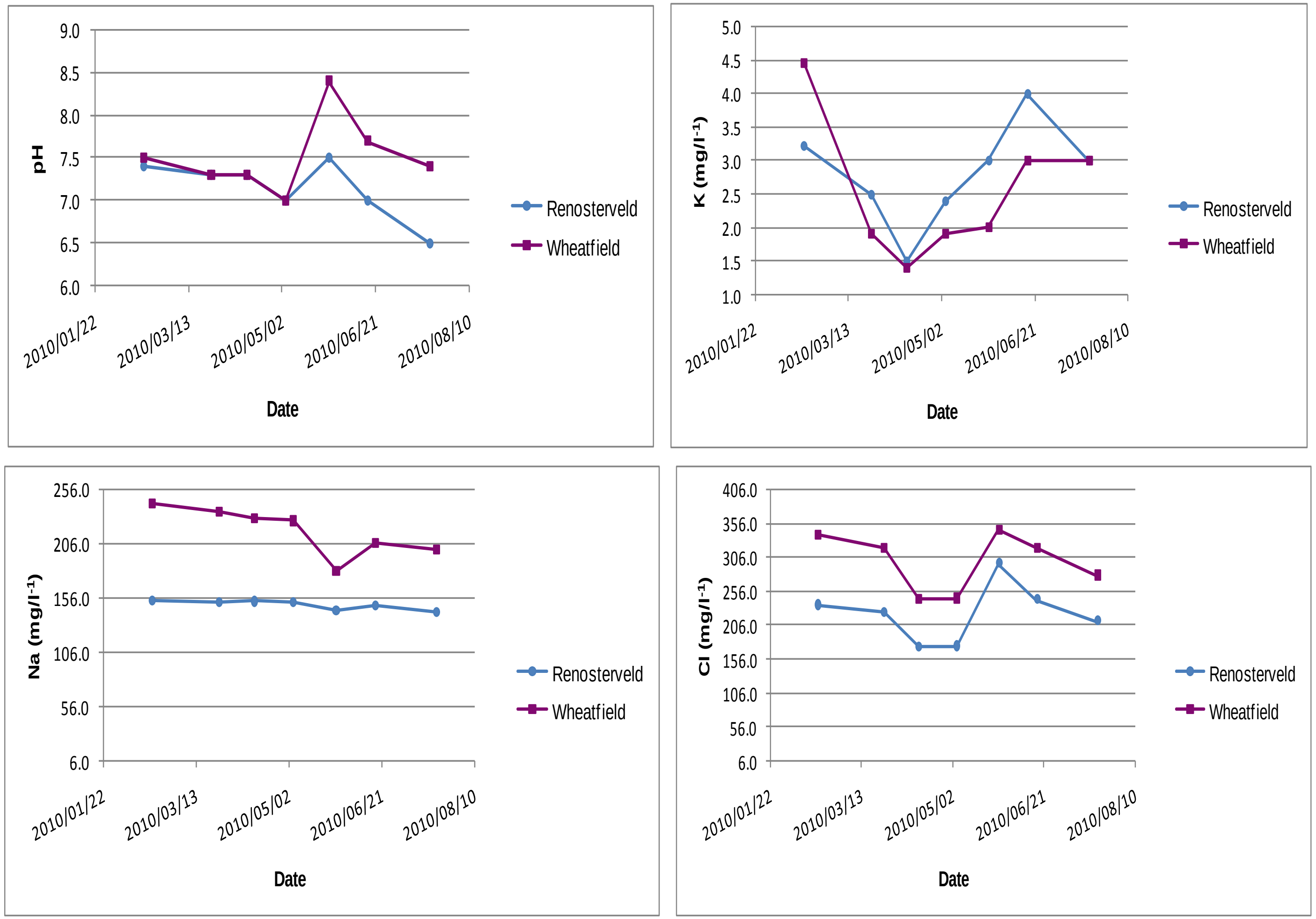
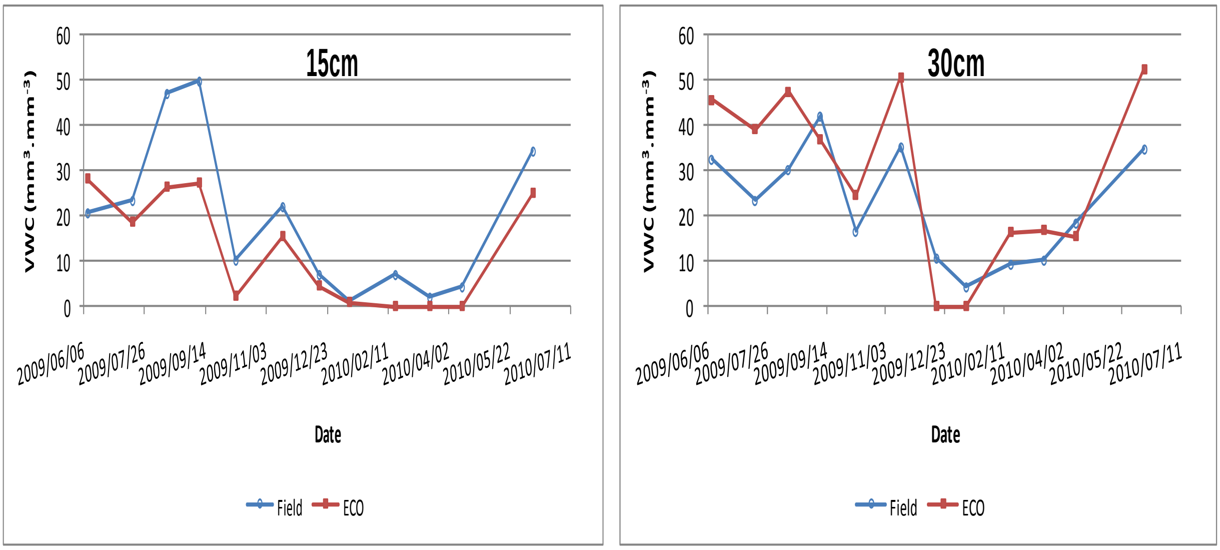


Figure 5.03 Graphs indicating the difference in pH, K^{+}, Na^{2+} and Cl^{-} for selected borehole water samples for the wheatfield and the Renosterveld for the period 17 February 2010 – 20 July 2010

5.3.2 Soil water content

Large differences were detected in the soil water behaviour between the wheatfield and the adjacent Renosterveld (Figures 5.04 a & b).

(a)



(b)

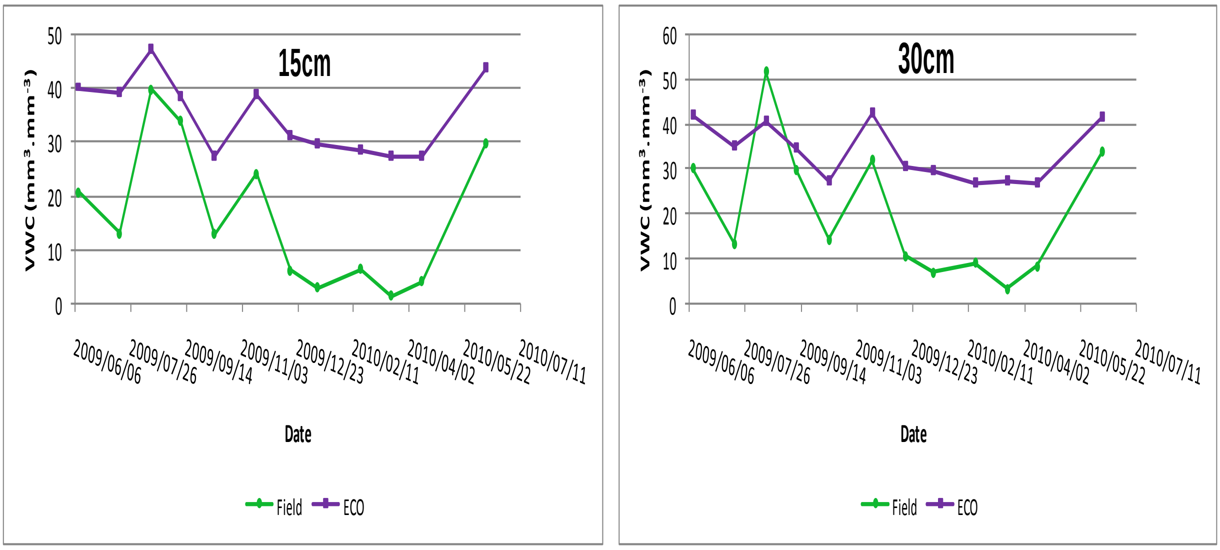


Figure 5.04 Graphs indicating the comparison of field (gravimetric soil water content) and ECH2O sensor measurements for (a) the Renosterveld and (b) the wheatfield for selected depths.

