SPATIAL VARIABILITY OF SOIL AND LAND SUITABILITY EVALUATION FOR SPECIFIC CROP RANGES FOR RAMBUḐA IRRIGATION SCHEME IN VHEMBE DISTRICT

BY

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A thesis submitted to the School Agriculture in fulfillment of the requirements for the degree of Doctor of Philosophy in Agriculture in the Department of Soil Science at the University of Venḓa

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DEDICATION

This is in memory of my beloved friend Mrs Mashudu Tsaṅwani and my sister in law Khathutshelo Netshidzivhani and her husband who passed-away tragically when I was still busy with this study. How I wished you have witnessed the conclusion of my studies!

You are our beloved!!

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DECLARATION BY CANDIDATE

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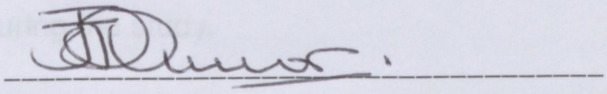
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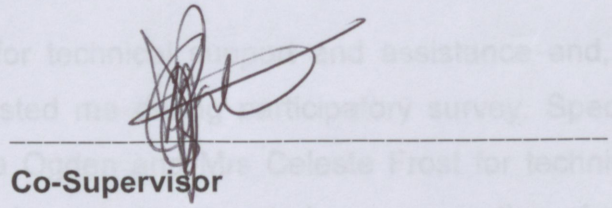
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LIST OF PUBLICATIONS AND SUBMITTED MANUSCRIPTS OF THIS THESIS

The following articles were published or manuscripts submitted based on chapter or combination of chapters of this thesis:

1. **Ṋethononda, L.O. & Odhiambo, J.J.O. (2011)**. Indigenous soil knowledge relevant to crop production of smallholder farmers at Rambuḍa Irrigation Scheme, Vhembe District South Africa. *African J. Agric. Res.* 6, 2576 – 2581.

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5. **Ṋethononda,** L.O., **Odhiambo, J.J.O. & Paterson, D.G. (2013).** Land suitability for specific crop ranges for Rambuḍa Irrigation Scheme using dynamic land suitability evaluation guidelines for small-scale communal irrigation schemes. *Ajar* (*Submitted*).

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EXECUTIVE SUMMARY

Rambuḍa Irrigation Scheme is a 120 hectare communal irrigation scheme established in 1952. There is no information on soil or basis for crop choices, consequently famers have been growing crops on trial and error basis using local knowledge of soil and empirical observations of crop performance under various soil and climatic conditions. Such information is insufficient to make appropriate land use decisions. The objective of this study was to investigate the spatial variability of soil at Rambuḍa Irrigation Scheme to provide a basis for land suitability evaluation for specific crop ranges.

A situation analysis, person-to-person interviews and participatory climate description and soil mapping were conducted. Information from participatory exercises was validated by recorded climatic data and soil survey. A total of 230 were collected from 100 x 100 m grid for laboratory analysis for sand, silt, clay, organic carbon, pH extractable phosphorus, extractable potassium; calcium and magnesium. Soil penetrability was measured using a 100 m grid. Data were subjected to descriptive statistical analysis for minimum, maximum, mean, standard deviation, coefficient of variation, and skewness. Semivariograms were analysed to describe spatial variability using GS+ 9.0 and spatial maps were interpolated using ordinary kriging technique to predict values of all variables for unsampled areas. Spatial maps were drawn using ArCGIS 9.0 and 9.3 Software while other maps where drawn using ArCMap View 3.0. The principles of the FAO guidelines were used to develop dynamic land suitability guidelines for small-scale communal irrigation schemes. The guidelines use participatory, bottom-up and interdisciplinary approaches. Land suitability evaluation was conducted at two levels; firstly, broad evaluation of biophysical resources and secondly, for specific crops by matching crop requirements and tolerance with land characteristics/land qualities of the mapping unit using a decision tree to decide the suitability the rating of the particular crop.

Results showed that famers knew the different types of soil found and the prevailing climatic conditions in the irrigation scheme based on their indigenous soil classification knowledge and empirical observations. Farmers identified and described four soil types namely, Tshilogo, Dzwabo, Sengeṭavha and Tshiṭavha using local nomenclature. Hot, dry conditions during August to October and January

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*months were limiting to crop production. Soils were classified as belonging to Suurbekom, Hayfield, Ventersdorp and Stella families of Hutton soil form and Dipene and Caledon families of Oakleaf soil form. Coefficient of variation showed moderate to high variability of majority of measured soil properties for topsoil and subsoil horizons. Semivariograms of the majority measured soil properties were defined by an exponential model, except for topsoil sand, cone penetrometer resistance and subsoil Ca and Mg by a spherical model while subsoil P was defined by a Gaussian model. Semivariograms exhibited moderate spatial dependence for sand, silt, clay, subsoil cone penetrometer resistance, subsoil Ca and topsoil and subsoil Mg. Organic carbon, pH and P showed strong spatial dependence for topsoil and subsoil horizons, while cone penetrometer resistance, K and Ca showed strong spatial dependence for the topsoil horizons. The highest cone penetrometer resistance occurred below 22 cm implying that the soil was highly compacted as a result of continuous shallow tillage. Soils were very low in P and K despite a long history of application of kraal manure. Spatial maps showed high variability of soil properties for the topsoil in particular. There was positional relationship between the topsoil and the subsoil for all soil properties indicating the interaction among soil properties. Majority of mapping units were well suited (WS) and suited (S) for majority of specific crop ranges and only mapping unit **Ao** was marginally suited (MS) for citrus because of crusting, susceptibility to compaction and moderate drainage. Dynamic land suitability evaluation guidelines were successful for assessing land suitability for specific crop ranges at Rambuḍa Irrigation Scheme and will have to be tested in other irrigation schemes under different socio-cultural and biophysical conditions.*

