A SOILSCAPE SURVEY TO EVALUATE LAND FOR IN-FIELD RAINWATER HARVESTING IN THE FREE STATE PROVINCE, SOUTH AFRICA

by

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A dissertation submitted in accordance with the requirements for the Magister Scientiae Agriculturae degree in the Faculty of Natural and Agricultural Sciences, Department of Soil, Crop and Climate Sciences at the University of the Free State, Bloemfontein, South Africa.

September 2004

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Co-supervisor: Dr. M. Hensley

DECLARATION

I declare that the thesis hereby submitted by me for the Masters of Science in Soil Science degree at the University of the Free State is my own independent work and has not previously been submitted by me to another University / Faculty. I further cede copyright of the thesis in favour of the University of the Free State.

Semere Alazar

Signature ……………………………..

Date: September, 2004

Place: Bloemfontein, South Africa

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ABSTRACT

A SOILSCAPES SURVEY TO EVALUATE LAND FOR IN-FIELD RAINWATER HARVESTING IN THE FREE STATE PROVINCE, SOUTH AFRICA

Land evaluation is currently important in South Africa. Soilscape surveys can make a contribution in this connection by bridging the gap between land type surveys and detail surveys. Land Type Dc17 (area = 237 651 ha) east of Bloemfontein include the densely populated areas near Botshabelo and Thaba Nchu. The objective of this study was to subdivide Land Type Dc17 into smaller more homogeneous land units, to estimate the area of each unit suitable for maize and sunflower production using the In-field Rainwater Harvesting technique (IRWH), and to estimate attainable yields of these crops on the available areas. The soilscape survey technique was developed to serve this goal.

Soilscape is defined for this specific study as a mapping unit consisting of a portion of land mappable at a scale of 1:50 000 in such a way that it facilitates the identification of potentially arable land. Earlier Northcote (1978) described soil landscapes as areas of land that have recognizable and specifiable topographies and soils, that are capable of presentation on maps, and can be described by concise statements

The delineation of 66 soilscapes was done on 1:50 000 maps. Detailed pedological investigations were made on selected pedosequences of some soilscapes using 1:10 000 maps, soil pits, auger holes and depth probe observations. Nine soilscapes with a total area of 82 222 ha were found non-arable. For the remaining 57 soilscapes, covering an area of 155 429 ha, the improved knowledge gained during the detail studies was extrapolated to estimate the area of each one suitable for IRWH. The result was 56 875 ha, or 24 % of the total area of Dc17. The results of previous field experiments on relevant ecotopes predict the following maize yields in tons/ha/yr: conventional tillage = 82 000; simplest type of IRWH = 127 000. It is therefore estimated that this land type can provide the staple maize diet for about 600 000 people using IRWH.

The soilscape survey technique proved successful within this land type, but should be refined for application to other land types and other feasibility studies.

OPSOMMING

‘n *SOILSCAPE-OPNAME OM DIE LANDGESKIKTHEID VIR AFLOOPOPGARING IN DIE VRYSTAAT PROVINSIE, SUID-AFRIKA, TE BEPAAL*

Landevaluering is huidiglik belangrik in Suid-Afrika. *Soilscape* opnames kan ‘n bydrae maak in hierdie verband. Dit kan die gaping tussen landtipe- en detailopnames oorbrugLandtipe Dc17 (oppervlakte = 237 651 ha) oos van Bloemfontein sluit die digbewoonde gebiede van Botshabelo en Thaba Nchu in. Die doel van hierdie ondersoek was om Dc17 in meer homogene eenhede te onderverdeel, die oppervlakte geskik vir die produksie van mielie en sonneblom met die Afloopopgaringtegniek (AO) vir elke eenheid te raam, beraming van die moontlike obrengste van hierdie gewasse op die geskikte grond. Die *soilscape* opname tegniek is hiervoor ontwikkel.

Die afbakening van die 66 *soilscapes* is uitgevoer op 1:50 000 kaarte. Detail pedologiese ondersoeke is gemaak op geselekteerde toporeekse van sekere *soilscapes*. Daarvoor is 1:10 000 kaarte, toetsgate, boorgate en diepte metings as waarnemings gebruik. Nege *soilscapes*, met ‘n totale oppervlak van 82 222 ha, ongeskik vir bewerking, is geïdentifiseer. Op die oorblywende 57 *soilscapes*, met ‘n oppervlak van 155 429 ha is die verbeterde kennis, wat opgedoen is gedurende die detail studies, is ge-ekstrapoleer om die geskikte oppervlakte van die oorblywende *soilscapes*, vir AO te raam. Die resultaat was 56 875 ha, of 24 % van die totale oppervlakte van Dc17. Die resultate van vorige veldproewe op soortgelyke ekotope voorspel die volgende mielie-opbrengste (ton/ha/j): konvensionele bewerking = 82 000; eenvoudigste soort AO = 127 000 Daar word geraam dat hierdie landtipe stapelvoedsel aan 600 000 kan voorsien indien AO toegepas word.

Die *soilscape*-opnametegniek is suksesvol toegepas in hierdie landtipe, maar dit moet verfyn word vir toepassing in ander landtipes en ander uitvoerbaarheidstudies.

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AB	Abramskraal locality augered observation
AI	Aridity index (rainfall/evaporation)
a.m.s.l.	Above mean sea level
ARC	Agricultural Research Council
ARC-ISCW	Agricultural Research Council – Institute for Soil, Climate and Water
b	Basin cultivated
B	Bare field
BfII	Bultfontein2 locality augered observation
BfIII	Bultfontein3 locality augered observation
CC	Concave-Concave slope shape
CEC	Cation exchange capacity
Cl	Clay content
CL	Concave-Linear slope shape
co	Coarse (particle size fraction)
CON	Control field
CPF	Cumulative probability function
CV	Concave-Convex slope shape
Cv	Coefficient of variation
D	Deep drainage
ERD	Effective rooting depth
ET	Evapotranspiration
FC	Field capacity
fi	Fine (particle size fraction)
G	Gladstone locality pit observation
g	Gladstone locality augered observation
H	Honeyton locality
IRWH	In-field rain water harvesting
K	Kleinhoek locality
LC	Linear-Concave slope shape
LCC	Land capability classification
LL	Linear – Linear slope shape
Lm	Loam
LQ	Land quality
l/s	Litres per second
LV	Linear-Convex slope shape
MAP	Mean annual precipitation
MAR	Mean annual rainfall
me	Medium (particle size fraction)
MERD	Measured effective rooting depth
mg/l	Milligram per litre
MM	Maria Moroka locality pit observation
O	Organic mulch
OFS	Orange Free State
ot	Orthic A horizon
P	Papfontein locality
PAW	Plant available water
PDP	Pedon description program
R	Runoff
r	Runoff field
r^2	Coefficient of determination
re	Red apedal B horizon
Rf	Rooifontein locality augered observation
RSA	Republic of South Africa

S value	Sum of exchangeable Na, K, Mg, and Ca ions
s	Slypskip locality
S	Straw mulch
Sa	Sand fraction
SACU	Southern Africa Customs Union
Si	Silt content
SMS	Soil moisture storage
SPAC	Soil-plant-atmosphere continuum
Sr	Seroala locality augered observation
SS	Slope shape
Ta	Tabane locality augered observation
U	Utsig locality
VC	Convex-Concave slope shape
vf	Very fine (particle size fraction)
VL	Convex-Linear slope shape
VV	Convex-Convex slope shape
WHB	Water harvesting with basins
Wk	Wolwekop locality pit observation
WRC	Water Research Commission
W	Woodbridge1 locality pit observation
w	Woodbridge1 locality augered observation
WW	Woodbridge2 locality pit observation
ww	Woodbridge2 locality augered observation
XDR	X-ray diffraction
Y	Yoxford locality pit observation
y	Yoxford locality augered observation

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CHAPTER 1

INTRODUCTION

1.1 Introduction

In Sub-Saharan Africa an estimated 41 % of agricultural land is located in semi-arid regions (FAO, 1990). Small-scale farmers in the region are facing the difficult task of producing sufficient food for their own consumption while generating sufficient cash income for other needs. Similar conditions exist in many parts of South Africa. This country covers an area of 122.34 million ha with < 14 % suitable for dryland cropping, of which only about a quarter (about 4 million ha) is land of high potential for agriculture (Beukes, Bennie & Hensley, 1998).

In South Africa agriculture has a central role to play in building a strong economy and, in the process, reduce inequalities by increasing incomes and employment opportunities for the poor, while nurturing the inheritance of natural resources (National Department of Agriculture, 1998). Emerging farmers are believed to contribute about 13 % to national food production (Nonjabulo, 1995). These farmers often farm on marginal lands, with limited water supplies. About 26 % of South African rural households currently have access to a plot of land for crop production. Poverty is high in the Free State province with about sixty two percent of the population to live within recognized poverty levels (Free State Department of Agriculture, 2003).

The Free State Province covers about 10.62 % of South Africa or approximately 129 480 km^2. About 92 % of the area is used for agricultural production, with about 2 million ha under cultivation for crop production, about 100 000 ha under irrigation, and the rest of the area used as pasture for animal production (Department of Agriculture, 1996). The Free State produces 33 %, 51 % and 32 % of the country's maize, sorghum and wheat respectively; it is also the second largest producer of sunflower, groundnuts and dry beans (Free State Department of Agriculture, 2003). Hence the province is sometimes described as the "bread basket of South Africa". Agriculture contributes an average of 6.49 % to the Gross Geographic Product of the province (Free State Department of Agriculture, 2003). .

1.2 Motivation

1.2.1 Background

Proper land use is part of successful farming and proper land use relies on proper matching of land qualities with land-use requirements. Most of the land reform projects of land allocated to resource poor farmers after the 1994 democratic general elections failed. The land was allocated to small-scale emerging farmers to help themselves and participate in the greater economy in the south eastern part of the Free State. The study revealed that most of the land reform projects had failed largely as a result of unsatisfactory land evaluation prior to allocation of the land to settlers (Gaetsewe, 2001). Efficient land evaluation therefore emerges as currently being an important issue in South Africa.

The natural agricultural resources of South Africa have been evaluated in the form of land types at a scale of 1:250 000. A land type is an area of marked uniformity with regard to terrain form, soil pattern and climate (Van der Watt and Van Rooyen, 1995). Although land type data is useful for regional planning, the scale of the survey mitigates against its application for the detailed land use planning needed for crop producing areas. The intensity of the land type survey lends itself to decision making on land units larger than about 625 hectares. The sensitivity of crops to variation in soil properties requires detailed data on soil variation to one hectare and less.

South Africa needs subdivision of land types into smaller land units in regions suitable for dryland crop production. Conventional detailed soil survey techniques are suitable for this purpose but the time involved and the cost of these surveys restricts their widespread application, particularly with regard to small-scale farmers. To facilitate the process of land evaluation, promising areas need to be identified by subdividing the land type into smaller mapping units. These smaller mapping units have been termed soilscapes in this study. A soilscape survey helps facilitate the selection of areas for intensive survey. An appropriate scale for the delineation of soilscapes is 1:50 000. It bridges the gap between regional planning with land type data at a scale of 1:250 000, and land-use planning for detailed land use at a scale of 1: 10 000. The land types of the Free State (Land Type Survey Staff, 2004) are published as 1:250 000 maps and as a memoir books containing soil, terrain and climate information by the Agricultural Research Council.

Eloff (1984) evaluated the agricultural natural resources of the Free State. One of the land types delineated east of Bloemfontein was designated as Dc17, also termed “Sepane” by Eloff (1984). This land type forms the focus of this study.

1.2.2 Socio-economic conditions in the study area

The Thaba Nchu area will be used here to describe the area occupied by emerging farmers living on land purchased by the government, and by communal farmers living on Tribal Land. Although all this land is not part of Dc17, the socio-economic condition over the whole area is reasonably homogenous. The fact that the in-field rainwater harvesting crop production technique (IRWH) has been developed initially to assist these people explains why the focus is placed primarily on their socio-economic conditions (Section 1.2.3.1).

Land Type Dc17 includes three towns namely Thaba Nchu, Botshabelo and Dewetsdorp and large areas of commercial farms in the southern and north western parts of the land type. Emerging farmers and communal farmers occupy the remainder of the area. The Tribal Authority headed by Chief Moroka is responsible for land allocation in the Thaba Nchu area. At the village level the headman who is an elected representative of the village, represents the Tribal Authority (Kundhlande & Du Plessis, 2002). Dams like

Rustfontein, Moutloatsi Setlogelo, Woodbridge, Seroala, Rooifontein, and other smaller dams are used as a source of supplemental irrigation or domestic water consumption.

There is unfortunately only limited information regarding the socio-economy of the emerging and commercial farmers and their agriculture in the study area. However, Kundhlande & Du Plessis (2002) and Botha, Van Rensburg, Anderson, Hensley, Macheli, Van Staden, Kundhlande, Groenewalt & Baiphethi (2003) provide useful information. The subsistence farmers have become disillusioned about crop production due to a number of reasons, one of the main ones being the high frequency of crop failures. The introduction of the IRWH crop production technique could therefore play a valuable role in uplifting the productivity and therefore the income of these people. The villages in the study area and surroundings are diverse in terms of economic activity, demographic structure and location, and their response to new technologies. For example, in the southern part livestock rearing plays a major role in the production activities of the households, while in the northern part there tends to be more of a mix between livestock and crop production (Kundhlande & Du Plessis, 2002). The villages in the region also differ in the degree to which villagers are able to organize themselves into groups to pursue collective interests.

Kundhlande and Du Plessis, (2002) assessed the economic viability, social and environmental sustainability of the IRWH technique. The intended end users are farmers working under a wide range of conditions. Thus, it is important that the trial and assessment of new agricultural practices and techniques be carried out with a full understanding of the socioeconomic and agro-climatic conditions under which target farmers operate. Socio-economic information of the Thaba Nchu area indicates that sunflower and maize are among the common crops. Kundhlande & Du Plessis (2002) reported that in the Paradys and Yoxford villages in the year 2000/2001 about 18 ha of sunflower was cultivated. It was estimated that the average household in the Thaba Nchu area consists of 5 members and that such a household would need about 960 kg ha^{-1} of maize per year to provide its staple food (Botha *et al.*, 2003). This is a useful statistic as it makes it possible to calculate the average area of land needed to produce the amount of maize needed per family.

1.2.3 The feasibility of IRWH for the subsistence farmers in the study area

1.2.3.1 Climatic requirement of sunflower and maize

Sunflower is a crop which, compared to other crops, performs well under drought conditions; this is probably the main reason for the crop's popularity in the marginal areas of South Africa (National Department of Agriculture, 1998). Unfortunately, the crop is particularly sensitive to high soil temperatures during emergence and needs cool temperatures for root growth and rosette development. Higher temperatures are required during stem growth, flowering and yield formation (Table 1.1). The high soil temperature is especially the problem in the sandy soil of the Western Free State and the North West Province where it often leads to poor or erratic plant density (National Department of Agriculture, 1998). Sunflower grows well in areas with seasonal precipitation of 400 – 650 mm, and mean temperature of 13 – 30^{o}C (Sys, Van Ranst & Debaveye, 1991).

The sunflower plant has a deep and finely branched taproot system that can utilize water from deep soil layers, even deeper than 2 m (National Department of Agriculture, 1998). The maximum rooting depth is 3.5 m (Sys *et al*., 1991). Consequently the crop often performs well even during a dry season, especially in deeper soils or in soils with a water table (National Department of Agriculture, 1998). The water table should be at a depth of >1 m below the surface (Sys *et al.,* 1991) as the crop is sensitive to waterlogging (National Department of Agriculture, 1998). The unique water-use pattern and powerful root system of sunflowers makes this crop suitable for cultivation on the Swartland, Valsrivier, Sepane, Bonheim and Arcadia soils. Sunflower is capable of utilizing water from the clay horizons of these soils (National Department of Agriculture, 1998).

Table 1.1 Rainfall and temperature requirements of maize and sunflower (Sys *et al.*, 1991)

Crop	Climatic * characteristic	Degree of limitations expected **				
		0	1	2	3	4
Maize	P (mm)	750-600	600-500	500-400	400-300	<300
	T mean (^{0}C)	24-22 24-26	22-18 26-32	18-16 32-35	16-14 35-40	<14 >40
	T min(^{0}C)	17-16 17-18	16-12 18-24	12-9 24-28	9-7 28-30	<7 >30
Sunflower	P (mm)	650-500	500-400	400-300	300-200	<250
	T mean (^{0}C)	22-20 22-24	20-18 24-26	18-16 26-28	16-13 28-30	<13 >30

* P = rainfall during the growing season, T = temperature during the growing season
** 0 = no limitation; 1 = mild limitation; 2 = moderate limitation; 3 = severe limitation; 4 = not recommended

Soil water extraction by sunflower has been compared to spring wheat and barley, and Black, Brown, Halvorson & Siddoway (1981) reported that sunflower extracted both more total water as well as water deeper in the soil profile than either of these cereals. Similar results are reported (Figure 1.2) by Hensley, Botha, Anderson, Van Staden & Du Toit (2000). Sunflower extracted water from 1.35 m depth of soil, contrasting with dry pea that only removed soil water at the 0.15 and 0.45 m soil depths (Black *et al.,* 1981). Merrill, Tanaka & Hanson (2002) quantified root development of several crops with minirhizotrons. They found that sunflower's maximum rooting depth was 50 % greater than dry pea.

The difference in water remaining in the soil profile after sunflower and dry pea may influence future crop yields, especially during dry growing seasons. Sunflower exploits more soil depth than dry pea. Randy, Donald & Stephen (2003) indicated that crops following dry pea will have more available soil water than if sunflower is the preceding crop. Water depletion in 2.2 to 3.3 m soil depth zone was significantly greater for sunflower (48 mm) than for Sorghum (14 mm) (Stone, Goodrum, Schlegel, Jaafar &

Khan, 2002). The same results are reported by Botha *et al.* (2003) that beans following sunflower in rotation produced lesser yield than beans following maize.

In semi-arid sub-tropical regions of South Africa a major part of the growing season of sunflower is characterized by low rainfall and high evaporative demand. Since sunflower is a profligate water user its yield is likely to be constrained by water limitations (Connor & Sadras, 1992). For sustainable sunflower production, in areas where irrigation water is not available, in-field rainwater harvesting can be of paramount importance. Maize and sunflower yields obtained from the Feloane and Yoxford villages in the study area using IRWH showed a significant increase when compared to conventional tillage (Table 1.2).

Table 1.2 Maize and sunflower yields obtained at Feloane and Yoxford villages during the year 2001/2002 (Botha *et al.*, 2003)

Locality	Treatments	Maize yield (kg ha^{-1})	Sunflower yield (kg ha^{-1})
Feloane	CON	1987 [a]	1680 [a]
	IRWH-farmers*	3268 [b]	2137 [b]
	IRWH-training**	3642 [b]	2243 [b]
Yoxford	CON	1741 [a]	-
	IRWH-farmers*	2643 [b]	-
	IRWH-training**	2970 [b]	-

Column values followed by the same superscripts do not differ significantly at P = 0.05
CON = conventional tillage * = Farmers managed fields ** = Research managed fields.

Maize shows tolerance to a wide range of environmental conditions. It grows in areas with a wide range in growing season precipitation above about 500 mm, and range in mean temperature of 14 – 40 ^{o}C (Table 1.1). Maize is sensitive to frost, and also water stress especially from the beginning of flowering until the end of grain formation. Optimum germination temperature is 18 – 21 ^{o}C. The crop's growth is optimal over the mean temperature range of 18 – 32 ^{o}C (Sys *et al.*, 1991). Comparing the climatic requirements of both maize and sunflower given in Table 1.1 with the climatic data for the study area given in Table 2.3 reveals the following. Assuming a four month growing season for sunflower and maize planted early in January, the average growing season rainfall can be expected to be 296 mm (Table 2.3). The criteria in Table 1.1 indicate a severe limitation for sunflower and "not recommended" for maize**.** This confirms the marginal nature of Dc 17 for crop production with conventional production techniques.

1.2.3.2 Soil factors

Several methods are used to collect and store rainwater. It can be stored in reservoirs or directly in the soil for crop production using terraces, deep soil ripping, contour ridges, and other types of water collection methods. Those using the soil profile as a storage medium, eliminate the need for storage tanks and reduce evaporation at minimal cost (Abu-Zreig, Attom & Hamasha, 2002). This principle is sound for the farmers of the study area as they have little capital. This practice is widely recognized to increase soil water storage and agricultural production (Abu-Zreig *et al*., 2002). Abu-Zreig *et al* (2002) reported that the amount of rainwater retained within the field due to tied-ridging was largest in fine-textured soils (clay, clay loam and loam), and smallest in coarse-textured soils (sandy loam and sand). Drainage loss from fields with ridging without ties was largest in coarse-textured soils compared to fine-texture soils. In addition, drainage increased with seasonal rainfall depth. Compared to ridging without ties, tied-ridging increased the amount of drainage out of the root zone. Soils with subsoil drainage impeding material are therefore good for reducing this sort of water and associated nutrient loss. Zougmore, Mando & Stroosnijder (2004) reported that soils with a hardpan at 700 mm depth restricted sorghum root growth, but stressed that soils with impermeable barriers stored more water than those without barriers.

Differences between fine and coarse-textured soils are due to the fact that coarse-textured soils have high infiltration rates. This reduces the amount of surface runoff that is generated, and thereby reducing the soil water retained within the field by tied-ridging. Further, sandy soils have a low water holding capacity and macro pore flow is dominant. Thus, the surface runoff that is retained by tied-ridging in coarse-textured soils is quickly lost through drainage, hardly increasing soil moisture storage and evapotranspiration

(Wiyo, Kasomekera & Feyen, 2000). Eloff (1984) also evaluated soils with <10 % clay content as having low crop production potential.

In arid and semi-arid environments lack of rainfall, or a poor rainfall distribution, leads to low levels of vegetation for much of the year, such that the soil surface is normally bare at the beginning of the rainy season. As a result, soil crusting often occurs after the initial rains, due to the compacting effect of raindrops (Morin & Cluff, 1980; Valentin, 1991; Botha *et al*., 2003). These crusted surfaces induce reduced infiltration rates, generating runoff that changes the micro topography of the surrounding areas, enhances erosion and consequently loss of organic matter and nutrients (Bielders, Baveye, Wilding, Drees. & Valentin, 1995). Soil sealing and crusting, a common process in cultivated soils of semi-arid and arid regions like the study area, creates serious problems for crop production. This runoff can be harnessed with IRWH and used to enhance crop yield (Botha *et al*., 2003). Valentin & Steward (1991) described how waterlogging and subsequent slaking led to the formation of structural and depositional crusts in a tilled clay loam plot, showing that a surface crust can be formed regardless of kinetic energy of the rainfall.

All rainfall harvesting systems have three components namely a collection area, a conveyance system, and a storage area (Figure 1.3). The susceptibility of soils to surface sealing and crusting depends on a combination of several soil physical and chemical properties. Clay content, clay mineralogy and rainstorm characteristics are among the most significant factors that control the nature and extent of soil crust development (Mermut, Luck, Romkens & Poesen, 1995). Organic matter, and type and concentration of electrolytes are other factors that effect the arrangement of fundamental soil particles within the seal and crust. It is known that increasing electrolyte concentration causes an increase in flocculation of clay particles, which has an influence on crust formation (Mermut *et al*., 1995). Shainberg & Singer (1985) showed that electrolytes prevent dispersion, and the crust formed consisted of flocculated particles resulting in high permeability. Supporting evidence for this was obtained by a micromorphological study of crusts by Southard, Shainberg, and Singer (1988). They found that soil material suspended in water containing electrolytes resulted in less dense and more porous crusts

It is known that swelling and/or dispersion of soil colloids alters the geometry of soil pores and affects intrinsic soil permeability. Soils with high smectitic clay contents produce wide and deep cracks. This will facilitate infiltration, though those cracks will soon be closed due to the expansive nature of the clay minerals on wetting. Low infiltration can result from such geometric restrictions. The presence of iron oxides in clay coatings would result in less sealing. In some Irish soils, degree of seal development was low attributed to low clay content and high carbonate content (Mermut *et al*., 1995).

The effective soil depth is the depth of soil material that plant roots can penetrate readily to obtain water and plant nutrients. It is the depth to a layer that differs sufficiently from the overlying material in physical or chemical properties to prevent or seriously retard the growth of roots (Van der Watt & Van Rooyen, 1995). Effective rooting depth (ERD) is one of the factors that determine the land's potential for in-field rainwater harvesting for crop production in the study area. It is reported by Botha *et al.* (2003) that an effective rooting depth of around 1000 mm, of which at least 700 mm is soil can be considered as a minimum requirement for satisfactory maize, bean and sunflower production in the Thaba Nchu area. ERD is an important criteria particularly if chemical or physical attributes are constraining to root access. Knowing the water holding capacity is equally important and may lead to a change in cropping strategy. For example P607, a modal profile recorded in Table 2.1 (See Appendix 9 for the profile description), has ERD > 900 mm. This soil is clearly suitable for IRWH, whereas P608 is a soil of Kroonstad form which has an E horizon at a depth of 300 mm. This soil is unsuitable for IRWH as the E horizon will impair root development. It can become waterlogged and dry in one season making it unsuitable for plant root growth.

In the Land Type Survey of South Africa pedocutanic horizons are generally recorded as a root depth limiting material, e.g. Eloff (1984). Roots presumably enter cracks in the fairly dry soil, and then become squashed when the soil becomes wet and expands (Figure 1.1). Although this criterion is to some extent valid for conventional tillage, it seems inappropriate where IRWH is practiced, due to the fact that the soil remains wetter for longer in the vicinity of the basins (Botha *et al*., 2003).

Pedocutanic horizons may be recorded as a root depth limiting material, Eloff (1984). Roots presumably enter cracks in the fairly dry soil, and then become squashed when the soil becomes wet and expands (Figure 1.1). Although pedocutanic horizons may to some extent limit root growth where conventional tillage is practiced, soil remains wetter for longer periods (Botha *et al*., 2003) where IRWH is practiced.

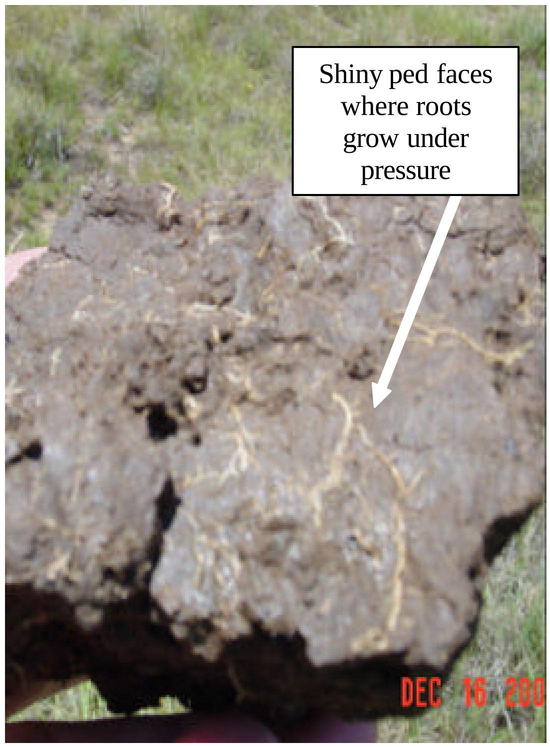


Figure 1.1 Flattened roots growing on ped faces in a pedocutanic B horizon (Photo by P.A.L le Roux)

Crops have differing abilities to extract water from a particular soil horizon. For example Figure 1.2 shows the potential soil water extraction of maize and sunflower from a melanic A horizon (0 – 400 mm) and pedocutanic B horizon (400 – 800 mm). The area of each rectangle, representing a soil depth of 300 mm, is proportional to the total extractable soil water (Hensley *et al.,* 2000). In all the layers sunflower extracts more water than maize, giving total values of 155 and 122 mm respectively for the root zone.

Water extraction patterns within the soil profile are generally indicative of root activity. Eghball & Maranville (1993) reported that greater root depth and water extraction from the lower profile was associated with greater corn yield and that this ability varied with cultivar.

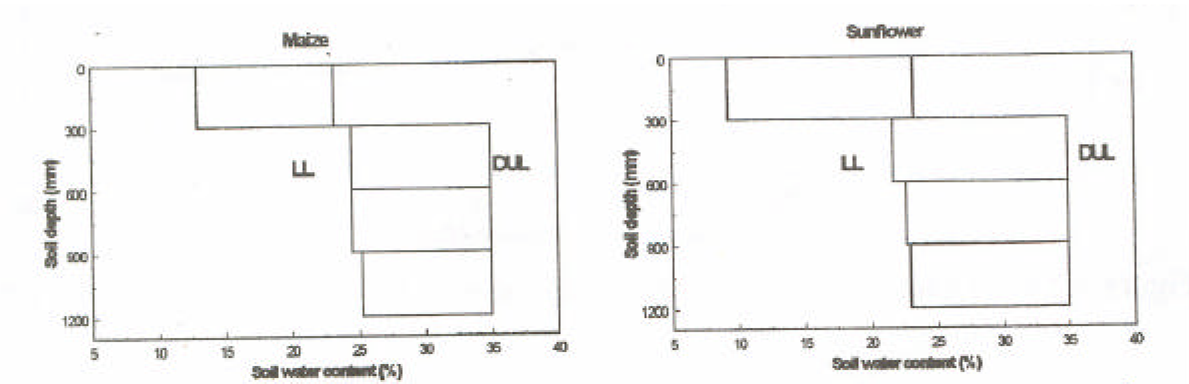


Figure 1.2 Soil water extraction diagrams for maize and sunflower expressed on the Glen/Bonheim-Onrus ecotope. Soil water content as a volume percentage. DUL = drained upper limit and LL = lower limit of soil water availability. (Hesley *et al*.,2000).

1.2.3.3 The IRWH technique

The lack of efficient water harvesting and water conservation techniques, in particular for smallholder crop production systems, is one of the most urgent problems faced by agriculture in the Southern African Development Community's (SADC) semi-arid areas (Kronen, 1994). The practice of rainwater harvesting has been developed by farmers as a way of combating the risks of mid-season droughts (Mwakalila & Hatibu, 1992). The interest in water harvesting for plant production is increasing as it increases crop production in rain-fed, semi-arid agricultural areas by increasing water availability for plants during the growing season (Reij, Mulder & Begemann, 1988; Abu-Zreig *et al*., 2002). The eastern Free State, as part of the semi-arid part of South Africa, shares the problem. In an effort to alleviate this problem Hensley *et al.* (2000) developed the in-field rainwater harvesting (IRWH) technique to combine the advantages of basin tillage, no-till and mulching. In IRWH the term 'in-field' refers to the transportation of water over a short distance of 2 m and delivering it to the 1 m wide basin (Figure 1.3). This system is regarded as a special form of water harvesting categorized as mini-catchment runoff farming (Oweis, Hachum & Kijne, 1999). It is particularly efficient for clay and duplex soils in semi-arid areas (Botha *et al.*, 2003).

Water harvesting is defined as the process of concentrating rainfall as runoff from a larger area for use in a smaller target area (Oweis *et al.*, 1999). Botha *et al.*, (2003) preferred to define water harvesting in a more general context as 'collection of runoff for its productive use. The term is used to describe a number of different practices that have been used for centuries in dry areas to collect and use rainfall more efficiently.

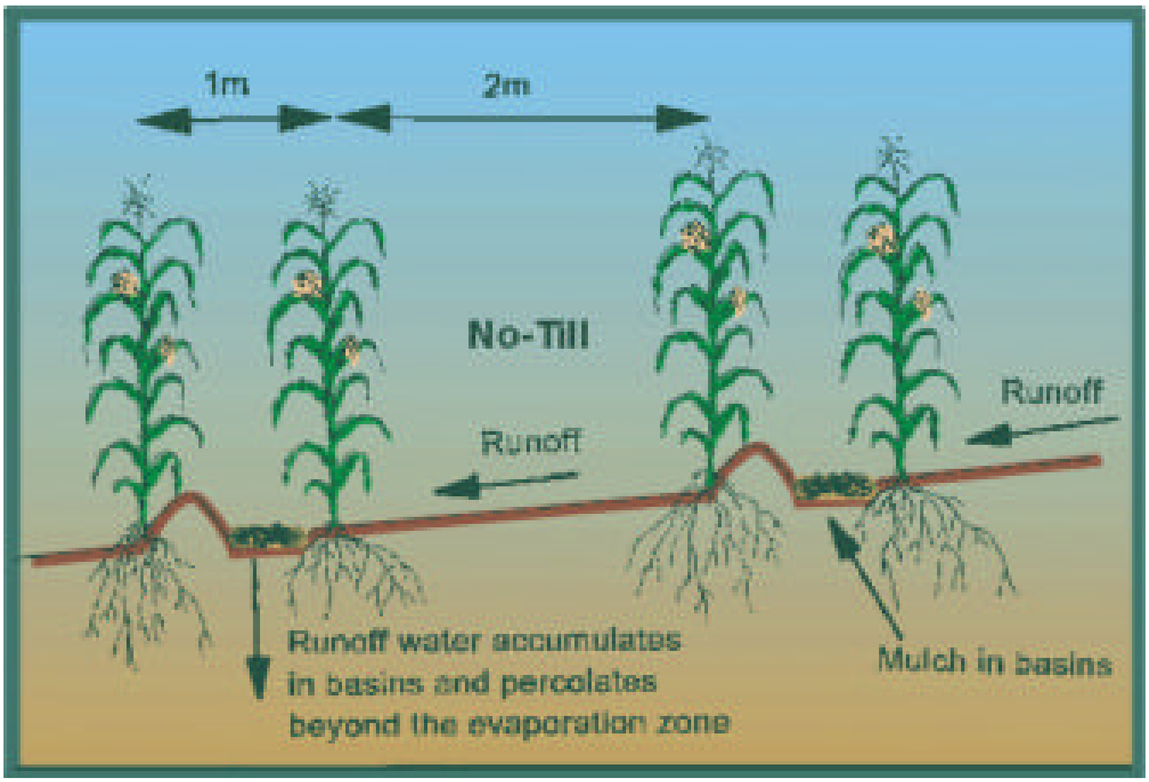


Figure 1.3 A diagrammatic representation of the in-field rainwater harvesting technique (Hensley *et al.*, 2000).

1.2.3.4 Results of relevant field experiments

Experiments with maize over the seasons 1996/97, 1997/98 and 1998/99 on four ecotopes at Glen and Thaba Nchu showed yield increases of around 50 % using IRWH compared to conventional tillage CON. A mean biomass increment of about 30 % was also reported over all the comparisons (Hensley *et al.*, 2000). This clearly confirmed the superiority of

IRWH over CON. In later studies different IRWH techniques were compared in field experiments at Glen on the Glen/Bonheim – Onrus ecotope during the 1999/2000, 2000/2001, and 2001/2002 seasons (Botha *et al.*, 2003). A range of treatments were tested in a series of experiments. The results of these experiments together with those reported by Hensley *et al.* (2000) were used to develop an empirical yield prediction model termed "crop yield predictor for semi-arid areas" abbreviated as CYP-SA (Botha *et al.*, 2003). The model was used together with long-term climate data to compile long-term (1922 – 2003) cumulative yield probability functions (CPF's) for maize and sunflower using IRWH. It is relevant to Dc17. The treatments studied were: conventional tillage (CON); bare basin and bare runoff strip (BbBr); organic mulch in the basin with a bare runoff strip (ObBr); organic mulch in the basin and organic mulch on the runoff strip (ObOr); organic mulch in the basin and stones on the runoff strip (ObSr); stones in the basin and organic mulch in the runoff strip (SbOr); stones in the basin and stones in the runoff strip (SbSr). Results are presented in Table 1.3 and Figures 1.4 and 1.5. For maize, yields were in the order ObSr> SbSr>ObOr>SbOr>ObBr>BbBr>CON (Table 1.3). For sunflower the order was the same. Sunflower is shown to respond better than maize to the IRWH treatment. Comparing the best IRWH treatment with CON the increments for maize and sunflower exceeded the conventional tillage method by 82 % and 130 % respectively.

Assuming that an average family in the Thaba Nchu area needs about 1 ton of maize per annum to provide their staple food (see section 1.2.2), it is possible to estimate the area of land needed to achieve this with the different tillage treatments described in Table 1.3. The estimated areas for CON and ObBr are 0.69 ha and 0.44 ha respectively, assuming a 50% probability of achievement. ObBr is probably the treatment most likely to be adopted by the subsistence farmers. However, since it is the basic food requirement that is at stake, a higher probability of achievement, say 80 %, *i.e.* success in 8 years out of 10, needs to be considered. The results in Figure 1.4 provide the information for making this estimate, yielding 1.29 and 0.60 ha for CON and ObBr treatments respectively. Since the price obtained for sunflower seed is often double that of maize and the predicted yields more than half of maize, Botha *et al* (2003) show that from a financial point of view sunflower is probably a better crop for the area. The results in Figure 1.5 predict that if sunflower was grown one could expect in 8 out of 10 years (80 % probability) to obtain a yield of 785 kg ha^{-1} using the ObBr IRWH treatment. The comparable yield for maize is 1670 kg ha^{-1}. This is useful information, together with that in Table 1.3, to help farmers to decide on which crop to grow in relation to the current market prices of maize and sunflower.

Table 1.3 Results obtained with the CYP-SA crop model over 81 seasons (1922 – 2003) of predicted yields (Kg ha^{-1}) at 50 % probability of achievement on the Glen/Bonheim – Onrus ecotope, using different tillage treatments**.** Simulations were done using 17 December as a planting date and for a root zone half full of water at planting (Botha *et al.,* 2003). See text for abbreviations.