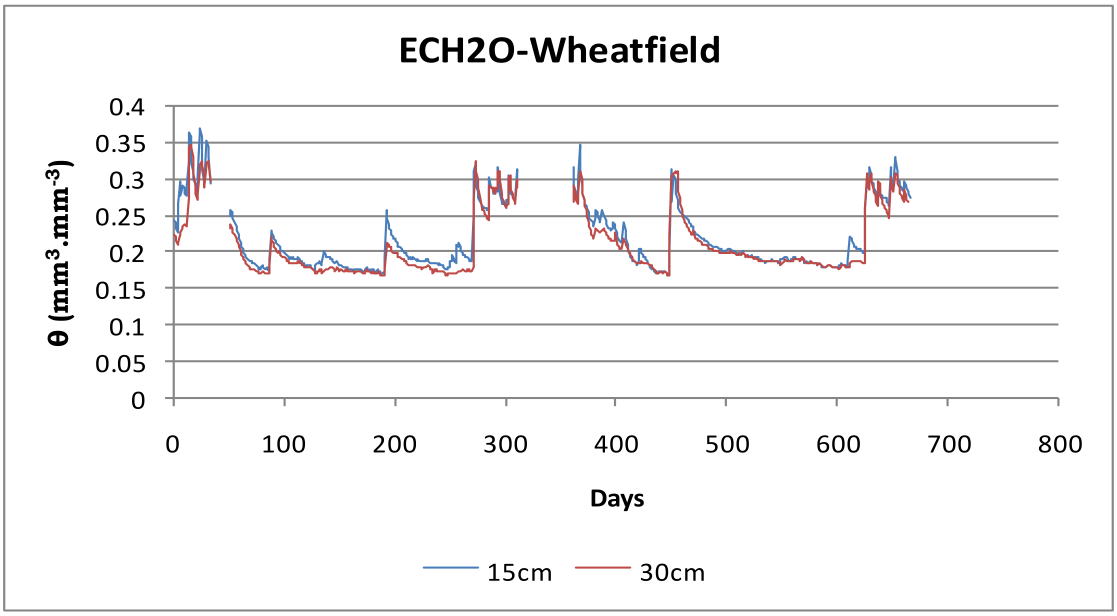
The wheatfield (Figure 5.04b) showed almost similar soil water content for the 15cm and 30cm depth measurement. It was noted that for periods after rainfall the 15cm depth was wetter than the 30cm depth measurement.

In the Renosterveld (Figure 5.04 a) the opposite was observed with the 30cm depth measurement being wetter than the 15cm depth measurement for most of the winter. The two methods of measurements correlated well with each other for the Renosterveld, but for the wheatfield, even though the same inclination was observed, the ECH2O sensors seemed to overestimate the water content for both depths. As ECH2O sensors log data on an hourly interval, the date and time had to correspond with the gravimetric samples, which were taken on a monthly basis, this may have caused the overestimation of water content for the wheatfield. In the Renosterveld the underground may be saturated for longer periods, which can cause defective measurements of soil water content with the ECH2O sensor (Figure 5.06).

In addition the HYDRUS-1D model was used to predict the soil water content for the respective depths in the wheatfield and the Renosterveld for a two year time period. Observation nodes were selected in the model at the 15cm and 30cm depth. The data generated by the model was then compared to the ECH2O sensor data for the same time period (Figure 5.05 and 5.06).

The ECH2O sensors showed almost similar water content for the 15cm and 30cm depth measurements in the wheat field. For periods after rainfall, the 15cm depth was wetter than the 30cm depth. In the Renosterveld the opposite effect was observed during winter periods, with the 30cm depth being wetter for longer periods. The higher water content at a 30cm depth means infiltration in the Renosterveld is much faster in the top horizon with water build-up from the bedrock or compacted E-horizon to the surface. In the wheat field water build-up is above the surface downward, causing water to accumulate on the soil surface, especially after larger rainfall events leading to faster runoff. This also explains the higher salt content in the wheatfield.

When compared to field measurement of the ECH2O sensors, predictions of soil water content using the HYDRUS-1D model were very promising. The model predicted the same general trend as the ECH2O's, however in some instances the ECH2O overestimated the soil water content, as indicated in the Renosterveld



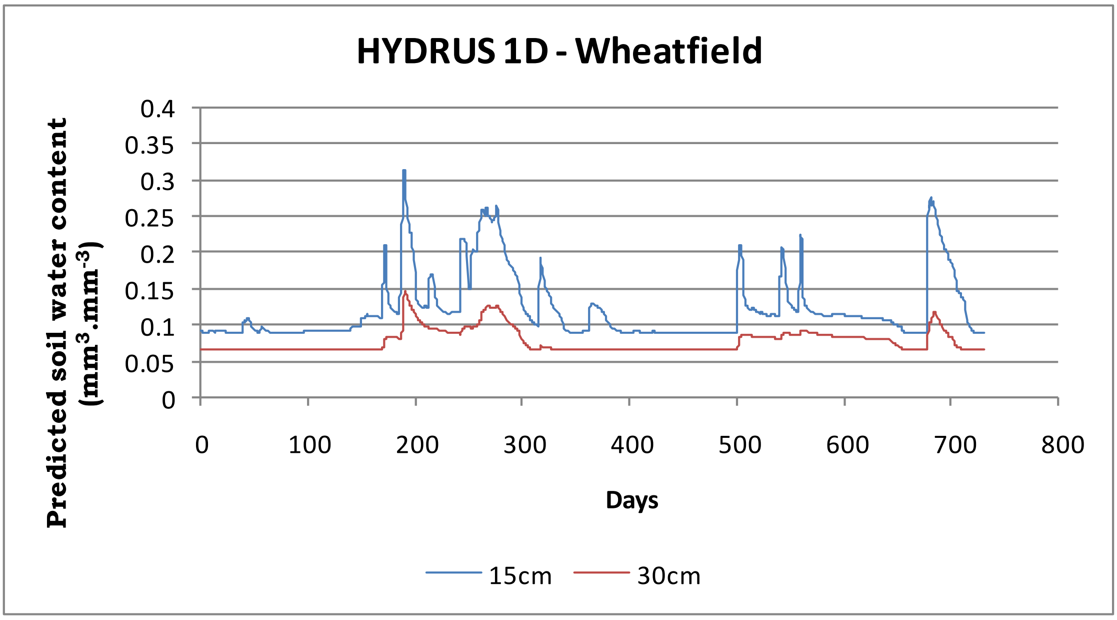
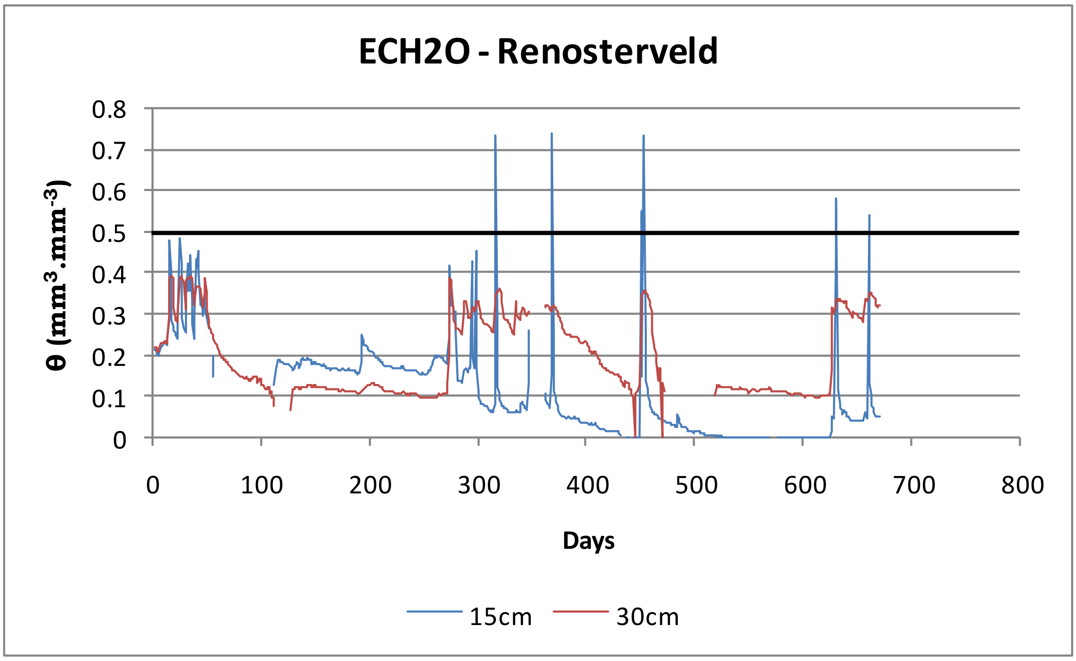


Figure 5.05 ECH2O sensor field measured soil water content compared to predicted soil water content at 15cm and 30cm depths for the wheatfield for the period 17 August 2008 – 16 August 2010.



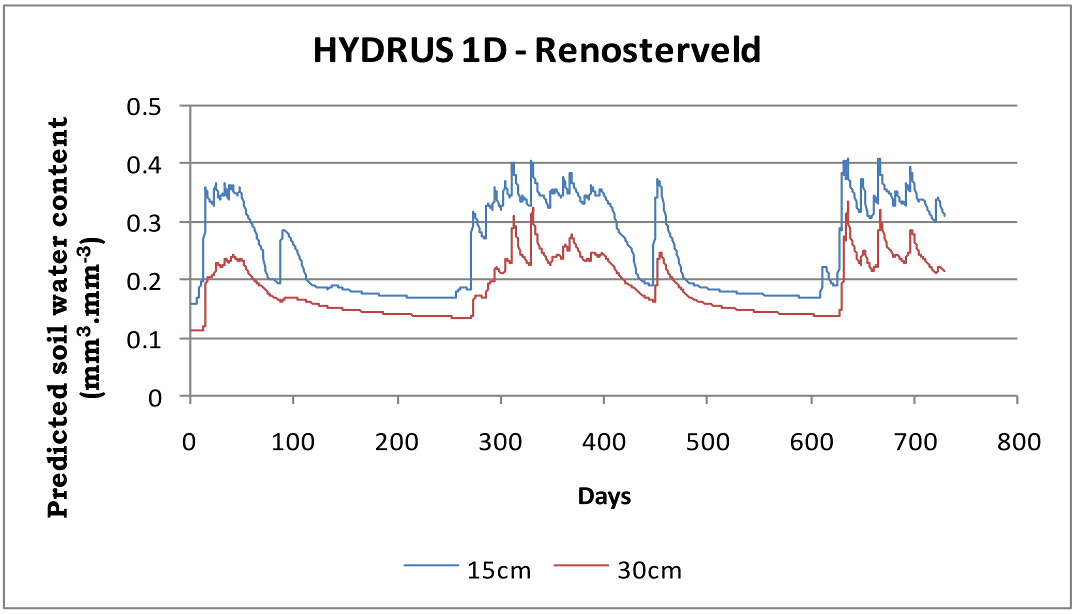


Figure 5.06 ECH2O sensor field measured soil water content compared to predicted soil water content at 15cm and 30cm depths for the Renosterveld for the period 17 August 2008 – 16 August 2010.