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ACRONYMS

ARC-ISCW	:	Agricultural Research Council – Institute for Soil Climate and Water
C:N	:	Carbon:Nitrogen Ratio
CV	:	Co-efficient of variation
DAAF	:	Department of Agriculture, Forestry and Fisheries
ESRI	:	Environmental Research Service Institute
FAO	:	Food and Agriculture Organization
FSSA	:	Fertilizer Society of South Africa
GIS	:	Geographic Information System
kPa	:	Kilo Pascal
LMU	:	Land Mapping Unit
LUT	:	Land Utilization Type
MS	:	Marginally suited
NERISA	:	Network on Irrigation Research and Extension in Small-scale Agriculture
NIIB	:	Net Irrigation Increment Benefit
NS	:	Not suited
PR	:	Penetrometer resistance
RESIS	:	Revitalization of Irrigation Schemes Programme
S	:	Suitable
SD	:	Standard deviation
TBVC	:	Transkei Bophuthatswana Venda Ciskei
USDA	:	United States Department of Agriculture
WS	:	Well suited

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CHAPTER ONE

GENERAL INTRODUCTION

1.1 Background of Rambuḍa Irrigation Scheme

Rambuḍa Irrigation Scheme was established in 1952. Soil studies, planning and construction-work of the irrigation scheme was done by consultants, but there is no information on soils or basis for crop choices. Although, according to a report by Murray *et al.* (1989), a soil study was conducted during the era of the former Venḍa homeland, neither a soil survey report nor a soil map could be found at the irrigation scheme or district office. Therefore, farmers have been growing crops on a trial and error basis using indigenous local knowledge of soils and empirical observations of the performance of crops under various climatic conditions in the area. According to T.P. Mukhanu (Personal communication, 2007), crop stands and yields differed widely across the irrigation scheme and the yields have been decreasing over the years.

Information on both physical and chemical properties of soils and their distribution is indispensable if sustainable development planning is to be made (Beek, 1977). Soil varies over time and space as a result of soil forming factors and anthropogenic activities, and this variation is known as spatial variability (Wilding, 2000). Spatial variability in soil properties has been reported to cause yield variability within and across the field (Iqbal *et al.*, 2005; Mzuku *et al.,* 2005). Spatial variability of soil properties across the land affects the distribution of soil mapping units and their suitability for various uses. Mapping units are defined as units of land that possess similar properties and have similar management requirements and are the elements used in land suitability evaluation (FAO, 1976).

Studies conducted in small-scale irrigation schemes focused mainly on socio-economic issues (Bembridge 2000; Lahiff, 1997; 2000) rather than technical issues relating to soils, irrigation practices and cultural practices affecting crop production. According to a report by Bembridge (2000), the main problems among small-scale irrigation schemes in South Africa are related to breakages and poor maintenance of irrigation infrastructure and equipment, shortage of water during droughts and poor cultural practices. Soil and climatic conditions of an area are important factors for successful and sustainable crop production. Such information is often not seriously

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considered even in development planning of most agricultural projects (Laker, 1982). This has led to the collapse of a number of food security and irrigation schemes in South Africa (Machete *et al.*, 2004; Limpopo Department of Agriculture, 2005).

Approaches used in land capability evaluation in South Africa were designed for large commercial farmers and serve little value if any for resource poor communal small-scale irrigation schemes (Hensley and Laker, 1981; Laker, 2004). According to a paper by Laker (2004), more has been done in land capability evaluation in South Africa since 1978, but seldom according to the whole range of principles outlined in the FAO guidelines (1976; 1983; 1985; 1996). The FAO guidelines stress imperative factors such as multidisciplinary approach and physical-biological factors that should be considered and class limits used to rate suitability class for each mapping unit (FAO, 1976; 1983; 1985; 1996). A review of land capability classification systems used in South Africa in the early 1980's revealed that planners in different regions used different systems that followed the USDA system of eight classes (van Niekerk, 1983; Laker, 2004). There was a need to develop a uniform national land capability evaluation system harmonize the use of soil information among users. An eight class system very similar to the USDA system was developed (Scotney *et al.*, 1987; Laker, 2004). The system assumed availability of capital, modern farming methods and good management which was not the case in the rural areas of South Africa where farming was mainly in the form of poorly resourced communal irrigation schemes. Thus, such a system was not appropriate for communal farming condition. Authors of the system clearly stated that it was not intended for irrigated agriculture (Scotney *et al.*, 1987).

Though the Agricultural Research Council-Institute for Soil Climate and Water (ARC-ISCW) had a rigorous system for the evaluation of the suitability of soils for irrigation, their approach has changed so much over the years to a point where they currently do not have a fixed land suitability system for irrigation (Laker, 2004). Instead, each case is individually considered according to its characteristics and requirements. There is a lack of publications regarding land suitability evaluation and planning for irrigation in South Africa (Laker, 2004). The paper further stressed the need for development of a localized land suitability evaluation approach for South Africa (Laker, 2004).

This study aims to investigate the spatial variability of soil properties at Rambuḍa Irrigation Scheme to provide basis for land suitability evaluation for specific crop ranges for the irrigation scheme.

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1.2 Justification

Rambuḍa Irrigation Scheme is the main source of household income and livelihood for the community of Dzimauli and surrounding villages. There is no soil and climatic information or basis for crop choices and this may lead to inappropriate crop choices, cropping programmes, irrigation scheduling, and cultural practices. There is a decrease in yields for main crops like maize and sweet potato and crop failures of newly introduced crops, but the cause of the problem is not known. Any change in land use or management practices requires thorough knowledge of bio-physical resources for an area (Beek, 1977; Laker, 2004). There is also sudden shift from furrow irrigation to overhead irrigation systems such as floppy and sprinkler irrigation and heavy mechanization in communal irrigation schemes through the Revitalization of Irrigation Schemes (RESIS) Programme without consideration of their suitability for different types of soil and management skills among plot-holders. Land assessment studies that were done were based according to the principles of the USDA land capability system. This was designed for large mechanized commercial farms and is not appropriate for resource-poor communal irrigation schemes in the rural areas in Vhembe District as well as in other provinces of South Africa.