Crop	Treatments						
	CON	BbBr	ObBr	ObOr	ObSr	SbOr	SbSr
Maize	1443	2234	2278	2406	2620	2388	2600
Sunflower	796	1431	1473	1700	1830	1685	1813

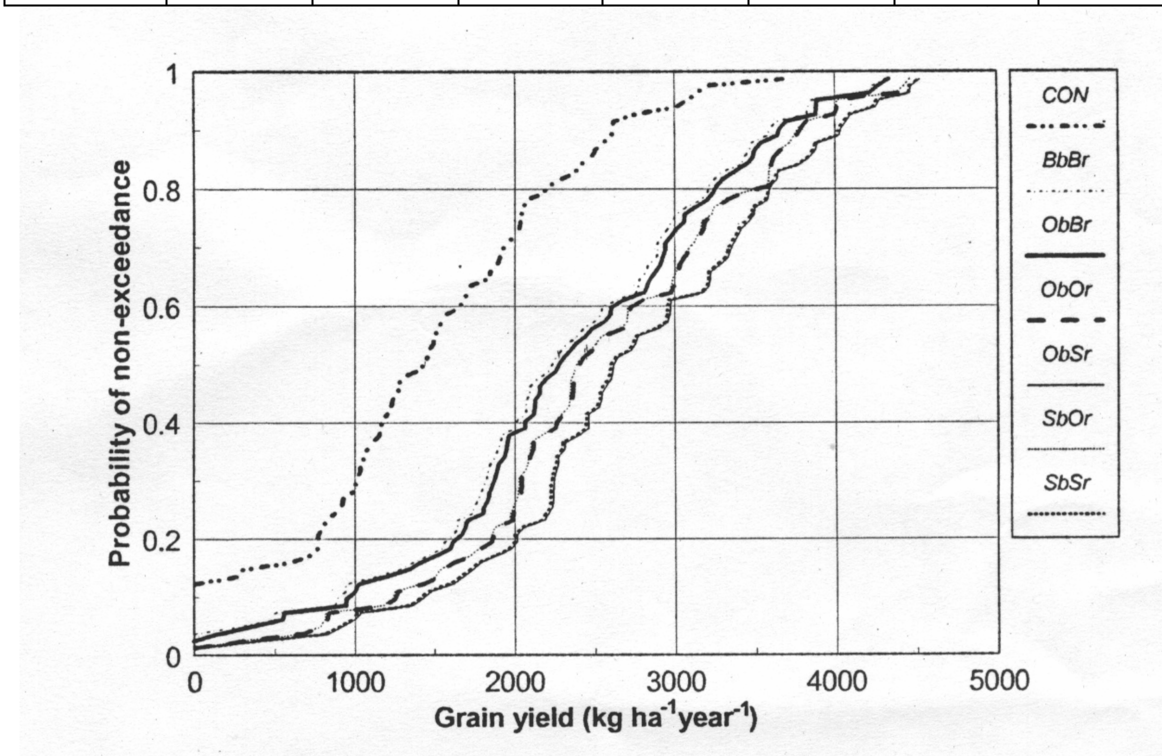


Figure 1.4 CPF's of maize yields over the period 1922-2003 predicted by the CYP-SA model for the Glen Bonheim-Onrus ecotope; maize planted on a 1/2 full profile on 17 December. Treatment symbols as defined for Table 1.3 (Botha *et al*., 2003)

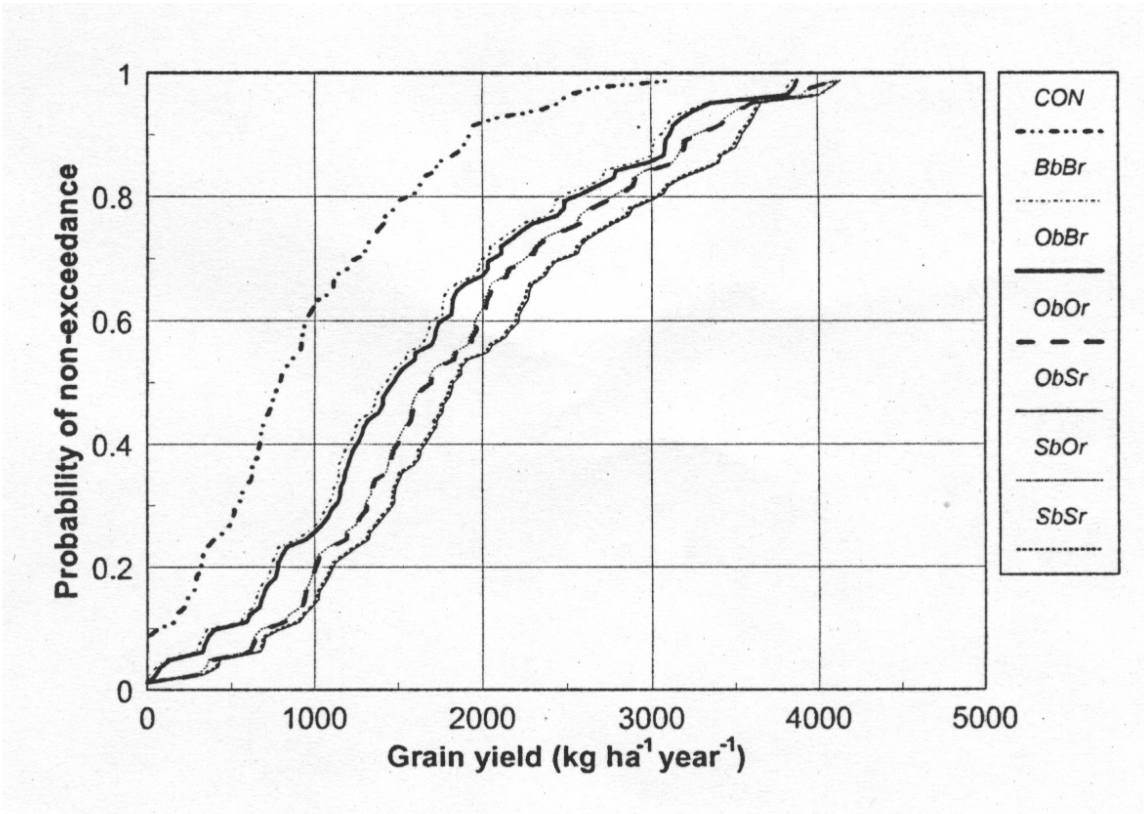


Figure 1.5 CPF's of sunflower yields over the period 1922-2003 predicted by the CYP-SA model for the Glen Bonheim-Onrus ecotope; maize planted on a 1/2 full profile on 17 December. Treatment symbols as for Table 1.3 (Botha *et al.*, 2003)

1.2.4 Summary

The major factors generally governing dryland cropping potential in South Africa are rainfall, slope, soil type, effective soil depth, and texture. One of the land types delineated east of Bloemfontein was designated as Dc17. It forms the focus of this study. Land type Dc17 is clearly marginal for commercial crop farming due mainly to low and erratic rainfall and unsatisfactory soils (Eloff, 1984). However, because it is a densely populated area, the need to optimize crop production techniques is accentuated. The climate is semi-arid, and precipitation use efficiency is low resulting in high risk of crop failure. Duplex soils and soils with vertic and melanic topsoils are common. Runoff rates and evaporation losses are high on these soils.

Detailed field experiments and long-term yield predictions clearly show the value of IRWH for subsistence farmers in the Thaba Nchu area. This provides a strong motivation for making a more accurate assessment of the arable area suitable for this technique in Dc 17, than that available from the Land Type Survey. The value of this estimate for particular soilscapes is that it will help to identify priorities.

1.3 Hypothesis

A soilscape survey of land type Dc17 will improve understanding of the distribution of soils in the landscape, which will enable a more reliable estimate to be made of the area of land that is suitable for the production of maize and sunflower using the IRWH technique, than that which is possible using land type data.

1.4 Objectives

To test the hypothesis the following objectives are set:

- (i) An improved understanding of the soilscape concept.
- (ii) To identify and describe dominant ecotopes in land type Dc17.
- (iii) To improve the land resource data of land type Dc17 by subdividing it into soilscapes delineated on 1:50 000 maps.
- (iv) To estimate the area in each soilscape that is suitable for maize and sunflower production using the IRWH crop production technique.
- (v) To make, long-term yield and risk predictions for each soilscape, for maize and sunflower using conventional and IRWH crop production techniques.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Soil, as an organized natural body is the product of its environment (Hubble, Isbell & Northcote, 1983). It forms in the uppermost part of the earth's crust from rocks of many kinds or from transported, mixed rock debris, be this alluvium, colluvium, aeolian material, or till (Van der Eyk, MacVicar & De Villiers, 1969). Its forma tion is regarded as a function of climate, organisms, topography, parent material and time (Jenny, 1941; Jamagne & King, 2003). The first four are the tangible factors which interact through time to create a number of specific processes leading to horizon differentiation and soil formation (Fitzpatrick, 1980). Several soil studies in arid and semi-arid areas indicate that soils show wide spatial variability resulting from differences in parent material, age of land surface, topography, water distribution, amount and intensity of rainfall and plant heterogeneity (Key, Delph, Thompson & Van Hoogenstyn, 1984; Wierenga, Hendrickx, Nash, Ludwig & Daugherty, 1987; Shmida & Burgess, 1988). These spatial variations of environmental conditions and their interactio ns result in spatial differentiation of soil characteristics (Buol, Hole, McCracken & Southard, 1989).

The focus of this research is on Land Type Dc17 which will be described as the "study area". According to the Land Type Survey Staff (2002), Land Type Dc17 contains land with a semi-arid climate in which duplex soils with prismacutanic and/or pedocutanic diagnostic soil horizons are dominant, and in addition vertic, melanic and red structured diagnostic horizons occur.

2.2 Land evaluation

2.2.1 Background

Land evaluation is defined as the process of assessment of land performance when used for a specified purpose (FAO, 1983). It predicts the use potential of land ? on the basis of its attributes (Rossiter, 1996) and involves the execution and interpretation of surveys and studies of landforms, soils, vegetation, climate and other aspects of land in order to identify and make a comparison of promising kinds of land use in terms applicable to the objectives of the evaluation (FAO, 1983). This implies that land should be evaluated for separate alternative uses that may not damage the environment in general while increasing yields and land productivity (Beek, 1978; Dent & Young, 1981). The main aim of land evaluation is therefore to provide information on potentials and constraints for the use of land, as a basis for making decisions on its use and management (Anaman & Krishnamara, 1994).

Land evaluation requires matching of the ecological and management requirements of relevant kinds of land use with land qualities (LQ's), whilst taking local economic and social conditions into account (FAO, 1983). A LQ is a complex attribute of land that acts in a distinct manner in its influence on the suitability of land for a specific use. Examples are water availability, erosion resistance, flooding hazard, nutritive value of pastures and accessibility (FAO, 1983; Sys *et al.*, 1991). The suitability of land varies for different land utilization types (LUT's).

A LUT is defined as "a use of land defined in terms of a product, or products, the inputs and operations required to produce these products, and the socio-economic setting in which production is carried out" (FAO, 1996). A large number of agricultural LUT's are theoretically possible. However, only those that are most relevant and acceptable by stakeholders should be retained for further consideration. In general, for LUT's focused on rain-fed crop production, the major requirements of concern are crop physiology, technology of management systems, and avoidance of land degradation (FAO, 1983).

2.2.2 Types of land evaluation procedures

Different types and methods of land evaluation have been developed. However, objectives of evaluation and types and forms of data available dictate the types and methods of the evaluation (Beek, 1978; FAO, 1983).

Physical land evaluation: involves an evaluation of land based on physical parameters (Beek, 1978). It assumes that permanent physical land resources determine land uses and considers that physically limited land is also economically unprofitable and ecologically unsustainable (Ahmed, 2003).

Economic land evaluation: involves evaluation on the basis of profitability. Its results (inputs and outputs) are expressed in economic or more specifically in financial terms (Beek, 1978).

Qualitative land evaluation: involves the expression of results in qualitative terms without calculating the costs incurred and the returns earned (Beek, 1978). The land's suitability for a specific land use is expressed qualitatively as highly, moderately or marginally suitable, or unsuitable (Beek, 1978; Sys *et al.,* 1991).

Quantitative land evaluation: involves the expression of results in numerical terms. It requires quantitative data from qualitative land evaluation (Van Diepen, Van Keulen, Wolf & Berkhout, 1991; Sys *et al.,* 1991).

Actual land suitability evaluation: refers to the present conditions of the land and it is based on direct observation with no or minor involvement of land improvements (Sys *et al.*, 1991; Rossiter, 1996).

Potential suitability evaluation: refers to the evaluation of land for a specific use for some time in the future after major improvements are made (Sys *et al.,* 1991).

2.2.2.1 USDA Land Capability Classification

Land Capability Classification System (LCC) refers to the classification of land according to the potential of the land for general kinds of land uses (FAO, 1976; Sys *et al.*, 1991). Capability is viewed by some as the inherent capacity of land to perform at a given level for a general use, and suitability refers to the adaptability of a given area for a specific kind of land use (FAO, 1976). LCC considers the long-term proper use of soils for crop production without degradation and starts with a soil survey including topography, soil and climate (Van Diepen *et al.*, 1991; Sys *et al.*, 1991). The data collected for these resources are used to identify and classify soil mapping units into different capability classes according to their actual and potential limitations. Limitations are the physical land characteristics that affect the intensity of use or require special management (Ahmed, 2003). The system provides three levels of evaluation categories, identified as capability class, capability subclass and capability unit (Sys *et al*., 1991). The capability class consists of soil groups with similar relative limitations according to which they are grouped into eight classes. The degree of limitations and severity increase from Class I to Class VIII (Sys *et al*., 1991).

2.2.2.2 Limitation method

The limitation method considers certain factors, defined as land characteristics or LQ's, which limit actual and/or potential use of the land (Sys *et al*., 1991). Land evaluation is based on the types and degree of limitation occurring in the tract of land being evaluated (Sys *et al.*, 1991). The system employs two evaluation procedures, the simple limitation method, and the number and intensity of limitations (Sys *et al*., 1991).

The simple limitation method considers the least favourable land characteristics and/or qualities limiting the land use. The number and intensity of limitations approach considers that a combination of factors can play a role in limiting the suitability of the land for a specific use. Thus, the procedure is employed to define land suitability classes according to the number and intensity of limitations (Sys *et al*., 1991). In both approaches the results of land suitability evaluation are expressed qualitatively and are categorized into highly, moderately and marginally suitable or unsuitable in a decreasing order of suitability classes.

2.2.2.3 Parametric method

In the parametric approach, single empirical numeric factors named as parameters, usually values of land characteristics are combined mathematically to give a final single numeric rating (Van Diepen *et al*., 1991; Sys *et al*., 1991). The parametric approach assigns ratings (depending on expert knowledge) to each parameter to decide the optimal and marginal suitability of land use requirements (Beek, 1978).

The ratings of selected parameters can be combined by additive, multiplicative complex procedures (Van Diepen *et al.*, 1991).

This approach approximates quantitative land evaluation as opposed to the other methods described earlier. The boundary between suitability classes is identified by the value of indices, although the line is drawn arbitrarily based on expert knowledge. The final results of each mapping unit can be compared with yield data so that the performance of the method is calibrated with actual land yield values or assessments (Sys, 1993). Disadvantages of this approach are misleading accuracy, arbitrariness of the choice of factors, and too great flexibility (McRae & Burnham, 1981). This is especially pronounced when parametric equations are formulated with no other verification than expert judgment (FAO, 1983).

2.2.2.4 FAO method

FAO (1976, 1983) sets out guidelines for land evaluation that could be applied at any scale. The procedure can be employed for suitability evaluations from global, through regional, to farm level (Dent & Young, 1981; Van Diepen *et al.*, 1991; Davidson, 1992). In the procedure, land mapping units are evaluated for a particular land use type in relation to its physical and socio-economic conditions. Therefore, the objective of the evaluation is for a defined use.

FAO (1976, 1983) recommends the procedures outlined in Figure 2.1. The following are some basic principles which need to be adhered to when making a suitability evaluation:

1. Highly suitable for one land use may be unsuitable for another.
2. Land suitability is assessed and classified for specific kinds of use.
3. Land suitability classes are defined by economic criteria.
4. A multi-disciplinary field of study must be involved in the evaluation processes.
5. Evaluation should be based on the existing local physical, social and economic conditions.
6. Suitability refers to land use on a sustainable basis.
7. Land evaluation should involve the comparison of two or more alternative kinds of land use.

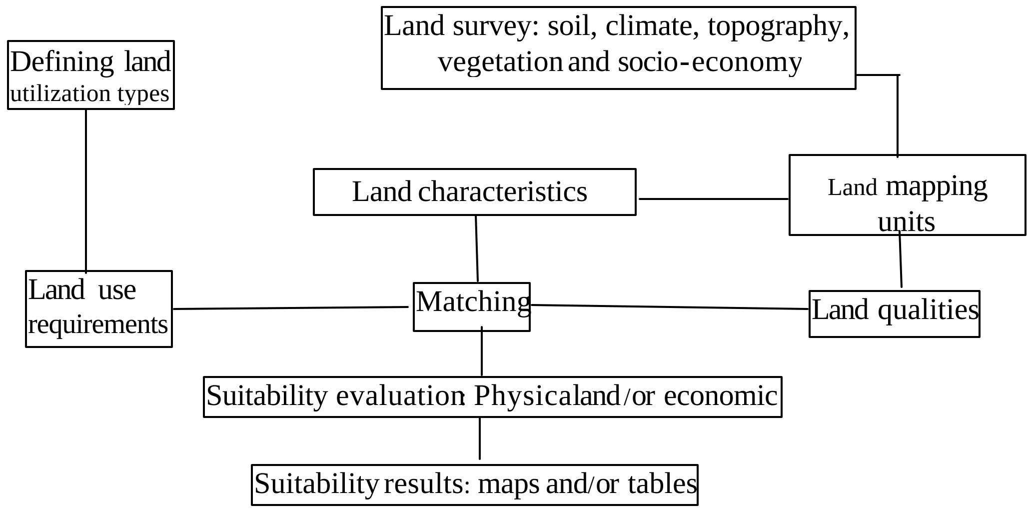


Figure 2.1 Schematized diagram depicting land suitability evaluation procedures according to FAO (1983).

The procedures described are only general guidelines to the evaluation process. The choice of approaches and procedures to be followed depends on the set of circumstances in question. Besides, there is an element of iteration, or a cyclic nature, in the procedures.

2.2.2.5 Yield estimates and statistical methods

Yield estimates refer to long-term average yields for individual crops and are given either as absolute or relative single values, or as yield classes. Crop yield estimates determined by production factors such as attributes of soil, topography, climate and management practices, which may have geographical variations, are used in many agricultural land evaluation exercises (Van Diepen *et al.*, 1991; Rossiter, 1996).

Yield data can be obtained from local farm records, experimental plots, sample plots, pot experiments and through interviewing farmers (McRae & Burnham, 1981). They can also be estimated by the use of deterministic crop growth models (Van Diepen *et al.*, 1991) and statistical methods (Beek, 1978; McRae & Burnham, 1981; Van Diepen *et al.*, 1991). The use of reliable calibrated crop growth models together with long-term climate data is probably the best method available for evaluating land for a specific purpose. This is a widely used procedure (Muchow, Hammer & Carberry, 1990; Monteith & Vermani, 1991; De Jager & Singels, 1990; Hensley *et al.*, 2000;

Botha *et al.,* 2003). This method has the important advantage that it provides recommendations concerning the best production techniques which take rainfall variability into account and therefore expresses results in terms of realistic probabilities (Botha *et al*., 2003). It is particularly appropriate and valuable in semi-arid areas.

Various statistical methods have been used to model relations existing between yield and production factors and to predict the yield potential of land mapping units (Van Diepen *et al*., 1991). This approach tries to allow quantitative determination of the effect of individual production factors (or land characteristics) on yield collected from different land mapping units. Like yield estimates, the use of statistical methods in land evaluation requires sufficient data collected over several years and/or growing seasons from a number of land mapping units (Ahmed, 2003).

2.2.2.6 Geographic Information Systems (GIS) and Computer Models

Geographical Information Systems (GIS) methods can help to relatively easily obtain topographic information including elevation, slope steepness, slope shape, aspect, and profile curvatures at a required scale. GIS methods that analyze and interpret environmental attributes (e.g. soil, topography and climate) can be used in land evaluation and other types of environmental studies (Burrough & McDonnell, 1998). Through mapping, GIS is particularly useful in understanding the spatial variability of most land characteristics, which could have a direct and/or indirect effect on land use. The technique can be used in deriving important properties, such as LQ's from original land characteristics (Burrough & McDonnell, 1998). Point data such as soil characteristics obtained from pits can be easily transformed to area data by averaging the values within land mapping units or by interpolation using GIS (Burrough, 1993, Burrough & McDonnell, 1998). GIS is a powerful tool for meaningful combination and presentation of information on areas of the earth. Lourens (1995) used the GIS/modelling system for both delimitation of drought stricken areas and indication of the intensity of the drought.

The development of computer software programs and techniques on land evaluation has allowed a more sophisticated, rapid and objective land evaluation analysis than ever before (Van Diepen *et al*., 1991; Rossiter, 1996). MacMillan, Pettapiece, Nolan & Goddard (2000) used GIS in linking soil to landform positions in soil/ landform models. These procedures resulted in the production of a new database that explicitly linked all soils to their most likely landform positions for over 28 000 polygons of the Alberta Soil Inventory Database. The fuzzy set theory land evaluation computer model applied in Thailand (Van Ranst, Tang & Sinthurahat, 1996), indicated that growing season rainfall and temperature, texture and structure, soil fertility, and drainage conditions form the most variable factors that influence suitability of the soils for rubber production

2.2.2.7 Indigenous knowledge

The use of indigenous farmers' knowledge is gaining momentum in land classification and suitability evaluation (Ahmed, 2003). Many studies indicate that indigenous land/soil suitability evaluation systems are largely based on management requirements and the actual productivity of land. In the mountains of Rwanda, for example, farmers evaluate their soil on the basis of fertility measured by crop yield in each growing season, depth of the soil, texture to indicate drainage and water retention conditions, consistence to explain workability, growth conditions of plants, erosion resistance and colour (Habarurema & Steiner, 1997).

Traditionally, farmers develop methods that optimally suite the dynamic natural and social environments in order to obtain their means of livelihood. However, traditional land evaluation is largely based on actual yield. Nevertheless, certain facts indicate that both modern and traditional evaluation approaches take some common land characteristics and qualities into consideration in land suitability classification. The difference is that modern land evaluation is based on quantitative data, laboratory analysis and field measurements. It seems to be true that valuable soil knowledge develops in cultures through long term interactions with the environment and the use of land resources (Sandor & Furbee, 1996).

2.2.2.8 Automated land evaluation system (ALES)

The Automated Land Evaluation System (ALES) is a computer program/tool used to implement the FAO (1976, 1983) land suitability evaluation methodology (Rossiter & Van Wambeke, 1989). It was developed by Rossiter & Van Wambeke (1989) and subsequently refined by Rossiter (1990) and Rossiter & Van Wambeke (2000). It offers a structure for a wide range of applications of expert knowledge in a computer system for a quick and reproducible assessment. Such a computer-aided decision support system provides a powerful tool in physical land evaluation. A decision procedure is a means of capturing and summarizing a reasoning process in a manner that allows systematic identification and evaluation of possible decision alternatives.

ALES usually accepts classified data (Rossiter & van Wambeke, 2000). It provides a structure to create models in terms of land characteristics, LQ's and land use requirements. The land characteristic of each separate mapping unit is obtained from the database to be used in the ALES model The land characteristics are classified by an ALES expert according to local and field conditions and/or experiment results on the LUR's of LUTs. Thus, ALES evaluates land mapping units according to expert knowledge. The relevant land characteristics are transformed to LQ's according their limitations or suitability to meet the use requirements of a LUT (FAO, 1976; FAO, 1983), known in ALES as severity level (Rossiter & Van Wambeke, 2000). ALES is employed in different parts of the world. Its application in suitability evaluation for some major food crops (barley, maize and tef) in the central parts of Ethiopia indicates that the high altitude areas have severe climatic limitations for the crops being considered in the study (Teshome, Yizengaw & Verheye, 1995). The application of ALES in Columbia also shows that rooting conditions, oxygen availability and hazards like frost are the main limiting factors in rubber production (Martinez & Vanegas, 1994).

2.2.2.9 Land type survey of South Africa

A land type is defined as an area of land than can be shown at 1:250 000 scale that displays a marked degree of uniformity with respect to terrain form, soil pattern and climate (Land Type Survey Staff, 1984). The aim of the land type survey in South

Africa was to make a systematic inventory of the natural agricultural resources of the country (Land Type Survey Staff, 1984).

The survey was carried out in the following manner: Each land area, covered by a 1:250 000 map, was surveyed in a stepwise fashion on each of its component 1:50 000 maps. First, areas displaying a marked uniformity of terrain form (called terrain types) were delineated on 1:50 000 topo-cadastral maps. Where available, satellite imagery was used to facilitate the task. The major soils in each terrain type were identified by traversing each terrain type, augering and observing exposures such as road cuttings and digging occasional soil pits. From this information, areas displaying a uniform terrain and soil pattern (called pedosystems) were delineated. Modal profiles of the main soils were described and sampled for detailed analysis. Next, a separate map showing the distribution of climate zones was drawn based on data from available climate stations, natural vegetation, soils, crop performance, altitude and topography. The climate map was superimposed upon the pedosystem map to produce a land type map, where each land type displays a marked uniformity in terms of terrain form, soil pattern, and climate. The boundaries of the land types were transferred from the 1:50 000 to 1:250 000 maps. Finally, an inventory of each land type was compiled to describe the terrain, soil and climate (Land Type Survey Staff, 2002).

The land type data is available in the form of paper copy maps and memoirs as well as in GIS format. It includes the following:

(i) Delineations of land types at a scale of 1:250 000.
(ii) Descriptions (called inventories) of the terrain and soil pattern in each terrain unit.
(iii) Detailed soil profile descriptions and detailed soil analyses of representative soil profiles (called modal profiles).
(iv) Detailed descriptions of the climate of each land type.

The soil and terrain inventory of Land Type Dc17 presented in Table 2.1 provides an example of the data presented for each land type in South Africa. The following information is included: the land type number; the climate zone in which the land type occurs; the modal profiles; geology; soils; terrain form; total area; estimated area available for agriculture. A description of the terrain and soil pattern in each terrain unit is given in Table 2.1 together with the area of the land type (239 080 ha). Profile descriptions of the representative soil profiles (modal profiles) are given in Appendix 2.1, and the detailed description of the climate is given in Table 2.2 and 2.3 and discussed in section 2.4.3. The Land Type Survey of most of the Free State Province was carried out by J.F. Eloff and A.T.P. Bennie. The data for many land types in the Province is therefore the same as that for the pedosystems defined in Eloff (1984). Land Type Dc 17 is one of these, and is named Sepane or DIII2sn (Eloff, 1984).

The land type survey effectively described the natural agricultural resources of South Africa. A total of 7200 land types and 3000 climate zones were identified (Land Type Survey Staff, 2004). The database contains profile descriptions and comprehensive soil analyses for 2 400 modal profiles (Land Type Survey Staff, 2004). The results provide a comprehensive register of soils and their distribution in South Africa. A common legend was drawn up for all the land type maps of South Africa. This legend is presented in each Memoir which accompanies a set of maps, e.g. Memoirs on the Agricultural Natural Resources of South Africa No4. Land Types of the Maps 2626 West Rand 2726 Kroonstad. The following broad soil patterns were identified and an appropriate symbol allocated to each one. To each land type on the maps the relevant symbol was recorded to indicate the dominant soil pattern. The broad soil patterns were as follows:

- Red or yellow apedal, freely drained soils (map units Aa – Ai)
- Plinthic catena: upland duplex and margalitic soils rare (map units Ba – Bd)
- Plinthic catena: upland duplex and/ or margalitic soils common (map unit Ca)
- Prismacutanic and/or pedocutanic diagnostic horizons dominant (map units Da – Dc).
- One or more of: vertic, melanic, red structured diagnostic horizons (map units Ea).
- Glenrosa and/or Mispah forms (other soils may occur) (map units Fa – Fc).
- Soils with a diagnostic ferrihumic horizon (map units Ga and Gb).
- Grey regic sand (map units Ha – Hd).
- Miscellaneous land classes (map units Ia – Ic).

Field experiments have shown that duplex and margalitic soils are suitable for IRWH (Hensley *et al.*, 2000; Botha *et al.*, 2003). The focus of this study is therefore on land types dominated by these soils. Details of the Ca, Da, and Ea land types are therefore presented below.

Plinthic catena: upland duplex and/or margalitic soils common (map unit Ca):

Unit Ca indicates land that qualifies as a plinthic catena but which has, in upland positions, margalitic and/or duplex soils that together cover more than 10 % of the total area.

Prismacutanic and/or pedocutanic diagnostic horizons dominant (map units Da – Dc)

Units Da – Dc accommodate land where duplex soils are dominant. Through an oversight the gleycutanic diagnostic horizon was omitted from the title. Upland soils that display duplex character include Estcourt, Sterkspruit, Swartland, Valsrivier and Kroonstad forms. After subtracting exposed rock, stones or boulders, more than half of the remaining land must consist of duplex soils. Da refers to land where duplex soils with red B horizons comprise more than half of the area covered by duplex soils. Db refers to land where duplex soils with non-red B horizons comprise more than half of the area covered by duplex soils. Dc indicates land that qualifies for inclusion in D but, in addition to the duplex soils, more than 10 % of the land type is made up of soil forms that have one or more of the following diagnostic horizons: vertic, melanic, red structured.

One or more of: vertic, melanic, red structured diagnostic horizons (map unit Ea)

This unit indicates land with high base status, dark coloured and/or red soils, usually clayey, associated with basic parent materials. A land type more than half of which is covered by soil forms with vertic, melanic and red structured diagnostic horizons qualifies for inclusion in Ea provided it does not qualify for inclusion in units A, B, or C. Land types in which these soils cover less than half of the area may also qualify for inclusion (i) where duplex soils occur in the non-rock land but where unit Ea soils cover a larger area than the duplex soils, or (ii) where exposed rock covers more than half the land type.

Table 2.1 Soil and terrain form inventory of land type data Dc17 (Land Type Survey Staff, 2002)

LAND TYPE : Dc17
CLIMATE ZONE : 46S

Occurrence (maps) and areas:
2826 Winburg (4750 ha) 2926 Bloemfontein (234330 ha)

Inventory by:
J.FEloff & A.T.PBennie

Area : 239080 ha

Modal Profiles:
P605 P607

Estimated area unavailable for agriculture: 4080 ha

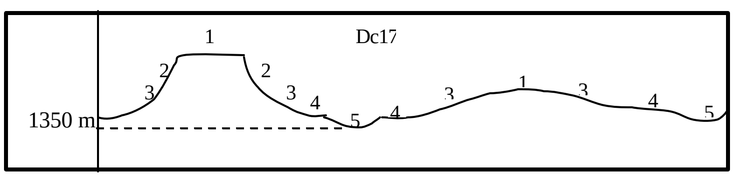
Terrain unit		1	1(1)	2	3	3(1)	4	5
% of land type	:	6	12	1	12	40	20	9
Area (ha)	:	14345	28690	2391	28690	95632	47816	21517
Slope (%)	:	2-8	1-2	90-150	12-45	2-3	0-2	0-3
Slope length (m)	:	50-500	100-700	100-400	100-600	300-1000	250-800	50-300
Slope shape	:	Z-Y	Z-Y	Z	X	Z-Y	Z	X-Z
MB0, MB1 (ha)	:	0	27255	0	0	92763	47816	18505
MB2 - MB4 (ha)	:	14345	1434	2391	28690	2869	0	3012

Soil series or land classes	Depth	MB	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	ha	%	Total ha	Total %	Clay content (%) A	E	B21	Hor	Texture Class	Limiting material
Soil-rock complex :	(mm)																							
Rock		4:	10042	70			2391	100	18648	65							31080	13						
Mispah Ms10, Williamson Gs16, Shorrocks Hu36,	100-250	3:	2152	15					4304	15							6455	2.7	10-20		15-25	A	LmfiSa - SaLm	R,so
Milkwood Mw11, Glengazi Bo31 Rashseni Bo21, Glendale Sd21	250-350	3:	1148	8					2869	10							4017	1.7	25-50		35-55	A	fiSaClL m - SaCl	R,vp,vr
Swartland Sw31, Sterkspruit Ss26,	100-250	3:	1004	7					2869	10							3873	1.6	10-20		40-50	B	fiSaCl	Vp,pr,
Swartland Sw31,Nyoka Sw41, Omdraai Sw42	100-250	0:			14345	50					33471	35	16736	35	3443	16	67994	28.4	15-30		40-60	B	fiSaCl-Cl	vp
Shepperdvale Va42,Lidley Va 41, Arniston Va31	100-300	0:			7172	25					19126	20	14345	30	3443	16	44086	18.4	15-30		45-60	B	fiSaCl-Cl	vp
Milkwood Mw11,Grythorne Mw21	300-600	0:									19126	20	9563	20	3873	18	32563	13.6	40-55			A	fiSaCl-Cl	R
Glengazi Bo31,Bonheim Bo41	250-400	0:									9563	10	3347	7	2582	12	15492	6.5	40-55		45-60	A	fiSaCl-Cl	vp
Estcourt Es36,Enkeldoom Es33	200-350	0:									4782	5	2391	5	646	3	7818	3.3	12-25	10-20	45-60	E	LmfiSa - SaLm	pr
Sterkspruit Ss26,	100-300	0:			5738	20					1913	2					7651	3.2	15-30		45-60	A	fisaLm-SaClLm	pr
Gelykvlakte Ar20	400-900	0:									4782	5	1434	3	1076	5	7292	3.1	40-60			A	fiSaCl-Cl	R
Mispah Ms10,Williamson Gs	100-300	0:			1434	5					2869	3					4303	1.8	10-15			A	fisaLm-SaClLm	R,so
Dundee Du10, Limpopo Oa46,	600-1200	0													3443	16	3443	1.4	15-35		25-35	B	fiSaClL m	
Stream beds		4													3012	14	3012	1.3						

MB = Mechanical limitations, MB0 = no limitation, MB1 = many stones but ploughable, MB2 = large stones and boulders, unplaughable, MB3 = very shallow soils on rock, MB4 = lack of soil
Slope shapes: X = concave, Y = convex, Z = straight
Depth limiting material: vp = pedocutanic B horizon, pr = prismacutanic B horizon, R = rock, so = saprolite

Terrain type A4 Geology: Sandstone, shale and mudstone of the Beaufort group with dolerite intrusions.

Terrain form sketch



2.3 The Natural Agricultural Resources of South Africa and the Free State Province

In Free State Province the most important factor limiting agricultural production is the availability of water (Eloff, 1984). This is true for much of South Africa**.** Rainfall is distributed unevenly across the country (Figure 2.2). At least one third of the country, particularly the north-western portion, have less than 400 mm of rain annually**.** This inadequate rainfall is the main reason for the relatively small portion of South Africa considered to be suitable for crop production (Figure 2.3). The study area is located in the Free State Province in the 400-600 mm rainfall region, an area of low potential for crop production.

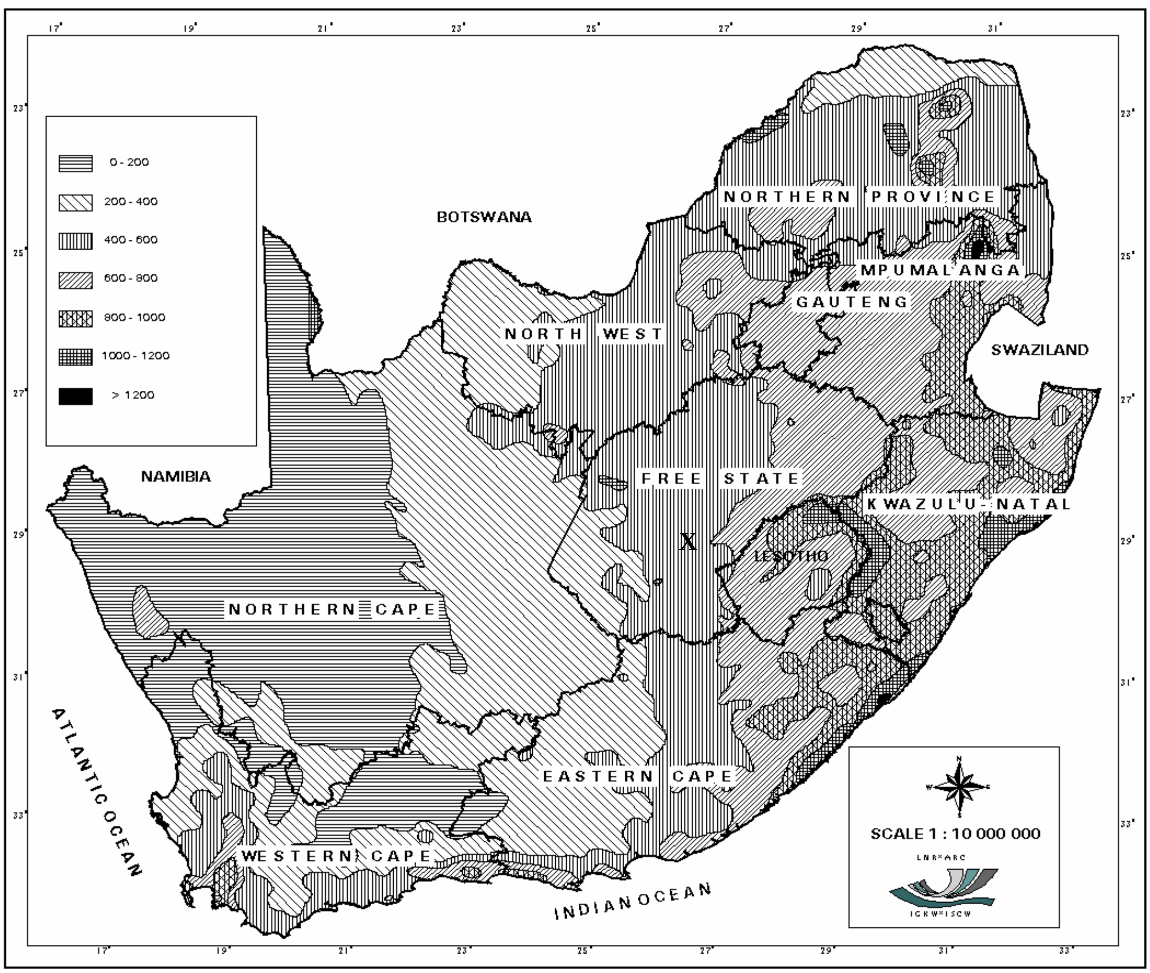


Figure 2.2 Mean annual rainfall (mm) in South Africa (Beukes, Bennie & Hensley, 2004). X = Study area

Sunflower and maize are crops adapted to semi-arid areas where they can grow under water stress conditions. In the past crop production in the Free State Province has generally been low in areas with mean annual rainfall (MAR) < 500 mm, effective rooting depth of < 600 mm and with clay content of < 10 % and > 35 % (Eloff 1984). Maize and all major cereal crops are members of the grass family, *Gramineae*. Maize is one of the oldest grains and one of the most productive food plants, being the leading cereal in terms of global production (about 600 million tons) and average yield of around 4 t/ha (FAO, 2000). The maize industry plays a very important role in the economy in South Africa. It is the largest locally produced field crop and most important source of carbohydrates in the Southern African Customs Union (SACU) for animal and human consumption. South Africa is the main maize producer in SACU, with an average production of approximately 9.0 million tons per annum over the past 10 years. Local consumption of maize amounts to approximately 7.4 million tons and surplus maize is usually exported(South Africa Year Book, 2002/03). The largest production areas of white maize are the Free State and North-West Provinces. The cultivated land of the Free State Province covers approximately 3.2 million ha, while natural veld and grazing cover approximately 8.7 million ha (South Africa Yearbook, 2002/03). Field crops contributed an average of 54.3 % to the gross agricultural income for the years 1983, 1988, 1991 and 1993 (Department of Agriculture, Free State Province, 1996).

The inherent limitations of the natural resource base of South Africa and variable climate require land users to be very circumspect in how they use and manage these resources so as to retain their productive capacity. This accentuates the importance of reliable land evaluation, which enables land-use planners and farmers to be aware of their production potentials and risks involved. The Conservation of Agricultural Resources Act, (Act 43 of 1983), allows the national Department of Agriculture to exercise control over the utilization of South Africa's natural agricultural resources. This legislation provides for the conservation of these resources through maintaining the land's production potential for future use (South Africa Yearbook 2002/03). The land type survey of South Africa provides a suitable basis for the evaluation of this potential.