Although the model adequately predicted water content at both depths, predictions were relatively weaker near the soil surface and progressively better with depth. It is inferred that soil parameters (i.e. lower bulk density, higher organic matter, and lower clay content) to influence water content predictions near the soil surface (0-15cm) as well as soil surface evaporation from fallow patches in the Renosterveld and bare wheatfield during summer periods.

5.3.3 FAO-modelling of evapotranspiration.

The FOA-PM model was used to determine reference evapotranspiration (ET_0) from weather data. From the ET_0 values, potensiaal evaporation and transpiration was calculated for the wheat field and the Renosterveld respectively. Transpiration and evaporation from soil occur concurrently and are dependent on climate and seasonal changes, soil water availability and the type of cover crop/vegetation (Rosenberg *et al*., 1983). These measurements were made to determine the impact of land-use change on the soil water balance (Figure 5.7, 5.8, 5.9).

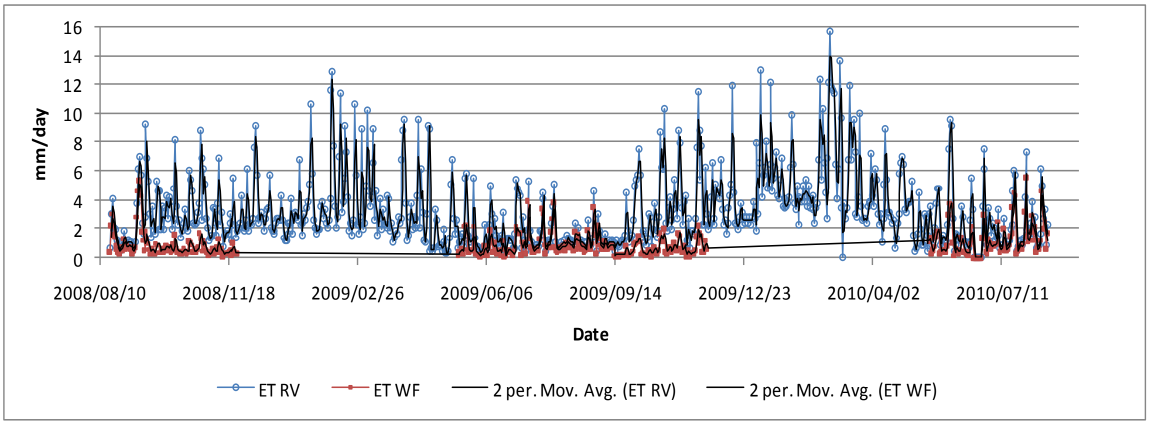


Figure 5.07 Estimated evapotranspiration (ET) for the Renosterveld and wheatfield respectively.

From stomatal conductance measurements in Chapter 4, it was found that the renosterbos is a plant that transpires year-round. Deeply penetrated roots (taproots), even if it is only a small fraction of the total rootstock, have the ability to absorb water from the water table and transfer it into the plant, thereby allowing the plant to maintain high transpiration rates during dry periods (Canadell *et al*., 1996). During summer periods (February 2009 and 2010) the potential transpiration (PT) values of the Renosterveld exceeded that from the wheatfield by far, as there was no actively growing wheat present during these periods except for a layer of wheat stubble (Figure 5.8). The highest potential evapotranspiration was calculated for 2010.

During the actively growing period for wheat, the ET values were very similar between the wheatfield and the Renosterveld (July 2009 and 2010), with Renosterveld values just exceeding that of the wheatfield for September 2008. A Lower transpiration rate in general was noted for the wheatfield and the Renosterveld for 2008/2009 than for 2009/2010. This may be attributed to a change in climate conditions such as lower rainfall and lower temperatures leading to lower transpiration rate. ET is dependent on rainfall as well as rainfall distribution on evaporative demand. All these factors may influence ET values

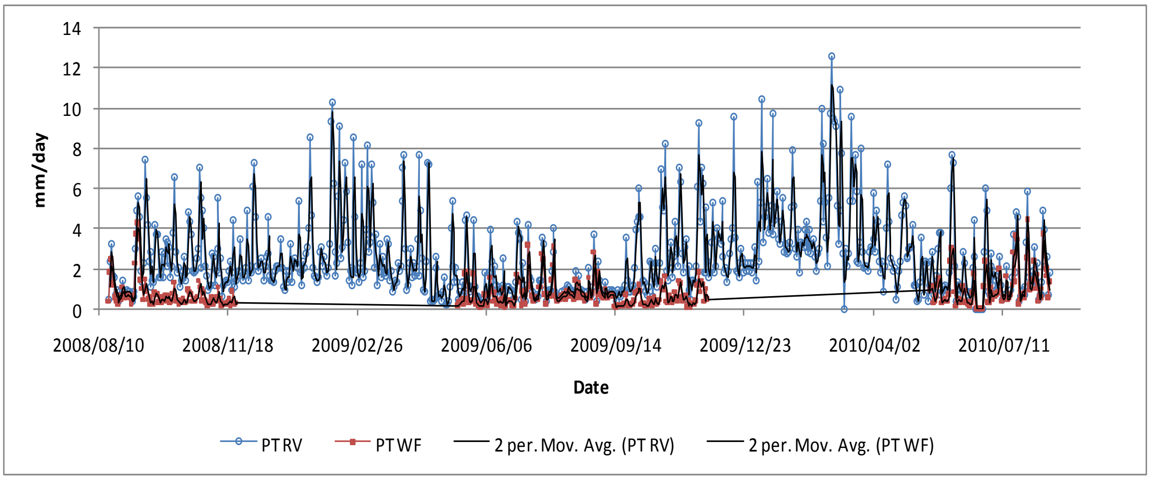


Figure 5.08 Estimated potential transpiration (PT) for the Renosterveld and wheatfield respectively.

From estimated ET and PT values we were able to calculate the potential soil evaporation for the Renosterveld and wheatfield (Figure 5.9). Fallow conditions were simulated for wheat from November to April, as soil is left bare during this time period.

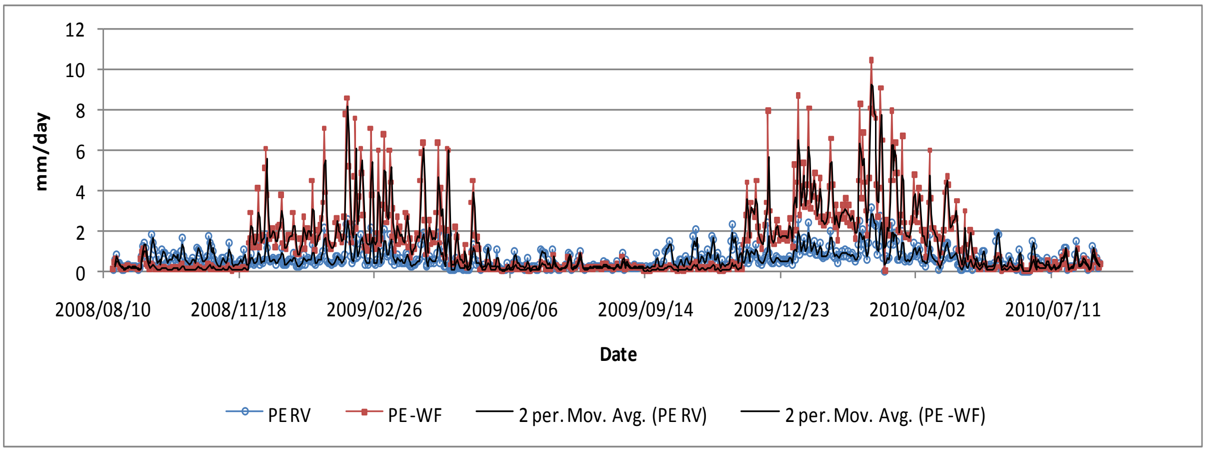


Figure 5.09 Estimated potential evaporation (PE) for the Renosterveld and wheatfield respectively.

Evaporation from the soil surface for the wheatfield and the Renosterveld is generally very similar for May to November, when wheat is actively growing and covers the soil completely. Potential evaporation is slightly higher for the Renosterveld than the wheatfield during this time period. In the Renosterveld bare patches develop as the annual winter veld dies back. After the first effective rainfall in May/June, grass and bulb species cover the bare patches and evaporation from soil surfaces decreases.

For the wheatfield the estimated evaporation is much higher during the summer (November to April) than for the Renosterveld. After harvesting (November), the wheatfield is left bare with only wheat stubble covering the soil surface. Late rainfall in November 2009 caused a great increase in evaporation from soil surface for the wheatfield and the Renosterveld.

5.3.4 HYDRUS-1D modelling of root water uptake for the wheatfield and the Renosterveld respectively.

The FAO-PM model was able to predict potential transpiration and evaporation. Calculated data, along with soil properties, root distribution and depth was imported into the HYDRUS-1D model and used to simulate root water uptake for the wheatfield and the Renosterveld (Figure 5.10 a & b). After the harvesting of wheat in November, root water uptake was set to zero in the model.