Investigation of spatial variability of soil properties of the area can provide a basis for delineation of mapping units for land suitability evaluation. Land suitability evaluation can provide information on land suitability for a range of crops. The systems and approaches of land capability evaluation that are currently used in South Africa are more applicable for skilled, large commercial farmers with access of finances and technology and not appropriate for small-scale communal irrigation schemes. Small-scale communal irrigation schemes are located in rural areas where majority of plot-holders are illiterate, poor, have limited access to technology and rely mainly on indigenous knowledge of biophysical resources to decide on land uses. In essence, dynamic land suitability evaluation guidelines that are flexible are required for small-scale communal irrigation schemes with limited resources in South Africa.

1.3 Hypothesis

It is hypothesized that farmers at Rambuḍa Irrigation Scheme are growing crops that they think are simple to grow and easy to sell without considering land suitability for

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such crops and proper agronomic practices. Crop suitability is largely influenced by soil physical and chemical properties and prevailing climatic conditions of the area. Spatial variability of soil properties influences crop performance and can provide information useful for the delineation and assessment of land suitability of map units for specific crop ranges for Rambuḍa Irrigation Scheme. Principles of FAO land evaluation guidelines (FAO, 1976; 1983; 1985; 1996) can be used to develop dynamic guidelines for land suitability evaluation for small-scale communal irrigation schemes.

1.4 Research questions

The study will attempt to answer the following questions:

1. Is crop suitability information available for the irrigation scheme?
2. Do farmers know the soils and prevailing climatic conditions and their implications on crop growth?
3. Which crops are grown and what other new crops do farmers want to grow at Rambuḍa Irrigation Scheme?
4. Which soils are found at Rambuḍa Irrigation Scheme and their distribution?
5. What are physical and chemical characteristics of the soils that may affect land suitability for specific crop ranges?
6. Is the ecotope appropriate for land suitability evaluations?
7. What land characteristics and/or land qualities restrict crop growth in the study area to evaluate map units suitability for specific crop ranges?
8. Can the land evaluation principles of the FAO (1976; 1983; 1985; 1996) be used to develop dynamic guidelines for land suitability evaluation for small-scale communal irrigation schemes?

1.5 General objective

The general objective of this study was to investigate the spatial variability of soil properties at Rambuḍa Irrigation Scheme in order to provide basis for land suitability evaluation for specific crop ranges.

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1.5.1 Specific objectives

The study will achieve the following specific objectives:

1. To review available literature, climatic, geological and land use information of the study area.
2. To investigate local knowledge of soils and climatic information relevant to crop production among farmers.
3. To describe and classify soils in order to map spatial distribution of soils found in the study area.
4. To determine physical and chemical soil properties through field measurements and laboratory analysis in order to describe spatial variability of soil properties across the irrigation scheme.
5. To describe soil ecotopes and their appropriateness for use in land suitability evaluation.
6. To draw crop suitability maps and tables for specific crop ranges for Rambuḍa Irrigation Scheme.
7. To develop dynamic land suitability evaluation guidelines for small-scale communal irrigation schemes.

1.6 General methodology and the outline of this thesis

Literature review was conducted to get information relevant to this study. A situation analysis was conducted. The results were used to develop a questionnaire used during a field survey and interviews to obtain information on knowledge and understanding of bio-physical resource and soil uses in the irrigation scheme. Participatory soil mapping was conducted with 31% of the farmers. A triple-A Framework approach was used (van Averbeke and Khosa, 2004). Semi-structured interviews were conducted with 76 of 104 farmers who were found in their respective plots. Results were presented to the farmers during the general meeting. This was done to verify the trustworthiness of findings and to solicit additional explanations for the observed phenomena. Base maps were drawn from aerial photographs. Sampling points and soil profile points were plotted and georeferenced using a global positioning system (GPS). Field-measured properties were recorded in the research file during field survey. Soil samples were collected for laboratory analysis. Descriptive statistics was used to analyze the data using SAS 9.0

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(SAS Institute Software, 2010). Data were computed for geostatistics analysis using GS+ Gammadesign 9.0 (Robertson, 2008) and ArcGIS Spatial Analyst 9.0 AND 9.3 (ESRI, 2006; 2009) to analyze spatial variability and to map selected soil properties. Dynamic land suitability evaluation guidelines for small-scale communal irrigation schemes were developed using the principles in FAO (1976; 1985; 1996).

This thesis consists of ten chapters. General introduction of the study and objectives are presented in Chapter 1 and the description of the study area is presented in Chapter 2 giving detailed account of locality, climatic description and land uses of the study area. Chapter 3 reviews land capability and suitability classification systems, land evaluation guidelines and; indigenous soil knowledge and soil use perspectives in developing countries. Chapter 4 presents results of assessment of local soil and climate knowledge relevant to crop production at Rambuḍa Irrigation Scheme using participatory techniques. Chapter 4 also presents principles and criteria used to describe; classify; make soil use decisions and participatory soil mapping as well as soil problems that affect crop production at Rambuḍa Irrigation Scheme. Chapter 5 presents results of soil studies, classification and soil mapping. Chapters 6 & 7 describe the spatial variability of selected soil physical and chemical properties. Chapter 8 describes the development of dynamic land suitability evaluation guidelines for small-scale communal irrigation schemes. Chapter 9 presents land suitability evaluation for specific crop ranges for Rambuḍa Irrigation Scheme using dynamic guidelines for land suitability evaluation for small-scale irrigation schemes and Chapter 10 gives the general conclusions and recommendations of this study.