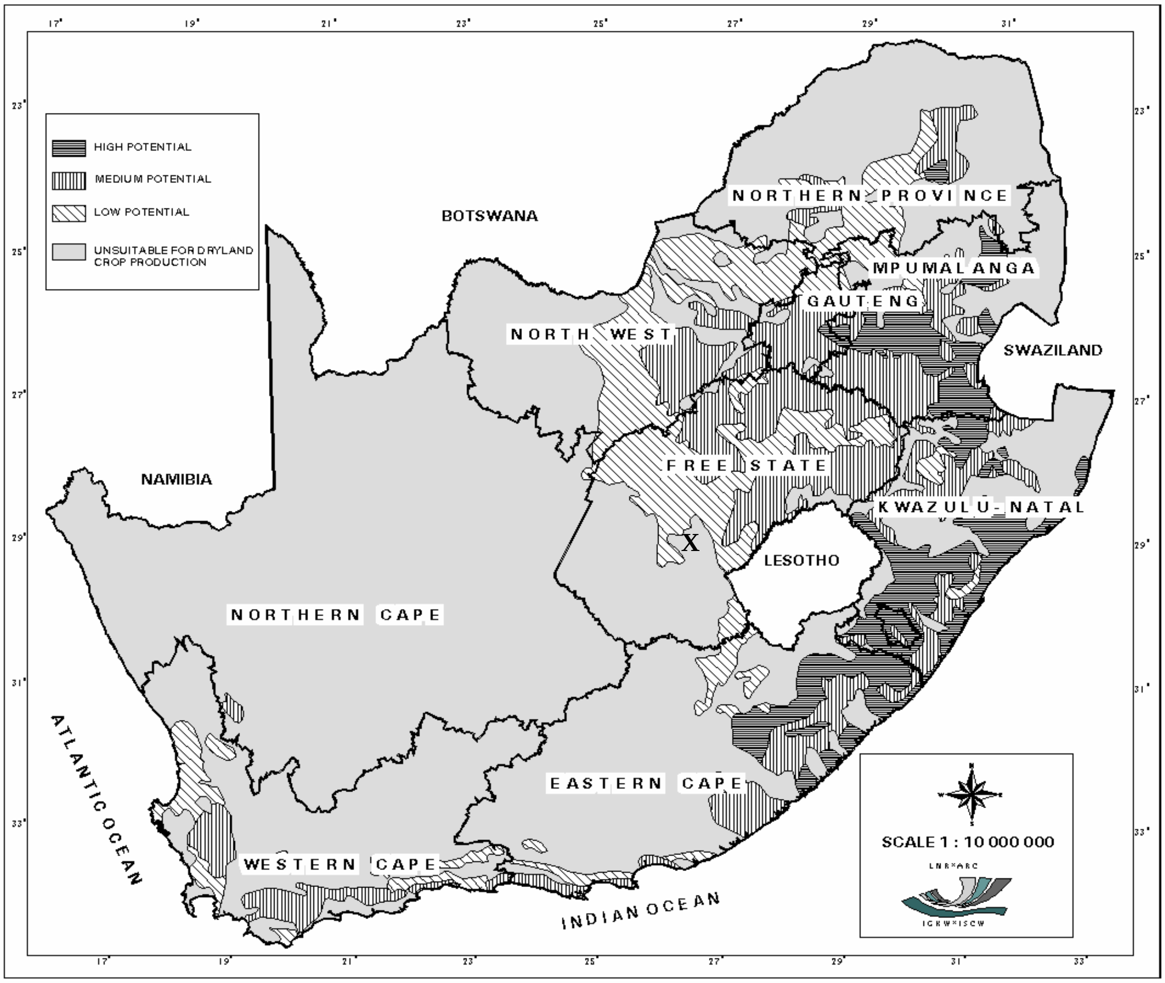


Figure 2.3 Generalized crop production potential of South Africa (Beukes *et al*., 2004). The Free State as the study area is located in the centre of the map (X).

Eloff (1984) evaluated the crop production potential of a portion of the Free State province. At that time the Department of Agriculture had subdivided the country into defined agroecological regions. Part of the current Free State Province was located in what was called the Free State Agro-ecological Region, and part was located in what was called the Highveld Agro-ecological Region (Scheepers, Smit and Ludick, 1984; Eloff, 1984). The study of Eloff (1984) was concerned with the Free State Agro-ecological Region, abbreviated as the Free State Region. The part of the Free State province located in the Highveld Region is shown in Figure 2.4. In order to make an estimate of the area of the Free State province that is suitable for IRWH, it is therefore necessary to consider two separate portions of the Free State Province *i.e.* that in the Free State Region, and that portion in the Highveld region. The information of the former is taken from Eloff (1984), and for the latter from Ludick & Wooding (1991). Details are presented in section 4.6.

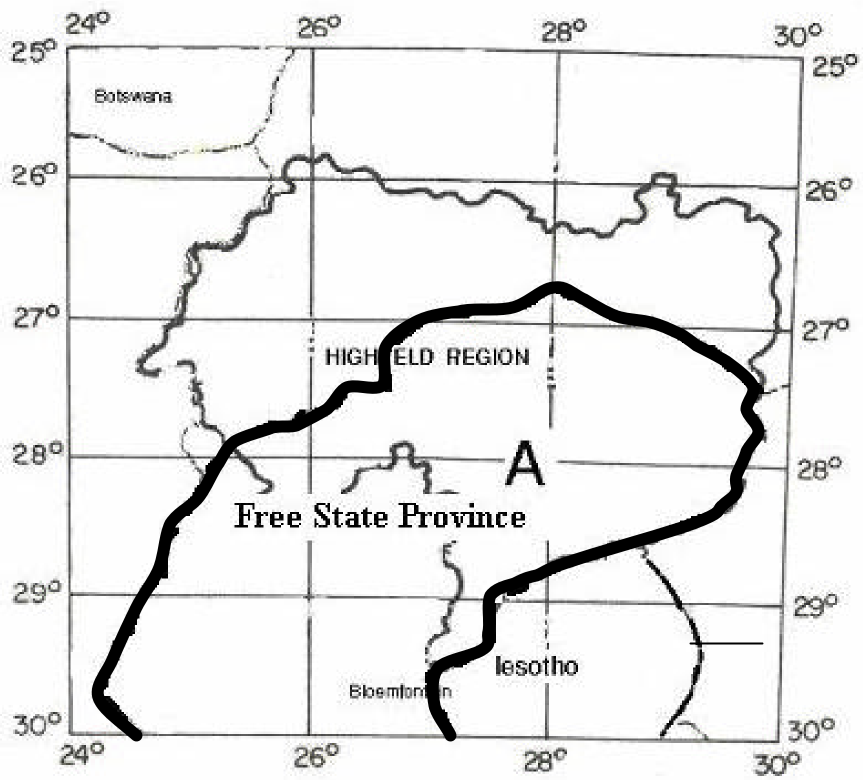


Figure 2.4 Map showing the portion of the Free State Province (boundary ▬)which occurs in the Highveld Region (boundary —), i.e. portion A (adapted from Scheepers, Smit & Ludick (1984).

2.4 The Natural Resources of the Study area

2.4.1 Geology

Parent material constitutes the initial state of a soil system. It determines the basic materials available for leaching and mineral formation, and strongly influences texture and related porosity and permeability. Rock type has a profound influence on soil formation, governing parameters like texture and availability of bases (Barshad, 1966;

Clemency, 1975). Different parent materials weather at very different rates (Chesworth, 1973; Clemency, 1975). The influence of parent material on soil characteristics increases with decreasing degree of weathering (Eberl, 1994).

The study area is situated geologically in the central eastern portion of the main Karoo basin of South Africa (Theron, 1970). This basin straddles the Palaeozoic and Mesozoic eras and occupies about half of the area of South Africa (Van der Eyk *et al.*, 1969; Buhmann, 1992). A stable floor comprising the Kaapvaal Craton underlies the Karoo Basin in the area. Sedimentary rocks of the Late Permian Adelaide, and Early Triassic Tarkastad Subgroup of the Beaufort Group, and the Late Triassic Molteno Formation of the Karoo Supergroup underlay the area (Bosch, 2001). On the 2926 Bloemfontein 1:250 000 scale geological sheet the Adelaide Subgroup is divided into Upper, Lower and Middle Stages of the Beaufort Group based upon palaeontological evidence. Purple and green shale and thick sandstone beds characterize the upper stage. The middle and lower stages are characterized by sandstone shale and mudstone (Theron, 1969).

2.4.1.1 Adelaide Subgroup

The Adelaide subgroup in the main Karoo basin consists of greenish (or bluish), grey, and greyish-red mudstone and grey, moderately to well-sorted, very fine- to medium-grained lithofeldspathic sandstone. Carbonaceous, black shale occurs near the Feloana Dam (Bosch, 2001). The Adelaide subgroup underlies approximately 80 % of the area on the 1:50 000 map 2926BB, but there are only occasional outctops. Outcrops are generally restricted to erosion gullies, especially the mudstone, whereas the sandstone often occurs in streambeds (Bosch, 2001).

2.4.1.2 Tarkastad Subgroup

The Early Triassic Tarkastad Subgroup generally has a greater abundance of both sandstone and red mudstone than the Adelaide Subgroup. In the southern portion of the Karoo Basin the Tarkastad Subgroup includes a sandstone-rich Katberg Formation and a mudstone-rich upper Burgesdorp Formation. The sandstone:mudstone ratio of the Tarkastad Subgroup decreases from the south to the north and it therefore becomes difficult to separate the Tarkastad subgroup and Burgesdorp Formations in the Free State Province. This difficulty is thus evident in the Thaba Nchu area (Bosch, 2001).

Rock of the Tarkastad Subgroup mostly outcrops along higher ground in the area of Moroto, Rakhoi, Mohono and Thaba Nchu mountains, the hill on the farms Leeuwfontein 129, Mooirand 321, Tuinbult 403, Schurwekop 31, and near Houtnek along the east-west striking dolerite ridge in the north (Bosch, 2001).

The results from the x-ray diffraction (XDR) analyses shows that the main mineral constituents of mudstone of the Tarkastad Subgroup are quartz (57 %), muscovite (10 %), hematite (9 %), ilmenite/smectite interstitial (8 %), clinochlore (7 %), plagioclase (4 %), and smectite (4 %) (average percentages given) (Bosch, 2001).

2.4.1.3 Molteno Formation

The composition of the Molteno Formation as described by Hancox (1998) is fine-grained to very coarse grained, yellowish grey, pale to moderate brown, pale blue and very light grey sandstone with subordinate dark grey, light to olive-grey, dark reddish-brown and dusky red siltstone, mudstone and coal. It was deposited mainly by shallow, braided rivers. The Molteno Formation only outcrops on the three highest mountains in the 1:50 000 map 2926BB Thaba Nchu at Mohono, Moroto and Thaba Nchu. It also occurs north of the map in the hill east of Rakahio. The result from the (XDR) analyses indicates that the main mineral constituents of the Molteno Formation mudstone are quartz (70 %), plagioclase (12 %), clinochlore (12 %), muscovite (5 %) and illmenite/smectite interstitial (4 %). Sandstone of the Molteno Formation has variable combination as shown in the description below of two separate samples. Variation is probably due to differences in source and depositional environment (Bosch, 2001). A petrographic study on a sample of Molteno sandstone from Mohono shows that the rock consists of quartz (92 %), mudstone fragments (2 %), and feldspar (1 %) in a matrix (5 %)

of sericite, iron oxide, chlorite and muscovite (few flakes). Sandstone from Thaba Nchu studied petorgraphically showed that the rock consists of grains of quartz (48 %), feldspar (1 %), and polycrystalline quartz (1 %) in a matrix of (50 %) of clay, calcite, chlorite, and minor iron oxide and magnetite (Bosch, 2001).

2.4.1.4 Dolerite

The dolerite in the study area belongs to the Karoo Dolerite Suite and is a dark grey to black, dense igneous rock that intruded the sediments of the Beaufort Group and Molteno Formations during the Jurrassic period (Bosch, 2001). The relatively hard nature and resistance of the dolerite to weathering and erosion has been responsible for the formation of hills, ridges and higher lying ground in the area. However not all the dolerite in the area forms noticeable topographic features. The dolerite intruded as dykes, sills and a possible basin like circular intrusion north of Rooikraal. The intrusions vary from a few centimeters to tens of meters thick and the shape and angle of the intrusions varies considerably. Approximately 10 % of the mapped area (1:50 000 map 2926 BB Thaba Nchu) is covered by dolerite. This estimate may be much higher because dolerite can also underlie soil-covered areas mapped as Adelaide or Tarkastad Subgroups.

The dolerite is finely to coarsely crystalline, porphyritic and locally glomeroporphyritic consisting of plagioclase and pyroxene that is sub-ophitic to ophitically and locally intergranularly intergrown (Bosch, 2001). The plagioclase is normally twinned, lath-shaped and locally displays zonal internal structure and is slightly altered to smectite. Olivine relics are present in small amounts, though these are mostly completely altered to smectites. A small amount of opaque minerals are present, probable magnetite, ilmenite and hematite.

2.4.1.5 Colluvium

Colluvium is the unconsolidated, heterogeneous, and incoherent mass of soil material and/or rock fragments deposited by soil downslope movement. Colluvium is associated with the slopes of ridges and hills, although its distribution is irregular. The colluvium occurs in small, irregular shaped pockets, with large portions being covered with younger soils and vegetation, which in the absence of a drilling program did not permit its mapping (Bosch, 2001).

2.4.1.6 Alluvium

Alluvium is a water transported material deposited along the rivers, streams or depressions in the landscape. The type of landform in the study area can be described as destructional. Net erosion is occurring, resulting in sediments being eroded and transported rather than being deposited along the rivers and streams. This accounts largely for the lack of alluvium on the map. However, small localized deposits of alluvium occur next to the streambeds of the Leeuspruit, Korannaspruit and the Sepane streams. They are too small to show on the 1:50 000 cadastral map sheet (Bosch, 2001). The best exposure of alluvium occurs just west of the railway bridge on Palmietspruit 26 east of Rooifontein. The alluvium here is approximately 3 m thick and 20 m wide and is exposed along the side of the bank of the stream for about 500 m (Bosch, 2001).

2.4.1.7 Economic geology

Economically the study area is unimportant as no significant mineral deposits have been found or exploited in the area. However dolerite is locally excavated and crushed as a stone aggregate for road building material, concrete and a filling material. Mudstone in the area is potentially suitable for the manufacture of bricks. Deposits of sand, probably suited for building and plaster sand is present in alluvial deposits but these are so small that their economic potential is limited. Groundwater is the most important exploitable natural resource in the area. It is pumped primarily for human and livestock consumption and has a high potential for irrigation purposes. The probability of drilling a successful borehole in the area is high, above 60 %, and the chance of a borehole yielding more than 2 l/s are between 20 % and 30 %. The water quality is generally very good, containing less than 30 mg/l of dissolved solids (Bosch, 2001).

2.4.2 Topography

Topography refers to the outline of the earth's surface (Fitzpatrick, 1980). It modifies the distribution of water (Moore, Gessler, Nielsen & Peterson, 1993), and gives rise to local differences in soil water regime (Duchaufour, 1998). It affects erosion, colluviation, and illuviation patterns, and results in aspects that can have an effect on the microclimate (Fanning & Fanning, 1989). Topography influences pedogenetic processes by its effect on particle stability (Beckett, 1968; Parsons, 1978); drainage and the amount of water in the soil (Fitzpatrick, 1986); surface and subsurface water flow, and erosion and deposition distributions in the landscape (Conacher & Dalrymple, 1977; Daniels & Hammer, 1992; Gerard, 1992; Lark 1999); the redistribution of sediments, solutes and the distribution of various organic fractions over a landscape (Chen & Chiu, 2000) and the status of organic matter in the soil profile (Raghubanshi, 1992). These influences result in soils that generally vary continuously downslope while they tend to remain similar along contour lines (Duchaufour, 1998).

Topography influences soils in many ways, for example, the thickness of the pedon is often determined by the nature of the relief. On flat or gently sloping sites there is always the tendency for material to remain in place and cause the pedon to be thick. As the angle of the slope increases so does the erosion hazard, resulting in thin soils on strongly sloping ground (Fitzpatrick, 1980). The land type soil and terrain inventory (Table 2.1) provides examples of this. Terrain morphological unit (TMU) 2 is defined in Figure 2.5. In TMU 2, with 90 – 150 % slope, and straight slope shape (Z), the land cover is 100 % rock. In TMU 1(1) with 1 – 2 % slope and straight-convex slope shape (Z – Y), the soil is 50 % Swartland form with the depth of the A horizon alone 100 – 250 mm. The thin soil depth occurring in steep and convex slopes is an indication of rapid removal of weathered material (Virgo & Holmes, 1977; Parsons, 1978; Birkeland, 1999). This removal of finer particles and soluble salts of Ca, Mg and Na from upper steeper slopes is due to hillside pedogenic processes (Parsons, 1978; Agbu, Ojangu & Olson, 1989; Nizyeimana & Bicki, 1992). Rapid runoff and shallow soils limit water infiltration and retard soil development (Parsons, 1978). On the other hand, materials eroded from steep upper slopes are deposited in concave flatter low lying slopes (Parsons, 1978). Concentrations of fine particles, soluble minerals and organic carbon characterize these landscape positions (Nizyeimana & Bicki, 1992). This can be seen in Table 2.1. Lower slopes are areas of water accumulation and are often poorly or imperfectly drained. Areas on TMU 5 with a slope of 0-3 %, and with convex-linear slope shape, consist of about 16 % of soils of Dundee series in which the distinguishing diagnostic horizon is stratified alluvium (Table 2.1).

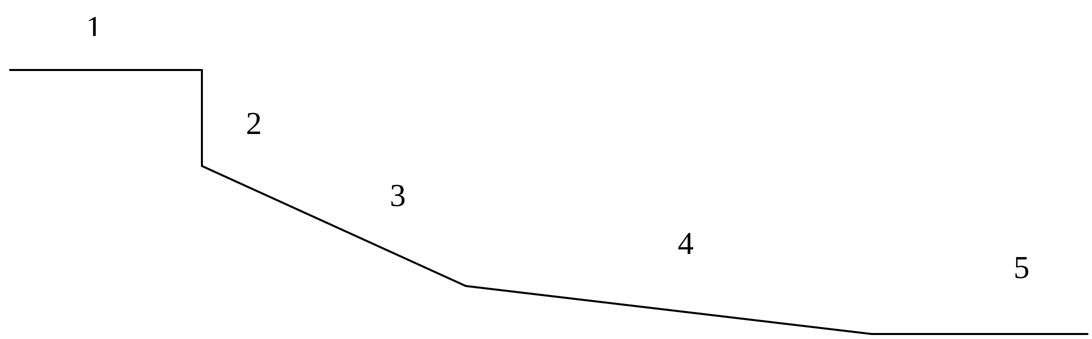


Figure 2.5 Terrain morphological units (TMU's) 1= crest, 2 = scarp, 3 = midslope, 4 = footslope, 5 = valley bottom (Soil Classification Working Group, 1991)

The abbreviations used in Figure 2.6 are useful when describing the topography at a particular site. It needs to be kept in mind that topography has a major influence in pedogenesis in the study area, and hence the value of these abrevations. In Figure 2.6, the first letter L means contours that are approximately the same distance apart *i.e.* . the slope is even. The second letter L means contours are approximately straight lines *i.e.* . no tendency towards convex or concave. The first V means that the slope is becoming steeper and the second V shows that water is dispersing sideways. This situation promotes dryness. The first C indicates that slope is decreasing and the second C shows that water is accumulating towards the centre. This condition promotes wetness.

The following slope shape symbols were used in the Land Type Survey of South Africa, and are therefore presented in Table 2.1: Concave (X), convex (Y), and straight (Z). These symbols used and those in Figure 2.6 can be compared as follows: C = X, V = Y and L = Z Different combinations of X, Y and Z presumably mean that both slope shapes occur. At that small scale it would be difficult to present the detail given in Figure 2.6.

The study area consists of an irregular landscape with gently undulating plains broken by hillocks, ridges and mountains, which are clearly depicted in the terrain form sketch in Table 2.1. The dominant TMU's are 3(1), 4, 3 and 1(1) comprising an estimated 40 %, 20 %, 12 % and 12 % of the total area respectively. The slope shapes are straight–convex, straight, concave and concave–straight (Table 2.1). However it needs to be noticed here that in Table 2.1 the soil depths reported are misleading. Pedocutanic B horizons were considered as a root and water impeding layer. Because of this the percentage of shallow soils has been exaggerated. Soils present in TMU 3(1), 4, 5 belong mostly to the Valsrivier, Swartland, Sterkspruit, Estcourt, Arcadia, and Dundee forms (Table 2.1). Part of the land type is characterized by non-arable stony areas or areas with shallow soils (MB3 or MB4 in Table 2.1). They constitute about 20 % of the land type, with 59 % of this land in TMU's 1 and 3.

The information presented in Table 2.1 shows that there is tight link between process and pattern. This makes the prediction of soil attributes from topography attractive and, in many respects, successful (Sobieraj, Elsenbeer, Coelho & Newton, 2002). The success rate depends on the quality of expert knowledge available.

2.4.3 Climate

Climate is the principal factor governing the rate and type of soil formation (Fitzpatrick, 1986). It influences the intensity of weathering and leaching (Birkeland, 1999). Low temperatures slow down organic matter decomposition and soil formation (Fanning & Fanning, 1989).

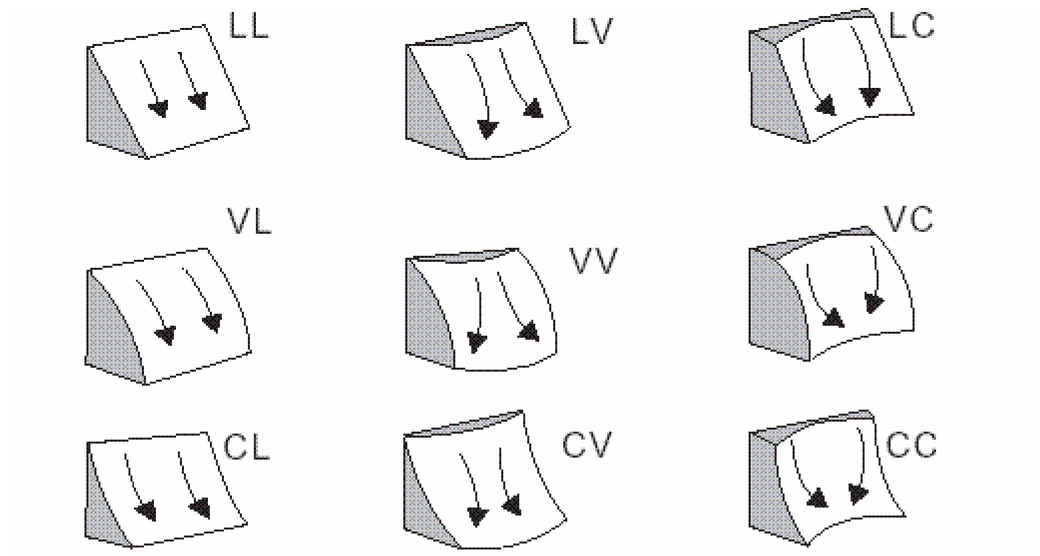


Figure 2.6 Slope shape is described in two directions: The first and second letters describe the downslope and lateral or contour patterns respectively. (Adapted from Schoeneberger, Wysocki, Benham & Broderson, 2002) L = Linear, V = Convex, C = Concave, ? = Surface flow pathway

Soils vary, depending on the climate. Temperature and moisture amounts cause different patterns of weathering and leaching. Wind redistributes sand and other particles especially in arid regions. The amount, intensity, timing, and kind of precipitation influence soil formation. Seasonal and daily changes in temperature affect water effectiveness, biological activity, rates of chemical reactions, and kinds of vegetation (USDA, 2004).

Climate is not only important in soil formation but also in land suitability evaluation. Important characteristics in land evaluation are rainfall, temperature and radiation (Sys *et al.*, 1991). Rainfall and temperature and their distribution over the year are the main factors for differentiation globally into agro-climatic zones (Sys *et al.*, 1991). In line with this, for Land Type Dc17 climate data (Table 2.2) was an important factor in defining and delineating the land type boundaries (Land Type Survey Staff, 2002).

The study area occurs in climate zone No. 46S (Table 2.2). It is a summer rainfall area where most of the rain occurs in January, February and March. Temperature during these months is relatively high. Low temperatures are experienced during winter for 120 - 150 days from May 15 stretching up to September 15 Table 2.2, (Eloff, 1984). There is frost hazard during June and July (Table 2.2). The mean aridity index (AI) for the study area equal to 0.232 (Table 2.3) has been calculated from the nearby Glen meteorological station (Table 2.3) where rainfall and temperature data of 81 years (1922-2003) and class A pan evaporation data for 42 years (1958-2000) are available (Botha *et al.*, 2003). According to UNEP (1992) and Stewart & Robinson (1997) semi-arid areas have aridity index (AI) of 0.2 – 0.5. Therefore the high evaporative demand, relatively low rainfall, and average AI of 0.23 (Table 2.3) makes the study area semi-arid. Worst conditions for crop production generally occur during December and January with AI values of 0.23 and 0.30 respectively. Rainfall during these months is generally very erratic with much of it in the form of high intensity rainfall events. March rainfall is the second highest (Tables 2.2 and 2.3) and also most reliable, with the additional advantage that during this month it has the lowest evaporative demand resulting in a relatively favourable AI value of 0.46.

Table 2.2 Data for climate zone 46S (Land Type Survey Staff, 2002)

Month	Rainfall (mm)	Temperature (^{0}C)		
	Rm	Tx	Tn	Tm
Jan	87.3	30.2	14.8	22.5
Feb	77.6	28.9	14.6	21.8
Mar	81.7	26.6	12.3	19.5
Apr	49.3	23.2	7.7	15.5
May	21.5	19.8	3.1	11.5
Jun	8.0	16.9	-0.9	8.0
Jul	10.2	17.5	-0.9	8.3
Aug	13.3	19.9	1.1	10.5
Sep	21.4	24.1	5.5	14.8
Oct	45.9	26.1	9.4	17.8
Nov	66.9	27.9	12.1	20.0
Dec	64.5	29.6	14.0	21.8
	R =551			

Rm = Mean of mean monthly rainfall totals from all stations
R = Mean annual total rainfall from the mean annual totals from all stations
Tx = Mean daily maximum temperatures for each month from all stations
Tn = Mean daily minimum temperatures for each month from all stations
Tm = Monthly mean temperatures

This feature can be used to advantage by planting crops with a short growing season early in January so that they flower during a favourable period. Examples are sunflower and the new short season-growing maize cultivars (Hensley *et al*., 2000).

2.4.4 Vegetation

Vegetation types play an important role in the formation of soils (Buol *et al*., 1997; Fanning & Fanning, 1989). Moist Cool Highveld Grassland of the grassland biome covers the study area (Bredenkamp & Van Rooyen, 1996). Currently about 60 percent of the original vegetation has been destroyed by farming and urban development. Grassland covers the plains and pristine grass and low bushes grow on the hills, ridges and mountains. Redgrass (*Themeda triandra*) is the dominant grass species when the veld is in pristine condition (Bredenkamp and Van Rooyen, 1996). The combination of erratic rainfall and cold winters has resulted in the dominance of this grass species. A portion of the Thaba Nchu Mountains and hills in the southeastern portion of the map (2926BB Thaba Nchu) are covered with pine and eucalyptus trees (Bosch, 2001). The condition of veld in the Thaba Nchu area has suffered from over grazing, resulting in considerable soil erosion (De Villiers, 1998 & Dreyer, Fourie & Kok, 1999). In this study, the role of vegetation was considered to contribute little to the spatial variability of the soils within the soilscapes because the plant species distribution is reasonably homogenous.

Table 2.3 Long-term monthly and annual climate data from the Glen meteorological station (ARC-ISCW data); Rain and temperature data: 1922 – 2003; Evaporation: 1958 – 2000 (Botha *et al.*, 2003)

Item	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Long-term mean
Rain (mm)	8.1	11.6	19.3	49	68.2	66.6	83.4	77.6	80.7	49.3	19.9	9	542.7
Evap (mm)*[1]	93.5	140.6	197.5	239.1	256.0	291.6	276.5	207.7	177.1	126.1	110.6	81.9	2198.2
Max T*[2]	17.8	20.6	24.4	25.4	28.3	30.2	30.8	29.5	27.4	23.9	20.5	17.9	24.8
Min T*[2]	-1.6	0.9	5.2	9.2	12.0	14.0	15.3	14.8	12.6	7.8	2.8	-1.1	7.5
AvT*[2]	8.1	10.7	14.8	17.5	20.1	22.0	23.0	22.1	19.9	15.8	11.6	8.2	16.2
AI*[3]	0.087	0.083	0.098	0.205	0.266	0.228	0.302	0.374	0.456	0.391	0.180	0.110	0.232

*[1] Class A pan *[2]T = temperature in ^{o}C; mean values for the month *[3] AI = rainfall/pan evaporation

2.4.5 Soils

2.4.5.1 Land type Information

In Land Type Dc17 soils with prismacutanic and/or pedocutanic diagnostic horizons are dominant (Land Type Survey Staff, 2002). Other than exposed rock, stones or boulders, more than half of the remaining land consist of duplex soils. Upland soils that display duplex character include Estcourt, Sterkspruit, Swartland, Valsrivier and Kroonstad forms. In addition to the duplex soils more than 10 % of the land type is made up of soil forms that have one or more of the following diagnostic horizons: vertic, melanic and red structured (Land Type Survey Staff, 2002). The number 17 describes a specific map unit.

2.4.5.2 Genesis and characteristics of the main soils of Land Type Dc17

a) Duplex Soils

Duplex soils are 'texture contrast' soils with a sharp boundary (less than 10 cm thick) between a relatively coarse textured A horizon, and a finer textured B horizon. A duplex soil is a soil with relatively permeable topsoil overlying a very slowly permeable diagnostic horizon which is not a hardpan (Van der Watt & Van Rooyen, 1995). There is no doubt that these soils can form either in a single or binary parent material (MacVicar, 1978).

Duplex morphology is favoured by one or more of the following conditions present in varying degrees: a low ferrous iron reserve of the parent material; a slow rate of release of iron from primary minerals; reduction and removal of ferric iron; high exchangeable sodium percentage; non expansive rather than expansive clay minerals (MacVicar, 1978). Duplex soils can be divided into red, yellow, brown, dark and gleyed soils on the basis of subsurface soil colour. This is followed by a further series of physical and chemical subdivisions which include surface crusting, hard setting structure in the subsoil, the presence of a bleached horizon between the A and B horizons, and soil reaction trend (acid, neutral or alkaline) (Belford & Gregory, 1992).

Because the A horizons are relatively coarse textured they have a low water holding capacity and the structure is usually weak**.** Chemical cementing agents are present in some profiles, and these can lead to hard layers within the profile**.** In Australian soils the clay in the B horizons is usually kaolinite**.** Subsoils with kaolinitic clay usually have a massive structure, with few large cracks or fissures, so that their permeability to water and roots is low but variable**.** This means that the A horizon can easily waterlog because of the abrupt change in the rate of water movement at the A/B junction (Belford & Gregory, 1992).

Common soils of the study area that are present in the inventory of land type (Table 2.1) are discussed below. The prismacutanic B has an abrupt transition with an overlying orthic A or E horizon (Soil Classification Working Group, 1991). It accommodates modal duplex character, namely an increase in clay content across an abrupt transition from the overlying orthic A (or E horizon in the case of Estcourt form) to the prismacutanic B. The structure is at least one grade stronger and two grades harder or firmer than that of the overlying horizon. The prismacutanic B-horizon accommodates the classical concept of the solodized solonetz B in which prismatic or columnar structure has developed under an abrupt transition, and with cutanic character conspicuous as colour differences between ped interiors and exteriors.

The upper surface of the prismacutanic B is normally found within 500 mm of the soil surface. A G horizon rather than a prismacutanic B develops when the overburden is excessively thick, and particularly when it is coarse textured, due to increased hydromorphy (Soil Classification Working Group, 1991).

The processes involved in the development of E horizon include eluviation and illuviation of silicate clay and, in the better-drained soils, it includes associated iron oxides (Fanning & Fanning, 1989). These soil forms are correlated with Alfisols of the USDA soil classification system (MacVicar., De Villiers, Loxton, Verster, Lambrechts, Merryweather, Le Roux, Van Rooyen, & Harmse, 1977). The dominant processes in most Alfisols are those that produce a subsurface horizon relatively enriched in layer silicate clays, and those that cycle nutrients in upper horizon, mostly by promoting organic matter decomposition. The processes include the selective loss of clays in A and E horizons by dispersion and lateral transport, dissolution of clays in A and E horizons and leaching of dissolved constituents, neosynthesis of clays in the B horizon from dissolved constituents, clay production in the B horizon by weathering of primary minerals, and residual concentration of clay by selective dissolution of more soluble minerals (Buol *et al*., 1997). Because of their highly leached nature, soils of the Estcourt form are naturally low in many of the elements needed for plant growth, such as nitrogen, phosphorus, potassium, sulphur, copper, manganese, zinc, molybdenum and sometimes boron.

The E horizon becomes thicker in wetter places compared to drier places. This was observed on soils with sandstone parent material in Pennsylvania where the E horizon was slightly thicker on the north west (NW) compared to the south west (SW) slope. These aspect differences were probably caused by less evaporation on "shaded" NW slopes compared to "sunny" SW slopes, resulting in generally higher water levels and more effective eluviation and illuviation on the NW slope (Brian & Edward, 1991).

The well developed duplex soils of the Sterkspruit and Estcourt forms and partly developed duplex soils of the Valsrivier and Swartland forms occur in Land Type Dc17.

Soils of the Sterkspruit form covers about 4.8 % of Land Type Dc17 and occurs on TMU 1 (7 %) and TMU 3 (10 %). Soils of the Estcourt form covers about 3.3 % and occurs on TMU 3(1) (5 %), 4 (5 %) and 5 (3 %) (Table 2.1). Here TMU 1 (1) refers to the upper crest and TMU 1 (2) refers to the lower crest. The same with the other TMU's.

Soils of the Swartland form are most common one in the land type, covering about 28 % of the total area of Land Type Dc17 and occurs on TMU's 1(1) (50 %), 3(1) (35 %), 4 (35 %) and 5 (16 %). Soils of the Valsrivier form covers about 18 % of Land Type Dc17 and occurs on TMU's 1(1) (25 %), 3(1) (20 %), 4 (30 %) and 5 (16 %) (Table 2.1).

b) Margalitic soils

The term 'margalitic' refers to A horizons with strongly developed structure that are dark coloured with a high base status, Ca and Mg being the predominant exchangeable cations (Van der Watt & Van Rooyen, 1995). Margalitic soils include those with vertic A or melanic A diagnostic horizons

i) Arcadia form (vertic A horizon)

The majority of Arcadia soils in South Africa exhibit dark grey to black topsoil colours and contain lime in or immediately below the A horizon as in the Rustenburg family (Buhmann & Schoeman, 1995). The horizon sequence of the Arcadia form is vertic A / unspecified material. Vertic A horizon refers to a dark coloured-horizon with a high clay content and with swell-shrink properties (Van der Watt & Van Rooyen, 1995). The clay mineral is predominantly smectitic clay. They have the capacity to swell and shrink markedly in response to water changes (Soil Classification Working Group, 1991; Wilding, Smeck & Hall, 1983). Such expansive materials have a characteristic appearance. The structure is strongly developed, ped faces are shiny and consistence is highly plastic when moist and sticky when wet. Swell-shrink potential is attested typically by the formation of conspicuous vertical cracks in the dry state and the presence, at some depth, of slickensides. However, the presence of slickensides is apparently also a function of vertical thickness, being dependent on the total volume of the material which swells and shrinks (Soil Classification Working Group, 1991). Some of the vertic diagnostic horizons are formed by progressive hydrolysis of the underlying rock. Others have formed in fine textured sediments which either contains large amounts of expanding lattice clay or else montmorillonite. The principal process taking place in these soils is the constant churning of the upper horizons, and differential movement of the soil mass accompanying changes in water content resulting in a "self-ploughing" action (Fitzpatrick, 1980).

When the soil dries and cracks some of the surface horizon tends to fall into the cracks. When the soil becomes wet and expands, high pressures develop which are released by upward movement of the material. Annual repetition of this cycle results in churning of the soil down to the depth of cracking which is usually about 1 m, hence the relatively deep, uniform pedon. An additional result of the release of pressure is the formation of the wedge structure and slickensides, as a result of one part of the soil moving and slipping over another part. It appears that two of the important requirements for the formation of these soils are a period of complete saturation with water, and secondly a marked dry season (Van der Eyk *et al.*, 1969; Fitzpatrick, 1980). The period of complete saturation causes anaerobism and reducing conditions. On the other hand, the marked dry season causes many of the basic cations to remain in the system thus producing suitable conditions for the formation of montmorillonite. Their development is encouraged by a high content of plagioclase feldspars, ferromagnesian minerals and carbonates. Deficiencies of certain minerals in the parent material can sometimes be supplied by seepage. Usually they tend to become confined more to basic or carbonate parent material as the climate becomes more humid, the reason being that, both of these materials produce large amounts of cations which maintain suitable conditions for the formation of montmorillonite. In some humid environments, they are confined to sedimentary rock containing montmorillonite and carbonates. Within the footslope soils, clay content was higher and the distribution of clay becomes more constant with depth than in the upslope pedons (Lee, Sears, Graham, Amrhein & Vali, 2003). The higher clay content in footslope soils relative to the scarp and midslope soil is due to the precipitation of smectite in the non-leaching environment and the deposition of fine particles carried in suspension from upslope. The deposition of the fine particles on the footslope is a continuing process in this environment of accumulation (Brad, Robert, Thomas & Christopher, 2003). Smectite is the predominant mineral in the clay fraction of vertic footslope soils (Lee *et al*., 2003).

Vertization, or vertisolization (Duchaufour, 1998), represents a collection of sub-processes occurring in vertisols in which the soil shrinking and swelling is evident at the landscape, pedon, and microscopic levels (Wilding & Tessier, 1988). Subhumid and semiarid climates favour the development of vertisols and they are usually old soils (Fanning & Fanning 1989). The most frequent physiographic positions for vertisols are flat areas, particularly flood-plains, valley bottoms and gentle footslope positions (Buhmann & Schoeman, 1995).

Most typically, vertic horizons in South Africa have a black or very dark colour caused but the same properties that give melanic A horizon its dark colour. However examples are known of grey, yellow brown and red vertic horizons. Colour is thus not diagnostic for the horizon but is used to differentiate within the form. In marshy situations the vertic horizon overlies a G horizon, otherwise it most commonly overlies either basic igneous rock or soil material with a very strong structure (Soil Classification Working Group, 1991). In the northern regions of the Republic of South Africa vertisols cover an area of about 1 654 700 ha; they are particularly associated with mafic igneous parent rocks, subdued relief, and an annual precipitation of 500–700 mm (Buhmann & Schoeman, 1995).

Mineralogical analyses of some 30 vertic horizons have shown that the montmorillonite content of the clay fraction is commonly of the order of 60-80 percent (Van der Eyk *et al*., 1969).

There is a large overlap between the rainfall regimes under which melanic and vertic soils occur, with a skew towards a 50 mm higher rainfall bracket for melanic horizons (Buhmann and Schoeman, 1995).

The Arcadia soil form covers about 3 % of the land type and is represented by the Gelykvlakte series which occurs mainly on midslope or TMU's 3(1) (5 %), foot slope or TMU 4 (3 %) and valley bottom or TMU 5 (5 %) (Table 2.1).

ii) Melanic soils (Bonheim and Milkwood forms)

In South Africa, soils with a melanic A horizon are of restricted aerial extent, approximately 2.3 million ha or about 2% of the territory (Van der Merwe, Laker & Buhmann, 2002). They constitute an agriculturally important soil resource. Their favourable physical and chemical properties, especially their high porosity and water holding capacity, their relatively high levels of organic matter and nutrients, and near-neutral pH values make these soils very fertile. Melanic A horizons develop from either mafic igneous (37.3 %) or sedimentary rocks (44.0 %). Dolerite (22.7 %) and sandstone (21.5 %) constituted the most common parent lithology (Van der Merwe *et al.,* 2002). Earlier these horizons were thought to form only under grass vegetation, but they have now been shown to occur under coniferous forests as well (Southard & Southard, 1989). In such forests fire probably plays a major role in their genesis (Takahashi, Dahlegren & Sase, 1994). One of the processes taking place in these soils is the decomposition and incorporation of organic matter into the mineral matter (Buol *et al*., 1997). This process is fairly complete because the supply of organic matter is small while the activity of the soil fauna is high due to the basic nature of the soil and high summer temperatures (Fitzpatrick, 1980).