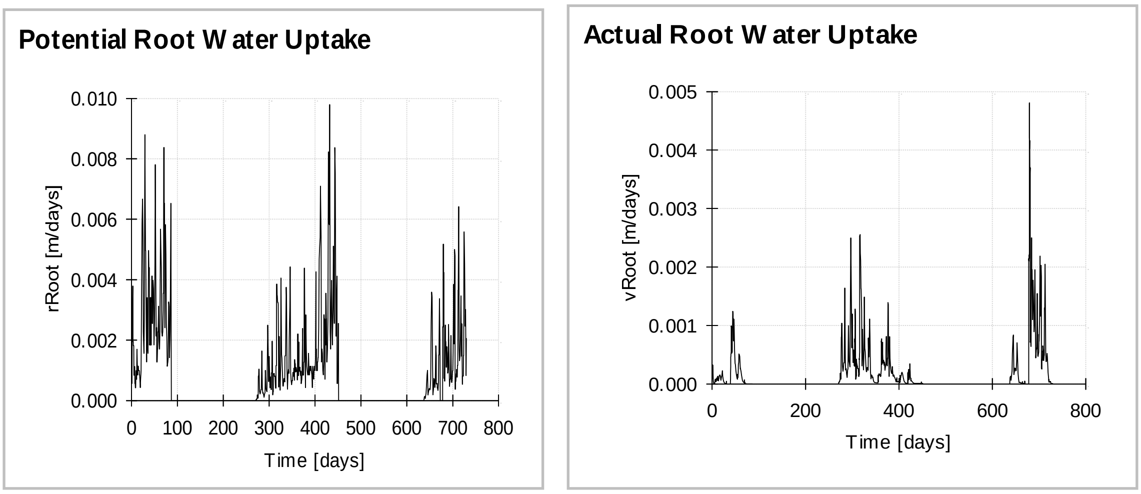
Simulations generated by the model indicated that the potential and actual root water uptake for Renosterveld is noticeably higher than for the wheatfield. The predicted potential root water uptake is more than the predicted actual root water uptake for both the wheat and Renosterveld. For the Renosterveld root water uptake deteriorates during summer months, which were expected as water resources became limited. The atmospheric evaporative demand (AED) is greater during the summer and therefore plant transpiration increases. It is also during this time period (November to March) that the renosterbos is in full bloom and the demand for water and nutrients is greater (Chapter 4).

To comply with the AED, it was suggested that the plant utilizes all of the stored winter water before it makes use of into the groundwater, which enables the plant to survive these dry summer months.

Mid winter 2009 was relatively dry and both wheat and Renosterveld endured a lot of water stress (Figure 5.07). As the root distribution of wheat is restricted to top soil layer (50cm) it, wheat may be subjected to a greater water stress when compared to the renosterbos. The renosterbos is buffered against dry spells because of its deep root penetration and physiological aspects (Chapter 4).

Late rainfall occurred during November 2009 (68mm), as wheat had already been harvested the model did not simulate water uptake for that period. For Renosterveld there was a sudden increase in root water uptake (day 447, Figure 5.10) and it stayed relatively high until January 2010, after which root water uptake decreased again until early May.

(a)



(b)

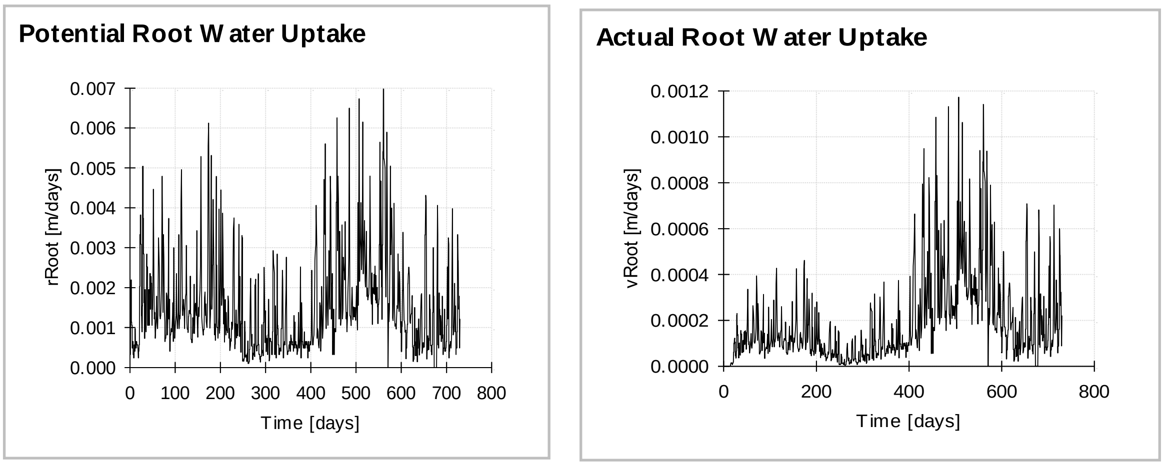


Figure 5.10 Predicted potential and actual root water uptake for (a) the wheatfield and (b) the Renosterveld for the period 17 August 2008 – 16 August 2010.

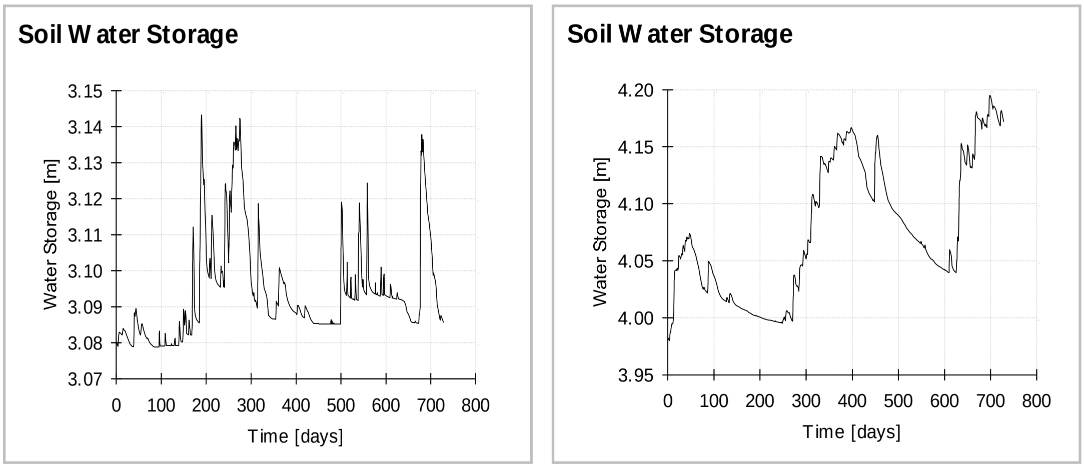
Predicted soil water content for the wheatfield and Renosterveld respectively are indicated in Figure 5.11. Soil water content of the Renosterveld is larger compared to the wheatfield. This may be attributed to the slightly higher clay content and more rapid water infiltration in the Renosterveld (Chapter 3).

Fluctuations in the soil water storage are influenced by the rate of water infiltration, total amount of rainfall, rainfall distribution, run-off and rate of soil evaporation and transpiration.

Soil water storage was higher for the Renosterveld in Desember 2009/January 2010 than for the wheatfield. This occurrence may be attributed to the late rainfall that occurred during November 2009 (day 55, Figure 5.11). During this period wheat had already been harvested and as therefore the rate of evaporation from the soil surface was much higher than the rate of infiltration. In the Renosterveld water infiltration was faster and water was immediately utilized by the roots near the soil surface (10cm – 40cm) of the renosterbos.

Rainfall events are clearly visible in the storage fluctuations, although the wheatfield reacts quicker to rainfall events, whereas in the Renosterveld water is immediately utilized by the renosterbos, before it can be stored in the soil.

HYDRUS predicted the total amount of water stored in the wheat and Renosterveld. This, however, is not the amount of plant available water (PAW). Only a percentage of the water stored is available to the plant. The rest of the water feeds into the water table, causing the water tables to rise. For the wheatfield the amount of seepage water is more than for the Renosterveld as indicated in Figure 5.11 (b). For the Renosterveld the amount of water stored at deeper soil depth is more than for the wheatfield, but surface evaporation in the Renosterveld is less. During the winter period (wheat growth period) the amount of water utilized by wheat is more than for the Renosterveld. We consequently predict that water resources are replenished by the groundwater table in the Renosterveld during the dry summer months to comply with the plants water demand.



(a) (b)

Figure 5.11 Predicted soil water storage for (a) the wheat field and (b) the Renosterveld for the time period 17 August 2008 – 16 August 2010.

5.3.5 Hydrological flow paths

From the combination of soil classification information, the knowledge of the change in soil densities as a result of the human impact and hydrological modelling, different water flow paths in the soils could be indicated. These are shown in Figure 5.12. From this indication it is also clear that similar soils may differ in their reaction related to land use. It is mainly the Glenrosa, Swartland and Klapmuts soil forms that will be affected. However, natural compaction of any of these forms also existed in the Renosterveld depending on the position in the landscape.