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CHAPTER TWO

DESCRIPTION OF THE STUDY AREA

2.1 Locality

Rambuḍa Irrigation Scheme is situated along the Mutale River between Tshagumbu and Tshala Rivers in the Mutale Municipality, Vhembe district of Limpopo Province in South Africa between 22°46' 00" S and 22°48' 00" S latitude and between 30°25' 30" E and 30°27' 00" E longitude (Figure 2.1). The irrigation scheme is situated 40 km north of Thohoyandou.

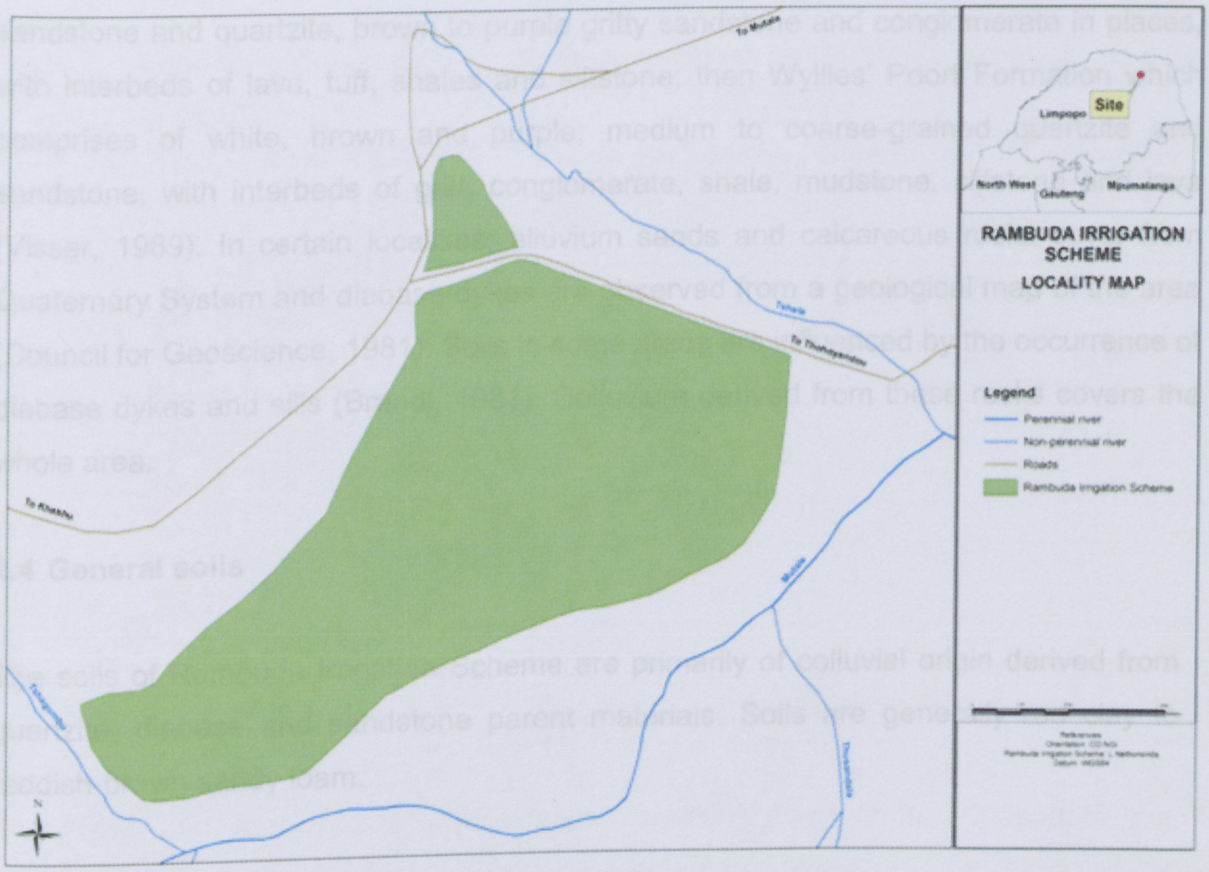


Figure 2.1 Locality map of Rambuḍa Irrigation Scheme

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2.2 Topography

The study area extends from the terraces 635 m to 665 m above sea level. The slopes descend from the north to south towards the Mutale River. The topography of the area can be described as level with undulating gentle slopes ranging between 0.5 and 2% gradients.

2.3 Geology

Rambuda area is underlain by rocks of Soutpansberg Group, which comprises of volcanic and sedimentary rocks succession that is subdivided into six Formations (Johnson *et al.*, 2006). However, Rambuḓa Irrigation Scheme is restricted to only two Formations; Fundudzi Formation which is composed of pale-coloured quartzitic sandstone and quartzite, brown to purple gritty sandstone and conglomerate in places, with interbeds of lava, tuff, shales and siltstone; then Wyllies' Poort Formation which comprises of white, brown and purple, medium to coarse-grained quartzite and sandstone, with interbeds of gritt, conglomerate, shale, mudstone, siltstone and lava (Visser, 1989). In certain localities, alluvium sands and calcareous rocks cover from Quaternary System and diabase dykes are observed from a geological map of the area (Council for Geoscience, 1981). Soils in some areas are influenced by the occurrence of diabase dykes and sills (Brandl, 1981). Colluvium derived from these rocks covers the whole area.

2.4 General soils

The soils of Rambuḓa Irrigation Scheme are primarily of colluvial origin derived from quartzite, diabase and sandstone parent materials. Soils are generally red clay to reddish-brown sandy loam.