The large contribution of sedimentary rocks is a reflection of the large aerial extent of these specific geological strata rather than preferential formation from these rock types. On the other hand, the large contribution of mafic igneous rocks, especially dolerite, indicates preferential formation of melanic horizons from these rocks. Melanic soils are not restricted in South Africa to a specific topographic positions and are common in crest (22 %), midslope (32 %), footslope (16 %), and valley bottom positions (30 %)(Van der Merwe *et al.,* 2002). They are associated with gentle slopes or flat-lying areas. Climate has been identified as a dominant soil-forming factor and as many as 75 % of the melanic soils have formed under climatic conditions which are characterized by contrasting seasons. A mean annual precipitation of 550–800 mm and an AI of 0.2–0.5 (semi-arid) is particularly conducive to their formation. Soils developed from parent materials and TMU's normally characteristic for melanic horizons did not develop melanic characteristics in areas with an annual precipitation of <500 mm. This is probably due to a lack of additions of organic matter (Van der Merwe *et al*., 2002). Melanic soils usually contain 0.5 to 3 % organic carbon and 20 – 75 % clay (Hutson, 1983).

A melanic A horizon is by definition a well-structured, dark-coloured horizon with a high base saturation and a moderate to high organic matter content that lacks the swell-shrink properties of vertic soils (Soil Classification Working Group, 1991; WRB, 1998). In terms of pedogenesis, as defined by MacVicar *et al.* (1977), melanic soils occupy a position between vertic, humic, and orthic A horizons. A particular question of interest concerns the environment of soil formation, which can be described in terms of climate, parent material, topography, vegetation and time (Jenny, 1941).

Processes of even a mild nature, active over extended periods of time, have an effect similar to aggressive conditions, prevailing over a short time interval. An impressive amount of information concerning the soil-forming factors: climate, parent material, and relief is contained in the memoirs accompanying land-type maps in South Africa (Land Type Survey Staff, 2002), though the collation and interpretation of these data is sadly lacking (Van der Merwe *et al.*, 2002). Depending on the subsoil horizon the melanic soils are classified into Milkwood; Bonheim, Willowbrook, Inhoek, Immerpan and Steendal forms (Soil Classification Working Group, 1991). Among these soil forms Milkwood and Bonheim are the common ones in Land Type Dc17 (Table 2.1). The Milkwood soil form is characterized by melanic A overlying hard rock. It covers about 13.6% of the land type (Table 2.1). The Bonheim soil form has a melanic A horizon overlying a pedocutanic B horizon, and unspecified material. The structure of the B horizon can be of subangular / fine angular blocky to medium / coarse angular blocky (Soil Classification Working Group, 1991). It covers about 6.5 % of Land Type Dc17 and is represented by Glengazi and Bonheim series (MacVicar *et al.*, 1977) and occurs mainly on TMU's and valley bottom positions (Table 2.1).

c) Shallow soils

Soil forms other than duplex and margalitic soils present in the area are shallow soils of the Mispah, and Glenrosa forms. This is a soil form characterized by orthic A horizon overlying a continuous hard layer of rock**.** It is shallow because the hard rock offers extreme resistance to root and water penetration**.** It includes horizontally oriented, hard, fractured sediments, which have distinct vertical channels containing soil material (Soil Classification Working Group, 1991). Soils of this sort occur principally in mountainous areas, but can also occur in many other places such as on flat rock surfaces scraped bare by ice (Fitzptrick, 1980). Most of the processes taking place in these soils are operating very slowly because there is only a small amount of water passing through the system (Fitzptrick, 1980). However, the small amount of organic matter contributed by the sparse vegetation is quickly humified. The presence of many faunal passages and faecal pellets does not indicate a high level of biological activity. Such features once formed tend to become preserved in hot dry environments.

Because of the thin vegetation cover often found in these soils, the soil surface is subject to deflation and rapid runoff, both processes causing a removal of the fine material resulting in the concentration of gravel at the surface. However, some of the textural differences may be enhanced by weathering in situ. These soils tend to be restricted to flat or gently undulating situations (Fitzptrick, 1980).

Mispah together with Glenrosa and shallow Hutton soils cover about 4.5 % of the area in the land type Dc 17 and occupy mainly TMU's 1, 1(1), 3 and 3(1) (Table 2.1).

The lithocutanic B horizon is found in pedologically young material, not predominantly rock and not predominantly alluvial or aeolian in origin. It occurs in situations where the dominant soil forming processes have been rock weathering, the formation of orthic top soil horizons and, commonly clay illuviation that gives rise typically to lithocutanic horizons.

2.5 Soilscape

2.5.1 Introduction

The term soilscape has been used in different contexts. Buol, Hole & MacCracken (1974) defined it as a polypedon cluster. More recently, Buol *et al.* (1997) defined a soilscape as the pedologic portion of the landscape viewed from a vantage point in the landscape rather than from above it. They described the location of the boundary as follows: "The location of the boundary depends on the purpose of the mapper. If a team of pedologists were set to stakes in the ground to delimit a soilscape at a full scale, the objective of the workers would determine the selection of one out of several boundaries. The purpose might be to show a soilscape as a dynamic unit, in which soil drainage ways are included along with soils of adjacent elevations, because they are all genetically related to each other by pedogeomorphic processes.... The soilscape boundaries may be located along drainage divides. Ridgetop soil boundaries are thus partitioned between adjacent drainage basins. The purpose may be to stress land use potential. This leads to the delineation of fairly homogenous soilscapes. Figure 2.7 provides an example of a soilscape in accordance with this definition. Duchaufour (1998) defined soilscape as referring to vegetation and soil together, an integral part of 'landscape types'. He defined a landscape type unit as a mapping unit integrating geomorphology, vegetation and soils.

Finke & Montanarella (1999) define a soilscape as that portion of soil cover which groups soil bodies having a former or present functional relationship, and that can be presented at a scale of 1:250 000. A soilscape in their terms is therefore evidently a three dimensional collection of soils in the landscape consisting of a number of catenas distributed on a hillside.

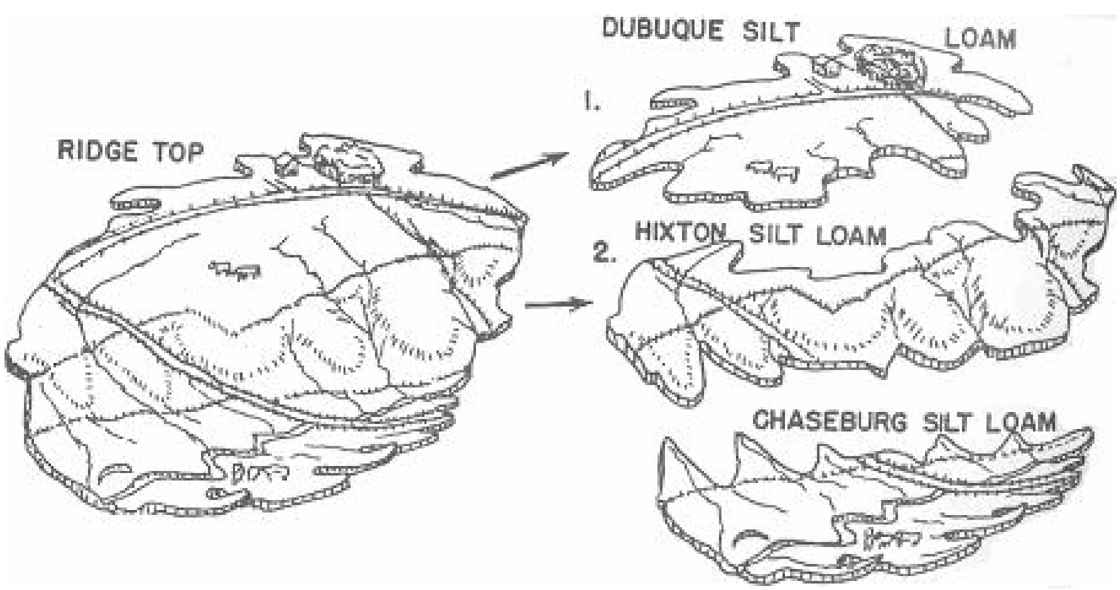


Figure 2.7 Left is a soilscape consisting of a sequence of three soils from a ridge crest to the bottom of a small valley (Hole & Lee, 1955).

A soil body is a portion of land with an imprecisely known pedogeographic boundary at the lowest taxonomic categorical level (Hole & Campbell, 1985)

2.5.2 Considerations in soilscape surveying

In Europe, soilscapes are information layers in the database used to display soil properties or soil behaviours on maps; the individual soilscapes should show a characteristic behaviour (Finke & Montanarella, 1999). Therefore, at a more detailed scale, each soilscape should have characteristic functional relationships between the soil bodies of which it is composed. The aspects of soil genesis are given preference in defining the "soil catena" within which transfers of water, matter and energy are responsible for the vertical and lateral differentiation of the soils (Huggett, 1975). This view can, however, hardly ever be used as a basis to actually map soilscapes at more detailed scales than 1:250,000. The reason for this is that many types of functional relationships exist, and these are scale and area dependent. Thus, this approach is not suited for mapping at a predefined scale (Finke & Montanarella, 1999). As discussed in section 2.7 mapping depends on the objective of the mapper and hence considerations in soilscape survey.

2.5.3 Soilscape definition and delineation

Finke & Montanarella (1999) proposed the use of the SOTER-methodology (ISRIC, 1993) as the minimum standardized way to define and delineate soilscapes in Europe. The concept of soilscapes and soil sequences involves morphological and pedogenetic criteria at the origin of their differentiation (Jamagne & King, 2003). The common examples of classification criteria include scale and spatial arrangement for the morphological criteria, factors of differentiation, degree of relationship, and time for pedogenesis. Different genetic factors prove to be dominant in the definition of certain soilscape or sequences, as explained by the examples which follow.

- If the nature of the *parent material* is the dominant factor, there is a lithosequence - gentle slopes cut across contrasted stratigraphic units with variable substrate depth.
- If *relief* dominates, there is a toposequence - transfer of dissolved products or particles from upstream to downstream.

- If *climate* dominates, there is a climosequence - e.g oceanic to continental sequences, or elevation sequences.
- If *water tables* dominate, there is a hydrosequence - influence of permanent water table, distance to the hydrographic collector.
- If *time* dominates, there is a chronosequence - progressive soil differentiation of different materials, geomorphological origins of relief units such as the secession of terraces.
- If *human* action is the dominant factor, there is an anthoroposequence - resulting from deforestation, input or removal of material, construction of agricultural terraces.

Of course, different qualifiers may be applied to the same soilscape where the most frequent sequences that are closely linked to the dominance of one genetic factor seem to be topographical and lithological sequences (Jamagne & King, 2003).

A fundamental requirement is that map scale must accommodate legible delineations of the smallest size map units. From a cartographic viewpoint, delineated polygons at 1:250,000 should be consistent with field areas of at least 1.5 km^2. Since soilscapes are mapping units, one soilscape may be presented by more than one polygon (Finke & Montanarella, 1999).

2.5.4 Expert knowledge

Intuitive knowledge of the soil surveyor governs the delineation of soil units. This intuitive knowledge is qualitative, gained by experience, and the rationale behind the decisions cannot be stated (Hudson, 1992). Employing intuitive knowledge is an accepted method for soil mapping (Sinowski & Auerswald, 1999). Long-term research knowledge has confirmed the validly of such intuitive knowledge. For example in the case of the Land Systems of Western New South Wales, they implemented numerical factors of expression for information contained in the map unit descriptions: relief category, percent area occupied by each facet, and dominant soil type in each facet. They noticed that it is only by devising such strategies (which might combine models, indices, expert knowledge, and/or direct measurement) that they would be able to manage the soil resource to achieve desired ends (Wander, Walter, Nissen, Bollero, Andrews &

Cavanaugh-Grant, 2002). This procedure was also used in SOTER differentiating criteria, where mandatory data are missing; the SOTER database will accept expert estimates for such values flagging it as such in the database (ISRIC, 1993).

Zhu & Band (1994) developed a knowledge based approach to data integration for soil mapping and in their model they used the famous formula of Jenny, *i.e.* $S = f(E)$, where S represents soil formation, E is the vector of environmental conditions and f reflects the relationship between soils and the formative environment. It is approximated using the empirical knowledge of local experts who, have been studied the phenomenon and its distribution and its environmental conditions. Knowledge about the phenomenon of soil formation and its environments from existing maps can also be used to approximate roughness index (RI) as Zhu & Band (1994) did to approximate f in the above case.

CHAPTER 3

PROCEDURE

3.1 Introduction

Because this was a pioneering exercise in soilscape surveying, the procedure was not clearly defined from the beginning. An appropriate procedure was developed as the survey progressed. The outcome is that with regard to some aspects, procedures and results are intermingled. This also explains why the full definition of a soilscape, as used in this study, appears as a result and not in the literature review. It matured as the survey proceeded, and is therefore to a large extent a result of the work.

In tribal areas permission for access from the respective local headmen was obtained with the help of the local agricultural extension workers of the Department of Agriculture, or members of the ARC-ISCW research team workers in the area. On commercial farms permission was obtained by direct communication with the owners.

3.2 Fieldwork

After studying the land type data and geology of Land Type Dc17, a field trip was made to form a picture of the lay of the land and improve existing knowledge. Several pedosequences of hillslopes with varying shapes were selected for preliminary investigation. These hillslopes would later be delineated as soilscapes or parts of a soilscape. The distribution of soils on the hillslopes were investigated with profile pits (73), soil auger observations (92), erosion gullies, a depth probe and surface features. The position, direction and distance between observations were determined by applying current understanding of the distribution of the soil pattern. The profile pits were replaced by depth probe measurements as the understanding of the terrain improved.

The soils were classified using Soil classification, a taxonomic system for South Africa (Soil Classification Working Group, 1991). The topography was described using the five element terrain morphological unit model and slope shapes used by the National Soil Survey Centre, USDA (Schoeneberger *et al*., 2002).

3.3 Delineation of soilscapes

The area covered by Dc17 is defined mainly on the 1:250 000 Land Type map 2926 Bloemfontein, with a small portion on 2826 Winburg (Land Type Survey Staff, 2002). Topo-cadastral maps of the area at a scale of 1:50 000 were used as base maps. Ortho-photo maps at a scale of 1:10 000 were used for the intensive study of selected areas. A 1:250 000 geological map was used to define the geology needed for delineating soilscapes.

The study area considered the delineation of soilscapes was based on the hypothesis that the main soil forming factors are relatively homogenous. Delineation was done on 1:50 000 maps, initially in the office, followed by field checking. Soil variation was expected to be associated with slope, slope length, slope shape, and parent material. In line with the agronomic objective of the study, built-up areas were delineated separately. Soilscapes considered unsuitable for cultivation, due to most of their areas being covered by stony, steep or rough surfaces, were also delineated separately

The soilscape borders were selected in such a way that the topography and geology of the delineated areas were as homogenous as possible. Ridge tops and streams were the main features used as boundaries. The resultant soilscapes therefore generally consisted of hillslopes of the land type.

3.4 Studying soil patterns of selected soilscapes

A number of soilscapes were selected and studied in detail. For adequate representative sampling of soils and landform, measurements along transects were made using 1:10 000 ortho-photo maps. Soil profiles were studied using mainly profile pits dug with a back actor, and also by augering. Soils were classified according to Soil classification: a taxonomic system of South African (Soil Classification Working Group, 1991). The location of observation points was recorded with GPS-12 for the profiles (Appendix 4.4) and augered points (Appendix 4.5), and GPS map76S for the depth probe tested points (Appendix 4.6). Soil samples were collected per horizon from representative pits for standard laboratory analysis for particle size distribution, pH, exchangeable bases (Ca, Mg, K, Na) and cation exchange capacity (CEC). Some chemical results from land type modal profiles are also included (Land Type Survey Staff, 2002).

Transect placement and sampling intervals along transects were determined with expert knowledge in an effort to capture the full range of soil variability within each soilscape. All observations were classified in the field as being within a particular terrain morphological unit (TMU) 1, 2, 3, 4, or 5 (Figure 2.5). The topography at each site was also classified as having one of the slope shapes described in Figure 2.6 ie VV, VL, VC, CC, CV, CL, LL, LC, or LV. The procedure was to study selected areas thoroughly and then extrapolate the results to unobserved portions of the soilscape. In this respect 73 profiles were thoroughly studied from soil profiles, 94 from augered points and 231 points in 40 soilscapes were tested for the effective rooting depth using the depth probe (Figure 3.1).

Digital data of the 1:50 000 maps of the study area was provided by the Geography Department of the University of the Free State. Kriging model of the GIS continuous trend surface analysis methods was used in the interpolation and mapping of elevation points to develop contours. The slope percent was determined from the terrain analysis of the Arcview3.2. The range of slope classes differentiated were 0-1 %, 1-2 %, 2-3 %, 3-4 %, 4-5 %, 5-6%, 6-7%, 7-8% and >8%. Slope classes less than 3 % were considered potentially arable. The stream network was created by hydrologic modeling, part of Arcview3.2, which helped to delineate soilscape polygons. Ridgetops and streams were the boundaries for soilscapes. The percent of area covered by each slope class was calculated from the number of counts that each specific slope percent covered (from the histogram)

Figure 3.1 Steel probe used to estimate the effective rooting depth. The marks on the probe are at 100 mm intervals.

Soilscapes were transferred to the 1:250 000 geological map from where the percentage of dolerite in each soilscape was estimated. The transfer was achieved using a light table.

3.5 Estimation of the area suitable for IRWH

This was the last part of the field work where all the experience gained during the previous steps was employed. Each soilscape was studied in the field using the 1:50 000 maps. It was traversed on appropriate roads. Roughness index and the percent of arable land in a given soilscape were estimated applying expert knowledge. Effective rooting depth (ERD) was determined by a steel probe (Figure 3.1). The steel probe was hammered in to the soil vertically until it intercepted root restricting layer, and the depth read from the markings on the probe. All the coordinates of the tested points were recorded by GPS (Figure 3.2). Other relevant field observations were also recorded. The

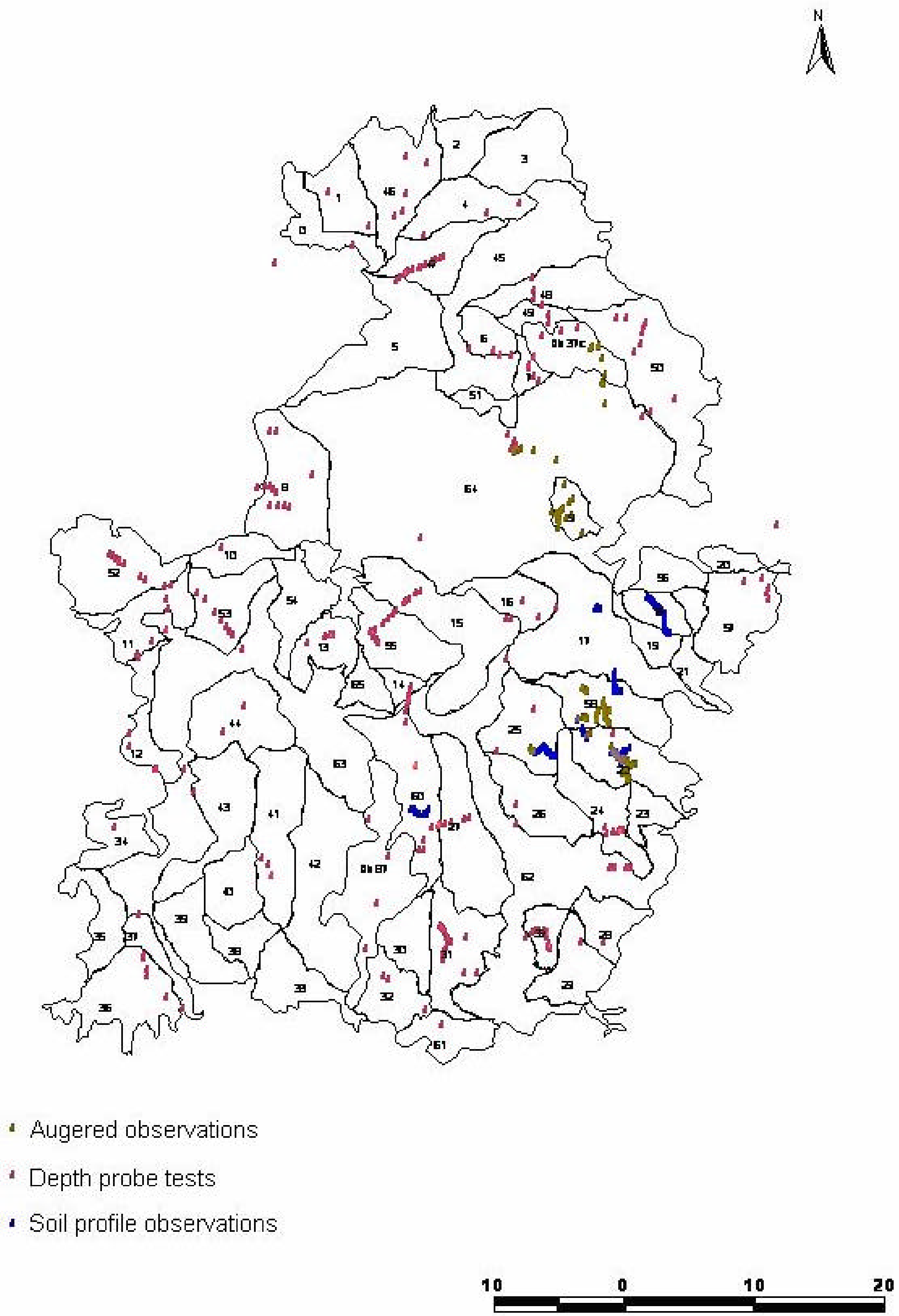


Figure 3.2 Observation points (profile pits, augered and depth probe)

force with which restricting layers such as saprolite and rock resisted the steel probe was initially tested on profiles where these layers were visible. The knowledge obtained of how it feels when it is on a rock and when it is on hard pan provided guidelines for estimating ERD.

Soils of the Estcourt form were considered shallow as it can be both waterlogged and very dry in the same year. Maize and sunflower are sensitive to these conditions. Estcourt soils were identified easily as they lie in specific landscape positions and can be augered for identification of the E horizon.

3.6 Estimating the yield potential

The CDF's developed by Botha *et al*, (2003) estimating yield potential of maize and sunflower, as discussed in section 2.5, were used to estimate the yield potential of each soilscape.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

The soilscape concept has been developed to provide a procedure for subdividing land types into smaller more homogenous units. The procedure is aimed at facilitating the stepwise process from small scale to large scale mapping needed for the intensive land use planning. Once a suitable definition of a soilscape had been formulated it was possible to make the delineations on 1:50 000 maps. The detailed studies of soil distribution on selected soilscapes provided the background information needed for extrapolation to those soilscapes on which detailed studies had not been made

4.2 Definition of soilscape

Soilscapes subdivide a land type and provide areas with reduced soil variation compared to that in land type. Soilscape is defined for this specific study as a mapping unit consisting of a portion of land mappable at a scale of 1:50 000 in such a way that it facilitates the identification of potentially arable land. It consists of a hillslope or combination of hillslopes, with a characteristic pedosequence of which the lower boundary is a drainage line and the upper boundary a crest. In areas of low relief it may include the watershed between two drainage lines. It is logical that as relief gets lower, topography becomes increasingly less important as a factor of soil formation and hence, in such cases, the possibility of including a combination of hillslopes in one soilscape. In conditions where relief is more pronounced its upper boundary would generally be a watershed, and lower boundary a drainage line, resulting in its form being that of hillslope or three dimensional representation of a pedosequence. It contains one or more mappable ecotopes and because of its predictable soil distribution pattern it can be extrapolated to other soilscapes of the same kind with reasonable accuracy

Although each soilscape within a land type will have a specific characteristic regarding soil pattern and topography, it is possible to identify groups of similar soilscapes in a particular land type that significantly differ from other groups. The focus here on the delineations of characteristic hillslopes needs to be highlighted. This is also a fundamental concept in the delineation of land types. The inventory sheet (Table 2.1), which plays an important part in the presentation of land type data, bears witness to this.

As catchments are the important land units in hydrological studies, hillslopes, or the sides of catchments, are the important macro land units in pedological studies. Hence the value of soilscapes as useful reference mapping units for soil information. The fact that drainage lines are generally formed where the geology offers least resistance to landscape erosion supports the soilscape concept, exposing any discontinuity in the geology, and in such cases causing the soils on one side of a stream to be different from those on the other side

4.3 Improved knowledge regarding the relationship between environment and soil pattern

Effective extrapolation necessitates the estimation of the values of an attribute at unsampled points outside an area covered by existing measurements (Burrough & Mcdonnel, 1998). In this study extrapolation of soilscape characteristics from places studied in detail to others was made merely based on expert knowledge developed through the study process. Our sampling procedure was modified from time to time during field studies in order to achieve the desired goal of estimating the percentage of arable land, suitable for IRWH, in each soilscape

Details of the 405 field observations made are presented in Appendices 4.4 (73 soil profiles), 4.5 (94 auger holes) and 4.6 (238 depth probe readings). The interpretation of the data is presented in processed form in Appendix 1. It needs to be kept in mind that observations were only made at sites where the soil was not visibly shallow, gentle even slopes received the greatest attention.

The results in Appendix 1 (a) show that, about 60 % of the observations had ERD > 700 mm. Concerning the slope, deeper soils were found on the gentle slopes (1-3 %) constituting about 45 % of the observations. It can also be observed from the data in Appendix 1a that the percentage of deep soils on the 0-1 % slope class is 9 % relative to the 28 % and 17 % on the 1-2 and 2-3 % slopes respectively. This can be attributed to the fact that the 0-1 % slopes are either in the 1 or 5 positions. When they are on TMU 1 the effect of the dolerite and other surface rock has retarded pedogenesis. At TMU 5 there will often be E-horizon development, especially in slope shape CC. The E-horizon makes the soil unsuitable for IRWH due to excessive hydromorphy close to the surface which impairs root proliferation. As the slope percent increases to the range of 2-3 % pedogenetic processes are enhanced due to the accumulation of colluvium and a more favourable water regime. These promote better chemical and physical weathering and hence deeper soil formation

A critical factor that determines soil depth in this land type is the slope shape. Relatively large areas with 0-1 % slopes on higher lying TMU's have convex-convex (VV) slope shapes. Examples are the TMU1 in Tables 4.13 and 4.14. These are dry sites where the rate of soil formation is low compared to soil erosion. This observation is not clearly exposed in Appendix 1, mainly because observations at these sites would often not have been made because of visible soil shallowness. However, where observations were made at sites with a VV slope shape and slope class 0-1 %, 80 % were found to be shallow

On slopes of more than 3 % the number of observations with ERD > 700 mm are small (Appendix 1b). Only about 15 % of all the observations were located on slopes > 3 % (Appendix 1a). The 15 % was composed of 6 % with ERD > 700 mm and 9 % with < 700 mm (Appendices 4.1b and 4.1c).

In accordance with these observations it was concluded, that slopes which are even (LL) and gently sloping (1-3 %), reasonably long and on TMU 3/4 or 4 (typical in soilscapes 27, 53) have deep soils. Such sites provide suitable environments for pedogenesis. Unexpected areas of Avalon and Westleigh soils of favourable depth were found on soilscapes 9, 46 and 50. It is postulated that patches of Molteno sandstone could have influenced pedogenesis at these sites. The clay content of the Molteno is very low. The even gently sloping topography of these soilscapes correlates well with this distribution. Soilscape 50 adjoins a map unit (Db37c) of Land Type Db37 included as an island within the boundary of land Type Dc17 (Figure 4.1). Land type Db37 also occurs to the east of Dc17. Avalon and Westleigh soils occur on even gently sloping terrain units 3 and 4 of the land type. Molteno sandstone occurs on the hill tops. Soilscapes with these features may be included in land type Db37. The presence of Avalon (1.1 %), Valsrivier (64.3 %), Dundee (5 %) and other soils in Db37, with no signs of melanic or vertic properties, could be the reason why Land Type Db37c (Appendix 10) is delineated separately within land type Dc17 (Land Type Survey Staff, 2002). A large part of Db37c is suitable for crop production using IRWH

Shallow soils were found on steeper slopes (> 5%) and also on sandstone shelves or places where its influence was extended. Table 4.1 shows some examples. This information was useful for extrapolation purposes *i.e.* to areas with similar altitude and parent material. There are of course areas with similar altitude but with deeper soils (Appendix 4, 5, 6)This could be either due to a different parent material or a different pedogenetic environment. Shallow soils were of Mispah, Glenrosa and Mayo soil forms.

Table 4.1 Localities where sandstone shelves resulted in shallow soils

soilscape No.	Altitude (m)	Locality
61	1580	Pamic
61	1560	Toch Gekregen 57
28	1560	Mentros-Popolars
12	1540	Paardekraal 114
9	1519	Victoria 127
9	1517	Mafan 683
18	1511	Maria Moroka
12	1500	Vaalkop
22	1494	Woodbridge1
40	1480	Watervrede (quarry)
58	1480	Gladstone
64	1480	Seroala
64	1466	Seroala
41	1460	Across Lusthof
51	1460	Bonolo 52
60	1440	Uitkyk

The information described in this section, and the experience gained in collecting it, contributed a great deal to the expertise used to estimate the percentage of arable land suitable for IRWH in each soilscape. The later step was accomplished by means of many field visits during which all the soilscapes delineated on 1:50 000 maps were studied.

4.4 Soilscapes

4.4.1 Background

Land type Dc17 was classified into the 66 soilscapes shown in Figure 4.1. Among them 9 covering an area of 82 222 ha (Appendix 2), were considered unsuitable for crop production as they consist of townships, hilly areas, small dams or rough areas. The remaining 57 soilscapes, covering an area of 155 429 ha (Appendix 3), were classified into 6 classes based on the estimated percentage of arable area suitable for IRWH (Table 4.2). The total area in Dc17 estimated to be suitable for IRWH is 56 875 ha (Table 4.20)

Table 4.2 Soil classes according to estimated percent of arable land for IRWH

Soilscape class	Estimated arable area (%)		RI (%)	Mean RI (%)
	Range	Average		
Class 1	70 – 80	78	10	10
Class 2	50 – 69	61	10 – 30	21
Class 3	40 – 49	44	20 – 50	34
Class 4	30 – 39	35	30 – 60	42
Class 5	20 – 29	23	30 – 70	57
Class 6	<20	13	60 - 80	72

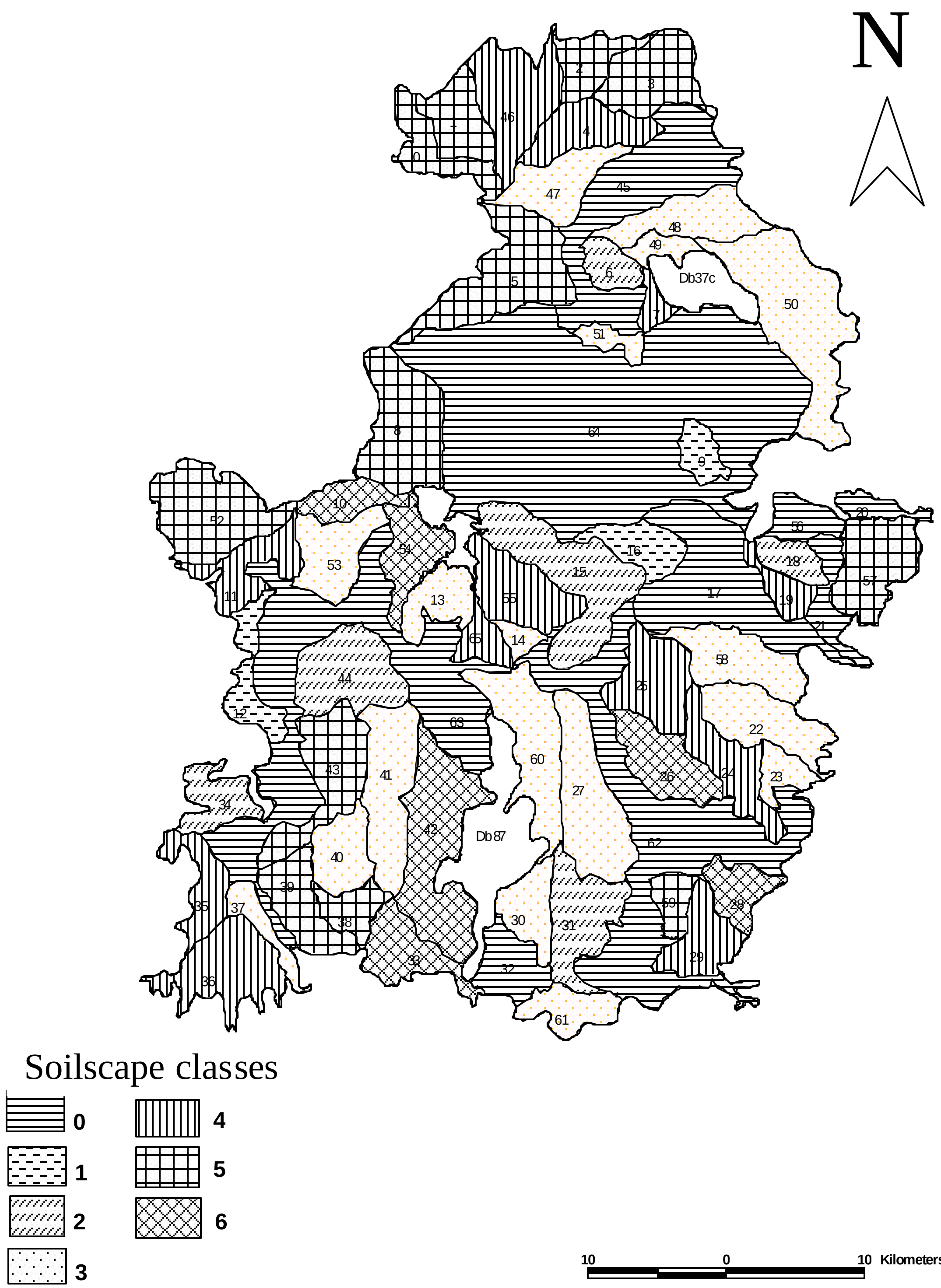


Figure 4.1 Classes of soilscapes identified in land type Dc17

The detailed investigation carried out on selected soilscapes resulted in the identification of five important characteristics which could influence the percentage of arable land suitable for IRWH in each soilscape. These characteristics were: the estimated portion of the area covered by dolerite outcrops; the relief; an estimate of roughness, termed the roughness index (RI); portion of the area covered by slopes < 3 % and between 1-3 %. Details regarding these characteristics are presented for each soilscape in each class. As RI was the one shown to be correlated to the estimated percent of arable area suitable for IRWH, summarized details are presented in Table 4.2

4.4.2 Class 1

The soilscapes of this class contains a high percentage (70 – 80 %) of arable land suitable for IRWH (Table 4.2). It covers 2.1 % of the total area of the land type and contributes an estimated 3838 ha (6.7 %) to the total arable area suitable for IRWH (Table 4.3). Soilscape 12 has a relatively low percentage of arable land, mainly due to the relatively high percentage of dolerite and high relief. Higher reliefs are dolerite capped hills. The higher the local relief, the higher the chance of dolerite occurrence, and the lower the chance of arable land. Dolerite can influence low lying areas advantageously in the form of weathered rock particles that settle as colluvium in TMU 4 or 5. It contributes base rich material which plays an important part in the genesis of smectite clay minerals. Relatively high levels of iron and aluminium oxide also serve to promote flocculation of clay particles

Table 4.3 The characteristics of the soilscapes in class 1

Soilscape No.	Area (ha)	Dolerite (%)	Relief (m)	RI (%)	Steepness		Estimated arable area	
					1-3 %	< 3 %	%	(ha)
9	1112	1	40	10	37.59	94.42	81	901
16	1899	5	72	10	24.12	86.68	81	1538
12	1943	7	100	10	41.79	86.46	72	1399
TOTAL	4954							3838
MEAN				10			78	

4.4.3 Class 2

The soilscapes of this class covers 7.4 % of the total area of the land type, and contributes 1046 ha (18.4 %) to the estimated arable area of Dc17 (Table 4.4). It is characterized by variable occurrence of dolerite. Unlike the soilscapes of Class 1 low relief correlates with a high dolerite cover. Soilscape 18, Maria Moroka, is representative of this class and is discussed in detail in section 4.4.3.1. This class is estimated to contribute 10 460 ha of arable land (Table 4.4)

Table 4.4 The characteristics of the Soilscapes in Class 2

Soilscape No	Area (ha)	Dolerite (%)	Relief (m)	RI %	Steepness 1-3%	Steepness <3%	Estimated arable area (%)	Estimated arable area (ha)
34	1906	3	46	20	39.24	96.22	64	1220
15	5762	5	120	25	37.68	94.08	53	3054
44	3929	5	60	10	36.01	91.40	63	2475
31	3529	0	80	20	38.06	90.93	64	2259
6	1211	30	40	30	44.59	87.37	56	678
18	1210	30	40	20	31.65	77.02	64	774
TOTAL	17547							10460
MEAN				21			61	

4.4.3.1 Maria Moroka

The Maria Moroka soilscape is soilscape number 18 and typical of Class 2. It is located on the 1:10 000 orthophoto map 2926BD8. It is situated south of the town of Thaba Nchu and occupies an area of 1210 ha (Table 4.5). It currently forms part of the Maria Moroka game reserve. It is characterized by a chain of dolerite hills at its southern end. Using expert knowledge it is estimated to have RI of 20 %, with 64 % of its area considered to be arable. The soil pattern in the soilscape was studied by making 21 soil pits, 19 of them down the representative pedosequence AB shown in Figure 4.2. Detailed results are presented in Appendix 4, with the symbol MM preceding the profile numbers. MM1 is located at the lower end of the pedosequence and MM18 at the top. MM19, MM20 and

MM21 were located at another site to test a particular hypothesis about the soil pattern. Summarized results of the study are presented in Figure 4.3 and Tables 4.6 and 4.7.

The soilscape is characterized by slopes ranging from 0 to 40 %, with approximately 80 % of the area with < 8 % slope. The local relief ranges from 1500 m above sea level at the Groothoek Dam water level, to 1540 m near the peak named Three Sisters. The two features make it a class A2 terrain type according to the criteria used in the land type survey of South Africa (Land Type Survey Staff, 2002). The area of slope <3 % amounts to 77 % of the total area, and 774 ha is estimated to be arable (Table 4.4). The AB transect across the soilscape is about 4 km long (Figure 4.3).

Table 4.5 General properties of the Maria Moroka soilscape.