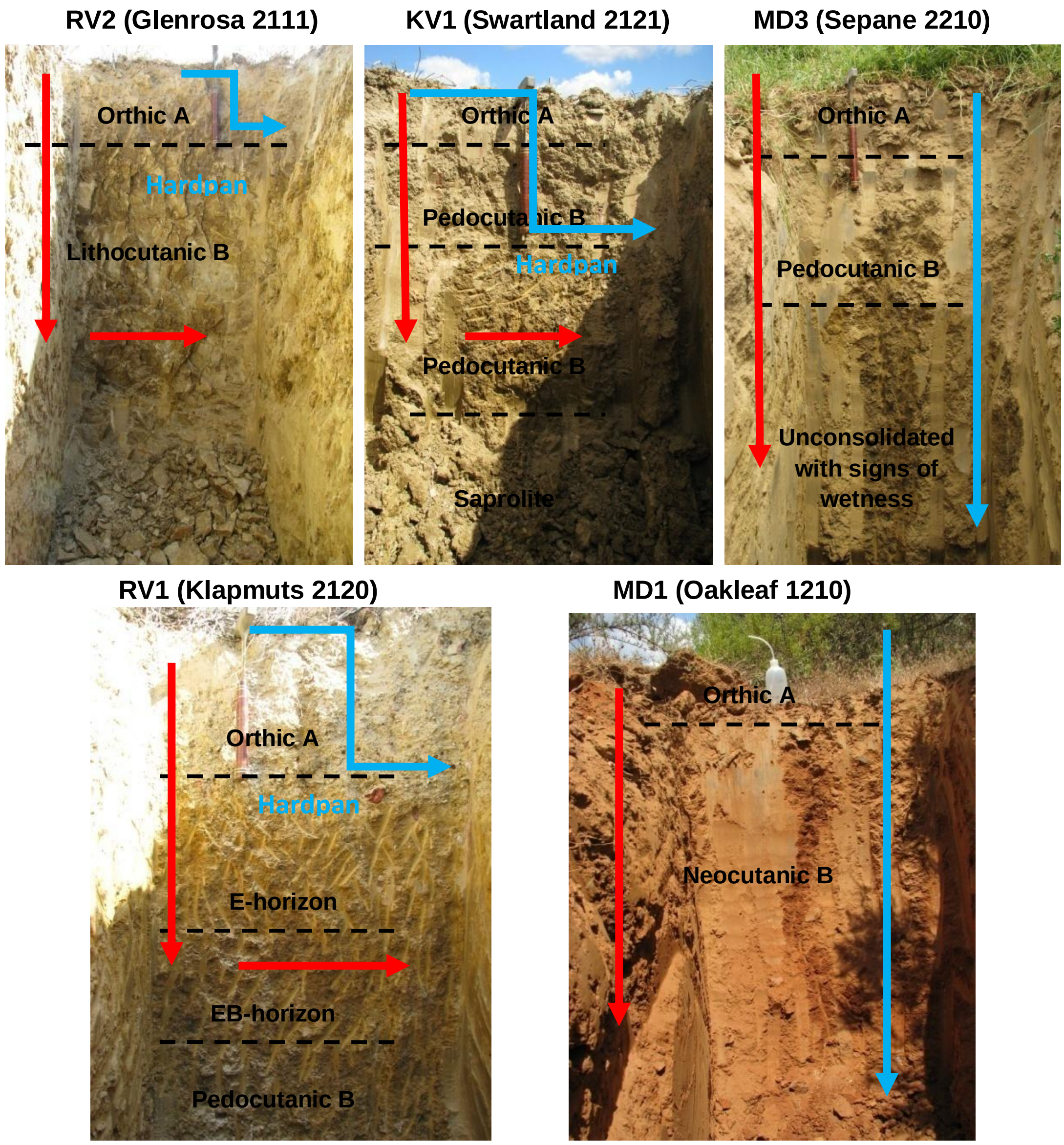


Figure 5.12 Photo illustrations of the dominant soil types in wheatfields (Blue) and Renosterveld (Red) with their hydrological flow paths as determined through Hydrus modelling.

5.4 Conclusion

This study clearly shows changes in soil moisture regimes between the wheatfield and the Renosterveld.

The shallow root distribution of wheat compared with the much deeper root penetration of the renosterbos, together with transpiration and borehole data, concludes that the change from Renosterveld to dryland wheat cropping, affected the soil water balance and led to the formation of perched soil water tables. Higher EC values were also observed for the borehole in the wheat field, suggesting that salts are mobilized by the rising groundwater table

From Chapter 4 we were able to establish that the leaves of the renosterbos are oval shaped and covered in fibrous hair that enables the plant to utilise water from the atmosphere such as dew-drops and limit water loss during dry summer months. It is important that plant physiological aspects needs to be taken into account when simulations are carried out as these aspects play an important role in transpiration and water utilisation.

The HYDRUS model was very useful in predicting soil water fluxes and root water uptake. In some instances the model underestimated the soil water content. It is important that the model be correctly parameterised and that all factors are taken into account. This may often prove to be a difficult task. In this study the amount of water intercepted by wheat and Renosterveld from the atmosphere during high relative humidity (dew), was neglected and this may need some further investigation. However, the measured number of nights dew occurred is above 60% for this region. The amount of actual precipitation is difficult to quantify.

When correctly parameterised the HYDRUS-1D model is relatively easy to use and is adaptable to most conditions. It can be used to predict water availability, drainage, run-off, soil water content and root water uptake. Growing support and credibility of the model has led it to become a tool that can accurately predict soil moisture fluxes. It is however, imperative that data used in the model be as accurate as possible, as models like these can only be as accurate as the input.

5.5 References

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CHAPTER 6. CONCLUSIONS AND RESEARCH RECOMMENDATIONS

6.1 Comments

Plant water relations of *Elytropappus Rhinocerotis* with specific reference to soil restrictions on growth were indicated in this study. Up to now researchers only looked at Renosterveld from a conservational point of view. They acknowledged that agricultural pressure is a major threat for the biodiversity associated with Renosterveld. The effect land-use change had on subsurface water fluctuations of the surrounding areas where transformation took place received more attention in recent research.

From this research and literature it was indicated that biodiversity is being threatened in the lowlands of South Africa, (Heydenrych and Littlewort, 1995). In the Western Cape, Renosterveld has shown the most significant decline of all the vegetation types (McDowell and Moll, 1992), with less than 5% being formally conserved and the remainder belonging to private landowners or restricted to precipitous hilltops where ploughing is impossible (O'Farrel *et al*., 2009). This research also indicated that fragments of natural vegetation stabilized soils and balanced hydrological processes in the soil, contributing to the ecological functionality of the region (O'Farrell, 2009; Hobbs, 1992). In South Africa, farmers perceived Renosterveld as native vegetation that provides soil stability and can act as a windbreak (O' Farrell, 2005), however soils on which Renosterveld occur was perceived as fertile and therefore large areas of Renosterveld has been removed for agricultural purposes, mainly wheat cultivation.

The IUCN recommended that 10% of Renosterveld be formally conserved (Midoko-Iponga, 2004; O'Farrel *et al*., 2009) to prevent its extinction and the biodiversity associated with it. To enable this, Renosterveld needs to be re-established on formerly cultivated lands, now left bare and degraded. This research contributed largely to the understanding of the viability of such claims. The significance of deep rooted vegetation and their contribution to the whole-ecosystem is still poorly understood. The survival of natural vegetation species in arid and semi-arid areas has been shown to depend on the plant's ability to tap into permanent water tables when water resources are in short supply. The removal of deep rooted natural vegetation resulted in rising water tables has and the translocation of salts stored in the sub-soils. This occurrence is similar to the Australian dryland salinity. Dryland salinity is affecting agriculture worldwide; some countries are more affected than others.

With alternative farming practices and planning, dryland salinity can be managed effectively. The restoration and management of Renosterveld or any other vegetation type would be costly at first

(Herling *et al*., 2009). We argue that if farm management do not realise the importance of rehabilitating degraded areas, dryland salinity could become a major threat to sustainable agriculture in non-irrigated areas such as the Swartland.

6.2 Conclusions

Once an area has been converted to a cropping system, various factors may influence the re-establishment of Renosterveld and needs to be taken into account when rehabilitation is considered. The root study conducted for this research concluded that the importance of the deep rooted plants for the Renosterveld is poorly understood. This study further highlighted the importance of soil limitations and human activities affecting deep root development.

The re-establishment of Renosterveld is vulnerable to soil limiting factors, soil types and human activity. The re-growth of renosterbos is poor in previously cultivated areas, especially in areas where the ridge and furrow system has previously been implemented. Research indicated that the re-growth of renosterbos tends to be denser in some areas than others and preferred the side of the ridge, where the B-horizon has been disturbed.

It is concluded that deep rooted native vegetation, such as the renosterbos, has the ability to utilize winter water, and additionally water from the water table below, therefore contributing to regulating water tables and the salt balance. The removal of this vegetation type could cause water tables to rise, thereby mobilizing salts that have been trapped in the underlying weathering zone (i.e. shale).

It was established that the renosterbos has an extraordinary capability of adapting itself to its surrounding environment. It may take a while for renosterbos to establish itself in an area, but after reaching maturity the plant is well adapted to its surrounding environmental conditions. The physiological abilities of the plant to adapt itself to withstand water loss through transpiration and evaporation, as well as making use of all available water resources have been highlighted in this study.

Intensive monitoring of soil water content for the wheatfield en Renosterveld showed remarkable differences in the water balance. Data collected throughout the study (e.g. root distribution, rooting depth, phenology, soil characteristics, transpiration etc.) was used in a hydrological model for simulation of the wheat and Renosterveld water use characteristics. Modelling proved to be quite useful in predicting soil water content and root water uptake, although care should be taken with parameterization of the model. Differences in soil water content between the wheat field and the Renosterveld were quite pronounced. Field data were compared to HYDRUS-1D predicted data (a one-dimensional water flux model). Field measured ECH2O sensor data compared well with the predictions of soil water content using the HYDRUS-1D model.

The overall importance of renosterbos can be highlighted as follows:

1. Regulating the water fluxes of the environment.
2. Give shelter to small animals.
3. Enhance the richness in biodiversity as shrubs and bulbs associated with the renosterbos will benefit.
4. Strips of renosterbos can impact positively on salinity problems within the region and overland flow.
5. The deep-rooted renosterbos is also associated with bringing much needed nutrients to the soil surface.
6. The greater water use efficiency of the renosterbos may impact positively on the saline seep that reaches the river, during summer months.

6.3 Research Recommendations

Little is known about the underground habits of our native natural vegetation (Scott and van Breda, 1937). Very little research has been done on the soil properties that may affect plant growth and ultimately the re-establishment of Renosterveld, further research is needed into the acclimatisation of the renosterbos in various climatic and soil conditions.

Further research is needed on the impact of land-use change on the soil water balance. It might be useful to look at other forms of land-use in areas where dryland salinity is problematic.

Predicted root-water uptake and soil water storage simulations were carried out for both the wheat field and the Renosterveld. The model was useful in predicting soil water fluxes and root water uptake. When correctly parameterised the model showed promising results. Once understood the model proved to be easy to use. It may be useful to investigate other hydrological models and compare various modelling techniques. For hydrological modelling to be effective, continuous data collection is of great importance. Modelling is dependent on active monitoring of water tables, soil water content, collecting weather data on continuous basis and keeping record of annual growth patterns and cropping systems.