2.5 Climate

Rambuḓa Irrigation Scheme lies in the subtropical climatic region. The climate is characterized by warm to hot summers with mild to cool winters. Long-term climatic data to describe the climatic conditions for Rambuda Irrigation Scheme were obtained from the Agricultural Research Council. (ARC-ISCW, 2010).

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2.5.1 Temperatures

The temperatures are warm to hot during summer with mild to cool winter temperatures, particularly during the months of June and July (Table 2.1). The mean daily monthly minimum temperature experienced during winter varies between 9.2°C and 12°C and the mean monthly maximum temperature ranges from 23.5°C to 30.0°C. According to the USDA Soil Taxonomy's conversion to soil temperature (air temperature +1), the irrigation scheme is classified as thermic (hot) (Soil Survey Staff, 1990). Average daily maximum temperatures are close to 30°C which is indicative that temperatures of the area exceed this reading during the year. The lowest recorded daily temperature was 1.9°C on the 26th of July 1994 and the highest recorded temperatures 40.5°C and 42.4°C were recorded on the 24th and 25th of February 1994, respectively.

Table 2.1 Long-term mean monthly climatic conditions at Rambuḍa Irrigation Scheme (ARC-ISCW, 2010)

Month	Min Temp (°C)	Max Temp (°C)	Rainfall (mm)	Relative humidity (%)		Class-A Pan evaporation (mm)	Wind run (km/day)	Sunshine hours (h)	ET_0 ET_{ref} mm/month	Aridity index
				08h00	14h00					
Jan	19.6	30	178.4	84.7	40.5	197.8	108.3	6.9	151.9	1.17
Feb	19.6	29.1	208.3	84	41.4	160.8	104.1	6.8	128.8	1.62
Mar	18.5	28.5	154.7	87.2	42.8	163.1	90.8	6.9	130.2	1.19
April	15.8	27.2	39.9	86.5	38.5	131.1	78.1	7.1	108	0.37
May	12	25.6	15.7	87.8	35	122.6	75	7	96.1	0.16
June	9.4	23.5	20.7	87	32.4	100.4	79.5	6.7	81	0.26
July	9.2	23.1	17.2	86.5	32.1	111.4	88.9	7.1	86.8	0.20
Aug	10.9	25	8.9	84.2	30.1	143.2	100.2	7.6	105.4	0.08
Sep	13.7	27.4	21.3	84.1	32.7	175.1	115.8	7	123	0.17
Oct	16	28	61.6	81.3	35.7	191.2	121.6	7.3	139.5	0.44
Nov	17.8	29.2	103.4	83.3	38.9	203.5	113.1	7.8	150	0.69
Dec	19	29.7	126	84	39.2	195.8	105	7.5	158.1	0.80

The growth and development of most plants is strongly temperature-dependent. For some crops the time required to reach the harvestable stage may be expressed in terms of temperature-time values known as heat units (Janick *et al.*, 1981). Heat units are obtained by calculating time in relation to the temperature above certain minimum. For, instance if, the minimum growth temperature requirement of a crop is 10 °C, then a day with mean temperature of 15.6 °C would provide 5.6 °C days of heat units. Thus, any day with an average temperature of 5 would provide 0 degree-days of heat units

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(Janick *et al.*, 1981). The threshold temperature varies between species. For maize the threshold temperature is 10 °C (Bonhomme, 2000, du Plessis, 2003) and for peas the threshold temperature is 8 °C (DAFF, 2011). The threshold temperature for sweet potato in South Africa is 10 °C (van der Berg and Laurie, 2004). The daily heat unit values can be summed for the season to derive cumulative seasonal heat units. This is more predictive of plant growth and development than time alone. This information is critical for proper crop choice and planting programme (Janick *et al.*, 1981).

2.5.2 Rainfall

This area receives summer rainfall with most of the rain (208.3 mm) falling during the month of February (Table 2.1). The highest daily rainfall of 180.2 mm and 427.6 mm were recorded on the 12th and the 13th February 2000, respectively. The area is classified as a high rainfall zone. The area situated in the eleven (11) year drought cycle agro-climatic zone (ARC-ISCW, 2004). The mean annual rainfall is 956 mm with most rain falling between November and March months (Table 2.1).

2.5.3 Relative Humidity

Relative humidity (RH) is the ratio of the actual amount of moisture in the air to the maximum amount in saturated air at a given temperature (Janick *et al.*, 1981). Relative humidity is determined by other climatic variables such as rainfall, wind, temperature and evaporation. The mean monthly relative humidity figures range from 81.3 to 87.8% in the morning (08h00) and 30.1 to 42.8% in the afternoon (14h00), (Table 2.1). Relative humidity figures of 30-40% are too low and not favourable for plant growth, particularly during hot, dry months.

2.5.4 Evaporation

Evaporation is influenced by temperature, wind, and vegetation of the area (Allen, 2006). High temperatures experienced during summer, particularly during the hot, dry months, of August-September, increase the rate of evaporation (Table 2.1). When high evaporation figures coincide with low afternoon relative humidity, supplementary soil water through irrigation is necessary for optimum crop yields. Choice of a suitable irrigation system is critical to minimize the effect of evaporation on crop growth in this

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area. The area is characterized by high evaporation figures during September to January (Table 2.1). This could be attributed to hot dry conditions and strong winds experienced during the same period (Table 2.1).