Slope steepness (%)	0 - 1	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6	6 - 7	7 – 8	> 8	Total
Area (ha)	549	210	173	97	56	23	16	16	70	1210
(%)	45.4	17.4	14.3	8	4.6	1.9	1.3	1.3	5.8	100

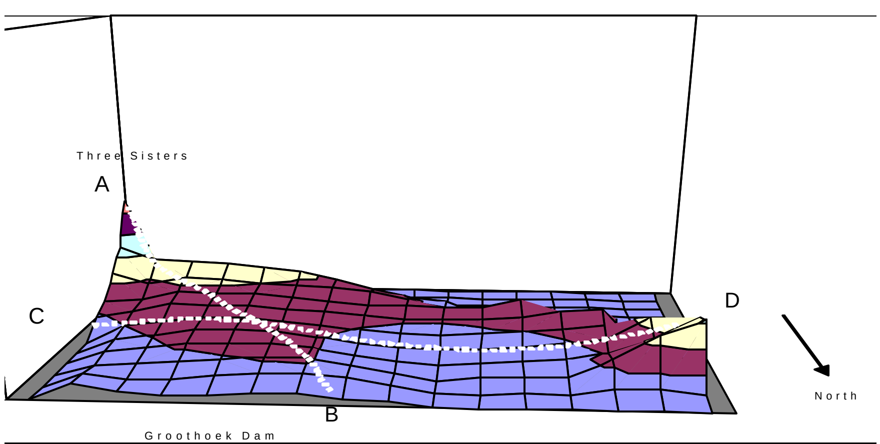
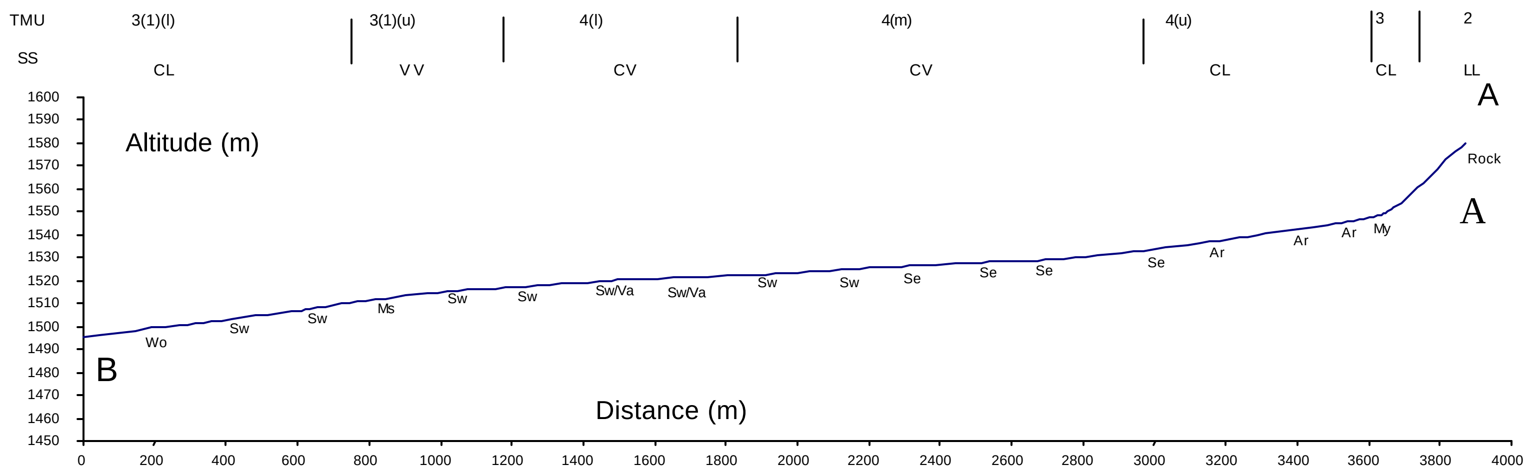


Figure 4.2 Three-dimensional view of Maria Moroka. Dotted lines are transects AB and CD. Elevation classes are at 20 m intervals

The relationship between the observable factors of soil formation, *i.e.* topography and parent material, and the kind of soil formed in this soilscape, are recorded in Table 4.6A few additional observations were made at selected points to verify hypotheses formulated on the basis of the results of pedosequence AB. These were used to describe the hypothetical transect CD. Results are presented in Table 4.7



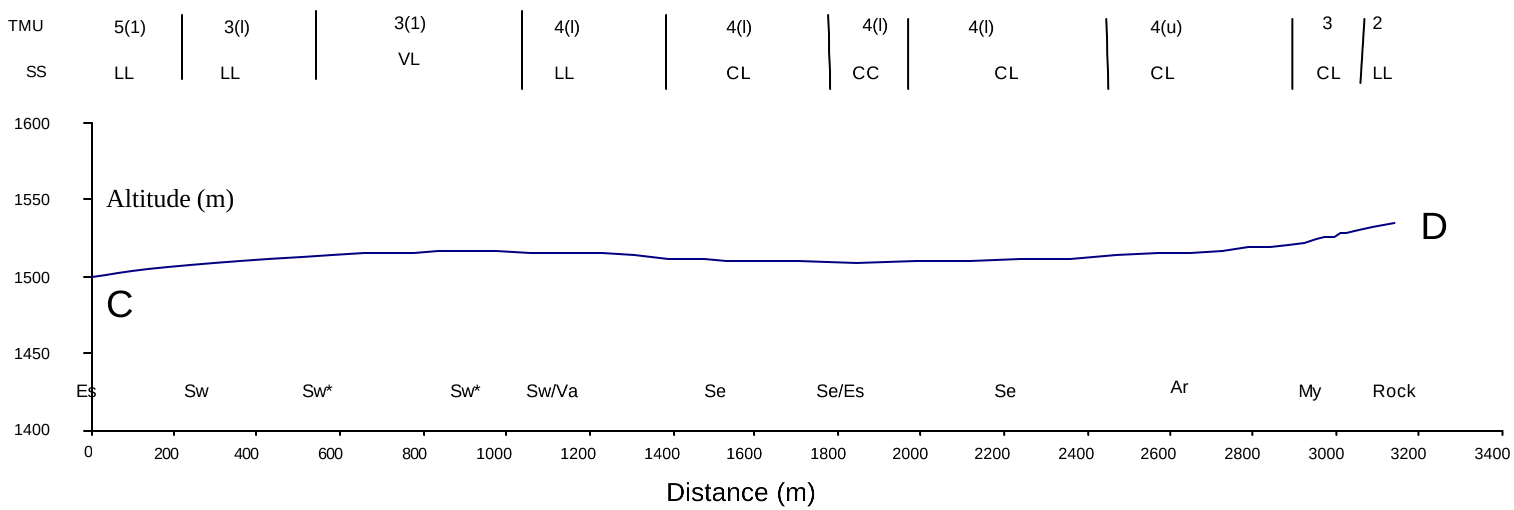


Figure 4.3 Soil distribution on the Maria Moroka soilscape; transects AB and CD.
TMU = terrain morphological unit; SS=slope shape.

Details of the soil distribution are presented in Table 4.6 and the notes which follow. The characteristic soil forms of the soilscape in relation to the location are indicated

Table 4.6 Soil pattern of catena AB on the Maria Moroka soilscape

TMU	Slope (%)	Slope shape	Parent material	Soil form		ERD* (mm)
				Dominant	Subdominant	
2	>15	LL	Dolerite	Rock	Milkwood, Mispah	300
3	8 - 12	CL	Dolerite	Mayo	-	500
4(u)	2 - 3	CL	Dolerite	Arcadia	-	900
4(m)	1 - 2	CV	Sandstone	Sepane	Swartland	900
4(l)	1 - 2	CV	Sandstone	Swartland	Valsrivier	800
3(1)(u)	2 – 3	VV	Sandstone	Swartland	Mispah	200-800
3(1)(l)	1.5 – 2.5	CL	Sandstone	Swartland	Willowbrook	800

*Effective rooting depth

Table 4.7 Properties of catena CD on the Maria Moroka soilscape

TMU	Slope (%)	Slope shape	Parent material	Soil form		ERD * (mm)
				Dominant	Subdominant	
2	>10 - 7	LL	Dolerite	Rock	Milkwood, Mispah	
3	3 - 3.5	CL	Dolerite	Mayo	-	
4(u)	2	CL	Dolerite	Arcadia	-	
4(u)	1.5 - 2	CL	Sandstone	Sepane	-	
4(l)	1.5	CC	Sandstone	Sepane	Estcourt	
4(l)	1.5	CL	Sandstone	Sepane	-	
4(l)	2.5	LL	Sandstone	Swartland	Valsrivier	1200
3(1)	<1	VV	Sandstone	Swartland	-	500
3(2)	1.5	VL	Sandstone	Swartland	-	1000
3(2)	2	LL	Sandstone	Swartland	-	1100
5(1)	3	LL	Sandstone	Estcourt	-	

*= Effective rooting depth

The data in Figure 4.3, Tables 4.6 and 4.7 are interpreted as follows:

1. Rock outcrops, Mispah and Milkwood soil forms occur if the lithology is dolerite on TMU 2 with >10 % slope and LL and VL slope shapes.
2. Mayo soil form occurs if the lithology is dolerite on TMU 3, with 8 – 12 % slope and CL slope shape.
3. Arcadia soil form occurs if the lithology is dolerite on TMU 4(u), with 2 – 3 % slopes and CL or CC slope shapes.
4. Sepane soil form occurs if the lithology is sandstone with little dolerite influence from upslope on TMU 4, with 1 – 2 % slope and CL and CV slope shapes.
5. Deeper Swartland and Valsrivier soil forms occur if the lithology is sandstone on TMU4 with < 1 % slope, and CV slope shape.
6. Willowbrook soil form occurs if the lithology is sandstone on TMU $3^{(1)}$(l), with 1.5 – 2.5 % slope and LV, LL slope shapes where the water table is high.
7. Mispah soil form occurs if the lithology is sandstone where it forms shelves in TMU 3(1) (u) with slope about 2 % and VV slope shape.
8. Estcourt soil form occurs if the lithology is sandstone on TMU4, with 1.5 % slope and CC slope shape.

4.4.4 Class 3

The soilscapes of this class contains 48 339 ha (20.3 %) of the total area of the land type, and estimated 21 392 ha (37.6 %) of the arable area of Dc17 (Table 4.8). It is characterized by a high roughness index of 20 – 50 %, a wide range of relief (17 – 223 m) and area covered by dolerite ranging from 0 – 30 % in the different soilscapes.

Portions of three soilscapes representing this class were studied in detail i.e. Woodbridge 2 and Yoxford (No. 22); Gladstone (No. 58) and Wolwekop (No. 60).

4.4.4.1 Woodbridge 2

Woodbridge 2 is located on the 1:50 000 topocadastral map 2926BD. It forms part of soilscape No. 22. It is characterized by a few dolerite dykes. Part of the soilscape is under cultivation.

Table 4.8 The characteristics of the Soilscapes in class 3

Soilscape No.	Area (ha)	Dolerite (%)	Relief (m)	RI %	Steepness 1-3 %	Steepness <3 %	Estimated arable (%)	Estimated arable Area (ha)
23	1104	1	65	40	50.45	97.46	42	464
47	2733	2	80	50	43.21	96.78	40	1093
49	825	30	40	40	25.21	95.64	42	347
30	1952	0	86	30	41.44	94.62	42	820
48	3019	5	109	20	37.69	94.10	48	1449
58	3262	3	101	40	42.77	93.13	42	1370
22	3371	3	120	50	47.23	93.06	40	1348
60	4403	5	47	30	23.26	91.44	49	2158
40	2191	15	120	40	35.10	90.83	42	920
41	4275	5	85	40	41.87	89.75	42	1796
53	2809	20	60	30	42.51	89.53	49	1376
61	1780	2	60	30	53.93	88.09	49	872
27	4721	3	100	30	36.22	86.21	49	2313
13	1991	5	43	30	33.95	80.81	42	836
50	7386	3	223	30	42.09	78.24	42	3102
37	1173	0	40	20	26.00	75.28	48	563
51	771	10	17	30	36.06	74.45	42	324
14	573	15	60	30	30.19	71.55	42	241
TOTAL	48339							21392
MEAN				34			44	

Soilscape 22 is characterized by a slope that ranges from 0 to 6 % where about 93 % is in the slope classes 0 to 3 % (Appendix 3). The relief on the Woodbridge 2 portion ranges from 1 460 m above sea level north of the Wildebeesspruit River to 1 531 west of Woodbridge 2 village. The terrain type is A2 (Land Type Survey Staff, 2002). The soilscape have a RI value of 50 % with 40 % of arable land. Four soil pits along transect AB and six augered holes along transect CD were studied (Figure 4.4). Profile WW1 is located at the upper end of the pedosequence and WW4 at the lower end (Appendix 4). A few additional auger observations were made at selected points to verify hypotheses formulated on the basis of the results of pedosequence AB. These were used to describe the hypothetical transect CD (Figure 4.5 and Tables 4.9 and 4.10).

Table 4.9 Woodbridge2: Soil pattern of transect AB

TMU	Slope (%)	Slope shape	Parent material	Soil form		ERD* (mm)
				Dominant	Subdominant	
2	> 15	LL	Dolerite	Rock	Milkwood, Mispah	<300
3	1.5 – 2	CL	Sandstone/ Dolerite	Valsrivier	Milkwood, Mayo, Mispah, Bonheim	1100
4	1 – 1.5	CV	Sandstone	Swartland		1000
5	< 1	CL	Sandstone	Estcourt	Valsrivier	900

*= Effective rooting depth

Table 4.10 Woodbridge 2: Soil pattern of transect CD

TMU	Slope (%)	Slope shape	Parent material	soil form		ERD* (mm)
				Dominant	Subdominant	
3	3.5	LL	Sandstone	Swartland	Valsrivier	
1	2	VV	Sandstone	Swartland	Valsrivier	1000
3(l)	1.5	CV	Sandstone	Valsrivier		
4(u)	2.5	CL	Sandstone	Valsrivier		
4(l)	2	VL	Sandstone	Swartland	Valsrivier	
5[(1)]	1.5	CC	Sandstone	Estcourt		

*= Effective rooting depth

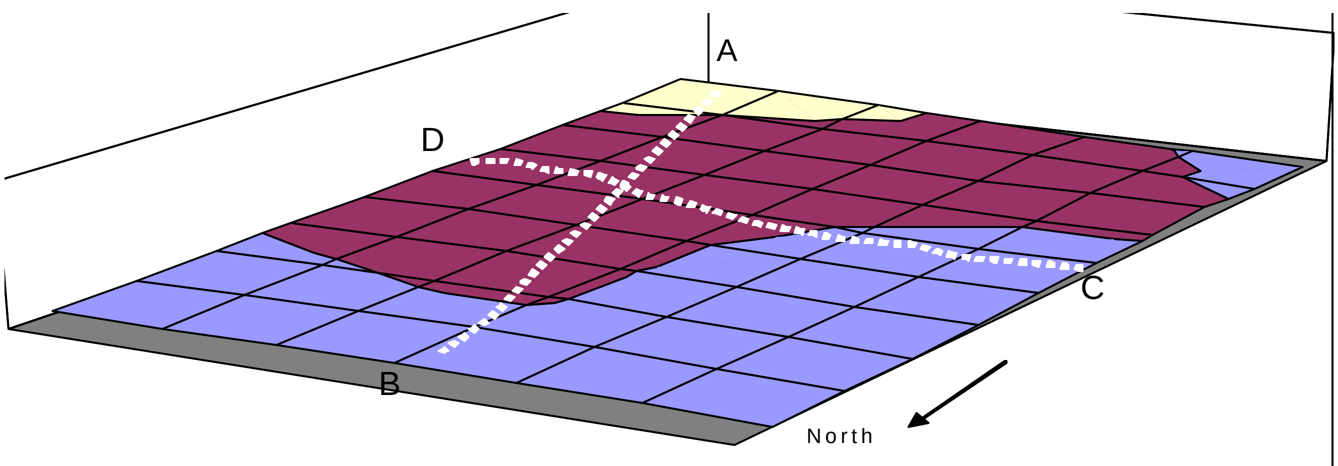


Figure 4.4 Three-dimensional view of Woodbridge 2. Dotted lines are transects AB and CD. Elevation classes are at 20 m intervals.

The data of Woodbridge 2 (Figure 4.5 and Tables 4.9 and 4.10) can be interpreted as follows:

1. Rock and soils of the Mayo, Mispah, and Milkwood forms occur on TMU2 with slope > 6 % and LL, VL slope shapes if the lithology is dolerite.
2. Soils of the Swartland and Valsrivier forms occur on sandstone on TMU's 3 and 4, with 1-3 % slopes and slope shapes LL, CV, VL and CL; TMU 4, with 1 - 1.5 % slope, and CV slope shape; and TMU 4(l), with 2 % slope, and VL slope shape.
3. Soil of the Estcourt form occurs if the lithology is sandstone on TMU 5 with <2 % slope, and CC slope shape.

4.4.4.2 Yoxford

Yoxford is located on the 1:50 000 topocadastral map 2926BC. It is part of soilscape 22 and characterized by small dolerite dykes. It is located in the Middle Beaufort geology. It has a number of dissecting streams. A limited part of Yoxford is under cultivation. The local relief ranges from 1580 m above sea level at summit east of the village to 1505 m towards the stream north of the village. More than 80 % of the soilscape has a slope of less than 8 %. This makes the soilscape terrain type A2 (Land Type Survey Staff, 2002). The expert estimate of the RI and percent of arable land is considered similar to Woodbridge 2 as they are parts of the same Soilscape 22. The soil pattern in this part of the soilscape was studied by making 13 soil pits along transect AB, (Figures 4.6 and 4.7), and 26 augered holes. Detailed results are presented in Appendices 4 and 5, with the symbol "Y" preceding the profile numbers for the pits and "y" preceding the numbers of each augered hole. Y1 is located south of the pedosequence and Y10 at the north eastern end. Y11, Y12 and Y13 were located at other sites to verify the hypotheses formulated on the basis of the results of pedosequence AB. These points together with the auger observations were used to describe the hypothetical transect CD. Results are presented in Figure 4.7 and Tables 4.11 and 4.12. Figure 4.6 shows a three dimensional view of the soilscape. About 20 % of the observed profiles have an ERD >700 mm.

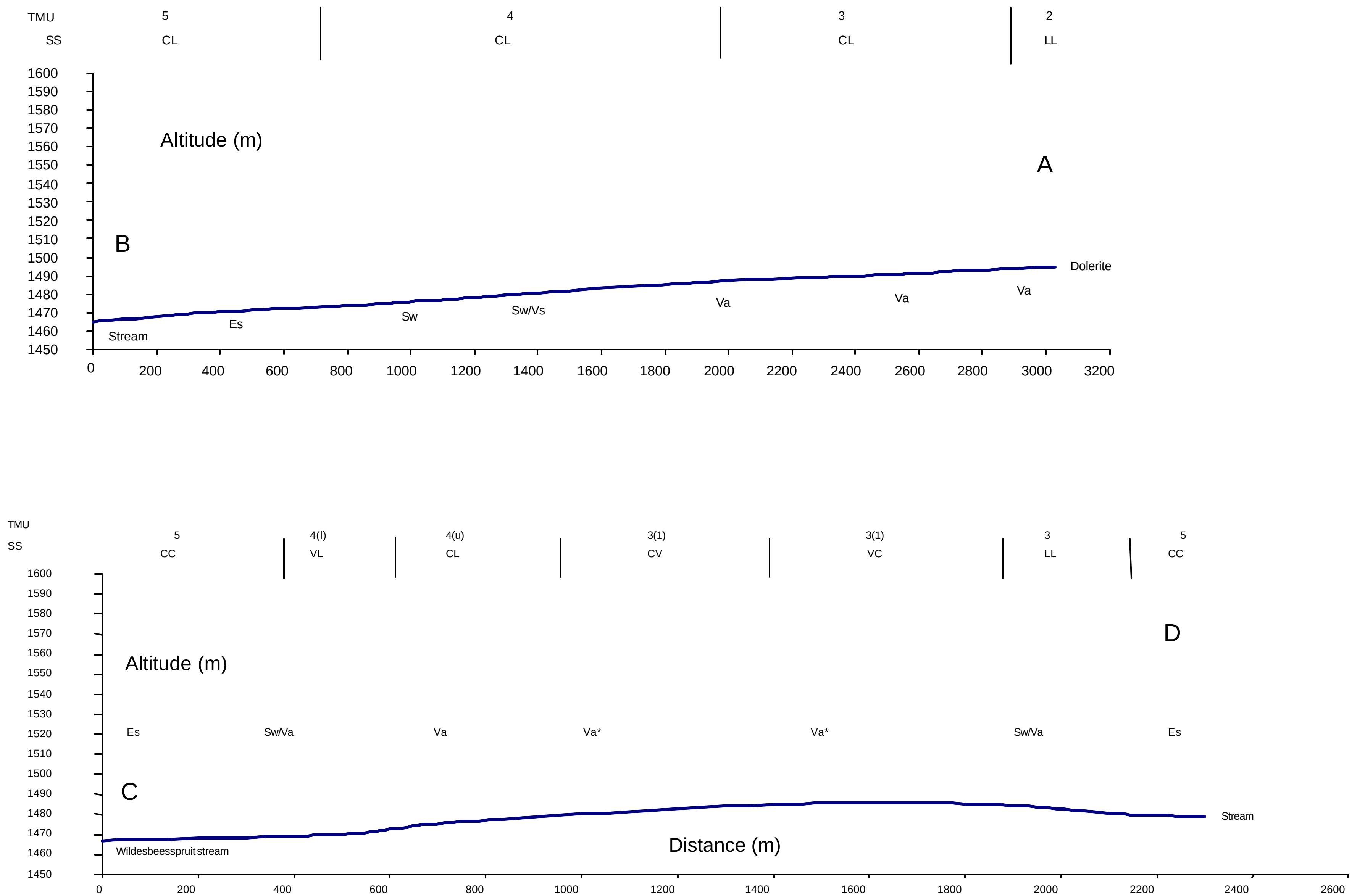


Figure 4.5 Soil distribution of Woodbridge 2 transects AB and CD. TMU = terrain morphological unit; SS = slope shape.

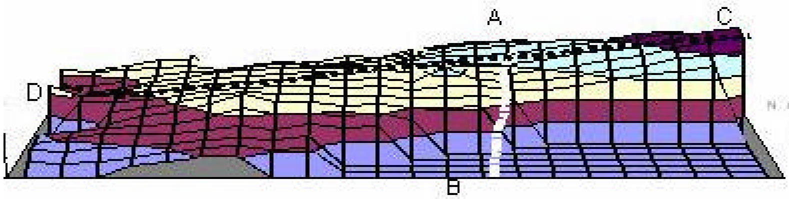


Figure 4.6 Three-dimensional view of Yoxford. Dotted lines are transects AB and CD. Elevation intervals are 20 m.

The following is a summary of some generalised conclusions regarding the information presented in Figure 4.7 and Tables 4.11 and 4.12:

1. Shallow soils of the Mispah, Milkwood and Bonheim forms occur on sandstone and dolerite on TMU's 1 and 3, with slopes varying from 1 % to 5 % and CV slope shape.
2. Soils of the Swartland and Valsrivier forms occurs where the lithology is sandstone on TMU's 3 and 4, with 1 – 5 % slope, and slope shapes LL, LC, CL and CV.
3. Soils of the Estcourt form occur if the lithology is sandstone on TMU's 3, 4 and 5 on slopes of between 0 to 3 % slope with CC slope shape.

Table 4.11 Soil pattern of catena AB of Yoxford soilscape

TMU	Slope (%)	Slope shape	Parent material	Soil form		ERD* (mm)
				Dominant	Subdominant	
5	< 1	LC	Sandstone	Estcourt		
4	3	CC	Sandstone	Estcourt		
3	2.5	CC	Sandstone	Estcourt		500
3	2	LC	Sandstone	Valsrivier		900+
4	2	LC	Sandstone	Swartland		700+
3(1)	1	CL	Sandstone	Sepane	Estcourt	600
3(1)	< 1	CL	Sandstone	Swartland		1000
3(2)	< 1	LC	Sandstone	Swartland		1000
5(1)	< 2	CC	Sandstone	Estcourt		350

*Effective rooting depth

Table 4.12 Soil pattern of catena CD in Yoxford soilscape

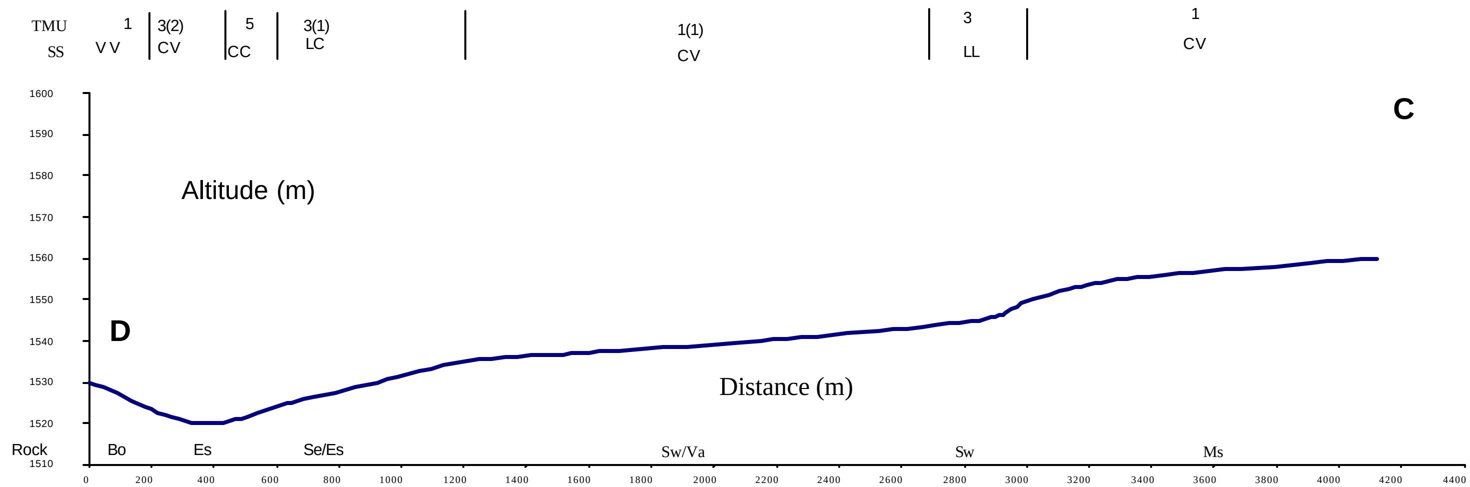
TMU	Slope (%)	Slope shape	Parent material	Soil form Dominant	Soil form Subdominant	ERD* (mm)
1	1	CV	Sandstone	Mispah	Swartland	
3	3 – 5	LL	Sandstone	Swartland		
3(1)	< 1	CV	Sandstone	Swartland	Valsrivier/Estcourt	1000
3(1)	1.5 – 2	LC	Sandstone	Sepane		300
5	2	CC	Sandstone	Estcourt		
3	3	CV	Sandstone/Dolerite	Bonheim		
3	4.5	CV	Sandstone	Mispah	Milkwood	

*Effective rooting depth

4.4.4.3 Gladstone: Part of Soilscape No.58

Gladstone soilscape is located on the 1:50 000 topocadastral map 2926BD. It forms part of Soilscape 58. Soilscape 58 is characterized by small dolerite dykes constituting an estimated area of 3 %. Part of the soilscape was previously cultivated and part of it is currently under cultivation. Soilscape 58 is characterized by a slope ranging from 0 to >8 % with about 93 % in the slope classes 0 to 3 %, and 97 % less than 8 % (Appendix 3) This makes the soilscape terrain type A2 (Land Type Survey Staff, 2002). The local relief of the Gladstone portion ranges from 1 533 m above sea level at the summit east of the village to 1 455 m towards the stream west of the village (Figure 4.8).

Soilscape 58 is estimated to have an RI value of 40 %, and with 42 % of its area arable (1 370 ha) (Table 4.8). The soil pattern on the Gladstone portions of the soilscape was studied by making 13 soil pits and 25 auger holes along transect CD and AB (Figures 4.8 and 4.9). Detailed results are presented in Appendices 4 and 5, with the symbol “G” preceding the profile numbers for the pits and “g” preceding the numbers of each augered hole.



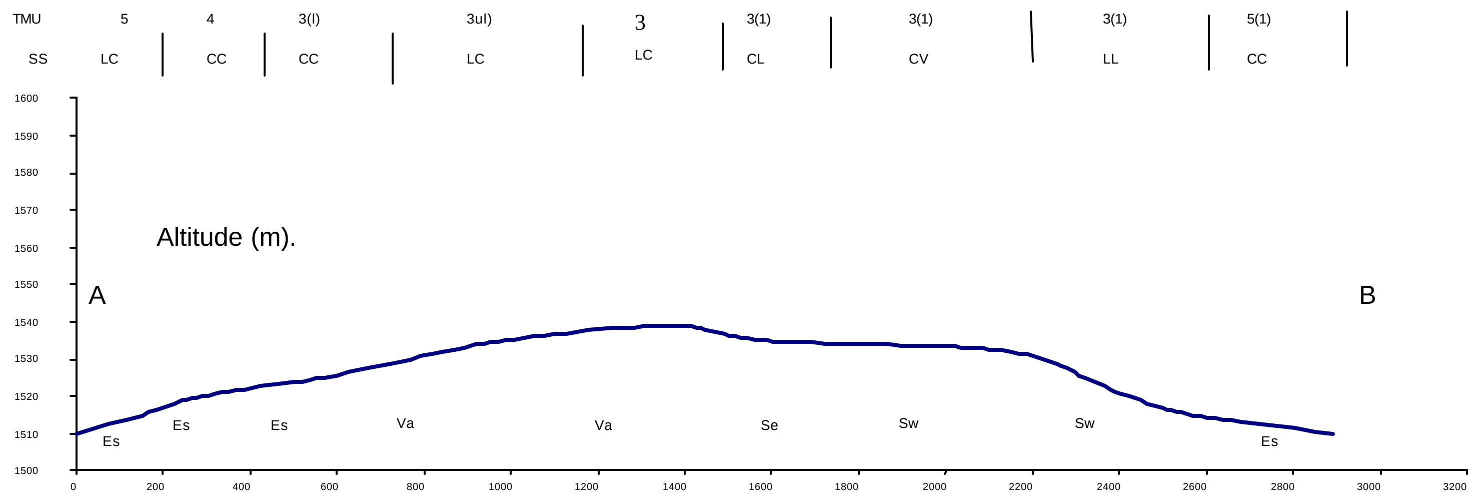


Figure 4.7 Soil distributions of the Yoxford transects AB and CD.
TMU = terrain morphological unit; SS = slope shape.

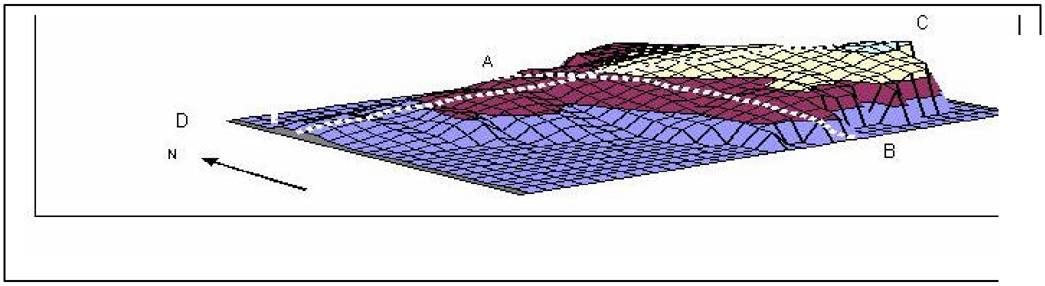


Figure 4.8 Three dimensional view of Gladstone. Dotted lines are transects AB and CD. Elevation classes are at 20 m intervals.

The following is a summary of some generalised regarding information presented in Figure 4.9 and Tables 4.13 and 4.14.

1. Rock outcrops and Mispah soil forms occur if the lithology is dolerite or sandstone on TMU 4 with <1 % slope and slope shape LV.
2. Mayo and Bonheim forms occur if the lithology is dolerite on TMU 3 on 1 to 3 % slopes with LV and VV slope shapes.
3. Soils of the Swartland/Valsrivier form occur if the lithology is sandstone on TMU's 3 and 4 with 1 – 3 % slope and CL, CV, LV and LL slope shapes.
4. Estcourt soil form occurs if the lithology is sandstone on TMU's 4 and 5 with <2 % slope and CC and CL slope shape.

Table 4.13 Soil pattern of transect AB Gladstone

TMU	Slope %	Slope shape	Parent material	Soil form		ERD* (mm
				Dominant	Subdominant	
5	< 1	CL	Sandstone	Estcourt	Swartland	400
4	1.5	LV	Sandstone	Valsrivier	Milkwood	800
$3^{(1)}$(l)	1.4 – 1.5	LV	Sandstone	Swartland	Mayo	600
$3^{(1)}$(m)	1.6	LV	Sandstone/Dolerite	Bonheim	Arcadia	550
$3^{(1)}$(u)	1.5	LV	Dolerite	Mayo	Swartland	550
$3^{(1)}$	< 1	LV	Sandstone	Mispah		< 500
$3^{(1)}$	2.5	LL	Sandstone/Dolerite	Bonheim		
$4^{(1)}$	2	CC	Sandstone	Sepane		
$5^{(1)}$	< 1	CC	Sandstone	Estcourt		

*Effective rooting depth

Table 4.14 Soil pattern of transect CD Gladstone

TMU	Slope %	Slope shape	Parent material	Soil form		ERD* (mm)
				Dominant	Subdominant	
1	< 1	VV	Dolerite	Rock	Milkwood	
3	2.5	LL	Dolerite	Bonheim	Swartland	
4	2	CC	Sandstone	Sepane	Swartland	
$3^{(1)}$	2.5	VL	Dolerite	Bonheim	Swartland	
$3^{(2)}$	< 1	LL	Dolerite	Mispah		
$3^{(2)}$	2.5	LL	Dolerite	Bonheim		
$3^{(2)}$	1 – 2	LV	Dolerite	Mispah		100
$3^{(3)}$(u)	1.5 – 3	LV	Dolerite	Bonheim		600
$3^{(3)}$(l)	1.5 – 3	LV	Sandstone	Swartland		600
4	1 – 2	CL	Sandstone	Valsrivier	Swartland	800
5	2.5	CL	Sandstone	Estcourt	Sepane	500

*Effective rooting depth

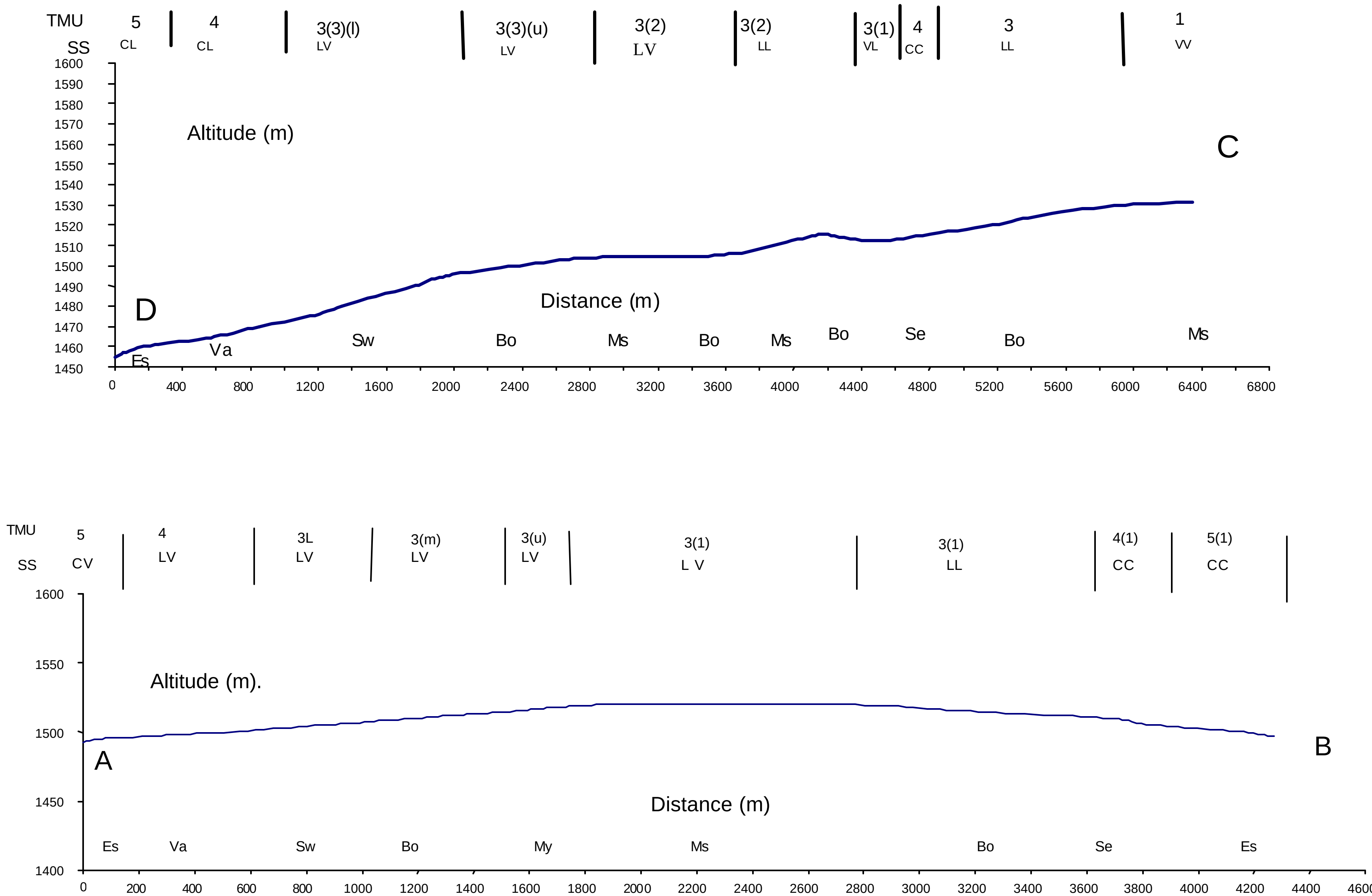


Figure 4.9 Soil distributions of Gladstone soilscape transects AB and CD.
TMU = terrain morphological unit; SS = slope shape.

4.4.4.4 Wolwekop: Part of Soilscape No. 60

Wolwekop is located on the 1:50 000- topocadastral map 2926BC. Soilscape 60 is bordered on the west by land type Db87c and in the east by the Modder River. It is characterized by dolerite dykes constituting an estimated 5 % of the area. Part of the soilscape is under cultivation. Slopes range from 0 to >8 % with about 91 % in the slope classes 0 to 3 % (Appendix 3). This makes the soilscape terrain type A2 (Land Type Survey Staff, 2002). The local relief ranges from 1460 m above sea level at the border of the land type Db87c to 1420 m towards the Modder River.

For the soilscape the RI and arable percentages are estimated at 30 and 49 respectively, giving an estimated arable area of 2 158 ha (Table 4.8). The soil pattern in the soilscape was studied by making 7 soil pits along transect AB (Figure 4.10). Detailed results are presented in Appendix 4 (Sites marked Wk). Summarized results of the study are presented in Figure 4.11 and Table 4.15.

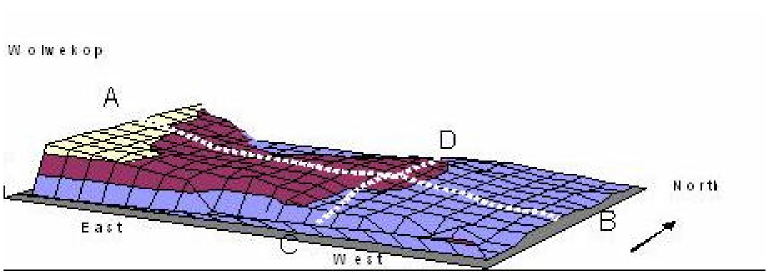


Figure 4.10 Three-dimensional view of Wolwekop. The dotted lines are transects AB. Elevation classes are at 20 m intervals.