A lot of information is available on cropping (e.g. wheat) systems in the Western Cape, but very little is available on our native vegetation types, in particular Renosterveld. Specie identification is still very vague and very little research has been done on the phenology of the renosterbos since the early work M.R. Levyns. For Renosterveld to regain its rightful place in the CFK, effort is needed in understanding the renosterbos as a unit, as it is the heart of the Renosterveld.

The fight should turn to developing new and cost efficient salinity management options for farmers that is effective over the long term. Ways to manage the restoration and re-establishment of Renosterveld effectively, as a tool to manage dryland salinity within the farming community should be investigated.

Renosterveld has once been an extremely common vegetation type and therefore it was poorly represented in herbaria (Levyns, 1926). Today its conservation is deemed critical as researchers have found no proof that this vegetation exists anywhere else.

Renosterveld's survival is critical for the conservation of various bulb species that occur between the renosterbos and as well as the extinction of certain tortoise species who is said to occur only in Renosterveld.

From a soil scientific viewpoint its conservation holds great advantages in for both water and salt restriction in management practices.

We need to understand the importance of preserving natural vegetation where pertinent and encouraging the re-establishment of this native vegetation type in areas where it is most needed can create a win-win situation for farming and biodiversity. The farming community need to realise the important role natural vegetation play in the ecosystem and in sustaining biodiversity.

6.4 References

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Appendices

Appendix 1: Geological Map Legend

Geological Code	Descriptions
As	Alluvium
Asg	Gravelly clay/loam soil
br	Silicified breccia
Cg	Hybrid granodiorite
Cm	Conglomerate, grit and sandstone; often reddish brown
Lagoon	Marsh
My	Mylonite
Nb	Schist and fine-grained greywacke with beds and lenses of quartz schist and limestone
Nbr	Greenstone with dolomite and chert lenses
Nf	Grey, feldspathic conglomerate, grit and sandstone with minor shale
Nk	Quartz schist with phyllite beds and minor limestone and chlorite-schist lenses
Nm	Greywacke and phyllite with beds and lenses of quartzite schist, limestone and grit; quartz-sericite schist with occasional limestone lenses
Nm(l)	Greywacke and phyllite with beds and lenses of quartzite schist, limestone and grit; quartz-sericite schist with occasional limestone lenses
Nn	Phyllite, medium-grained to gritty greywacke, feldspathic and sericitic quartzite, limestone, dolomite, and feldspathic and calcareous grit
Npo	Phyllite shale, schist and greywacke with dark-grey limestone, sporadic quartzitic sandstone beds and conglomerate beds
Ny	Diorite and gabbro
Og	Thinly bedded sandstone, silstone and mudstone, mainly reddish
Op	Grey to reddish quartzitic sandstone with minor grit, conglomerate and reddish shale lenses
Opa	Grey-blue, massively bedded diamicite with erratics
Ope	Planar-bedded, light-grey, coarse-grained quartzitic sandstone with occasional thin layers of vein quartz pebbles
O-Sc	Shale, arenaceous shale, tillite, grit and conglomerate
QB1	Consolidated to unconsolidated sand and gravel with marine shells
QB1	Consolidated to unconsolidated sand and gravel with marine shells

Qg	Loam and sandy loam
Qgg	Gravelly clay/loam soil
QP	Aluminium phosphate on quartz porphyry
QP1	Consolidated to unconsolidated phosphatic sand, clay and shelly gravel
Qq	Silcrete/Ferricrete
Qq/Qf	Silcrete/Ferricrete
Qs	Light-grey to pale-red sandy soil
Qv	Vein-quartz
Qw	Dune sand, in places highly calcareous
Sg	Light coloured, medium-grained quartzitic sandstones, with thin micaceous siltstone beds interbedded
Ss	Thick bedded, coarse-grained, light-grey quartzitic sandstone

Appendix 2: Soil Data

Appendix 2.1: Exchangeable Cation Analyses

	Depth	Ca	Mg	K	Na	ECEC	ECaP	EMgP	ESP	Ca:Mg
			cmolc/kg				%	%	%	
KV Swartland	10cm	5.09	1.55	0.20	0.52	7.36	69.23	21.03	7.03	3.29
KV Swartland	30cm	10.67	9.35	0.82	0.36	21.19	50.35	44.12	1.68	1.14
KV Swartland	60cm	7.55	9.93	0.77	0.43	18.67	40.43	53.16	2.28	0.76
KV Swartland	90cm	6.49	5.07	0.37	0.36	12.28	52.81	41.27	2.94	1.28
RV Klapmuts	20cm(1)	1.40	1.38	0.25	0.25	3.28	42.74	42.14	7.56	1.01
RV Klapmuts	20cm(2)	1.10	1.09	0.24	0.23	2.67	41.15	41.03	8.80	1.00
RV Klapmuts	60cm	3.28	7.74	0.79	0.33	12.15	26.99	63.77	2.76	0.42
RV Klapmuts	90cm	3.98	9.50	1.40	0.34	15.22	26.16	62.39	2.23	0.42
RV Glenrosa	30cm(1)	3.00	6.94	0.99	0.34	11.27	26.61	61.57	3.01	0.43
RV Glenrosa	30cm(2)	2.73	6.35	0.82	0.34	10.24	26.71	61.97	3.36	0.43
RV Glenrosa	60cm	2.78	8.00	1.61	0.33	12.72	21.89	62.90	2.56	0.35
RV Glenrosa	90cm	7.58	8.50	1.81	0.28	18.17	41.73	46.80	1.53	0.89
MD Oakleaf	15cm	0.98	0.47	0.18	0.33	1.96	50.11	23.91	16.85	2.10
MD Oakleaf	30cm	1.79	1.26	0.19	0.27	3.52	50.94	35.81	7.79	1.42
MD Oakleaf	60cm	1.09	1.75	0.24	0.29	3.37	32.28	52.02	8.65	0.62
MD Oakleaf	100cm	0.95	2.36	0.38	0.41	4.11	23.21	57.52	10.06	0.40
MD Sepane	30cm	2.92	0.41	0.16	0.30	3.79	77.15	10.86	7.80	7.11
MD Sepane	60cm	3.24	1.81	0.22	0.23	5.50	58.94	32.90	4.11	1.79

Appendix 2.2

Profile nr: RV1

Lat + Long: 33° 23' 40.6'' / 19° 1' 15.5''

Altitude:

Terrain Unit: Midslope

Slope: 1 %

Aspect: Straight

Wetness Class:

Transitional Form:

Soil form and family: Klapmuts Bossieveld (2120)

WRB:

Soil Map Unit:

Vegetation / Land use: Fynbos (Renosterveld)

Parent Material:

Underlying Material: Malmesbury Shale formation

Geological Group / Formation:

Horizon	Depth (mm)	Description	Diagnostic horizon
A	0-200	Dry; dry colour: very pale brown 10YR7/4; moist colour: yellowish brown 10YR5/6; structure: moderate medium subangular blocky; consistence: loose, friable; few gravel 2-6mm; bleached surface crust; few roots; clear transition.	Orthic
E	200-400	Dry; dry colour: brownish yellow 10YR6/8; moist colour: yellowish brown 10YR5/8; structure: moderate medium subangular blocky; consistence: hard, firm; common gravel 2-6mm; few roots; clear transition.	E-horizon
EB	400-500	Dry; dry colour: yellowish brown 10YR5/6; moist colour: yellowish brown 10YR5/8; common medium prominent black manganese, magnetite mottles; structure: moderate coarse subangular blocky; consistence: hard, firm; common clay cutans; common gravel 2-6mm; few roots; clear transition.	Pedocutanic
B	500-1200	Dry; dry colour: yellowish brown 10YR5/6; moist colour: yellowish brown 10YR5/8; many medium prominent black manganese, magnetite mottles; structure: moderate coarse subangular blocky; consistence: hard, very firm; common clay cutans; common gravel 2-6mm; few roots; clear transition.	Pedocutanic

Profile nr: RV2

Lat + Long: 33° 23' 40.4" / 19° 1' 14.8"

Soil form and family: Glenrosa Overberg (2111)

Altitude:

WRB:

Terrain Unit: Midslope

Soil Map Unit:

Slope: 1 %

Vegetation / Land use: Fynbos (Renosterveld)

Aspect: Straight

Parent Material:

Wetness Class:

Underlying Material: Malmesbury Shale formation

Transitional Form:

Geological Group / Formation:

Horizon	**Depth (mm)**	**Description**	**Diagnostic horizon**
A	0-200	Dry; dry colour: very pale brown 10YR7/4; moist colour: yellowish brown 10YR5/6; structure: moderate subangular blocky; consistence: loose, slightly firm; sandy clay loam; few gravel 2-6mm; common roots; clear wavy transition.	Orthic
B	200-900+	Dry; dry colour: yellowish brown 10YR5/4; moist colour: dark yellowish brown 10YR4/4; structure: medium subangular blocky; consistence: very hard, firm; clay loam; common gravel 2-6mm; few roots; gradual transition.	Lithocutanic

Profile nr: MD1

Lat + Long: 33° 0' 0'' / 18° 0' 0''	**Soil form and family:** Oakleaf Caledon (1210)
Altitude:	**WRB:**
Terrain Unit: Midslope	**Soil Map Unit:**
Slope: 32 %	**Vegetation / Land use:** Fynbos (Mountain Renosterveld)
Aspect:	**Parent Material:** Granite
Wetness Class:	**Underlying Material:** Granite
Transitional Form:	**Geological Group / Formation:**

Horizon	**Depth (mm)**	**Description**	**Diagnostic horizon**
A	0-300	Dry; dry colour: reddish yellow 5YR6/6; moist colour: yellowish red 5YR4/6; structure: weak; consistence: loose, slightly firm; fine sandy laom; few angular fine gravel; gradual smooth transition; common roots.	Orthic
B	300-1200	Dry; dry colour: yellowish red 5YR5/6; moist colour: yellowish red 5YR4/6; structure: weak; consistence: slightly hard, slightly firm; sandy clay; few angular fine gravel ; gradual transition; few roots.	Neocutanic