2.5.5 Aridity index

Aridity index (AI) is a numerical indicator of the degree of dryness of the climate at a given location (UNEP, 1992). These indicators are important in identifying, locate or delimit areas that suffer from a deficit of available water for land use and agriculture. It measures the average water available in the soil of a region and reflects the moisture content of the soil and the stress derived from scarcity (Arora, 2002). The aridity index aims to identify the months when irrigation is necessary (Xhang *et al.*, 2009). It has been used to study irrigation demand (Xhang *et al.*, 2009); irrigation scheduling of crops (Hill, 2002) and to estimate change in runoff (Arora, 2002). It is estimated by using three common primary means namely pan evaporation measurement, an estimate of potential evapotranspiration based on weather data, and a reference evapotranspiration (Allen, 2006). Potential evapotranspiration (ET_0) has been widely used to estimate AI (Eamus *et al.*, 2000) and recently reference evapotranspiration (ET_{ref}) has been reported to be more practical to estimate AI than ET_0 (Deursen, 1995; Allen, 2006; Xhang *et al.*, 2009; Xhang *et al.*, 2011). Reference evapotranspiration (ET_{ref}) has a more practical application than the other two (Allen, 2006) and has been widely use to estimate AI (Xhang *et al.*, 2011). In areas where ETref can be calculated, ET_{ref} would be the better divisor of precipitation to estimate AI (Juan Weldeman, personal communication, 2013). Therefore, ET_{ref} was chosen define the aridity index for Rambuda Irrigation Scheme (Table 2.1) The FAO ET_0 3.1 calculator was used to calculate reference evapotranspiration for RIS according to the FAO standards (FAO, 2009) and AI was calculated as follows:

$$Aridity\ index = \frac{P}{ET_{ref}} \qquad (2.1)$$

Where P is monthly precipitation and ET_{ref} is the monthly reference evapotranspiration.

Regions where AI is greater than unity are broadly classified as dry since the evaporative demand cannot be met by precipitation (Arora, 2002). The UNEP (1992)

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classifies dryness of the regions of the world as follows: <0.05 hyper arid; 0.05-0.2 arid; 0.2-0.50 semi-arid; 0.5-0.65 dry sub-humid and >0.65 as humid. These classes were used to define monthly climatic conditions of Rambuḓa Irrigation Scheme. Rambuḓa Irrigation Scheme is experiences dry conditions from April to October with August being the driest months with an aridity index of 0.08 (Table 2.1). Humid conditions are experienced from November to March and the aridity index is greater than >0.65 threshold. Supplementary irrigation is critical for sustainable crop production, particularly during the hot dry months of August to October.

2.5.6 Frost and hail incidences

The area has frost pockets in places, particularly in the low lying sections of the irrigation scheme towards Tshala and Mutale rivers (Figure 2.1), particularly during the month of July. The average hail incidence is only one day of light hail per year, therefore the area may be regarded as hail free.

2.5.7 Wind

The long-term average daily wind run ranges from 75.0 km/day to 121.6 km/day as per (Table 2.1). Wind run increases above 100 km/day as from August to February with the highest wind run recorded during the months of September to October (Table 2.1). The highest wind run experienced in the area is 121.6 km/day. High daily wind run encourages high evapo-transpiration which is not favourable for the growth of many plants and may necessitate supplementary irrigation for sustainable crop production.

2.5.8 Sunshine hours

The average total daily sunshine hours during the months vary from 6.7 to 7.8 hours (Table 2.1). The longest average daily sunshine hours were recorded during October to January months (6.9-7.8 hours). Shorter average daily sunshine hours are experienced during February (7 hours) and March (6 hours). These are attributed to cloudy weather conditions experienced during these months as these months fall within the rainy period (Table 2.1). Sunshine hours determine the photoperiod of the area which is a critical factor influencing flowering of most crops (Janick *et al.*, 1981). Short-day crops will delay flowering until the photoperiod is short enough to induce

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flowering and long-day crops will not flower unless the photoperiod is long enough to induce flowering (Warner, 2009). Sweet potato for example will not flower and produce tubers, if the number of hours of sunshine is too short. High number of overcast that may be experienced during the growing season will reduce sweet potato yield (van der Berg and Laurie, 2004).

2.6 Land use

The irrigation scheme has a total area of 120 ha, demarcated into 104 terraced plots of 0.24-1.28 ha. The plots are subdivided into subplots with sizes ranging between 300 m^2 and 900 m^2. There are 104 farmers who are farming in the irrigation scheme. Rambuḍa irrigation scheme is a communal irrigation scheme. The chief is the custodian of land and allocates plots to families. Each plot holder pays an annual rental fee of R1.50 for a 0.107 ha or R18.00 for a 1.28 hectare plot. This money is deposited into the Limpopo Provincial Treasury Account. The main land uses are sweet-potato and maize production under short furrow irrigation. Other common crops grown in the irrigation scheme include beans and Chinese spinach. There are several mango trees and banana plants on the borders of the plots.

The main source of water is the Tshala River. Water is supplied from a weir into the main concrete canal that supplies water by gravity into the four balancing dams on the irrigation scheme. Water is distributed from the balancing earth dams to specific plots by secondary canals. Short earth furrows are used to irrigate the crops planted on ridges. An irrigation programme/schedule is used to allocate irrigation times. The irrigation scheme is divided into six (6) management blocks and each block is allocated a full day of irrigation per week.