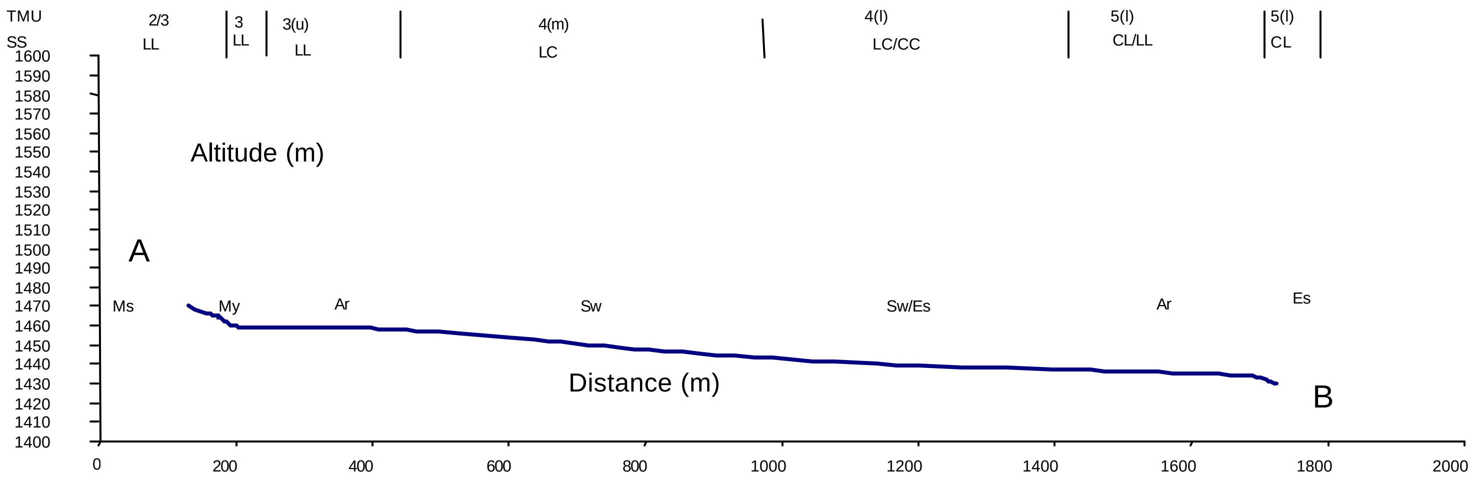


Figure 4.11 Soil distributions of Wolwekop soilscape transect AB.
TMU = terrain morphological unit; SS = slope shape.

Table 4.15 Soil pattern of transect AB Wolwekop

TMU	Slope %	Slope shape	Parent material	Soil form		ERD* (mm)
				Dominant	Subdominant	
2/3	> 15	LL	Dolerite	Rock	Milkwood, Mayo, Mispah,	
3	8 – 10	LL	Dolerite	Mayo	Milkwood	
3(u)	3 – 4	LL	Dolerite	Arcadia	Mayo	800
4(m)	2 – 3	LC	Dolerite/ sandstone	Swartland	Arcadia	800
4(l)	1 - 2	CL/LL	Sandstone	Swartland/ Estcourt	Swartland	900 230
5(u)	< 1	CL	Dolerite	Arcadia		700
5(l)	< 1	CL	Alluvium	Estcourt		

*Effective rooting depth

Generalised conclusions from the information in Figure 4.11 and Table 4.15:

1. Mayo, Mispah, and Milkwood soil forms occur if the lithology is dolerite on TMU 2/3, with >8 % slope and LL and VL slope shapes.
2. Arcadia soil form occur where the parent material is dolerite on TMU's 3 and 4 with LL or CL slope shapes.
3. Swartland soil form occurs if the lithology is sandstone on TMU's 3 and 4, with < 3 % slope and LC slope shape.
4. Estcourt soil form occurs if the lithology is sandstone on TMU's 5 and 4 with < 2 % slope and CC or CL slope shape.

4.4.5 Class 4

The soilscapes of this class cover 29 860 ha or 12.6 % of the total area of the land type, and 10 447 ha or 18.4 % of the estimated arable area of Dc17 (Table 4.16). This soilscape class is characterized by a relatively high RI of 30 – 60 %, relief of between 20 – 125 m and dolerite coverage ranging from 1 – 20 % (Table 4.16). Part of Soilscape No 25 representing this class was studied in detail and is described in section 4.4.5.1.

Table 4.16 Soilscapes in class 4.

Soilscape No.	Area (ha)	Dolerite (%)	Relief (m)	RI (%)	Steepness 1-3 (%)	Steepness < 3 (%)	Estimated arable (%)	Estimated arable Area (ha)
19	1090	5	36	40	45.50	70.37	39	425
36	3985	3	46	40	19.12	94.60	36	1435
55	3263	10	100	40	30.80	88.11	36	1175
65	1085	1	94	40	33.18	82.12	36	391
4	2633	5	74	40	34.90	94.99	36	948
29	2370	7	95	40	57.17	92.78	36	853
7	645	2	20	50	36.74	81.86	35	226
25	3253	3	64	30	38.15	93.33	35	1139
24	2824	1	125	50	38.35	97.63	35	989
46	4233	3	85	30	39.03	95.84	35	1482
35	1989	7	65	60	24.18	92.56	32	637
11	2490	20	75	40	32.97	86.67	30	747
TOTAL	29860							10447
MEAN				42			35	

4.4.5.1 Woodbridge 1: Part of Soilscape No. 25

Soilscape 25 is located on the 1:50 000 topocadastral map 2926BD. It is characterized by few dolerite dykes constituting an estimated 3% of its area, with its remaining part covered by Middle Beaufort sandstone. Part of the soilscape is under cultivation. It is characterized by a slope ranging mainly from 0 to 5 % with < 2 of the area having slopes > 5 %, and about 93 % in the slope classes < 3 % (Appendix 3). The local relief ranges from 1506 m to 1450 m above sea level. This makes the soilscape terrain type A2 (Land Type Survey Staff, 2002). About 50 % of the total observed profiles have more than 700 mm depth. Using expert knowledge the soilscape is estimated to have an RI value of 30 % with 35 % of its area, or 1 139 ha consisting of arable land (Table 4.16). The soil pattern on the Woodbridge 1 portion of the soilscape was studied by making 15 soil pits and three auger holes along transect AB (Figures 4.12 and 4.13).

Detailed results are presented in Appendix 4, with the symbol “W” preceding the profile numbers for the profile pits. W1 is located at the eastern end of the pedosequence and W15 at the western end. The three additional auger observations were made to the west of W15. Results are presented in Figure 4.13 and Table 4.17. The indicated soil forms on transect AB are all observed while those on transect CD, except observations on TMU 1(1) are predicted.

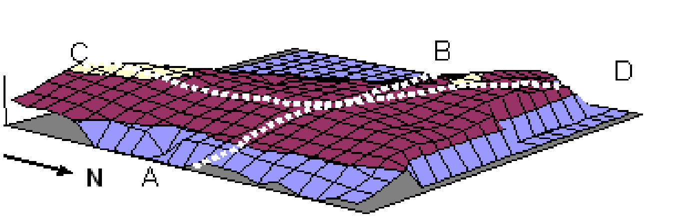


Figure 4.12 Three-dimensional view of Woodbridge 1. Dotted lines are transects AB. Elevation classes are at 20 m intervals.

Generalised conclusions from the information in Figure 4.13 and Table 4.17 follows:

1. At all the sites the lithology was sandstone. This is therefore a common factor to all the comments.
2. Shallow (ERC < 600 mm) soils of the Swartland form occur on TMU's 3 and 4 with slopes of 2.5 – 4.5 % with slope shapes VL, LL, LV and LC.
3. Slightly deeper (ERD 600 – 800 mm) soils of the Swartland form occur on TMU's 1 and 3 with slopes less than 2.5 % and various slope shapes.
4. Soils of the Estcourt form occur on TMU's 1 and 4 and slope shapes LC and CC.
5. Soils of the Sepane form with ERD > 700 mm occur on TMU's 1 and 5 with slopes < 2 % and slope shape LC.
6. Soils of the Avlaon/Clovelly form with ERD > 800 mm occur on TMU 1/3 with around 1 % slope and slope shape LL.

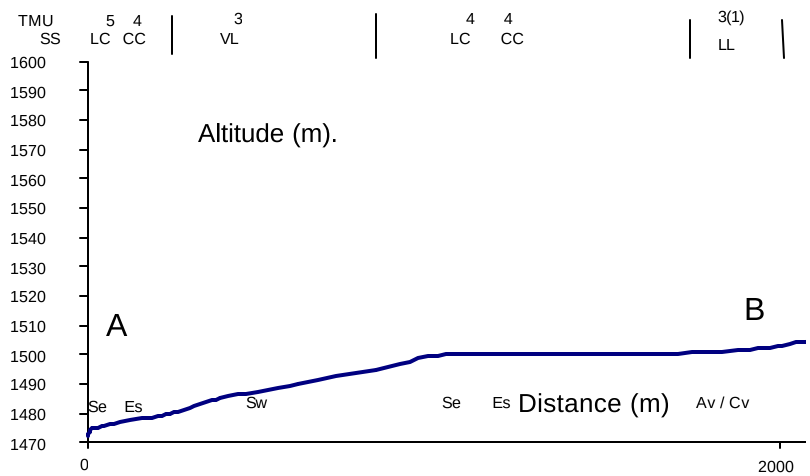


Figure 4.13 Soil distribution of the soilscape Woodbridge 1 transects AB. TMU = terrain morphological unit; SS = slope shape.

Table 4.17 Soil pattern of transect AB Woodbridge1

TMU	Slope (%)	Slope shape	Parent material	Soil form Dominant	Soil form Subdominant	ERD* (mm)
5	2.5	LC	Alluvium	Sepane		800+
4	2.5	CC	Sandstone	Estcourt		500
4/3	2.5 – 4.5	LL/LV/LC	Sandstone	Swartland		500
4	1.5	LC	Sandstone	Sepane		700
4	1.5	CC	Sandstone	Estcourt		300
$3^{(1)}$	1.5	LL	Sandstone	Clovelly / Avalon		800+
$1^{(1)}$	1	LL	Sandstone	Clovelly		800+
$3^{(2)}$(u)	2	CV	Sandstone	Swartland		
$3^{(2)}$(l)	1.5	CV	Sandstone	Swartland		

*Effective rooting depth

4.4.6 Class 5

This class contains 37 293 ha or 15.7 % of the total area of the land type, and 8 527 ha or 15 % of the estimated arable area of Dc17 (Table 4.18). This soilscape class is characterized by a high RI of 30 – 70 %; local relief ranging from 36 – 130 m, and with a wide range in dolerite coverage i.e. 1 – 40 %.

Table 4.18 Soilscapes in class 5

Soilscape	Area	Dolerite	Relief	RI %	Steepness		Estimated arable	
No.	(ha)	(%)	(m)		1-3%	<3%	(%)	Area (ha)
1	2317	20	40	60	47.52	95.04	24	556
3	3382	7	71	30	37.02	93.73	21	710
2	1848	3	36	60	44.70	90.64	20	370
39	2629	10	127	50	44.77	90.30	25	657
57	3525	1	97	60	46.64	88.79	20	705
43	3933	10	115	50	43.68	88.10	25	983
59	1127	7	80	60	41.17	87.58	24	271
52	4790	15	115	50	39.46	83.01	25	1198
38	1407	20	86	60	45.49	80.60	28	394
5	5362	40	101	60	36.81	78.22	20	1072
8	4887	30	130	70	34.97	73.99	24	1173
0	2086	40	109	70	38.54	59.78	21	438
TOTAL	37293							8527
MEAN				57			23	

4.4.7 Class 6

This class contains 17 436 ha or 7.3 % of the total area of the land type, and 22 153 ha or 3.9 % of the estimated arable area of Dc17 (Table 4.19). This soilscape class is characterized by estimated RI values ranging from 60 – 80 %, local relief of 69 – 202 m, and estimated dolerite coverage of 2 – 40 %.

Table 4.19 Soilscapes in class 6.

Soilscape	Area	Dolerite	Relief	RI %	Steepness		Estimated arable	
No.	(ha)	(%)	(m)		1-3%	<3%	(%)	Area (ha)
10	1542	15	109	80	30.61	54.60	14	216
54	2433	30	79	70	31.89	63.71	12	292
42	6277	30	202	80	42.76	70.69	12	753
28	1695	40	121	70	56.17	76.70	15	254
33	2547	25	148	70	43.19	86.53	9	229
26	2942	2	69	60	51.56	92.56	16	471
TOTAL	17436							2215
MEAN				72			13	

An important characteristic of the soilscapes in classes 5 and 6 are the relatively large portions considered non-arable because of rough topography, i.e. high RI values. A strong negative correlation between the estimated arable and RI percentage is exposed. It is well demonstrated in the results presented in Table 4.2 showing classes 5 and 6 having mean RI values > 56 % and estimated arable area values < 24 %, compared to classes 1 and 2 for example with comparable values < 22 % and > 60 % respectively. These results indicate the advantage that could be gained for detail soil survey work by having large scale maps with narrow contour intervals which would expose rough areas clearly.

4.5 Evaluation of the soilscapes for sunflower and maize production

Of the total area of Land Type Dc17 of 237 651 ha, 56 875 ha or 24 % is estimated to be suitable for sunflower and maize production using IRWH. Studies by the ARC-Institute for Soil, Climate and Water with IRWH using different mulches and presented in section 1.2.3.3 were used to predict the potential production of the land type. The potential yields at 50 % probability of achievement in each soilscape is calculated from the area of arable land using the results given in Botha *et al.*, (2003) and results are presented in Tables 4.20 and 4.21 for maize and sunflower respectively. Yields were highest in treatments with organic mulch in the basin and stone mulch on the runoff strip (ObSr), followed by stone mulch in the basin and stone mulch on the runoff strip (SbSr) for both crops. All the IRWH techniques are shown to be significantly better than CON. A farmer can improve his production by implementing one of the IRWH techniques that fits his resources.

The most obvious IRWH technique to be immediately adopted by the subsistence farmers is the BbBr treatment. By implementing BbBr for example a farmer on soilscape 0 is predicted to have a 50 % chance of realising a maize yield of 979 kg ha y^{-1} compared to 632 kg ha y^{-1} using CON.

Table 4.20 Estimated maize yields (ton ha^{-1} yr^{-1}) on each soilscape using predicted yields with different techniques from Botha *et al.* (2003)

Soilscape No.	Arable area (%)	Arable area (ha)	CON	BbBr	SbSr	ObSr
0	21	438	632.1	978.6	1139.0	1147.7
1	24	556	802.4	1242.3	1445.8	1456.9
2	20	370	533.3	825.7	961.0	968.4
3	21	710	1024.8	1586.6	1846.6	1860.8
4	36	948	1367.8	2117.6	2464.5	2483.4
5	20	1072	1547.5	2395.7	2788.2	2809.7
6	56	678	978.6	1515.0	1763.2	1776.8
7	35	226	325.8	504.3	587.0	591.5
8	24	1173	1692.5	2620.2	3049.5	3072.9
9	81	901	1299.7	2012.2	2341.9	2359.9
10	14	216	311.5	482.3	561.3	565.6
11	30	747	1077.9	1668.8	1942.2	1957.1
12	72	1399	2018.7	3125.3	3637.3	3665.3
13	42	836	1206.7	1868.1	2174.2	2190.9
14	42	241	347.3	537.6	625.7	630.5
15	53	3054	4406.7	6822.3	7940.0	8001.1
16	81	1538	2219.6	3436.3	3999.3	4030.1
18	64	774	1117.5	1730.0	2013.4	2028.9
19	39	425	613.4	949.7	1105.3	1113.8
22	40	1348	1945.7	3012.3	3505.8	3532.8
23	42	464	669.1	1035.9	1205.6	1214.8
24	35	988	1426.3	2208.1	2569.8	2589.6
25	35	1139	1642.9	2543.5	2960.2	2983.0
26	16	471	679.2	1051.6	1223.9	1233.3
27	49	2313	3338.1	5167.9	6014.6	6060.8
28	15	254	366.9	568.0	661.1	666.1
29	36	853	1231.2	1906.0	2218.3	2235.4
30	42	820	1183.0	1831.5	2131.6	2148.0
31	64	2259	3259.1	5045.6	5872.3	5917.4
33	9	229	330.8	512.1	596.0	600.6
34	64	1220	1760.2	2725.1	3171.6	3196.0
35	32	636	918.4	1421.9	1654.8	1667.6
36	36	1435	2070.1	3204.9	3730.0	3758.7
37	48	563	812.5	1257.8	1463.9	1475.2
38	28	394	568.5	880.1	1024.3	1032.2
39	25	657	948.4	1468.3	1708.9	1722.0
40	42	920	1327.9	2055.8	2392.6	2411.0
41	42	1796	2590.9	4011.1	4668.3	4704.2
42	12	753	1086.9	1682.7	1958.4	1973.5
43	25	983	1418.8	2196.6	2556.5	2576.1
44	63	2475	3571.8	5529.8	6435.7	6485.2
46	35	1482	2137.9	3309.8	3852.0	3881.7
47	40	1093	1577.5	2442.2	2842.3	2864.2
48	48	1449	2091.1	3237.3	3767.7	3796.7
49	42	347	500.0	774.1	900.9	907.8
50	42	3102	4476.4	6930.1	8065.5	8127.6

Table 4.20 Continued

Soilscape No.	Arable area (%)	Arable area (ha)	CON	BbBr	SbSr	ObSr
51	42	324	467.3	723.4	841.9	848.4
52	25	1198	1728.0	2675.2	3113.5	3137.5
53	49	1376	1986.2	3074.9	3578.7	3606.2
54	12	292	421.3	652.2	759.1	764.9
55	36	1175	1695.1	2624.2	3054.2	3077.7
57	20	705	1017.3	1575.0	1833.0	1847.1
58	42	1370	1977.0	3060.7	3562.1	3589.5
59	24	270	390.3	604.3	703.2	708.7
60	49	2157	3113.2	4819.8	5609.4	5652.6
61	49	872	1258.6	1948.5	2267.7	2285.2
65	36	391	563.6	872.6	1015.6	1023.4
TOTAL		56875	82071	127060	147876	149014

Table 4.21 Estimated sunflower yields (ton ha^{-1} yr^{-1}) on each soilscape using predicted yields with different techniques from Botha *et al.* (2003)

Soilscape No.	Arable area (%)	Arable area (ha)	CON	BbBr	SbSr	ObSr
0	21	438	348.7	626.9	794.2	801.6
1	24	556	442.6	795.8	1008.2	1017.6
2	20	370	294.2	528.9	670.1	676.4
3	21	710	565.3	1016.3	1287.6	1299.7
4	36	948	754.5	1356.4	1718.5	1734.6
5	20	1072	853.6	1534.6	1944.3	1962.5
6	56	678	539.8	970.4	1229.5	1241.0
7	35	226	179.7	323.0	409.3	413.1
8	24	1173	933.6	1678.4	2126.4	2146.4
9	81	901	717.0	1288.9	1633.0	1648.3
10	14	216	171.8	308.9	391.4	395.1
11	30	747	594.6	1069.0	1354.3	1367.0
12	72	1399	1113.6	2001.9	2536.3	2560.1
13	42	836	665.6	1196.6	1516.1	1530.3
14	42	241	191.6	344.4	436.3	440.4
15	53	3054	2430.9	4370.1	5536.6	5588.6
16	81	1538	1224.4	2201.1	2788.7	2814.9
18	64	774	616.4	1108.2	1404.0	1417.2
19	39	425	338.4	608.3	770.7	777.9
22	40	1348	1073.3	1929.6	2444.6	2467.6
23	42	464	369.1	663.5	840.7	848.5
24	35	988	786.8	1414.4	1792.0	1808.8
25	35	1139	906.3	1629.3	2064.2	2083.5
26	16	471	374.7	673.6	853.4	861.4
27	49	2313	1841.4	3310.3	4194.0	4233.3
28	15	254	202.4	363.8	461.0	465.3
29	36	853	679.1	1220.9	1546.9	1561.4
30	42	820	652.6	1173.2	1486.4	1500.3
31	64	2259	1797.8	3232.0	4094.8	4133.2

Table 4.21 Continued

Soilscape No.	Arable area (%)	Arable area (ha)	CON	BbBr	SbSr	ObSr
33	9	229	182.5	328.0	415.6	419.5
34	64	1220	971.0	1745.6	2211.6	2232.3
35	32	636	506.6	910.8	1153.9	1164.8
36	36	1435	1141.9	2052.9	2600.9	2625.3
37	48	563	448.2	805.7	1020.8	1030.4
38	28	394	313.6	563.8	714.2	720.9
39	25	657	523.2	940.5	1191.6	1202.8
40	42	920	732.5	1316.8	1668.4	1684.0
41	42	1796	1429.2	2569.4	3255.2	3285.8
42	12	753	599.6	1077.9	1365.6	1378.4
43	25	983	782.7	1407.0	1782.6	1799.3
44	63	2475	1970.3	3542.1	4487.7	4529.7
46	35	1482	1179.3	2120.1	2686.1	2711.2
47	40	1093	870.2	1564.4	1982.0	2000.6
48	48	1449	1153.5	2073.7	2627.3	2651.9
49	42	347	275.8	495.8	628.2	634.1
50	42	3102	2469.3	4439.1	5624.1	5676.9
51	42	324	257.8	463.4	587.1	592.6
52	25	1198	953.2	1713.6	2171.1	2191.4
53	49	1376	1095.6	1969.6	2495.4	2518.8
54	12	292	232.4	417.8	529.3	534.3
55	36	1175	935.0	1681.0	2129.7	2149.7
57	20	705	561.2	1008.9	1278.2	1290.2
58	42	1370	1090.6	1960.5	2483.9	2507.2
59	24	270	215.3	387.1	490.4	495.0
60	49	2157	1717.3	3087.3	3911.5	3948.2
61	49	872	694.3	1248.1	1581.3	1596.1
65	36	391	310.9	558.9	708.2	714.8
TOTAL		56875	45272.9	81388.8	103115.2	104082.1

The results in Tables 4.20 and 4.21 signal the achievement of objectives 4 and 5. They show that using the simplist IRWH technique (BbBr) it is predicted that enough maize could be produced in Land Type Dc17 to feed about 635 000 people. If the best IRWH technique is adopted the number of people provided for would be 745 000.

4.6 Preliminary estimation of the area in the Free State Province that is suitable for IRWH

Eloff (1984) used four qualitative classes of crop production potential for each of the three parameters namely the amount of rainfall, effective rooting depth (ERD), and the clay content of the soil (Table 4.22). Based on this framework he developed guidelines for classifying the crop production potential of the Free State Region. He summed the values for each parameter to obtain an overall quantitative value for a particular land type. For example if a land type had rainfall of 400-500 mm, ERD of 600-900 mm and clay content of 15-25 %, then its summed value would be: 1+2+3 = 6. It would then be classified as having medium crop production potential (Table 4.23).

Table 4.22 Parameters and criteria used for assessing the crop production potential of pedosystems of the Free State Region (Eloff, 1984)

Parameters	Criteria	Crop production potential	Allotted value
Rainfall	< 400mm	No	0
	400 - 500 mm	Low	1
	500 - 600 mm	Medium	2
	> 600 mm	High	3
ERD*	< 300 mm	No	0
	300 - 600 mm	Low	1
	600 - 900 mm	Medium	2
	> 900 mm	High	3
Clay content	<10% & > 35%	Low	1
	10-15% & 25 - 35%	Medium	2
	15-25%	High	3

* = Effective rooting depth.

Table 4.23 Guidelines for the classification of crop production potential of pedosystems of the Free State Region (Eloff, 1984)

Guidelines		Crop production potential class
Sum of values in Table 4.22	Minimum allowable value for a single criterion	
3	1	Very low
4 - 5	1	Low
6 - 7	1	Medium
8 - 9	2	High

Eloff (1984) used the following symbols for his pedosystems which will be considered here to be suitable for crop production using the IRWH technique. For the purpose of this study a pedosystem can be considered to be equivalent to a land type.

D = Duplex soils dominant
K = Black and red clays dominant
P = Soils with a plinthic horizon dominant

There were many other pedosystems in the Free State region, but only those considered to be suitable for IRWH will be considered here. It will be assumed that what Eloff considered to be arable in the D and K type pedosystems (Table 4.24), even of low potential, will be suitable for IRWH. For the P type pedosystems (Table 4.25) the following procedure will be followed to obtain an estimate of the area suitable for IRWH. P type pedosystems are equivalent to these designated as Ca in the Land Type Survey. A definition of the dominant soil pattern in the Ca type is given at the end of Section 2.2.2.9. In line with this definition, 10 % of the total arable area of the P type pedosystems is taken as being suitable for IRWH (Table 4.25). For each pedosystem Eloff reported the total area, the area which occurred in the Free State Region, an estimate of the percentage that was arable, and an estimate of the cropping potential obtained using the procedure outlined in Tables 4.22 and 4.23. Results are presented in Tables 4.24 and 4.25.

Table 4.24 Pedosystems designated as D and K types of the Free State Region (Eloff, 1984) considered to contain areas suitable for crop production using the IRWH technique. All areas and estimates are from Eloff (1984). Note that Dc17 is described here as Sepane.

Pedosystems	Map legend	Total area (ha)	Area in the Free State Region (ha)	Estimated arable (%)	Crop potential class.	Estimated arable area in Fee State Region (ha)
Erosie	DI1es	29370	29370	10	Low	2937
Rooikop	DI1rk	13270	13270	15	Low	1991
Caledon	DII1cl	15290	15290	10	Low	1529
Lengana	DII1lg	94220	94220	15	Mediuim	14133
Rouxville	DII1rx	105390	105390	20	Low	21078
Smithfield	DII1sf	123420	123420	20	Low	24684
Wepener	DII1wp	47920	47920	15	Low	7188
Georgia	DII2gg	29160	20990	55	Medium	11545
Modderbult	DII2mb	214560	214560	35	Low	75096
Modderivier	DIII1mr	63980	63980	25	Low	15995
Rooibloem	DIII1rb	223190	109890	15	Low	16484
Roelofsberg	DIII1rg	127720	127720	30	Medium	38316
Sepane	DIII1sn	239080	239080	10	Low	23908
Saryna	DIII1sr	202500	80480	30	Medium	24144
Mazelspoort	KI2mp	123300	123300	20	Low	24660
Erfenis	KI4ef	86460	86460	10	Low	8646
Total						312334

Combining the results from Tables 4.24 and 4.25 provides an estimate of the area in the Free State Region considered suitable for IRWH, *i.e.* 365 093 ha. This assessment is conservative, (a) because plinthic soils may also be suitable for IRWH, (b) and because the estimates made during this study indicate that the Sepane pedosystem, for example contain considerably more than 10 % of arable land.

Table 4.25 Pedosystems designated as P types of the Free State Region (Eloff, 1984) considered to contain areas suitable for crop production using the IRWH technique. All areas and estimates are from Eloff, 1984

Pedosystems	Map legend	Total area (ha)	Area in the Free State Region (ha)	Est.% arable	Estimated crop potential.	Estimated arable area (ha) in FS Region
Virginia	PI1vg	97270	11250	80	High	9000
Bainsvlei	PII1bv	398000	398000	55	Medium	218900
Thalia	PII1th	156400	156400	60	Medium	93840
Egmont	PIII 1em	95610	95610	70	Medium	66927
Senekal	PIII 1se	352250	35500	70	Medium	24850
Wesselskop	PIII 1wl	62950	61300	70	Medium	42910
Wonderkop	PIII 2wk	129250	44810	65	Medium	29127
Belvedere	PIII 4bd	33490	1910	70	Medium/high	1337
Genadeberg	PIII 4gn	88980	88980	45	Medium	40041
Paul Roux	PIII 4pr	29740	940	70	Medium	658
Total						527590 (10% = 52759)

Scheepers *et al.* (1984) used the Land Type Survey data as basis for the assessment of the agricultural potential of the Highveld Region. Ludick and Wooding (1991) adjusted the assessment to enable results to be expressed for each magisterial district. This makes it possible to evaluate the potential for IRWH of the magisterial districts of the Free State Province which were located in the Highveld Region i.e. portion A in Figure 2.4. Ludick & Wooding(1991) give the areas of the following classes of land for each magisterial district, which sum to the total area of the district:

(a) area unavailable for agriculture;
(b) area suitable for grazing only;
(c) area suitable for veld improvement, effective rooting depth (ERD) < 400 mm;
(d) area suitable for crop production, ERD > 400 mm.

For each magisterial district the area of each land type was subdivided into these four classes. Section (d) areas of land types designated as Da, Db, Dc and Ea were considered suitable for IRWH, as well as 10 % of those designated as Ca. Results for each magisterial district are presented in Table 4.26. Notice that the focus here is on land types that are mainly marginal for crop production.

Table 4.26 Areas in the magisterial districts of the Free State Province in the Highveld Region estimated to be arable using IRWH (adapted from Ludick and Wooding, 1991).

District	Estimated area suitable for IRWH(ha)
Bethelehem	4037
Bothaville	0
Bultfontein	37643
Clocolan	2537
Ficksburg	0
Fouriesburg	0
Frankfort	62941
Harrismith	4394
Heilbron	95468
Hennenman	0
Hoopstad	2897
Koppies	2504
Kroonstad	21153
Ladybrand	2789
Lindley	30982
Marquard	5860
Odendaalsrus	0
Parys	10846
Reitz	25740
Sasolburg	16339
Senekal	8678
Ventersburg	12071
Viljoenskroon	0
Vrede	93043
Vredefort	10345
Welkom	6965
Wesselsbron	19234
Total	476466

The total area estimated to be suitable for IRWH in the Free State Province is the sum of the totals from Tables 4.24, 4.25 and 4.26, *i.e.* 841 559 ha. For various reasons a considerable portion of this area has not yet been used for crop production. Development of these areas using IRWH could make a valuable contribution to agricultural production in the Free State Province, and elsewhere in South Africa on similar marginal areas.

CHAPTER FIVE

CONCLUSIONS

Any change in land use type and/or land redistribution requires efficient land evaluation. Because of the current situation in South Africa efficient land evaluation is therefore an important national issue. Soilscape surveys can make a valuable contribution in this respect.

The land types of South Africa can be subdivided into units that are more homogeneous. These units can be called soilscapes. The Land Type Survey of South Africa provides very useful information for regional planning. However, its importance for large scale planning is restricted. The scale of the survey is too small and the intensity of observations too low to accurately predict the distribution of soils in the land type. The survey was not designed to do this. There is a need to refine this valuable basic information to provide useful information for detailed land use planning. Soilscape surveys can bridge this gap.

The application of expert knowledge combined with land type data is a prerequisite for efficient delineation of soilscapes.

- It consists of a portion of land mappable at 1:50 000.
- It contains one or more ecotopes.
- It has characteristic pedosequences.
- It consists of a hillslope or combination of hillslopes.
- The lower boundary is a drainage line and the upper boundary a crest.
- Its soil distribution pattern is predictable and can be extrapolated to other soilscapes.
- It shares watersheds, hillslopes and drainage lines with catchments.
- It facilitates the identification of potentially arable land.
- It aims to facilitate detail surveys of marginal cropping land.
- It facilitates feasibility studies for intensive land use in general.

The procedure followed in the survey prohibits the description of the location and extent of specific ecotopes. However, it is possible to describe the dominant kind of ecotopes as follows: soils of the Swartland, Sepane, Valsrivier, Arcadia and Bonheim forms, with ERD of at least 700 mm, on slopes less than 3 %, on TMU's 3 and 4.

The soilscape definition has to be refined for South Africa. Like other small-scale survey concepts, it carries the potential to be applied differently by individuals, depending on the character of the land and land-use requirements. However, due to the larger scale of soilscape surveys, the problem is expected be relatively small. The contradictions in the literature regarding the definition of soilscapes do not apply in South Africa due to the existence of the land type survey.

Subdividing catchments into pedologically well divined component soilscapes could make a valuable contribution to hydrological studies because of the importance of hillslopes in these studies.

In this study a new efficient procedure for identifying land suitable for IRWH was developed. It consists of using a penetrometer to determine soil depth.

Characterization of the soilscapes of Land Type Dc17 led to a new estimate of the human carrying capacity of this densely populated area. This was achieved by making for each soilscape long-term maize and sunflower yield and risk predictions using the IRWH crop production technique. This showed that the land type could produce enough maize to feed about 600 000 people using IRWH, compared to previous estimates of 170 000 (based on land type data using conventional tillage).

Improved expert knowledge, particularly the interaction of parent material, TMU, slope, slope shapes and soil pattern, has led to the appreciation of future possibilities of facilitating intensive soil surveys using models incorporating GIS and computer technology.

REFERENCES

Abu-Zreig, M., Attom, M. & Hamasha, N., 2002. Rainfall harvesting using sand ditches in Jordan, *Agric. Water Manage*. 46, 183-192.

Agbu, P.A., Ojangu, A.G. & Olson, K.R., 1989. Soil-landscape relationships in the Sokoto Rima Basin, Nigeria. *Soil Science* 148, (2) 132-139.

Ahmed, M.A., 2003. Land suitability evaluation in the Jelo Catchment, Chercher Highlands, Ethiopia. PhD Thesis. University of The Free State, Bloemfontein.

Anaman, T. & Krishnamara, S., 1994. Integrating land evaluation and farming systems analysis for land use planning using a relational database. *ITC Journal* 4, 332-337.

Barshad, I., 1966. The effect of variation in precipitation on the nature of clay mineral formation in soils from acid and basic igneous rocks. *Proc. Int. Clay Conf. Jerusalem* 1, 167–173.

Beckett, P.H.T., 1968. Soil formation and slope development: I. A new look at Walther Penck's aufbereitung concept. *Zeitschrift fur Geomorphologie* 12, 1–24.

Beek K.J., 1978. Land evaluation for agricultural development: Some explorations of Land use systems analysis with particular reference to Latin America. International Publication No. 23, Institute for land reclamation and improvement, The Netherlands.

Belford, B. & Gregory, P., 1992. Cropping duplex soils. Farm note. Department of Agriculture, Western Australia. http://agspsrv34.agric.wa.gov.au/agency/pubns/farmnote/1992/F04692.htm (visited 10/12/03).

Beukes, D.J., Bennie, A.T.P. & Hensley, M., 1998. Optimization of Soil Water Use in The Dry Crop Production Areas Of South Africa: A Review. ARC-Institute for Soil, Climate and Water, Pretoria.

Beukes, D.J., Bennie, A.T.P. & Hensley, M., 2004. Optimization of Soil Water Balance Components for Sustainable Crop Production in Dry Areas of South Africa. In S.C. Rao & Ryan, F. (eds.). Challenges and Strategies for Dry Land Agriculture. CSSA Special Publication 32. Madison, Wisconsin.

Bielders, C.L., Baveye, P., Wilding, L., Drees, R. & Valentin, C., 1995. Tillage-induced spatial distribution of surface crusts on a sandy soil from Togo. *Soil Sci. Soc. Am. J.*, 60, 843-855.

Birkeland, P.W., 1999. Soils and Geomorphology (3rd ed.). Oxford University Press, New York and Oxford.

Black, A.L., Brown, P.L, Halvorson, A.D. & Siddoway, F.H., 1981. Dry land cropping strategies for efficient water use to control saline seeps in the northern great plains. *Agric. Water Manage* 4, 295–311.

Bosch. P.J.A., 2001. The Geology of the Thaba Nchu 2926BB 1:50 000 Scale MapSheet. Council for Geosciences Report, Pretoria.

Botha, J.J., Van Rensburg, L.D., Anderson, J.J., Hensley, M., Macheli, M.S., Van Staden, P.P., Kundhlande, G., Groenewald, D.G. & Baiphethi, M.N., 2003. Water conservation techniques on small plots in semi-arid areas to enhance rainfall use efficiency, food security, and sustainable crop production. Report no 1176/1/03. WRC, Pretoria.

Brad, D. L., Robert C. G., Thomas, E. L. & Christopher, A., 2003. Pedogenesis in a wetland meadow and surrounding serpentinic landslide terrain, Northern California, USA. *Geoderma*. In press.

Bredenkamp, G. & Van Rooyen, N., 1996. Moist Cool Highveld Grassland. In Low, A. B. & Robelo, A. G. (eds.). Vegetation of South Africa, Lesotho and Swaziland. Dep. Environmental Affairs & Tourism, Pretoria.

Brian, J. C. & Edward, J. C., 1991. Slope gradient and aspect effects on soils developed from sandstone in Pennsylvania. *Geoderma 49*, 199-213.

Buol, S.W., Hole F.D. & McCracken, R.J., 1974. Soil genesis and classification. Iowa State Univ. Press, Third print. Ames.360.

Buol, S.W., Hole F.D., McCracken, R.J. & Southard, R.J., 1989. Soil genesis and classification. Iowa State Univ. Press, Third ed. Ames.360.

Buol, S.W., Hole F.D., McCracken, R.J. & Southard, R.J., 1997. Soil genesis and classification. Fourth ed. Iowa State Univ. Press, Ames.

Buhmann, C., 1992. Smectite-to-illite conversion in a geothermally and lithologically complex Permian sedimentary sequence. *Clays Clay Miner*. 40, 53–64.

Buhmann, C. & Schoeman, J.L., 1995. A mineralogical characterization of vertisols from the northern regions of the Republic of South Africa. *Geoderma 66, 239–257.*

Burrough, P.A., 1993. Soil variability: A late 20th century view. *Soils and fertilizers* 56, 529-562.

Burrough, P.A. & McDonnel, R.A., 1998. Principles of geographical information systems. Oxford University Press, New York.

Chen, J.S. & Chiu, C.Y., 2000. Effect of topography on the composition of soil organic substances in a perhumid sub-tropical montane forest ecosystem in Taiwan. *Geoderma 96, 19-30.*

Chesworth, W., 1973. The parent rock effect in the genesis of soil. *Geoderma 10, 215–225.*

Clemency, C.V., 1975. Simultaneous weathering of a granitic gneiss and an intrusive amphibolite dike near Sao Paulo, Brazil, and the origin of clay minerals. Proc Int. Clay Conf. 157–172.

Conacher, A.J. & Dalrymple, J.B., 1977. The nine-unit land surface model: an approach to pedogeomorphic Research. *Geoderma* 18, 1-154.

Connor, D.J & Sadras, V.O., 1992. Physiology of yield expression in sunflower. *Field Crops Research* 30, 333-389.

Daniels, R. & Hammer, R.D., 1992. Soil Geomorphology. John Wiley & Sons Inc., New York.

Davidson, D.A., 1992. The Evaluation of Land Resources (2nd Ed.). Longman, Harlow.

Department of Agriculture - Free State Province, 1996. From entitlement to self reliance. Dept. Agric., Free State. Glen.

De Jager, J.M. & Singels, A., 1990. Economic quantification of climatic risk in maize production using a crop model. In R.C Muchow and J.A. Bellamy (eds.), Climatic risk in crop pdoduction: models and management in the semi-arid tropics and subtropics. Poster papers. CRISO, Brisbane, Australia.

De Villiers, G., 1998. The natural resources of the Thaba Nchu district with special reference to resource management. Acta Academica Supplementation 1, 1–33.

Dent, D. & Young, A., 1981. Soil survey and land evaluation. George Allen and Unwin, London.