Profile nr: MD2

Lat + Long: 33° 0' 0'' / 18° 0' 0''

Altitude:

Terrain Unit: Lower Midslope

Slope: 20 %

Aspect:

Wetness Class:

Transitional Form:

Soil form and family: Oakleaf Caledon (1210)

WRB:

Soil Map Unit:

Vegetation / Land use: Fynbos (Mountain Renosterveld)

Parent Material: Granite

Underlying Material: Granite

Geological Group / Formation:

Horizon	Depth (mm)	Description	Diagnostic horizon
A	0-300	Dry; dry colour: yellowish-red 5YR5/6; moist colour: reddish brown 5YR4/4; structure: weak; consistence: loose, friable; fine sandy loam; very few gravel 2-6mm; gradual transition; common roots.	Orthic
B	300-1200	Dry; dry colour: yellowish red 5YR5/8; moist colour: yellowish red 5YR4/6; structure: weak; consistence: slightly hard, firm; sandy clay; few angular fine gravel; gradual wavy transition; few roots.	Neocutanic

Profile nr: MD3

Lat + Long: 33° 0' 0'' / 18° 0' 0''

Altitude:

Terrain Unit: Footslope

Slope: 10%

Aspect:

Wetness Class:

Transitional Form:

Soil form and family: Sepane Crondale (2210)

WRB:

Soil Map Unit:

Vegetation / Land use: Fynbos (Mountain Renosterveld)

Parent Material:

Underlying Material:

Geological Group / Formation:

Horizon	**Depth (mm)**	**Description**	**Diagnostic horizon**
A	0-300	Dry; dry colour: light yellowish brown 10YR6/4; moist colour: brown to dark brown 10YR4/3; structure: subangular blocky; common gravel 2-6mm; clear smooth transition.	Orthic
B	300-600	Dry; dry colour: light yellowish brown 10YR6/4; moist colour: dark yellowish brown 10YR4/4; sandy clay loam; structure: subangular blocky; very firm; few gravel 2-6mm; diffuse transition.	Pedocutanic
C	600-900	Moist; moist yellowish-brown 10YR 5/4; sandy clay loam; structure: subangular blocky; diffuse transition.	Unconsolidated material, with signs of wetness

Profile nr: KV1

Lat + Long: 33° 23' 40'' / 19° 1' 12.3''

Altitude:

Terrain Unit: Midslope

Slope: 1 %

Aspect: Level

Wetness Class:

Transitional Form:

Soil form and family: Swartland Riebeeck (2121)

WRB:

Soil Map Unit:

Vegetation / Land use: Wheatfield

Parent Material:

Underlying Material: Malmesbury Shale formation

Geological Group / Formation:

Horizon	Depth (mm)	Description	Diagnostic horizon
A	0-300	Dry; dry colour: dark yellowish brown 10YR4/6; moist colour: dark yellowish brown 10YR4/4; consistence: loose, friable, sticky; bleached pores; common gravel 2-6mm; bleached surface crust; gradual transition.	Orthic
B	300-600	Dry; dry colour: very pale brown 10YR7/4; moist colour: dark yellowish brown 10YR4/4; structure: moderate subangular blocky; consistence: slightly hard, firm, sticky; few gravel 2-6mm; gradual transition.	Pedocutanic
C	600-700	Dry; dry colour: very pale brown 10YR7/4; moist colour: dark yellowish brown 10YR4/4; consistence: hard, firm; common clay cutans; few gravel 2-6mm; gradual transition.	Pedocutanic
R	700-1200	Dry; dry colour: reddish brown 2.5YR5/4; moist colour: red 2.5YR5/6; consistence: very hard; clear transition.	Hard Rock

Profile nr: KV2

Lat + Long: 33° 23' 41.3'' / 19° 1' 13.8''

Altitude: 1487 m

Terrain Unit: Midslope

Slope: 1 %

Aspect: Level

Wetness Class:

Transitional Form:

Soil form and family: Glenrosa Overberg (2111)

WRB:

Soil Map Unit:

Vegetation / Land use: Wheatfield

Parent Material:

Underlying Material: Malmesbury shale formation

Geological Group / Formation:

Horizon	Depth (mm)	Description	Diagnostic horizon
A	0-100	Dry; dry colour: very pale brown 10YR7/4; moist colour: yellowish brown 10YR5/6; consistence: hard, slightly firm; sandy clay loam; fine cracks; common gravel 2-6mm; bleached surface crust; clear wavy transition.	Orthic
B	100-900+	Dry; dry colour: yellowish brown 10YR5/4; moist colour: dark yellowish brown 10YR4/4; consistence: very hard, firm, slightly sticky; fine cracks; clay loam; gradual transition.	Lithocutanic

Appendix 2.3: Particle size analysis

Sample	Depth	Soil Profile	Bulkdensity	Very Coarse Sand (%)	Coarse Sand(%)	Medium Sand(%)	Fine Sand(%)	Very Fine Sand(%)	Coarse Silt (%)	Fine Silt (%)	Clay (%)
			(g.cm^{-3})	2.0mm-0.05mm					0.05-0.002mm		>0.002mm
KV1	0-10	Swartland	1.53	9.75	7.34	9.22	10.73	6.07	12.53	29.30	15.02
KV1	30	Swartland	1.54	16.11	10.72	8.95	6.04	2.66	12.84	26.72	15.92
KV1	60	Swartland	1.56	3.94	2.22	2.42	2.22	3.67	16.81	34.00	34.56
KV1	90	Swartland	1.58	5.35	4.87	5.33	6.87	5.85	8.26	23.04	40.13
RV2 (1)	20	Klapmuts	1.56	14.55	8.89	8.31	9.75	2.60	7.41	22.89	25.55
RV2 (2)	20	Klapmuts	1.58	16.84	9.36	8.67	9.13	6.61	5.17	17.01	27.08
RV2	60	Klapmuts	1.63	3.48	2.28	3.14	3.78	1.90	12.30	41.59	31.42
RV2	90	Klapmuts	1.70	4.64	2.41	3.58	3.97	1.20	10.19	41.45	32.25
RV1 (1)	30	Glenrosa	1.54	6.34	4.52	4.28	3.10	1.77	7.64	46.94	24.99
RV1 (2)	30	Glenrosa	1.52	5.35	7.66	5.45	3.91	2.95	6.88	43.83	23.28
RV1	60	Glenrosa	1.59	11.67	9.29	6.34	5.63	2.97	11.16	35.51	16.28
RV1	90	Glenrosa	1.67	7.95	5.72	6.35	6.33	4.09	14.74	35.14	18.73
MD1	0-15	Oakleaf	1.52	6.51	7.97	8.22	20.86	9.09	13.85	15.08	17.25
MD1	30	Oakleaf	1.57	7.44	9.08	8.89	17.47	9.60	11.04	15.11	19.76
MD1	60	Oakleaf	1.59	5.18	6.95	8.99	18.03	11.47	7.84	19.75	21.72
MD1	100	Oakleaf	1.61	6.31	7.29	8.91	17.24	9.11	9.35	16.56	25.10
MD3	30	Sepane	1.54	6.93	6.52	9.32	20.66	18.20	12.21	9.37	15.66
MD3	60	Sepane	1.58	3.29	4.62	7.32	18.18	16.68	14.62	16.90	18.37

Appendix 3: Chemical Analysis for borehole water samples

Appendix 3.1: Renosterveld borehole water sample analysis.

Date	Depth	pH	EC	F	Cl	NO3	SO4	Ca	Mg	Na	K	Ca	Mg	Na	K	F	Cl	NO3	SO4	Cations	Anions	SAR
	(m)		(mS/m)	(mg/l)								(mmol/dm^3)								(sum)		
2010/02/17	15.6	7.4	107.0	0.6	236.0		37.8	9.7	18.1	153.9	3.2	0.5	1.5	6.7	0.1	0.0	6.6	0.0	0.8	8.8	7.5	6.0
2010/03/10	15.4		108.5																			
2010/03/17	15.5		110.5																			
2010/03/25	15.1	7.3	110.0	0.5	225.0	0.0	37.0	9.0	16.0	152.3	2.5	0.5	1.3	6.6	0.1	0.0	6.3	0.0	0.8	8.5	7.1	6.3
2010/03/31	15.4		114.2																			
2010/04/06	15.1		111.4																			
2010/04/13	15.1	7.3	104.0	0.6	174.4	0.0	28.5	10.4	21.8	153.3	1.5	0.5	1.8	6.7	0.0	0.0	4.9	0.0	0.6	9.0	5.5	5.6
2010/04/20	15.2		107.6																			
2010/04/29	15.2		110.3																			
2010/05/04	14.9	7.0	105.0	0.4	175.5	0.0	28.4	10.3	22.2	152.8	2.4	0.5	1.9	6.6	0.1	0.0	4.9	0.0	0.6	9.1	5.6	5.5
2010/05/12	15.2		115.0																			
2010/05/19	14.2		108.7																			
2010/05/27	15.0	7.5	106.0	1.8	348.0	8.0	109.0	14.5	28.6	181.0	2.0	0.7	2.4	7.9	0.1	0.1	9.8	0.1	2.3	11.0	12.3	5.7
2010/06/01	14.5		111.1																			
2010/06/10	15.2		105.4																			
2010/06/17	15.2	7.0	104.0	0.2	244.0	0.0	36.0	10.0	23.0	150.0	4.0	0.5	1.9	6.5	0.1	0.0	6.9	0.0	0.8	9.0	7.6	5.4
2010/06/23	15.3		106.2																			
2010/07/05	15.1		102.8																			
2010/07/20	15.3	6.5	93.0	0.6	212.0	0.0	30.0	9.0	24.0	144.0	3.0	0.5	2.0	6.3	0.1	0.0	6.0	0.0	0.6	8.8	6.6	5.2

Appendix 3.2: Wheatfield borehole water sample analysis.