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CHAPTER THREE

REVIEW OF LAND EVALUATION SYSTEMS AND PRINCIPLES OF ETHNOPEDOLOGY USED IN DEVELOPING COUNTRIES

Abstract

There are several land capability and land suitability systems used around the world. The aim of this chapter is to present a review of land capability and suitability evaluation systems used around the world and in South Africa to provide a basis for the development of a dynamic land suitability evaluation system for small-scale irrigation schemes in South Africa. The most successful system is the USDA land capability classification system. This is evidenced by its adoption or development of its derivatives around the world. This has been widely criticized for being too rigid, lack of consideration for various uses; land users and socio-economic issues. The FAO Framework for Land Evaluation was developed to address some other limitations and to synergize information from different countries. The Framework for Land Evaluation is more of a scheme from which countries can develop their land suitability evaluation systems. South Africa attempted to develop her own land capability evaluation system, but it was a derivative of the USDA and could not address the challenges found in the country. There is still no uniform land suitability evaluation system or guidelines for small scale communal irrigated agriculture in South Africa, particularly one that considers the situation of resource-poor farmer. There is a need to develop dynamic land suitability evaluation guidelines for small scale communal irrigation schemes. The FAO Framework for Land Evaluation provides a suitable basis for such dynamic land suitability evaluation guidelines for small scale communal irrigation schemes. Such guidelines need to consider the aspirations and biophysical resource knowledge of the local people. In recent years, there is sufficient evidence of the important role of indigenous soil and soil use knowledge of the local people in soil surveys and land suitability evaluation in most developing countries. Some of the principles can be integrated with the principles used in modern soil classification and the FAO guideline for land suitability evaluation to develop guidelines for land suitability evaluation for small scale communal irrigation schemes.

3.1 Introduction

Extensive work on land evaluation has been done to ascertain land capability, agricultural potential and land suitability for given uses around the world, (Kliengbel and Montgomery, 1961; Brinkman and Smyth, 1973; FAO, 1976; 1983; 1985; 1996; Beek, 1978; Davidson, 1982; Hensley and Laker, 1981; Laker, 1982, 2004; Scotney *et al.*, 1987; van Niekerk, 1983; Turner and Scotney, 1993; Nethononda, 1996). These systems

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and approaches attempt to explain and predict the potential of land for one or more uses. Land suitability evaluation is necessary for proper land use planning to ensure optimum and sustainable utilization of natural resources in both developing and developed countries.

The aim of this chapter is to present a review of land capability and suitability evaluation systems and approaches used in South Africa and around the world to provide a basis for the development of dynamic land suitability evaluation guidelines for small-scale communal irrigation schemes in Vhembe District.

3.2 Systems of land capability and suitability evaluation

There are several methodologies of land capability and suitability evaluation used around the world today. The USDA land capability classification system is the primary system used or from which most systems that are used around the world were generated (Kliengbel and Montgomery, 1961). The widely used land capability classification system was originally developed by the United States Soil Conservation Services in the 1930s. This system was aimed for/at interpreting maps for farm planning and was concerned with physical land resource analysis. The results of such assessments are presented as capability classes to support broadly defined categories of use (Davidson, 1992). As this system became popular, several countries began to develop their own land capability classification according to the principles of the USDA land capability system.

The FAO decided to come up with some kind of methodological framework (FAO, 1976) to synergize land evaluation process around the world as countries were beginning to develop their own land capability systems which would have negatively affected information exchange among countries (Davidson, 1992). The FAO Framework for Land Evaluation (1976) was followed by a series of guidelines for rainfed agriculture (1983), irrigated agriculture (1985), guidelines for land use planning (1996).

According to Laker (2004), somewhat more has been done in land capability evaluation in South Africa since 1978, but seldom according to the whole range of principles outlined in the FAO documents cited above. It is important to distinguish between capability and suitability evaluation for proceeding discussion of land evaluation

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systems. Land capability classification and land suitability synonymous, but are often confused or regarded as similar (McRea and Burnham, 1981) and some regard these terms as interchangeable (FAO, 1976. Land capability classification is a system of grouping soils primarily on the basis of their capability to produce common cultivated crops and pasture plants without deteriorating over time. Land suitability classification is the appraisal and grouping of specific types of land in terms of their absolute or relative suitability for a specified king of use (FAO, 1976). Capability class does not indicate what the best use of land is, but only the range of what land can be used for without economic or social consideration (Dent and Young, 1981).

3.2.1 USDA Land Capability Classification System for Agriculture and its derivatives

The success of the USDA land capability classification system and its similar versions is proven by its adoption in several countries in Southern Africa and the rest of the world (Davidson, 1982; Laker, 2004). The system emphasizes possible adverse effects on the environment, permitting interpretation of merit of simplicity in stages. It is geared toward soil conservation, thereby protecting the more susceptible areas from cultivation. The system has often been criticized of being static and rigid in land capability classification (Smyth, 1981; Davidson, 1982; Laker, 1982).

A fundamental problem of the system and its derivatives is its evaluation methodology which by its negative approach cannot incorporate varying needs of different land uses (Davidson, 1982). Being geared on limitations rather than positive potential, i.e. towards emphasis on the soil erosion hazard, makes it less flexible. The fact that it does not take sufficient account of the differing requirements of different land uses, nor is its structure such that it can easily be adapted to do so, makes it more fixed (Davidson, 1982). It was designed for a production system which is virtually fixed: large scale mechanized farming; high management levels with good infrastructure (Laker, 1982). It especially does not suit the needs of developing countries. In developing countries, we usually meet with a technological transformation continuum where modern and traditional land uses operate side by side, sometimes linked by land uses characterized by so-called intermediate technologies (Beek, 1977).

The USDA land capability classification system is subjective in its evaluation and categorization of land to specific classes and the opinion of the evaluator who may or

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may not be experienced enough to give a correct judgment (Laker, 2004). The system cannot be applied in situations where several limiting factors have equal effect on the arability of land. Interactions between varying limiting factors are difficult to consider, especially if the set of precise criteria to be met have not been established (Laker, 1980; 2004).

Land evaluation always has three elements, namely land, people (socio-economy) and land uses (Hewitt and Van Wambeke, 1982). The human factor is the determinant of the management practices and their failure to prevent environmental damage (FAO, 1976). It is important to note that land has intrinsic advantages and disadvantages; therefore for capability evaluation to be meaningful, it needs to recognize these factors and such intrinsic properties have economic influences on land capability. These include social and economic factors governing the supply of land available for a particular use and market demand for the produce from that use. Socio-economic factors relevant to the planning and management of the current and proposed agricultural land uses in the area being evaluated should be considered (Davidson, 1982; Hewitt and Van Wambeke, 1982).