Dreyer, K., Fourie, L.J. & Kok, D.J., 1999. Assessment of cattle owner's perception and expectation and identification of constraints on production in Peri-Urban resource poor environment. Onderstepoort *J. Vet. Res.* 66, 95-102.

Duchaufour, P., 1998. Handbook of Pedology: Soils, Vegetation, Environment. Masson Editor, Paris.

Eberl, D.D., 1994. Clay mineral formation and transformation in rocks and soils. *Philos. Trans. R. Soc. London, Ser. A* 311, 241–255.

Eghball, B. & Maranville, J.W., 1993. Root development and nitrogen influx of corn genotypes grown under combined drought and nitrogen stresses. *Agron. J.* 85**,** 147–152.

Eloff, J.F., 1984. Die grondhulpbronne van die Vrystaatstreek. Ph.D. thesis, University of Stellenbosch.

Fanning, D.S. & Fanning, M.C.B., 1989. Soil Morphology, Genesis and Classification. John Wiley & Sons. New York.

FAO., 1976. A framework for land evaluation. FAO Soils Bulletin 32, FAO, Rome

FAO., 1983. Guidelines: Land evaluation for rainfed agriculture. FAO Soils Bulletin 52, Rome.

FAO., 1983. Guidelines for Land Use planning. FAO development series I, Rome.

FAO, 1990. An International Action Program on Water and Sustainable Agricultural Development. FAO, Rome.

FAO, 1996. Agro-ecological zoning guidelines. Soils Bulletin 73. FAO, Rome.

FAO, 2000. Tropical Maize: Improvement and production. FAO plant production and protection series No. 28. Rome.

Finke, P. & Montanarella, L., 1999. Basic Principles of the Manual of Procedures (Version 1.1) for the Georeferenced Soil Database of Europe. Options Méditerranéennes, Série B, vol. 34 (Web site visited 25/2/2002)

Fitzpatrick, E.A., 1980. Soils, Their formation, classification and distribution. Longman . London & New York.

Fitzpatrick, E.A., 1986. An introduction to soil science. Burnt Mill, Harlow, Essex : Longman Scientific & Technical. London & New York.

Free State Department of Agriculture. Overview by head of the department, 2003. http://www.glen.agric.za/home/hod.htm (visited 08/12/03).

Gaetsewe, H.E., 2001. Evaluation of land reform projects in the south eastern Free State. M.Tech. thesis. Technikon Free State, Bloemfontein.

Gerard, J., 1992. Soil geomorphology: An integration of pedology and geomorphology, Chapman & Hall, London.

Habarurema, E. & Steiner, K.G., 1997. Soil suitability classification by farmers in Southern Rwanda. *Geodrema, 75*: 75-87.

Hensley, M., Botha, J.J., Anderson, J.J., Van Staden, P.P., Du Toit, A., 2000. Optimizing rainfall use efficiency for developing farmers with limited access to irrigation water. WRC Report no 878/1/00. Pretoria.

Hole, F.D. & Lee, G.B., 1955. Introduction to soils of Wisconsin. In Soil genesis and classification. Iowa state Univ. Press, Fourth ed. Ames.

Hole, F.D. & Campbell, J.B., 1985. Soil landscape ana lysis. In Soil genesis and classification, Iowa state Univ. Press, Fourth ed. Ames.

Hubble, G.D., Isbell, R.F. & Northcote, K.H., 1983. Features of Australian soils. In Soils: An Australian view point, Division of Soils, CSIRO, Melbourne.

Huggett, R.J., 1975. Soil landscape systems: A model of soil genesis. *Geoderma* 13, 1–22.

Hudson, B.D., 1992. The soil survey as paradigm-based science. *Soil Sci. Soc. Am. J.* 56, 836–841.

Hutson, J.L, 1983. Estimation of hydrological properties of South African soils. Ph.D. thesis. University of Natal, Pietermaritzburg.

ISRIC., 1993. Global and National Soils and Terrain Digital Databases (SOTER). Procedures Manual. UNEP-ISRIC-FAO. ISRIC. Wageningen, Netherlands.

Jenny, H.I., 1941. Factors of soil formation. McGraw Hill: New York.

Jamagne, M. & King, D., 2003. The Current French Approach To A Soilscape Topology. In Soil Classification: A Global Desk Reference. H. Eswaran, T. Rice, R. Ahrens & B.A. Stewart (eds.). CRC Press, New York.

Key, L.J., Delph, L.F., Thompson D.B., & Van Hoogenstyn, E.P., 1984. Edaphic factors and the perennial plant community of a Sonoran Desert Bajada. *Southwestern Naturalist* 29, 211–222.

Kronen, M., 1994. Water harvesting and conservation techniques for smallholder crop production system. *Soil and Tillage Research 32*, 71-86.

Kundhlande, G. & Du Plessis, L.A., 2002. Understanding Rural Livelihoods: Case Study of Smallholder farmers In the Thaba Nchu District in the Free State Province. The Association of Agricultural Economics of South Africa (AAESA) Annual Conference. Bloemfontein.

Land Type Survey Staff, 2002. Land Type Soil and Terrain Inventories From Northern Cape, Free State, North West, Gauteng, Kwazulu-Natal and Eastern Cape Provinces. Land Type Survey Database. ARC-Institute for Soil, Climate and Water, Pretoria.

Land Type Survey Staff, 2004. Land Type Climate Zone Database for South Africa. ARC-Institute for Soil, Climate and Water, Pretoria.

Land Type Survey Staff., 2004. Soil Profile Information System and Database for South Africa. ARC-Institute for Soil, Climate and Water, Pretoria

Lark, R.M., 1999. Soil-landform relationships at with in-field scales: An investigation using continuous classifications. *Geoderma* 92, 141-165.

Lee, B.D., Sears, S.K., Graham, R.C., Amrhein, C. & Vali, H., 2003. Secondary mineral genesis from chlorite and serpentine in an ultramafic soil toposequence. *Soil Sci. Soc. Am. J.* 67, 1309–1317.

Lourens, U.W., 1995. A System for Drought Monitoring and Severity Assessment. PhD Thesis, University of the Orange Free State, Bloemfontien.

Ludick, B.P. & Wooding, J.G., 1991. An evaluation of the application and potential of agricultural land and production stability of dry land crops in the magisterial districts of the Highveld region. Tech. Commun. 224. Dep. Agric. Dev., Pretoria.

MacMillan, R.A., Pettapiece, W.W., Nolan, S.C. & Goddard, T.W., 2000. A generic procedure for automatically segmenting landforms into landform elements using DEMs, heuristic rules and fuzzy logic. Fuzzy Sets and Systems 112, 81-109.

MacVicar, C.N., 1978. Advances In Soil Classification And Genesis. Southern Africa. Proceedings of the 8th Congress of the Soil Science Society of Southern Africa, Dept. of Agric. Technical Services, Technical Communication No. 165.

MacVicar, C.N., Scotney, D.M., Skinner, T.E., Niehause, H.S. & Loubser, J.H., 1974. A classification of land (climate, terrain form, soil) preliminary for rainfed agriculture. *S. Afr. J. Agric. Ext*. 3, 21-24.

MacVicar, C.N., De Villiers, J.M., Loxton, R.F., Verster, E., Lambrechts, J.J.N., Merryweather, F.R., Le Roux, J., Van Rooyen, T.H. and Harmse. H.J. Von M., 1977. Soil classification - A binomial system for South Africa. Science Bull., 390. Dept. of Agric. Tech. Services, Pretoria.

Martinez, M.L. & Vanegas R,D., 1994. GIS applications for spatial planning in the Colombian Amazon region: A case study of the Guaviare colonization area Part I Diagnosis . *ITC Journal* 3, 215-223.

McRae, S.G. & Burnham, C.P., 1981. Land evaluation. Clarendon press, London.

Mermut, A.R., Luk, S.H., Römkens, M.J.M. & Poesen, J.W.A. 1995. Micromorphological and mineralogical components of surface sealing in loess soils from different geographic regions. *Geoderma* 66, 71-84.

Merrill, S.D., Tanaka D.L. & Hanson, J.D., 2002. Root length growth of eight crop species in Haplustoll soils. *Soil Sci. Soc. Am. J.* 66, 913–923

Monteith, J.L., & Virmani, S.M.,1991. Quantifying climatic risk in the semiarid tropics: ICRISAT experience. In R.C. Muchow & J.A. Bellamy (eds.) Climatic risk in crop production: Models and management for the semiarid tropics and subtropics. Proc. Int. Symp. Brisbane, Australia. C.A.B. International, Wallingford.

Moore, I.D., Gessler, P.E., Nielsen, G.A. & Peterson, G.A., 1993. Soil attribute prediction using terrain analysis. *Soil Sci. Soc. Am. J.* 53, 443–452.

Morin, J. & Cluff, C.B., 1980. Runoff calculation on semi-arid watersheds using a rotadisk rainulator. *Water Resour. Res.* 16, 1085-1093.

Muchow, G.L, Hammer, P.S. & Carberry, P.S., 1990. Optimising crop and cultivar selection in response to climatic risk. In R.C. Muchow and J.A. Bellamy (eds.), Proceedings of the International Symposium on Climatic Risk in Crop Production, Brisbane, Australia.

Mwakalila, S.S. & Hatibu, N., 1992. Rainwater harvesting for crop production in Tanzania. Proc. 3rd Ann. Sci. Conf. SADC-Land & Water Manag. Res. Programme. Harare, Zimbabwe.

National Department of Agriculture, 1998. Agricultural policy in South Africa. Pretoria.

Nell, J.P., 1991. Irrigation suitability of structured soils (Afrikaans). M.Sc.Agric. Dissertation. University of the Orange Free State, Bloemfontein.

Nizyeimana, E. & Bicki, T.J., 1992. Soil and soil-landscape relationship in the North Central region of Rwanda, East Central Africa. *Soil Science* 153, 225-236.

Nonjabulo, N., 1995. Report of the BATAT Technology Design Team Compiled by: http://www.nda.agric.za/docs/batat/tech.htm (visited 05/06/2004).

Northcote, K.H., 1978. Soils and Land Use. Atlas of Australian Resources, Division of National Mapping, Canberra.

Oweis, T., Hachum, A. & Kijne. J., 1999. Water harvesting and supplementary irrigation for improved water use efficiency in dry areas. IWMI contribution (No. 7) to System-Wide Initiative on Water Management (SWIM).

Parsons, R.B., 1978. Soil-geomorphology relationships in mountains of Oregon, *USA*, *Geoderma*, 21: 25-39.

Raghubanshi, A.S., 1992. Effect of topography on selected soil properties and nitrogen mineralization in a dry tropical forest. *Soil Biol. Biochem* 24, 145–150.

Randy, L.A., Donald, L.T. & Stephen, D.M., 2003. Yield and water use of broadleaf crops in a semiarid climate, *Agri. Water Manage.* 58, 255-266.

Reij, C., Mulder, P. & Begemann, L., 1988. Water Harvesting for Plant Production. World Bank Technical Paper No. 91. World Bank, Washington DC.

Rossiter, D.G. & VanWambeke, A.R., 1989. Automated Land Evaluation System, ALES User's Manual, version 3.01. Dept. of Agronomy, Cornell University, NY.

Rossiter, D.G., 1990. ALES: A framework for land evaluation using a microcomputer. Soil Use Management 6, 7-20.

Rossiter, D. G., 1996. A theoretical framework for land evaluation. *Geoderma* 72, 165-190.

Rossiter, D. & Van Wambeke, A., 2000. ALES, Automated Land Evaluation System. Version 4.65 User's Manual. SCAS Teaching Series T93-2. Revision 6. Department of Crop and Soil Sciences, Cornell University. Ithaca, NY.

Sandor, J. & Furbee, L., 1996. Indigenous knowledge and classification of soils in the Andes of Southern Peru. *Soil.Sci.Soc.Am.J*. 60, 1502-1512.

Scheepers, J.J., Smit, J.A. & Ludick, B.P., 1984. An evaluation of the agricultural potential of the high-veld region in terms of dry land cropping and livestock production. Tech. Commun. No. 185. Dep. Agric. Rep. S. Afr., Pretoria.

Schoeneberger, P.J., Wysocki, D.A., Benham, E.C. & Broderson, W.D., (eds), 2000. Field Book for describing and sampling soils. Version 2.0. Natural Resource Conservation Service, National Soil Survey Centre, Lincoln. Nebraska.

Shainberg, I. & Singer, J.M., 1985. Effect of electrolyte concentration on the hydraulic properties of depositional crust. *Soil Sci. Soc. Am. J*., 49, 1260-1263.

Shmida, A. & Burgess, T.L., 1988. Plant growth-form strategies and vegetation types in arid environments. In M.J.A. Werger, (ed.). Plant Form and Vegetation Structure, SPB Academic Publishing, The Hague, The Netherlands.

Sinowski, W. & Auerswald, K., 1999. Using relief parameters in a discriminant analysis to stratify geological areas with different spatial variability of soil properties, *Geoderma* 89, 113-128.

Sobieraj, J.A., Elsenbeer, H., Coelho, R.M. & Newton, B., 2002. Spatial variability of soil hydraulic conductivity along a tropical rainforest catena. *Geoderma* 108, 79-90.

Soil Classification Working Group., 1991. Soil classification - a taxonomic system for South Africa. Mem. Agric. Nat. Resource. No.15. Dept. Agric. Dev., Pretoria.

South Africa Yearbook., 2002/03. South Africa Government on line. The Provinces. http://www.info.gov.za/yearbook/2002/landpeople.htm (visited 15/03/2003).

Southard, R.J., Shainberg, I. & Singer, M.J., 1988. Influence of electrolyte concentration on the micromorphology of artificial depositional crust. *Soil Sci.* 145, 278-288.

Southard, S.B. & Southard R.J., 1989. Mineralogy and classification of andic soils in northeastern California. *Soil Sci. Soc. Am. Jour*. 53, 1784 – 1791.

Stewart, B.A. & Robinson, C.A., 1997. Are agro-ecosystems sustainable in semiarid regions? *Adv. In Agron.* 60, 191-228.

Stone, L.R., Goodrum, D.E., Schlegel, A.J., Jaafar, M.N. & Khan, A.H., 2002. Dry land cropping systems: water depletion depth of grain sorghum and sunflower in the Central High Plains. . *Agron. J.* 94, 936–943.

Sys, C., Van Ranst, E. & Debaveye, J., 1991. Land Evaluation. Part II, Methods of Land Evaluation. ITC Agricultural Publications. Brussels, Belgium.

Sys, C., 1993. Land Evaluation in the Tropics. *Pedologie* XLIII 1, 117-142.

Teshome Yizengaw. & Verheye, W., 1995. Application of computer captured knowledge in land evaluation, using ALES in Central Ethiopia. *Geoderma*, 66: 297 - 311.

Takahashi, T., Dahlegren R.A. & Sase, T., 1994. Formation of melanic epipedons under forest vegetation in the xeric soil moisture regime of Northern California. *Soil Sci. Plant nutrition* 40, 617-628.

Theron, J.C., 1969. 2926 Bloemfontein Geological map 1:250 000 Geological series map with explanatory notes, Geological Survey of South Africa, Pretoria.

Theron, J.C., 1970. Some Geological Aspects of the Beaufort series in the Orange Free State. PhD.thesis. University of the Free State.

UNEP., 1992. World Atlas of Desertification. Edward Arnold, Sevenoaks, UK. http://www.abdn.ac.uk/~gmi196/DrylandRivers/whatare/whatare1.htm (visited 20/02/2004).

USDA., 2004. National Resource Conservation Service. Soil Education.. http://soils.usda.gov/education/facts/formation.html (visited 26/02/2004).

Valentin, C. & Stewart, B.A., 1991, Methods for Assessment of Soil Degradation. CRC Press, Boca Raton.

Van der Eyk, J.J., Macvicar., C.N. & De Villiers, J.M., 1969. Soils of the Tugela Basin: A study in subtropical Africa. Report Vol 15, Natal Town and Regional Planning, Natal.

Van der Merwe, G.M.E., Laker, M.C. & Buhmann. C., 2002. Factors that govern the formation of melanic soils in South Africa. *Geoderma* 107, 165 – 176.

Van Der Watt, H.V.H. & Van Rooyen, T.H.,1995. A Glossary of soil science. Second edition. Soil Sci. Soc. SA, Pretoria.

Van Diepen, V.A., Van Keulen, H., Wolf, J. & Berkhout, J.A., 1991. Land evaluatio n: from intuition to quantification. *Advances in Soil Science* 15, 139-204.

Van Ranst, E., Tang, R.G. & Sinthurahat, S., 1996. Application of fuzzy logic to land suitability for rubber production in peninsular Thailand. *Geoderma 70*, 1–19.

Virgo, K.J. & Holmes. D.A., 1977. Soil and landform features of mountainous terrain in South Thailand. *Geoderma* 18, 207-225.

Wander, M.M., Walter, G.L., Nissen, T.M., Bollero, G.A., Andrews, S.S. & Cavanaugh-Grant, D.A. 2002. Symposium Papers: Soil Quality. Science and Process. *Agron. J.* 94, 23-32.

Wierenga, P.J. Hendrickx, J.M.H. Nash, M.H. Ludwig, J. & Daugherty., L.A. 1987. Variation of soil and vegetation with distance along transect in the Chihuahuan Desert. *J. Arid Environ.* 13, 53–63.

Wilding, L.P., Smeck, N.E. & Hall, G.F.1983. Pedogenesis and Soil Toxonomy. I. Concepts and Interactions. Elsevier, The Netherlands.

Wilding, L.P. & Tessier, D., 1988. Genesis of Vertisols: Shrink-Swell phenomena. In: L.P. Wilding & R. Puentes (eds.). Vertisols: Their distribution, properties, classification and management. Texas A & M University, Printing center, Texas.

Wiyo, K.A., Kasomekera, Z.M & Feyen, J., 2000. Effect of tied-ridging on soil water status of a maize crop under Malawi conditions. *Agric. Water Manage.* 45, 101–125.

World Reference Base for Soil Resources (WRB)., 1998. Food and Agriculture Organization of the United Nations. FAO, Rome.

Zhu, A.X., & Band, L.E., 1994. A knowledge-based approach to data integration for soil mapping. *Can. J. Remote Sens.* 20, 408–418.

Zougmore, R., Mando, A. & Stroosnijder, L. 2004. Effect of soil and water conservation and nutrient management on the soil–plant water balance in semi-arid Burkina Faso. *Agric. Water Manage*. 65, 103-120

APPENDICES

Appendix 1 The results of the 405 field observations interpreted in terms of the relationship between slope and slope shape on soil depth.

(a) The number of observations in different slope and soil depth classes

Slope (%)	EDR > 700 mm		ERD <700mm		Total
	No.	(%)	No.	(%)	
0-1	36	9	28	16	64
1-2	114	28	43	39	157
2-3	67	17	57	31	124
3-4	20	5	21	10	41
4-5	1	< 1	2	< 1	3
5-6	4	< 1	4	< 1	8
6-7	1	< 1	2	< 1	3
7-8			2	< 1	2
>8			3	< 1	3
Total	243	60	162	40	405

(b) Data showing the relationship between slope, slope shape and observations with ERD > 700 mm.

Slope (%)	LL	LV	LC	VL	VV	VC	CL	CV	CC	Total
0-1	11	3	1		2		7	5	7	36
1-2	52	11	13	7	3	2	11	6	9	114
2-3	30	7	10	3	3	1	5	2	6	67
3-4	9	2	4	1	1		1	2		20
4-5	1									1
5-6	3			1						4
6-7					1					1
7-8										0
>8										0
Total	106	23	28	12	10	3	24	15	22	243
%	43.62	9.47	11.52	4.94	4.12	1.23	9.88	6.17	9.05	

(c) Data showing the relationship between slope, slope shape and observations with ERD < 700 mm.

Slope (%)	LL	LV	LC	VL	VV	VC	CL	CV	CC	Total
0-1	3	6	2	1	8	1	3	1	3	28
1-2	9	2	3	7	4	1	5	6	6	43
2-3	12	3	14	4	13	1	3	3	4	57
3-4	4	4	2	3	5	1		1	1	21
4-5	1			1						2
5-6	2				1				1	4
6-7								2		2
7-8	1	1								2
>8					1	2				3
Total	32	16	21	16	32	6	11	13	15	162
%	19.75	9.88	12.96	9.88	19.75	3.70	6.79	8.02	9.26	

Appendix 2 Soilscapes considered unsuitable for cultivation for various reasons.

Soilscape No.	Area (ha)	Reasons
20	835	Rough, steep and rocky area
21	1529	Rough, steep and rocky area
32	2109	Dewetsdorp built up area and surrounding rough and rocky areas
45	7941	Rough, steep and rocky area
56	1330	Rough, steep and rocky area
62	13604	Rough, steep and rocky area
63	14400	Rough, steep and rocky area
64	33144	Botshabelo and Thaba Nchu built up area and surrounding rough and rocky areas
17	7330	Rough, steep and rocky area
Total	82222	

Appendix 3 The area of each of the 57 soilscape with some arable land, and details regarding the distribution of slope classes

Soilscape No.	Soilscape class	Area (ha)	Area (ha) of each slope (%) class									Slope class as part of the soilscape (%)									
			0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	>8	0-1	1-2	2-3	<3	3-4	4-5	5-6	6-7	7-8	>8
0	5	2086	443	392	412	306	162	112	62	44	153	21.24	18.79	19.75	59.78	14.67	7.77	5.37	2.97	2.11	7.33
1	5	2317	1101	564	537	82	33					47.52	24.34	23.18	95.04	3.54	1.42	0.00	0.00	0.00	0.00
2	5	1848	849	394	432	129	44					45.94	21.32	23.38	90.64	6.98	2.38	0.00	0.00	0.00	0.00
3	5	3382	1918	640	612	161	51					56.71	18.92	18.10	93.73	4.76	1.51	0.00	0.00	0.00	0.00
4	4	2633	1582	504	415	107	25					60.08	19.14	15.76	94.99	4.06	0.95	0.00	0.00	0.00	0.00
5	5	5362	2220	955	1019	414	245	159	120	59	171	41.40	17.81	19.00	78.22	7.72	4.57	2.97	2.24	1.10	3.19
6	2	1211	518	278	262	65	44	17	12	7	8	42.77	22.96	21.64	87.37	5.37	3.63	1.40	0.99	0.58	0.66
7	4	645	291	137	100	22	7	13	5	10	60	45.12	21.24	15.50	81.86	3.41	1.09	2.02	0.78	1.55	9.30
8	5	4887	1907	877	832	364	239	175	118	81	294	39.02	17.95	17.02	73.99	7.45	4.89	3.58	2.41	1.66	6.02
9	1	1112	632	238	180	34	11	10	7			56.83	21.40	16.19	94.42	3.06	0.99	0.90	0.63	0.00	0.00
10	6	1542	370	259	213	165	113	77	60	29	256	23.99	16.80	13.81	54.60	10.70	7.33	4.99	3.89	1.88	16.60
11	4	2490	1337	442	379	145	56	47	25	27	32	53.69	17.75	15.22	86.67	5.82	2.25	1.89	1.00	1.08	1.29
12	1	1943	868	451	361	108	44	36	26	17	33	44.67	23.21	18.58	86.46	5.56	2.26	1.85	1.34	0.87	1.70
13	3	1991	933	330	346	119	77	21	12	49	104	46.86	16.57	17.38	80.81	5.98	3.87	1.05	0.60	2.46	5.22
14	3	573	237	82	91	73	35	21	9	12	13	41.36	14.31	15.88	71.55	12.74	6.11	3.66	1.57	2.09	2.27
15	2	5762	3250	1284	887	189	52	40	20		40	56.40	22.28	15.39	94.08	3.28	0.90	0.69	0.35	0.00	0.69
16	1	1899	1188	283	175	64	22	29	30	13	101	62.56	14.90	9.22	86.68	3.37	1.16	1.53	1.58	0.68	5.32
18	2	1210	549	210	173	97	56	23	16	16	70	45.37	17.36	14.30	77.02	8.02	4.63	1.90	1.32	1.32	5.79
19	4	1090	271	237	259	80	40	31	20	15	137	24.86	21.74	23.76	70.37	7.34	3.67	2.84	1.83	1.38	12.57
22	3	3371	1545	936	656	149	53	32				45.83	27.77	19.46	93.06	4.42	1.57	0.95	0.00	0.00	0.00
23	3	1104	519	353	204	28						47.01	31.97	18.48	97.46	2.54	0.00	0.00	0.00	0.00	0.00
24	4	2824	1674	677	406	67						59.28	23.97	14.38	97.63	2.37	0.00	0.00	0.00	0.00	0.00
25	4	3253	1795	678	563	125	38	22	13		19	55.18	20.84	17.31	93.33	3.84	1.17	0.68	0.40	0.00	0.58
26	6	2942	1206	838	679	122	48	20	11	11	7	40.99	28.48	23.08	92.56	4.15	1.63	0.68	0.37	0.37	0.24
27	3	4721	2360	1019	691	223	98	59	14	15	242	49.99	21.58	14.64	86.21	4.72	2.08	1.25	0.30	0.32	5.13
28	6	1695	348	386	566	260	79	24	8	16	8	20.53	22.77	33.39	76.70	15.34	4.66	1.42	0.47	0.94	0.47
29	4	2370	844	731	624	110	34			12	15	35.61	30.84	26.33	92.78	4.64	1.43	0.00	0.00	0.51	0.63
30	3	1952	1038	467	342	63	13	12	4		13	53.18	23.92	17.52	94.62	3.23	0.67	0.61	0.20	0.00	0.67
31	2	3529	1866	790	553	180	51	39	10	16	24	52.88	22.39	15.67	90.93	5.10	1.45	1.11	0.28	0.45	0.68

Appendix 3 Continued.

Soilscape No.	Soilscape class	Area (ha)	Area (ha)of each slope (%) class									Slope class as part of the soilscape (%)									
			0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	>8	0-1	1-2	2-3	<3	3-4	4-5	5-6	6-7	7-8	>8
33	6	2547	1104	519	581	144	69	49	18	15	48	43.35	20.38	22.81	86.53	5.65	2.71	1.92	0.71	0.59	1.88
34	2	1906	1086	431	317	36	36					56.98	22.61	16.63	96.22	1.89	1.89	0.00	0.00	0.00	0.00
35	4	1989	1360	287	194	72	44	32				68.38	14.43	9.75	92.56	3.62	2.21	1.61	0.00	0.00	0.00
36	4	3985	3008	512	250	85	43	22	22		43	75.48	12.85	6.27	94.60	2.13	1.08	0.55	0.55	0.00	1.08
37	3	1173	578	191	114	107	35	28	31	38	51	49.28	16.28	9.72	75.28	9.12	2.98	2.39	2.64	3.24	4.35
38	5	1407	494	313	327	146	48	33	27	8	11	35.11	22.25	23.24	80.60	10.38	3.41	2.35	1.92	0.57	0.78
39	5	2629	1197	649	528	139	58	24	13	13	8	45.53	24.69	20.08	90.30	5.29	2.21	0.91	0.49	0.49	0.30
40	3	2191	1221	510	259	86	53	35	11	8	8	55.73	23.28	11.82	90.83	3.93	2.42	1.60	0.50	0.37	0.37
41	3	4275	2047	1011	779	240	109	48	17	7	17	47.88	23.65	18.22	89.75	5.61	2.55	1.12	0.40	0.16	0.40
42	6	6277	1753	1236	1448	725	462	277	140	87	149	27.93	19.69	23.07	70.69	11.55	7.36	4.41	2.23	1.39	2.37
43	5	3933	1747	818	900	220	78	56	30	22	62	44.42	20.80	22.88	88.10	5.59	1.98	1.42	0.76	0.56	1.58
44	2	3929	2176	788	627	155	62	30	10	6	75	55.38	20.06	15.96	91.40	3.95	1.58	0.76	0.25	0.15	1.91
46	4	4233	2405	886	766	103	24		24		25	56.82	20.93	18.10	95.84	2.43	0.57	0.00	0.57	0.00	0.59
47	3	2733	1464	689	492	88						53.57	25.21	18.00	96.78	3.22	0.00	0.00	0.00	0.00	0.00
48	3	3019	1703	556	582	119	29	15	15			56.41	18.42	19.28	94.10	3.94	0.96	0.50	0.50	0.00	0.00
49	3	825	581	108	100	36						70.42	13.09	12.12	95.64	4.36	0.00	0.00	0.00	0.00	0.00
50	3	7386	2670	1482	1627	645	327	160	143	90	242	36.15	20.06	22.03	78.24	8.73	4.43	2.17	1.94	1.22	3.28
51	3	771	296	140	138	48	20	16	11	14	88	38.39	18.16	17.90	74.45	6.23	2.59	2.08	1.43	1.82	11.41
52	5	4790	2086	993	897	296	157	111	60	49	141	43.55	20.73	18.73	83.01	6.18	3.28	2.32	1.25	1.02	2.94
53	3	2809	1321	608	586	158	44	40	15		37	47.03	21.64	20.86	89.53	5.62	1.57	1.42	0.53	0.00	1.32
54	6	2433	774	431	345	241	139	141	87	65	210	31.81	17.71	14.18	63.71	9.91	5.71	5.80	3.58	2.67	8.63
55	4	3263	1870	505	500	133	74	61	21	26	73	57.31	15.48	15.32	88.11	4.08	2.27	1.87	0.64	0.80	2.24
57	5	3525	1486	904	740	154	35	18	46	23	119	42.16	25.65	20.99	88.79	4.37	0.99	0.51	1.30	0.65	3.38
58	3	3262	1643	809	586	82	17	12	10	18	85	50.37	24.80	17.96	93.13	2.51	0.52	0.37	0.31	0.55	2.61
59	5	1127	523	225	239	90	29	7	5	6	3	46.41	19.96	21.21	87.58	7.99	2.57	0.62	0.44	0.53	0.27
60	3	4403	3002	580	444	102	36	40	21		178	68.18	13.17	10.08	91.44	2.32	0.82	0.91	0.48	0.00	4.04
61	3	1780	608	480	480	123	47	11	11	8	12	34.16	26.97	26.97	88.09	6.91	2.64	0.62	0.62	0.45	0.67
65	4	1085	531	196	164	90	40	19	16		29	48.94	18.06	15.12	82.12	8.29	3.69	1.75	1.47	0.00	2.67
Total		155429	74386	32289	27979	8714	3885	2304	1406	952	3514										

Appendix 4 Observations from soil profiles

Observation	Latitude (deg., min., sec.)	Longitude (deg., min., sec.)	Altitude (m)	Soil form	Slope shape	TMU	Slope (%)	Soil depth (mm)
G1	29,21.991	26,50.887	1517.26	My	LV	3	1.7	550
G2	29,21.930	26,50.897	1515.06	Bo	LV	3	1.6	550
G3	29,21.848	26,50.907	1513.00	Bo	LV	3	1.7	600
G4	29,21.783	26,50.882	1511.41	Sw	LV	3	1.5	450
G5	29,21.700	26,50.870	1509.09	Sw	LV	3	1.5	450
G6	29,21.612	26,50.850	1506.82	Sw	LV	3	1.5	600
G7	29,21.512	26,50.852	1504.14	Sw	LV	3	1.5	600
G8	29,21.348	26,50.851	1500.57	Sw	LV	3	1.5	600
G9	29,21.271	26,50.858	1498.37	Sw/Va	LV	4	1.1	800
G10	29,21.197	26,50.856	1496.74	Va	CL	4	1.1	800+
G11	29,21.131	26,50.856	1495.43	Es	CL	5	<1.0	350
G12	29,21.973	26,51.011	1512.78	Sw	LL	3	3.3	600
G13	29,21.940	26,51.133	1508.33	Es	CC	4	2	500
MM1	29,18.039	26,52.331	1499.20	Sw/Wo	CL	3[(1)](l)	0.9	900+
MM2	29,18.106	26,52.407	1502.17	Sw	CL	3[(1)](u)	1.7	800
MM3	29,18.194	26,52.513	1507.00	Sw	CL	3[(1)](u)	2.8	800
MM4	29,18.256	26,52.601	1511.21	Ms	VV	4(l)	1.8	200+
MM5	29,18.343	26,52.692	1515.19	Sw	VV	4(l)	0.9	850
MM6	29,18.425	26,52.806	1517.40	Sw	CV	4(l)	0.9	800+
MM7	29,18.525	26,52.926	1520.14	Sw/Va	CV	3	0.9	650+
MM8	29,18.610	26,53.037	1521.35	Sw/Va	CV	3	0.9	1200
MM9	29,18.697	26,53.135	1522.68	Sw	CV	4(m)	0.9	800
MM10	29,18.819	26,53.141	1524.91	Sw	CV	4(m)	0.9	650+
MM11	29,18.925	26,53.125	1526.33	Se	CV	4(m)	0.9	1100
MM12	29,19.023	26,53.117	1527.92	Se	CV	4(m)	0.9	1000
MM13	29,19.127	26,53.112	1529.19	Se	CV	4(m)	0.9	550+
MM14	29,19.259	26,53.114	1532.79	Se	CV	4(u)	1.56	900
MM15	29,19.353	26,53.209	1538.00	Ar	CL	4(u)	2.5	700
MM16	29,19.436	26,53.279	1542.81	Ar	CL	4(u)	2.9	1000+
MM17	29,19.503	26,53.337	1546.00	Ar	CL	4(u)	5	1000+
MM18	29,19.543	26,53.363	1551.43	My	LV	3	7.1	300
MM19	29,18.600	26,50.133	1475.89	Ar	CL	3	1.8	500
MM20	29,18.541	26,49.832	1487.35	Sw/Gs	LV	3	3.1	400+
MM21	29,18.516	26,49.895	1482.50	Sw	LL	4	2.8	700
Wk1	29,26.945	26,41.289	1450.33	Ar/Sw	LL	3	1.33	750+
Wk2	29,26.955	26,41.417	1446.05	Sw	LC	4	2.6	750+
Wk3	29,27.118	26,41.445	1444.05	Es	CC	4	1.2	900
Wk4	29,27.129	26,41.633	1440.13	Es	CC	4	0.9	800
Wk5	29,27.146	26,42.047	1438.00	Ar	CL	5	0.9	700+
Wk6	29,26.991	26,42.069	1432.40	Ar	LL	5	0.9	700+
Wk7	29,27.161	26,41.861	1431.13	Ar	LL	5	0.9	700+
Y1	29,24.885	26,51.233	1527.35	Es	LC	4	2.9	500
Y2	29,24.822	26,51.244	1530.63	Va	LC	3	2.5	900+
Y3	29,24.736	26,51.261	1534.13	Va	LC	3	1.5	900+
Y4	29,24.627	26,51.288	1538.26	Sw	CL	4/1	0.9	700+
Y5	29,24.595	26,51.053	1536..21	Sw	CL	1	0.9	600

Appendix 4 Continued.

Observation	Latitude (deg., min., sec.)	Longitude (deg., min., sec.)	Altitude (m)	Soil form	Slope shape	TMU	Slope (%)	Soil depth (mm)
Y6	29,24.603	26,51.177	1537.26	Sw	CL	4	0.9	500+
Y7	29,24.541	26,51.232	1537.79	Sw/Va	CL	3	1.5	1000
Y8	29,24.452	26,51.328	1533.94	Sw	LC	3	1.8	950+
Y9	29,24.351	26,51.426	1530.15	Es	LC	4	1.9	350
Y10	29,24.281	26,51.605	1530.24	Sw	LL	3/4	2.2	700
Y11	29,24.505	26,51.011	1530.69	Sw	CL	3	2.8	500
Y12	29,24.495	26,50.923	1534.32	Sw	LC	3	2.27	650
Y13	29,24.472	26,50.779	1529.40	Es	LC	3L	2	300
WW1	29,23.923	26,49.570	1493.77	Va	CL	3U	1.7	1200
WW2	29,23.734	26,49.464	1490.44	Va	CL	3	1.7	900+
WW3	29,23.491	26,49.319	1486.94	Va	CL	3	1.4	900+
WW4	29,23.191	26,49.140	1480.50	Sw	CL	4	1.2	800+
W1	29,24.617	26,48.169	1475.24	Se	LC	5	2.5	800+
W2	29,24.625	26,48.115	1477.68	Es	CC	4	2	500
W3	29,24.631	26,48.068	1479.29	Sw	LL	4	2	500
W4	29,24.637	26,48.015	1482.33	Sw	LL	3	4.1	500
W5	29,24.611	26,47.949	1490.79	Sw	LV	3	2.6	500
W6	29,24.560	26,47.819	1490.25	Sw	LC	3	2.3	500
W7	29,24.532	26,47.748	1493.00	Sw	LC	3	2.3	500+
W8	29,24.466	26,47.704	1494.17	Es	LC	3	2.1	300
W9	29,24.394	26,47.654	1495.36	Sw	LC	1/3	2	600
W10	29,24.334	26,47.612	1498.36	Sw	VV	1	0.9	600
W11	29,24.255	26,47.555	1497.29	Sw	VV	1	0.9	500
W12	29,24.367	26,47.487	1499.29	Sw	LC	1	0.9	800
W13	29,24.410	26,47.372	1499.14	Se	LC	1	1.5	700
W14	29,24.465	26,47.272	1499.88	Es	LC	1	1.2	450
W15	29,24.534	26,47.135	1503.12	Es	LC	1	0.9	600

Appendix 5 Observations from augered points.

Observation	Latitude (deg., min., sec.)	Longitude (deg., min., sec.)	Altitude (m)	Soil form	Slope shape	TMU	Slope (%)	Soil depth (mm)
W1	29,24.517	26,47.041	1506.00	Cv	LL	3	0.9	800+
W2	29,24.455	26,46.964	1505.64	Cv	LL	3	0.9	800+
W3	29,24.391	26,46.888	1505.60	Cv/Av	LL	3	1.2	800+
y1	29,24.860	26,51.371	1533.00	Se	LC	3	2.6	600 to uw
y2	29,24.856	26,51.493	1536.84	Se	LC	3	2	600 to uw
y3	29,24.953	26,51.530	1537.50	Se	LC	3	2.5	602 to uw
y4	29,24.812	26,51.257	1531.67	Es	CC	3	2.2	360
y5	29,24.776	26,51.252	1531.95	Se	CC	3	2.17	300 to uw
y6	29,24.844	26,51.331	1532.25	Se	CC	3	0.9	500 to uw
y7	29,24.814	26,51.389	1534.75	Va	CL	3	2.5	500+
y8	29,24.793	26,51.182	1531.05	Se	LC	3	1.8	500 to uw
y9	29,24.714	26,51.092	1534.06	Se	LC	3	2.2	400 to uw
y10	29,24.622	26,51.026	1535.21	Sw	LC	3	0.9	300
y11	29,24.530	26,50.968	1535.21	Pn	LL	3	2	400 to uw
y12	29,24.483	26,50.856	1531.40	We	LL	3	2.2	600+
y13	29,24.384	26,50.806	1527.93	We	LL	3	2	300+
y14	29,24.282	26,50.760	1526.36	Ss	LL	3	2.3	400+
y15	29,25.024	26,50.650	1540.95	Ms	LC	3	2.4	150+
y16	29,24.990	26,51.770	1546.95	Se	LC	3	2.3	500+
y17	29,25.959	26,51.880	1550.00	Ms	VV	3	2	150+
y18	29,25.187	26,51.455	1525.71	Es	LC	3	3.6	400+
y19	29,25.214	26,51.453	1523.93	Es	LC	3	3.8	500+
y20	29,25.268	26,51.444	1520.35	Es	LC	3	2.5	500+
y21	29,25.312	26,51.429	1518.18	Es	LC	3	2.3	500+
y22	29,25.305	26,51.348	1516.47	Lo	LL	3	2.8	500+
y23	29,25.415	26,51.478	1516.50	Lo	LL	4	2.5	500+
y24	29,25.488	26,51.577	1518.85	Sw	LL	4	3.6	500+
y25	29,25.591	26,51.597	1515.00	Es	LL	5	3.6	500+
y26	29,25.621	26,51.570	1516.09	Ss	LL	5	0.9	300+
ww1	29,23.721	26,49.730	1494.22	Sw/Va	LL	3	1.52	250+
ww2	29,23.763	26,49.614	1495.47	Va	VC	3	0.9	400+
ww3	29,23.118	26,49.103	1477.63	Va	CV	3	1.2	250+
ww4	29,23.062	26,49.317	1476.91	Va	CL	4	1.1	350+
ww5	29,23.073	26,49.445	1475.67	Sw/Va	VL	4	1.3	250+
ww6	29,23.083	26,49.589	1474.93	Es	CC	5	0.9	300+
g1	29,22.846	26,50.371	1498.75	Bo	LL	4	2.7	300
g2	29,22.846	26,50.372	1502.11	Bo	LL	3	2.6	500+
g3	29,23.016	26,50.420	1505.42	Bo	LL	1	1.1	550
g4	29,23.120	26,50.468	1504.91	Sw	LL	3	2.1	700+
g5	29,23.210	26,50.524	1501.07	Ar	LL	3	2.1	600+
g6	29,23.241	26,50.564	1498.44	Bo	LL	3	5	600+
g7	29,23.301	26,50.601	1495.00	Es	LL	5	1	400+
g8	29,22.775	26,50.459	1500.00	Sw/Va	VV	3	2.6	500+
g9	29,22.741	26,50.578	1505.75	Sw	VV	3	2.5	700+
g10	29,22.715	26,50.630	1509.00	Bo	VV	3	2.5	700+
g11	29,22.665	26,50.333	1502.63	Bo	LV	3	2.6	700+

Appendix 5 Continued.