Date	Depth	pH	EC	F	Cl	NO3	SO4	Ca	Mg	Na	K	Ca	Mg	Na	K	F	Cl	NO3	SO4	Cations	Anions	SAR
	(m)		(mS/m)	(mg/l)								($mmol/dm^3$)								(sum)		
2010/02/17	7.6	7.5	147.0	0.7	340.8	10.3	108.7	12.0	22.0	244.0	4.5	0.6	1.8	10.6	0.1	0.0	9.6	0.2	2.3	13.1	12.1	8.6
2010/03/10	8.2		155.2																			
2010/03/17	8.8		158.4																			
2010/03/25	8.1	7.3	156.0	0.6	321.0	7.0	100.0	11.9	18.1	236.0	1.9	0.6	1.5	10.3	0.0	0.0	9.0	0.1	2.1	12.4	11.3	8.8
2010/03/31	8.1		161.2																			
2010/04/06	8.9		158.4																			
2010/04/13	8.3	7.3	148.0	0.6	244.6	6.1	79.4	13.5	24.9	230.7	1.4	0.7	2.1	10.0	0.0	0.0	6.9	0.1	1.7	12.8	8.7	7.7
2010/04/20	6.9		150.6																			
2010/04/29	7.4		156.8																			
2010/05/04	7.4	7.0	148.0	0.6	245.6	5.1	79.9	13.5	24.4	228.0	1.9	0.7	2.0	9.9	0.0	0.0	6.9	0.1	1.7	12.7	8.7	7.6
2010/05/12	7.8		161.6																			
2010/05/19	7.0		153.7																			
2010/05/27	6.7	8.4	144.0	1.2	297.0	5.0	46.0	9.3	25.5	145.0	3.0	0.5	2.1	6.3	0.1	0.1	8.4	0.1	1.0	9.0	9.5	5.1
2010/06/01	6.3		149.5																			
2010/06/10	6.4		135.0																			
2010/06/17	5.9	7.7	140.0	1.1	322.0	6.0	111.0	14.0	28.0	207.0	3.0	0.7	2.3	9.0	0.1	0.1	9.1	0.1	2.3	12.1	11.5	6.6
2010/06/23	4.1		138.8																			
2010/07/05	5.5		137.6																			
2010/07/20	5.2	7.4	135.0	0.8	280.0	8.0	95.0	13.0	30.0	201.0	3.0	0.7	2.5	8.7	0.1	0.0	7.9	0.1	2.0	12.0	10.0	6.3

Appendix 4: Hydrological modelling

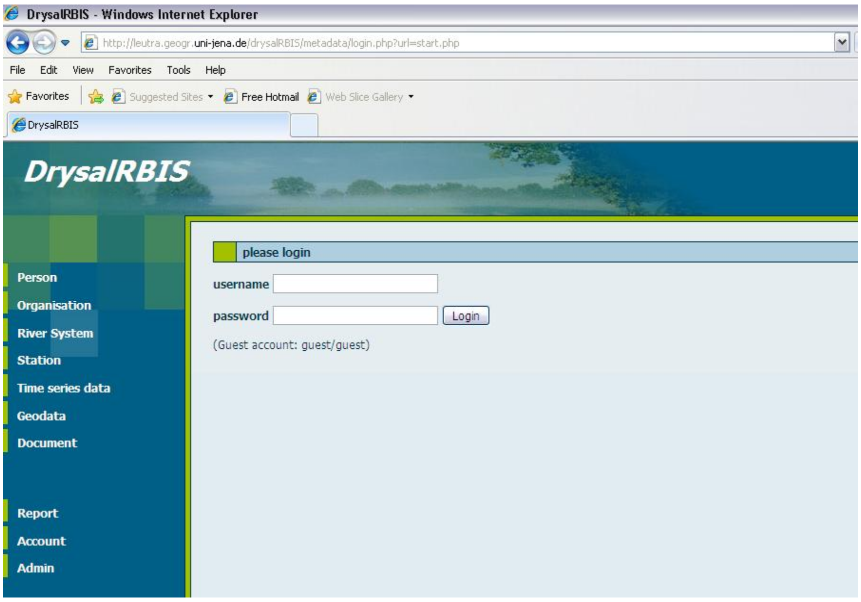
Appendix 4.1: DrysalRBIS

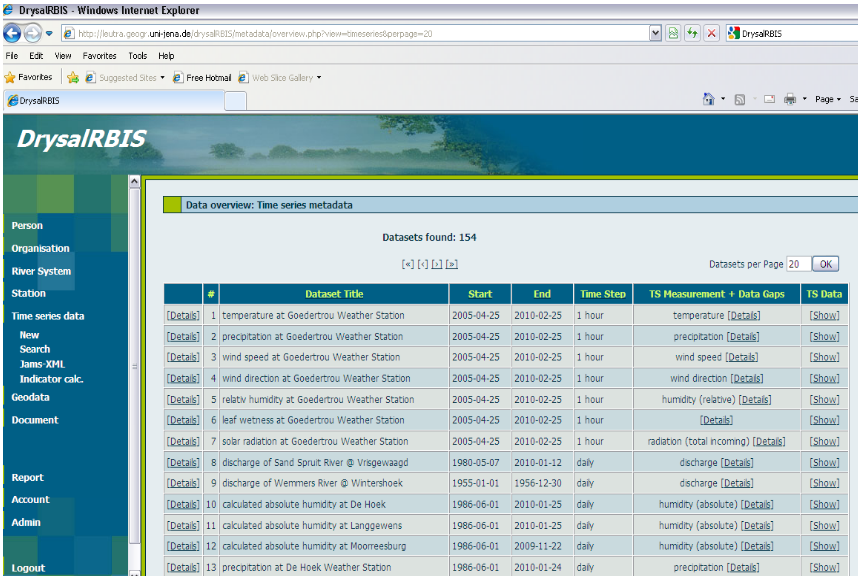
In 2005, the *Soil Science Department at Stellenbosch University* (South Africa) and the *Department of Geoinformatics at Friedrich Schiller University Jena* (Germany) initiated the collaborative research project DRYSAL to improve our understanding of regional dryland salinity DLS dynamics, salt sources and salt storages, as well as corresponding groundwater salinity dynamics and regional hydrology in intensively used agricultural areas of the Western Cape Province. This study region is characterized by a semi-arid winter rainfall climate with a meanannual rainfall of about 350 mm. The geology is dominated by table mountain sandstone forming the mountain ridge of the Langeberge, and deeply weathered Precambrian Malmesbury shale and other deep sea sediments in the foothill zone west of the mountain ridge.

The central aim of the first phase of DRYSAL (2005-2008, SUA 05/001) was to develop a thorough understanding of salinization dynamics based on the quantitative and qualitative measurement, modelling, and assessment of salt and water fluxes in small to medium-sized catchments representing the semi-arid conditions in the Berg River basin (Sandspruit basin: 151 km², Goedertrou experimental site: 0,3 km². Combining data from field studies in 1985 and 1986 complemented by data from chemical analysis of current boreholes and water quality measurements, it was found that the amount of salt transported from the catchment is significantly higher than the salt input by atmospheric deposition which is assumed to be the primary source of salts stored in the landscape. Borehole results indicated that enormous salt masses are still stored in the catchments which might be mobilised by altered land use practises or climate conditions. First model exercises showed that land management features like contour banks strongly affect hydrological fluxes and need to be considered in advanced process-oriented modelling. Also, the web-based data and information system *DrysalRBIS* was implemented during the first phase allowing all project partners and stakeholders the access, upload and processing of existing and actual geospatial data, hydro-meteorological data and information about water quality and salinity. (Helmschrot and Flügel, 2009).

References:

HELMSCHROT, J. and FLüGEl, W.A. 2009. Collaboration Research Project: Assessment of dryland salinity dynamics in the Western Cape Province, South Africa (DRYSAL). Link: http://leutra.geogr.uni-jena.de/drysalRBIS/metadata/login.php?url=start.php

(a)


(b)


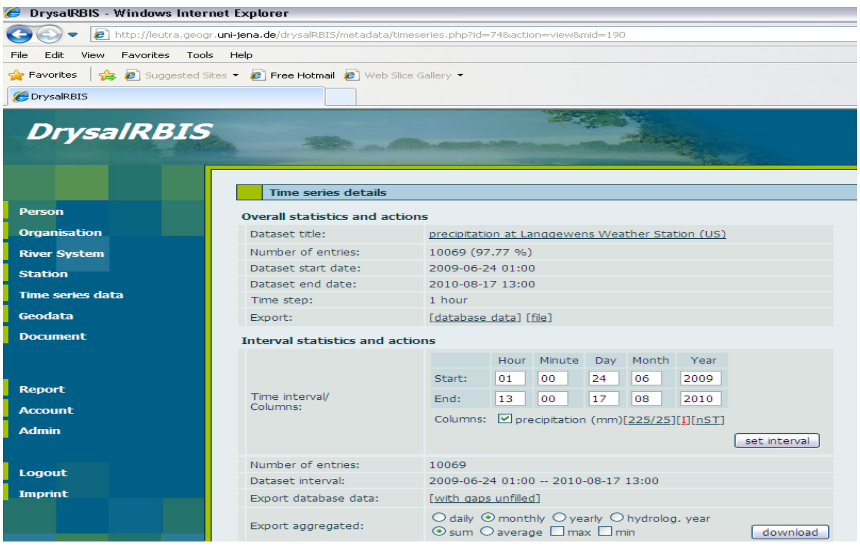
(c)


Figure 4.1 a, b and c: Images indicating the various steps followed in the DrysalRBIS program.

Appendix 5: Calculations of Soil Properties

Effective CEC:

ECEC = Ca_{ex}+Mg_{ex}+K_{ex}+Mg_{ex}+Titrateable acidity

Exchangeable Cations:

$Cation_{ex}$ = $Cation_{NH4OAc}$ – $Cation_{sat\ paste}$ (cmolc/kg)