Observation	Latitude (deg., min., sec.)	Longitude (deg., min., sec.)	Altitude (m)	Soil form	Slope shape	TMU	Slope %	Soil depth (mm)
g12	29,22.559	26,50.311	1507.14	Bo	LV	3	2.6	500+
g13	29,22.462	26,50.299	1511.07	Bo	LV	3	3.5	500+
g14	29,22.342	26,50.309	1515.00	Ms	LV	1	0.9	100
g15	29,22.788	26,50.375	1499.09	Se	CC	4	2.1	500+
g16	29,22.821	26,50.086	1488.52	Se	CC	5	2.5	600+
g17	29,22.875	26,50.968	1485.68	Se	LC	4	2.5	520 to uw
g18	29,22.859	26,50.947	1486.58	Ms	VV	4	3.5	300+
g19	29,22.972	26,49.976	1488.46	Va	LV	4	3.8	500+
g20	29,23.071	26,50.009	1492.22	Bo	VL	3	2.8	600+
g21	29,23.176	26,50.033	1493.33	Ar	VV	3	2.7	600+
g22	29,21.976	26,49.544	1505.16	Dol.outcrop	VV	1	0.9	50
g23	29,21.937	26,49.433	1503.52	Bo	VV	3	1.8	500+
g24	29,21.887	26,49.319	1501.43	Bo	VV	3	1.7	700+
g25	29,21.897	26,49.286	1502.50	Bo	CV	3	1.7	700+
AB 41	29,07.744	26,49.732	1474.76	Es	CL	4	0.9	250
AB 42	29,07.794	26,49.713	1475.71	Sw	CL	4	0.9	700+
AB 43	N/A	N/A	1502.38	Es	CL	4	1.14	500+
AB 44	29,07.809	26,49.445	1474.00	Av	CL	3	1.14	900+
AB 45	29,07.848	26,49.356	1475.26	Av	CL	3	1.14	750+
BfIII 36	29,10.115	26,50.128	1508.57	Ms/Gs	VV	1	0.9	100+
BfIII 37	29,09.296	26,50.008	1501.40	Es/Km	LV	3/4	0.9	500+
BfIII 38	29,09.247	26,49.942	1500.00	Ss/Sw/Va	LV	3	0.9	700+
BfIII 39	29,08.910	26,50.026	1505.45	We	LV	4	1.82	700+
BfIII 40	29,08.248	26,49.896	1480.00	Av	LV	5	1.74	600+
Sr27	29,12.499	26,47.835	1480.00	Sand stone	VV	1	3.08	No soil at all
Sr28	29,12.075	26,46.790	1466.67	Gs	VC	3	3.33	500
Sr29	29,12.027	26,46.133	1476.30	Sw	LC	3	2	500+
Sr30	29,12.107	26,45.995	1460.34	Sw	LV	1	1.9	500+
Sr31	29,12.101	26,45.814	1462.94	Sw	LV	1	0.9	500+
Sr32	29,12.209	26,45.778	1460.36	Sand stone	LV	1	0.9	shallow
Ta1	29,15.486	26,49.098	1509.49	Se	LC	4	1.05	700+
Ta2	N/A	N/A	1512.55	Se	CC	4	1.6	250+
Ta3	N/A	N/A	1513.47	Se	LC	4	1.6	700+
Ta4	N/A	N/A	1514.63	Sw	VL	3	1.6	shallow
Ta5	N/A	N/A	1519.55	Gs	VL	3	1.6	shallow
Ta6	N/A	N/A	1520.00	Sw/Va	CV	3	1.8	700+
Ta7	29,15.252	26,47.949	1528.00	Ms	VL	1	2.22	200+
Ta8	N/A	N/A	1525.71	Bo	CV	3	2	800+
Ta9	N/A	N/A	1522.86	Es	VL	5	1.9	300+
Ta10	29,14.975	26,47.967	1517.78	Es	CL	5	1.67	300+
Ta11	29,14.996	26,48.023	1519.26	Es	CL	5	1.67	300
Ta12	29,15.026	26,48.086	1512.50	Se/We	CL	3	1.9	600+
Ta13	29,14.785	26,47.956	1518.26	Se	CL	3	1.29	700+
Ta14	29,14.627	26,47.612	1514.84	Ar	LL	3	1.29	600+
Ta15	N/A	N/A	1519.31	Se	CV	5	1.29	700+
Ta16	29,14.663	26,47.823	1517.93	Expected G	CC	3	1.29	N/A
Ta17	29,14.672	26,47.908	1515.17	Se	CL	3	1.29	500+
Ta18	29,14.662	26,48.047	1512.41	Sand stone	VV	1	1.29	350+

Appendix 6 Observations from depth probe tests.

Observation	Latitude (deg., min., sec.)	Longitude (deg., min., sec.)	Altitude (m)	Slope shape	TMU	Slope %	Soil depth (mm)
001	29 17.968	26 29.353	1381.66	LL	3	0.9	shallow
002	29 17.923	26 29.657	1382.88	LL	4	0.9	750+
003	29 18.511	26 29.468	1390.80	LL	3/4	0.9	750+
004	29 18.910	26 29.567	1394.16	LL	4	0.9	750+
005	29 19.795	26 29.483	1408.48	LV	3	2.2	shallow
006	29 19.795	26 29.483	1407.87	CC	3	2.2	shallow
007	29 20.211	26 28.813	1422.50	LL	4	1.82	750+
008	29 20.799	26 28.123	1423.42	CC	4	1.18	shallow
009	29 20.907	26 28.202	1428.90	LL	4/1	1.18	750+
010	29 24.096	26 27.781	1495.96	VV	3	2.67	450
011	29 24.585	26 27.773	1492.61	LL	4	2.22	750+
012	29 25.558	26 29.068	1517.90	VV	1	0.9	500
013	29 25.551	26 29.097	1516.38	LL	1	1.18	700+
014	29 25.461	26 30.501	1499.92	LV	3	1.82	750+
015	29 23.942	26 32.291	1445.67	LL	3	1.14	750+
016	29 22.807	26 33.271	1425.55	LL	3	0.9	750+
017	29 27.457	26 39.302	1483.77	CL	3	2.22	750+
018	29 28.890	26 40.273	1502.66	CC	3	1.21	>700
019	29 29.327	26 34.532	1489.86	LL	1	3.64	500
020	29 29.082	26 34.256	1478.28	CL	3/4	2.5	800+
021	29 26.390	26 30.976	1483.77	LL	4/3	3.64	800+
022	29 27.969	26 27.209	1498.70	VL	4	1.33	800+
023	29 29.834	26 34.719	1461.21	LC	3	2.11	800+
024	29 29.844	26 34.741	1517.60	LL	3	2.35	450
025	29 31.556	26 28.483	1504.80	LL	4	2.22	800+
026	29 35.219	26 42.179	1492.00	LL	4	1	700+
027	29 35.830	26 42.944	1504.49	LC	4	1.82	800+
028	29 34.030	26 40.399	1514.55	LL	3/4	1.74	800+
029	29 33.878	26 40.160	1521.87	LC	3	2.22	700
030	29 32.776	26 39.262	1534.97	VC	3	2.11	450
031	29 30.898	26 39.731	1499.92	LC	4	1.38	700+
032	29 28.617	26 41.659	1459.38	VL	4	1.82	600
033	29 28.617	26 41.921	1453.59	LL	4	1.82	800+
034	29 28.253	26 41.921	1451.46	VL	4	1.82	300
035	29 25.204	26 41.465	1442.31	LL	4	0.9	700+
036	29 25.205	26 41.468	1424.33	VV	3	0.9	550
037	29 25.205	26 41.468	1360.32	LV	4	3.33	800+
038	29 15.774	26 36.309	1347.52	VV	4	3.33	450
039	29 13.273	26 34.526	1380.74	LL	4	2.89	750+
040	29 11.483	26 34.274	1342.34	LL	4	2.2	800+
041	29 11.484	26 34.276	1339.60	LL	4	1.74	800+
042	29 04.556	26 41.357	1393.55	LL	4	2.11	800+
043	29 03.285	26 40.272	1367.94	LL	4	1.18	800
044	29 02.320	26 39.962	1397.51	VL	4	1.67	700
045	29 02.531	26 38.713	1390.80	LV	4	1.9	800+
046	29 02.972	26 38.015	1396.59	LL	3/4	2.5	800+
047	29 03.766	26 36.758	1376.48	LL	4	2.35	800+
048	29 01.594	26 40.476	1406.65	LL	4	3.08	800

Appendix 6 Continued.

Observation	Latitude (deg., min., sec.)	Longitude (deg., min., sec.)	Altitude (m)	Slope shape	TMU	Slope (%)	Soil depth (mm)
049	29 01.604	26 40.477	1432.56	LC	4	1.82	800+
050	29 00.080	26 37.434	1445.36	LV	4	0.9	350
051	28 59.160	26 41.415	1441.40	VV	3	2.35	400
052	29 00.310	26 44.125	1442.92	VV	4	2	400
053	28 59.030	26 45.844	1462.13	LV	3/4	1.29	800+
054	29 01.891	26 44.300	1444.14	LL	4	1.82	800+
055	29 02.294	26 44.565	1453.29	LV	1/4	0.9	800+
056	29 33.646	26 44.013	1474.01	LV	4	1.74	800+
057	29 33.646	26 44.014	1520.04	VV	3	0.9	500
058	29 32.191	26 49.476	1550.82	LV	3	3.64	800+
059	29 32.273	26 50.541	1608.43	VV	1	3.08	400
060	29 32.273	26 50.542	1541.37	LL	4	3.08	400
061	29 27.540	26 46.290	1516.68	LV	3	3.33	500
062	29 27.536	26 46.289	1485.29	LC	4/1	3.33	700+
063	29 26.717	26 45.274	1505.71	VV	1	2.22	400+
064	29 24.529	26 47.050	1496.26	CL	3	0.9	700
065	29 22.737	26 47.991	1459.99	LV	4	1.18	700+
066	29 18.544	26 46.373	1449.93	LL	4	1	800+
067	29 18.310	26 47.109	1453.29	LV	4	1	450+
068	29 18.959	26 45.898	1438.35	CC	4	2.35	450+
069	29 19.055	26 45.664	1431.34	CC	4	2.35	800+
070	29 19.054	26 45.663	1497.48	LV	4	2.35	700+
071	29 20.674	26 50.775	1513.33	LC	3	3.64	800+
072	29 23.710	26 50.263	1496.26	VC	3	1.74	800+
074	29 17.145	26 57.710	1577.04	LC	3	3.08	800+
075	29 17.293	26 56.902	1561.19	LV	3	2.86	750
076	29 17.558	26 58.007	1605.38	LL	3	5	700
077	29 18.021	26 58.024	1601.42	VV	3	6	700
078	29 17.745	26 57.969	1600.20	LL	3	3.33	700
079	29 14.941	26 58.372	1455.42	VV	3	1.33	400
080	29 12.039	26 45.677	1457.86	LL	3	1.8	800
081	29 11.887	26 45.894	1462.43	LL	3	1.8	100
082	29 11.668	26 45.837	1458.77	LL	3	1.38	700
083	29 11.417	26 45.541	1452.37	LL	3	1.74	700
084	29 09.274	26 46.947	1452.07	LL	4	1.3	700
085	29 09.015	26 46.709	1465.78	CC	1	1.74	450
086	29 08.702	26 46.418	1471.88	VV	3	1.21	700
087	29 08.207	26 45.586	1463.34	VL	3	5	800
088	29 08.203	26 45.043	1449.63	LV	4	1.6	800
089	29 08.205	26 45.045	1449.93	LL	4	1.6	800
090	29 08.028	26 44.794	1446.58	LL	3	1.67	800
091	29 08.025	26 44.793	1431.34	LL	1	1.33	400
092	29 07.933	26 43.645	1420.67	VL	3	3.08	700
093	29 08.549	26 46.473	1467.00	LL	1	1.29	200
094	29 08.211	26 46.622	1474.01	VV	3	2	400
095	29 08.211	26 46.620	1473.71	VL	3	2	400
096	29 07.311	26 47.052	1448.41	LV	1	1.82	700
097	29 06.776	26 47.320	1447.50	VL	1	1.9	700

Appendix 6 Continued.

Observation	Latitude (deg., min., sec.)	Longitude (deg., min., sec.)	Altitude (m)	Slope shape	TMU	Slope %	Soil depth (mm)
098	29 06.473	26 47.307	1442.92	LL	1	1.33	700
099	29 06.052	26 46.987	1437.44	CC	5	0.9	800+
100	29 05.812	26 46.647	1449.93	LL	3	1.82	800
101	29 05.464	26 46.580	1459.99	LL	1	1.29	800
102	29 04.982	26 46.488	1469.14	LL	3	1.9	800
103	29 07.111	26 47.957	1463.65	LL	1	0.9	300
104	29 07.007	26 48.768	1465.48	LL	3	1.33	700
105	29 06.509	26 50.580	1504.49	VV	3	8	200
106	29 06.563	26 51.034	1502.36	LV	3	2	700
107	29 06.705	26 51.902	1517.29	LC	3	3.33	800
108	29 06.855	26 51.856	1512.72	LC	3	1.86	800
109	29 07.135	26 51.758	1506.02	LC	3	2.22	800
110	29 07.578	26 51.694	1499.92	LL	3	2	800
111	29 07.958	26 51.464	1488.03	LL	4	2	800
106+	29,29.212	26 51.809	1577.04	LL	4	2.2	700+
107+	29,29.195	26 51.681	1580.08	LL	3	2.2	700+
108-	29,29.195	26 51.567	1582.22	LL	3	2.6	500-700
109---	29,29.195	26 50.992	1586.48	VV	3U	3.3	700+
110---	29,29.195	26 50.942	1587.09	LL	3U	3.8	700
111B	29,29.195	26 50.773	1579.17	CC	5	2.35	700+
112B	29,27.663	26 51.418	1541.37	VV	3	5	<500
113---	29,27.686	26 51.294	1547.47	VV	3	2.2	500
114+	29,27.697	26 51.239	1550.52	VL	3	2.2	700+
115-	29,27.719	26 51.121	1550.21	VL	3	2.5	600+
116-	29,27.772	26 50.884	1555.09	VL	3	3.1	500
117+	29,27.828	26 50.627	1547.77	CC	3	1.2	700+
118B	29,27.276	26 44.032	1450.24	CC	5	0.9	700+
124B	29,17.931	26 41.457	1429.21	LL	5	1.6	400
125–	29,18.035	26 41.314	1431.04	LL	3	1.74	700+
126+	29,18.299	26 40.989	1435.00	VC	3	2.2	700+
127–	29,18.417	26 40.849	1427.99	LL	4	5	400
128+	29,18.476	26 40.782	1427.68	LL	3	3.5	700+
129+	29,18.967	26 40.199	1403.30	CC	5	0.9	1000+
129+B	29,18.794	26 40.400	1399.95	CC	3	1.6	1000+
130++	29,19.090	26 40.051	1405.74	LL	3	1.8	700+
131++	29,19.298	26 39.803	1406.65	LL	3	2	700+
132++			1399.79	LL	3	2.66	700+
133++	29,19.600	26 39.442	1392.94	CL	4	3.3	700+
134-	29,19.692	26 39.228	1405.13	LL	3	2	500+
135+	29,20.167	26 39.603	1414.88	LL	3	2.7	700+
136			1522.72	VV	3	2.7	200
137–	29,20.005	26 39.483	1415.80	VV	3	2.7	300
138–	29,19.863	26 39.367	1407.87	VV	3	3.5	300
139–	29,19.739	26 39.269	1400.56	VV	3	2.5	300
141+	29,19.862	26 37.412	1383.79	LV	3	2.5	700+
142+	29,19.871	26 37.315	1398.12	LV	3	1.6	700+
143-	29,19.872	26 37.291	1398.42	VV	3	1.6	300
144+	29,19.954	26 36.988	1380.44	CC	3	2	700+

Appendix 6 Continued.

Observation	Latitude (deg., min., sec.)	Longitude (deg., min., sec.)	Altitude (m)	Slope shape	TMU	Slope (%)	Soil depth (mm)
146+	29,20.199	26 36.213	1379.22	VL	3	1.8	700+
147B	29,27.723	26 42.261	1434.08	CC	5	0.9	700+
149+	29,27.628	26 42.539	1429.21	CC	5	0.9	700+
150-	29,27.614	26 42.582	1443.23	CC	5	3.3	<500
151-	29,27.588	26 42.684	1449.02	VL	4	1.6	<500
152+	29,27.542	26 42.890	1447.50	LL	3	1.6	700+
153++	29,27.478	26 43.185	1452.07	LL	3	1.4	700+
154++	29,27.337	26 43.826	1446.28	VC	4	1.2	700+
156++	29 04.148	26 42.288	1418.84	LL	3	1.1	800+
157++	29 04.237	26 42.112	1412.75	LL	3	1	800+
158++	29 04.331	26 41.932	1413.66	LL	3	1	800+
159++	29 04.429	26 41.741	1412.44	LL	3	1	800+
160++	29 04.519	26 41.462	1410.92	LL	3	1.5	800+
161++	29 04.608	26 41.183	1398.73	LL	3	2.3	800+
162++	29 04.627	26 41.118	1390.50	LL	3	1.43	800+
163++	29 04.717	26 40.838	1381.66	LL	3	1.4	800+
164++	29 04.807	26 40.637	1387.75	LL	3	1.4	800+
165-	29 04.862	26 40.537	1381.66	VV	3	2.7	300
166-	29 04.922	26 40.441	1379.52	LL	3	3	400
167++	29 05.044	26 40.239	1365.50	CC	4	1.3	700+
168++	29 05.175	26 40.064	1363.37	LL	4	1.2	800+
170++	29 13.866	26 33.720	1386.84	LL	4	2.7	700+
171++	29 13.798	26 34.033	1403.30	LL	3	1.8	700+
172++	29 13.753	26 34.235	1408.18	LL	3	1.5	700+
173++	29 13.911	26 34.450	1409.40	LL	3	1	700+
174++	29 14.023	26 34.612	1412.14	LL	3	2.2	700+
175++	29 14.593	26 34.325	1412.14	LL	3	1.6	700+
176++	29 14.592	26 34.654	1410.92	LL	3	2.5	700+
177++	29 14.598	26 34.952	1405.43	LL	3	2.9	700+
178++	29 14.619	26 35.257	1403.30	LL	3	1.1	800+
179++	29 16.347	26 32.029	1403.91	CC	3	1.74	700+
183-	29 16.696	26 26.748	1449.63	CL	3	2.5	500
184++	29 16.787	26 26.907	1444.45	LL	3	1.9	700+
185	29 16.879	26 27.069	1440.79	LL	3	1.5	700+
186B	29 16.952	26 27.207	1436.83	CC	5	2	700+
187++	29 16.995	26 27.269	1433.17	CL	4	2	700+
188++	29 17.121	26 27.488	1432.56	VL	3	1.6	700+
189–	29 17.559	26 28.243	1417.62	VL	3	2.7	500
190–	29 17.725	26 28.478	1412.44	VL	3	2.5	500
192–	29 20.509	26 33.127	1473.71	VL	3	3.08	400
193-	29 20.354	26 32.992	1458.16	VL	3	3.64	400
194-	29 19.910	26 32.648	1437.13	LL	3	1.74	400
195	29 19.778	26 32.536	1437.44	LL	1	2	400
196	29 19.570	26 32.354	1429.51	CC	3	1.9	700+
197+	29 19.326	26 32.136	1423.72	CC	3	1.43	700+
198-	29 19.022	26 31.842	1422.20	CL	3	2.67	700+

Appendix 6 Continued.

Observation	Latitude (deg., min., sec.)	Longitude (deg., min., sec.)	Altitude (m)	Slope shape	TMU	Slope (%)	Soil depth (mm)
199+	29 18.494	26 31.286	1412.14	CL	3	1.67	700+
200+	29 18.210	26 30.973	1411.53	LL	3	1.74	700+
H01	29 32.630	26 47.997	1561.80	LL	3	3	700+
H02	29 32.482	26 47.978	1564.23	LL	3	3.3	700+
H03	29 32.419	26 47.970	1567.89	LL	3	2.3	700+
H04	29 32.139	26 47.883	1570.33	LL	3	2	900+
H05	29 31.966	26 47.829	1566.37	VL	1	0.9	500
H06	29 31.908	26 47.808	1574.60	VV	1	0.9	700+
H07	29 31.894	26 47.691	1577.04	LL	3	2	700+
H08	29 31.876	26 47.425	1570.33	VV	3	2.1	700+
H09	29 31.889	26 47.333	1568.20	LL	3	2	700+
H10	29 31.970	26 47.154	1560.58	LL	3	2.3	700+
H11	29 32.120	26 46.888	1553.57	LL	3	3.8	700+
K01	29 31.768	26 42.781	1484.07	CL	1	1.6	700+
K02	29 31.806	26 42.812	1482.85	CL	1	1.6	700+
K03	29 31.896	26 42.874	1482.24	LL	3	0.9	700+
K04	29 32.036	26 42.976	1489.25	VV	1	0.9	700+
K05	29 32.178	26 43.078	1489.25	VL	3	1	700+
K07	29 32.308	26 43.200	1489.56	VL	3	1.05	700+
K08	29 32.374	26 43.279	1489.86	LL	3	1.25	700+
P02	29 23.398	26 41.006	1412.44	CL	3	2.5	800+
P03	29 22.906	26 40.972	1410.00	LL	3	2	700+
P04	29 22.627	26 41.038	1428.29	VL	3	8.3	100
P05	29 22.473	26 41.076	1446.28	VL	3	4.1	100
P06	29 22.375	26 41.068	1452.07	VV	2	10	100
P07	29 22.194	26 41.044	1442.31	LL	3	7.1	500
P08	29 21.892	26 41.134	1422.20	LL	3	4.1	700+
Rf33	29,10.571	26,51.885	1506.45	LV	3	1.25	900+
Rf34	29,10.372	26,52.230	1511.67	LV	5	0.9	400+
Rf35	29,09.839	26,53.432	1530.67	CV	5	3.33	1100+
S01B	29 33.190	26 28.683	1495.65	CC	5	0.9	300+
S02	29 33.317	26 28.742	1496.57	LL	3	1.05	300+
S03	29 33.798	26 28.830	1504.19	VV	1	1.08	900+
S04	29 34.060	26 28.840	1512.72	VL	1	1	500
S05	29 34.874	26 29.766	1511.20	VV	1	0.9	500
S06B	29 35.361	26 30.595	1516.68	CC	5	0.9	700
U01	29 32.592	26 43.054	1486.51	LL	3	0.9	900+
U02	29 32.823	26 42.966	1490.47	CL	3	1.8	800+
U03	29 32.920	26 42.941	1490.47	CL	1	1.8	700+
U04	29 33.229	26 42.916	1500.84	LL	1	1.6	800+

Appendix 7 Profile MM4: Mispah

Profile No	: MM4	Soil form	: Mispah
Map/photo	: 2926BD EUREKA	Soil family	:1100
Latitude & Longitude	: 29° 18’ 26’’ S, 26° 52.60’ 14’’E	Surface rockiness	: None
Land type No.	: DC 17	Surface stoniness	: None
Climate zone	: 46S	Occurrence of flooding	: None
Altitude	: 1511.21	Wind erosion	: None
Terrain unit	: Footslope	Water erosion	: Partially stabilized
Slope %	: 1.8	Vegetation/Land use	: Grazing land
Slope shape	:CV	Water table	: None
Aspect	:West	Described by	: S.A. Tekle, M. Hensley & P.A.Le Roux
Microrelief	: None	Date described	: 12/2002
Parent material of solum	: Mudstone	Weathering of underlying material	: Moderate physical, moderate chemical
Underlying material	: Sandstone	Alternation of underlying material	: Calcified

Horizon	**Depth (mm)**	**Description**	**Diagnostic horizons**
A	0 – 200	Colour; brown; structure; apedal massive; consistence: weak; few roots; clear smooth transition.	Orthic
C	200+	Colour; greysh brown; structure; apedal massive; consistence: weak; few roots; clear smooth transition.	Saprolite

Appendix 8 Profile G1: Mayo

Profile No	: G1	Soil form	: Mayo
Map/photo	: 2926BD EUREKA	Soil family	: 1200
Latitude & Longitude	: 29° 21' 99'' S, 26° 50' 89''E	Surface rockiness	: None
Land type No.	: DC 17	Surface stoniness	: None
Climate zone	: 46S	Occurrence of flooding	: None
Altitude	: 1517.56 m	Wind erosion	: None
Terrain unit	: Midslope	Water erosion	: Partially stabilized
Slope %	:2.9	Vegetation/Land use	: Grazing land
Slope shape	: CV	Water table	: None
Aspect	:	Described by	: S.A. Tekle, M. Hensley & P.A.Le Roux
Microrelief	: None	Date described	: 12/2002
Parent material of solum	: Mudstone	Weathering of underlying material	: Moderate physical, moderate chemical
Underlying material	: Sandstone	Alternation of underlying material	:

Horizon	**Depth (mm)**	**Description**	**Diagnostic horizons**
A	0 – 350	Black	Melanic
B	350– 550	Geogenic mottling	Lithocutanic
C	550+	Olive mudstone	Saprolite

Appendix 9 National profiles

Profile No / Field No: P605

National soil Profile No	: 45	Soil form	: Milkwood
Map/photo	: 2926BD Bloemfontein	Soil family	: graythorne
Latitude + Longitude	: 29° 27' 24'' / 26° 34' 48''	Surface rockiness	: None
Land type No.	: DC 17	Surface stoniness	: None
Climate zone	: 46S	Occurrence of flooding	: None
Altitude	: 1460m	Wind erosion	: None
Terrain unit	: Footslope	Water erosion	: Sheet moderate
Slope %	:3	Vegetation/Land use	: Grassveld, open
Slope shape	: Straight	Water table	: None
Aspect	:North	Described by	: J.F Eloff
Microrelief	: None	Date described	: 7207
Parent material of solum	:	Weathering of underlying material	:
Underlying material	: Basic extrusive rocks		

Horizon	Depth (mm)	Description	Diagnostic horizons
A11	0 – 400	Moist state, moist colour: black 10YR2.5/1; texture: clay; structure: moderate medium subangular blocky; consistence: firm; gradual wavy transition.	Melanic
A12	400– 700	Moist state, moist colour: very dark grey 10YR3/1; texture: clay; structure: moderate medium subangular blocky; consistence: very firm; few; few fine <2-6 mm lime concretions; gradual wavy transition.	Melanic
C	700-700+	Saprolite Moist state; moist colour: dark grayish brown 10YR4/2; texture: clay; structure massive; consistence: very firm; non-hardened free lime, moderate effervescence; few; few fine <2-6 mm lime concretions.	

Profile No / Field No: P606

National soil Profile No	: 46	Soil form	: Sterkspruit
Map/photo	: 2926 Bloemfontein	Soil family	: Sterkspruit
Latitude + Longitude	: 29° 27' 0'' / 26° 40' 36''	Surface rockiness	: None
Land type No.	: Db 87	Surface stoniness	: None
Climate zone	: 46S	Occurrence of flooding	: None
Altitude	: 1460m	Wind erosion	: None
Terrain unit	: Footslope	Water erosion	: Sheet slight
Slope %	: 1	Vegetation/Land use	: Grassveld, open
Slope shape	: Straight	Water table	: None
Aspect	: East	Described by	: J.F Eloff
Microrelief	: None	Date described	: 7207
Parent material of solum	:	Weathering of underlying material	:
Underlying material	: Shale, tillite		

Horizon	Depth (mm)	Description	Diagnostic horizons
A1	0 – 250	Moist state, moist colour: black 10YR2.5/1; texture: clay; structure: moderate medium subangular blocky; consistence: firm; gradual wavy transition.	Orthic
B2	250 – 550	Moist state, moist colour: dark brown 7.5YR3/2; texture: fine sandy clay loam; structure: massive; consistence: slightly firm; few; few fine <2 -6 mm sesquioxide concretions; abrupt smooth transition	Prismacutanicc
C	550 - 550+	Saprolite	

Profile No / Field No: P607

National soil Profile No	: 47	Soil form	: Varsrivier
Map/photo	: 2926 Bloemfontein	Soil family	: sheppardvale
Latitude + Longitude	: 29° 19' 0'' / 26° 46' 48''	Surface rockiness	: None
Land type No.	: Dc 17	Surface stoniness	: None
Climate zone	: 46S	Occurrence of flooding	: None
Altitude	: 1460m	Wind erosion	: None
Terrain unit	: Midslope	Water erosion	: Sheet slight
Slope %	: 2	Vegetation/Land use	: Grassveld, open
Slope shape	: Straight	Water table	: None
Aspect	: South	Described by	: J.F Eloff
Microrelief	: None	Date described	: 7207
Parent material of solum	:	Weathering of underlying mat erial	:
Underlying material	: Lithology unknown or generalized		

Horizon	Depth (mm)	Description	Diagnostic horizons
A1	0 – 300	Moist state, moist colour: dark brown 7.5YR2/2; texture: fine sandy loam; structure: massive; consistence: friable; few; few fine <2.6 mm sesquioxide concretions; abrupt smooth transition.	Orthic
B21	300 – 600	Moist state, moist colour: dark brown 7.5YR3/2; texture: clay; common fine distinct yellow, brown and red mottles; structure: strong medium angular blocky; consistence: slightly firm; many clay cutans; few; few fine <2 -6 mm sesquioxide concretions; gradual way transition	Pedocutanic
B3	600 – 900	Moist state; moist colour: dark brown 10YR3/3; texture: fine clay; common fine faint yellow mottles; structure: moderate medium angular blocky; consistence: firm; non hardened free lime; strong effervescence; few clay cutans; few gravel2 -6 mm; few fine <2 -6 mm; gradual wavy transition.	Pedocutanic
C	900 – 900+		Unconsolidated material without signs of wetness

Profile No / Field No: P608

National soil Profile No	: 48	Soil form	: Kroonstad
Map/photo	: 2926 Bloemfontein	Soil family	: bluebank
Latitude + Longitude	: 29° 8' 0'' / 26° 46' 48''	Surface rockiness	: None
Land type No.	: Db 37	Surface stoniness	: None
Climate zone	: 46S	Occurrence of flooding	: None
Altitude	: 1450m	Wind erosion	: None
Terrain unit	: Midslope	Water erosion	: Sheet slight
Slope %	: 2	Vegetation/Land use	: Grassveld, open
Slope shape	: Convex	Water table	: 300 mm
Aspect	: West	Described by	: J.F Eloff
Microrelief	: None	Date described	: 7207
Parent material of solum	:	Weathering of underlying material	:
Underlying material	: Lithology unknown or generalized		

Horizon	Depth (mm)	Description	Diagnostic horizons
A1	0 – 300	Moist state, moist colour: dark brown 7.5YR3/2; texture: fine sandy loam; structure: massive; consistence: friable; few; few fine <2.6 mm sesquioxide concretions; abrupt smooth transition.	Orthic
E	300 – 500	Wet state, moist colour: brown 10YR5/3; texture: fine sandy loam; few fine faint yellow mottles, structure: single grain; consistence: sticky slightly plastic; common; common medium 6-25 mm sesquioxide concretions; gradual way transition	E -horizon
B2	500 – 500+	Wet state; moist colour: brown to dark brown 10YR4/3; texture: clay; many fine distinct yellow, brown and red mottles; structure: moderate coarse angular blocky; consistence: very sticky, plastic, common clay cutans; few; few fine <2 -6 mm sesquioxide concretions.	Gleycutanic

Profile No / Field No: P609

National soil Profile No	: 49	Soil form	: Avalon
Map/photo	: 2926 Bloemfontein	Soil family	: Soetmelk
Latitude + Longitude	: 29° 0' 48'' / 26° 49' 0''	Surface rockiness	: None
Land type No.	: Db37	Surface stoniness	: None
Climate zone	: 46S	Occurrence of flooding	: None
Altitude	: 1550m	Wind erosion	: None
Terrain unit	: Footslope	Water erosion	: Sheet slight
Slope %	: 1	Vegetation/Land use	: Agronomic cash crops
Slope shape	: Convex	Water table	: None
Aspect	: North	Described by	: A.T.P. Bennie
Microrelief	: None	Date described	: 7303
Parent material of solum	:	Weathering of underlying material	:
Underlying material	: Lithology unknown or generalized		

Horizon	Depth (mm)	Description	Diagnostic horizons
A1	0 – 300	Dry state; dry colour: dark brown 7.5YR3/4; texture: fine sandy loam; structure: single grain; consistence: soft; few; few fine <2-6 mm sesquioxide concretions; clear smooth transition.	Orthic
B21	300 – 600	Moist state, moist colour: brown to dark brown 7.5YR4/4; texture: fine sandy clay loam; structure: single grain; consistence: slightly firm; few, few fine < 2-6 mm sesquioxide concretions; clear smooth transition	Yellow brown apedal
B22	600 – 750	Gleycutanic: Moist state; moist colour: Strong brown 7.5YR5/6; texture: fine sandy loam; structure: single grain; consistence: loose; many; many medium 6-25 mm sesquioxide concretions; clear smooth transition.	Soft plinthic
C	700 – 750 +	Texture: clay	

Profile No / Field No: P610

National soil Profile No	: 50	Soil form	: Valsrivier
Map/photo	: 2926 Bloemfontein	Soil family	: Sheppardvale
Latitude + Longitude	: 29° 7' 12'' / 26° 55' 24''	Surface rockiness	: None
Land type No.	: Db37	Surface stoniness	: None
Climate zone	: 46S	Occurrence of flooding	: None
Altitude	: 1550m	Wind erosion	: None
Terrain unit	: Midslope	Water erosion	: Sheet moderate
Slope %	: 2	Vegetation/Land use	: Grassveld, open
Slope shape	: Straight	Water table	: None
Aspect	: West	Described by	: J.F. Eloff
Microrelief	: None	Date described	: 7207
Parent material of solum	:	Weathering of underlying material	:
Underlying material	: Lithology unknown or generalized		

Horizon	Depth (mm)	Description	Diagnostic horizons
A1	0 – 300	Moist state; moist colour: brown to dark brown 10YR4/3; texture: fine sandy clay loam; structure: massive; consistence: very firm; few; few fine <2-6 mm sesquioxide concretions; clear smooth transition.	Orthic
B2	300 – 550	Moist state, moist colour: dark greyish brown 2.5YR4/2; texture: clay; common fine faint reddish brown mottles; structure: moderate course angular blocky; consistence: firm; many clay cutans few, few fine < 2-6 mm sesquioxide concretions; gradual smooth transition	Pedocutanic
C	550 – 550 +	Gleycutanic: Moist state; moist colour: olive 5Y5/3; texture: clay; common fine distinct yellow mottles; structure: weak medium angular blocky; consistence: firm; few clay cutans; few, few fine <2-6 mm sesquioxide concretions; few fine <2-6 mm lime concretions.	

Appendix 10 Soil and terrain form inventory in the land type Db37 (Land Type Survey Staff, 2002).

LAND TYPE : Db37
CLIMATE ZONE : 46S — 2826 Winburg (65720 ha)
Area : 94220 ha

Estimated area unavailable for agriculture: 2220 ha

Terrain unit

		1	1(1)	3	3(1)	4	5
% of land type	:	1	11	3	52	23	10
Area (ha)	:	942	10364	2827	48994	21671	9422
Slope (%)	:	1-2	0-2	6-35	1-3	0-2	0-1
Slope length (m)	:	200-700	20-50	500-1500	50-300	400-1000	50-300
Slope shape	:	Z-Y	Z-Y	Z	Z	Z	Z-X
MB0, MB1 (ha)	:	0	10364	0	48994	21671	8009
MB2 - MB4 (ha)	:	942	0	2827	0	0	1413

Soil series or land classes	Depth	MB :	1 ha	1 %	1(1) ha	1(1) %	3 ha	3 %	3(1) ha	3(1) %	4 ha	4 %	5 ha	5 %	Total ha	Total %	Clay content (%) A	Clay content (%) E	Clay content (%) B21	Hor	Texture Class	Depth limiting Materia
Soil-rock complex :	(mm)																					
Rock		4:	659	70			1979	70							2638	2.8						
Mispah Ms10, Williamson Gs16, Shorrocks Hu36	100-250	3:	188	20			424	15							612	0.7	10-25		15-30	A	LmfiSa-SaClLm	R, so
Glendale Sd21 Milkwood Mw11, Glengazi Bo31	250-400	3:	94	10			424	15							518	0.6	20-45		35-50	B	fiSaCl	R, vp
Shepperdvale Va42	100-250	:							19598	40	14086	65	1413	15	35097	37.3	20-30		55-65	B	Cl	vp
Lindley Va 41, Arniston Va31,	100-250	0:			5182	50			17148	35	2601	12	471	5	25402	27.0	12-25		40-55	B	fiSaCl-Cl	vp
Nyoka Sw41, Omdraai Sw42, Swartland Sw31	100-200	0:							4899	10	3251	15	754	8	8904	9.5	12-30		40-65	B	fiSaCl-Cl	vp
Rietvlei We12	300-450	3:			4664	45			1470	3					6134	6.5	12-30		20-35	A	fiSaLm-SaClLm	sp
Dundee Du10, jozini Oa36	>1200	0:											4711	50	4711	5.0	15-45			A	fiSaLm-SaCl	
Bluebank Kd16, Kroonstad Kd13	450-600	0:							2940	6	1084	5	283	3	4306	4.6	15-25	10-20	40-60	E	fiSaLm	G
Milkwood Mw11, Glengazi Bo31	300-450	0:							2450	6	650	3	377	4	3477	3.7	35-50		40-55	A	fiSaCl	R,vp,sp
Soetmelk Av36	500-700	0:			518	5			490	1					1008	1.1	12-25		20-35	B	fiSaClLml	sp
Stream beds 3		4:											1413	15	1413	1.5						