The system does not consider a multidisciplinary approach in land capability evaluation. The integration of physical, economical and social factors in land evaluation requires knowledge from different specialists, such as soil scientists, environmentalists, agronomists, horticulturalists, economists, social scientists and agriculturalists from the beginning of land evaluation process (Hensley and Laker, 1981).

The USDA land capability system has many limitations for small-scale agriculture in areas where land is scarce and modern technology is limited. In less developed areas of South Africa, the chief (traditional leader) is the custodian of land. Any activity on the land must receive blessing from the chief (traditional leader) before any work commences. Suitability of land is not only determined by its potential for the envisaged use, but may be limited by social beliefs and cultural issues. A land may be considered not suitable for agriculture or any other use except religious worship (Nethononda, 1996). A land evaluation system that fails to recognize this relationship will be inappropriate for these areas.

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3.2.2 FAO Framework for Land Evaluation

In response to the problems experienced with the application of the USDA's land capability system, especially in developing countries, the FAO developed a dynamic and flexible framework for land evaluation (Smyth, 1981; Davidson, 1982; Laker, 2004). The FAO Framework of Land Evaluation (1976) was preceded by a background paper, a draft and the proceedings of two meetings of international expert consultants and the summaries of the system are given by Davison (1992); Dent and Young (1981), provided an examination of methods of evaluation in detail. The framework (FAO, 1976) was supported by a series of guidelines for land evaluation for rainfed agriculture (FAO, 1983), irrigated agriculture (FAO, 1985) and guidelines for land use planning (FAO, 1996).

FAO Framework for Land Evaluation (1976) is more of a scheme than a capability classification system. It is a scheme upon which several suitability classification approaches or models can be built (Davidson, 1992). An important attribute of the scheme is its ecological foundation and recognition of land use type as a starting point and land evaluation procedures are then executed with close reference to land use type, and consequently resulting in a suitability assessment relevant to land use type (Beek, 1977).

3.2.2.1 Concepts of land use and land utilization types

The FAO (1976) Framework for Land Evaluation distinguishes between a land use and land utilization type (LUT). The former is the use to which the land is put, better known as major land kind of land use, which is a subdivision of rural land use, e.g. pasture land, forestry for recreation, and the latter is a type of land use described in detail. LUT's are not only described according to actual land uses or crops, but also with respect to such factors as market, capital intensity, labour intensity, technology employed, infrastructure requirements, size and configuration of land holdings, land tenure and income levels (Davidson, 1982).

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3.2.2.2 Concepts ecotope and mapping unit

An ecotope is defined as an area of land within which the variation of natural resources is limited to the degree that the potential agricultural production and techniques will be uniform and will differ from adjoining ecotopes (MacVicar *et al.*, 1974). In other words, natural resource units which are so similar that their differences are unlikely to be meaningful in agriculture are grouped together to form an ecotope. Differences are based on climate, soil and slope and one ecotope will vary from another in terms of difference in either one; two or all of the three attributes. Climate patterns, soil forms and topography can vary widely and different combinations of these natural resources which have similar properties have been grouped and indicated as ecotopes. There are no definite and clear-cut class limits on which classification of ecotopes is made and thus experience forms an integral factor for correct demarcation. Ecotopes provide a means for collecting data, storing and retrieving agricultural potential data, such as best farmer potential (MacVicar, 1974).

Mapping unit is defined as a specific area of land that can be delineated on a thematic map and whose land characteristics can be determined (Rossiter, 1996). FAO (1976) defines mapping unit as a mapped area of a land with specified characteristics. It is defined in terms of natural resources surveys of soil, vegetation, topography.
The main causes of variation of mapping units in a local area are soils and/or land form variability which is determined by the scale and intensity of study (FAO, 1976). The principles used to describe ecotopes are very similar to those used in describing mapping unit of a land.

3.2.2.3 Land qualities and land characteristics

Land units have land characteristics and land qualities which are used as criteria for their classification (Davidson, 1992). Land characteristics are measureable properties of land such as soil depth, temperature, rainfall, day-length, evaporation etc. (FAO, 1976). Thus, land qualities are determined by a combination of many land characteristics and one land characteristic may influence many land qualities (Rossiter, 1996).

Land quality is a component regime of physical land conditions with specific influence on land use performance (Beek, 1978). Each land quality acts in a manner distinct

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from the actions of the other land qualities in influencing suitability of land for a specified kind of land use (FAO, 1976). They are more abstract than land characteristics, which are the attributes of land that can be measured or estimated. Land qualities may be edaphic, climatic, agronomic, and geographic or related to hazard (Rossiter, 1990). A land quality is a composite of several land characteristics which are more or less independent of other land qualities, and has significant predictive value for land use (Forbes *et al.,* 1982). In other words, land qualities are inferred from land characteristics, which are measurable attributes of land such as texture, slope, pH, etc. A land quality cannot be generally used when making soil surveys, since identical land qualities may result from combinations of different soil characteristics (Forbes *et al.,* 1982).

It is difficult to characterize the soil regimes affecting agricultural processes, water, nutrients, gas, biotics, foothold, toxicities, and mechanical strength. It is also difficult to measure the soil conditions that affect successful management operations and response to physical input. However, for the interpretation of soil information, attempts should be made to synthesize the relevant measurable soil properties into assessment factors that have a specific influence on these processes and activities. There are four groups of land qualities and these are listed in the FAO (1976; 1983; 1985; 1996). The general grouping of land qualities according the FAO (1976) Framework for Land Evaluation are listed as follows:

1. Major land qualities related to plant growth
2. Major land qualities specifically related to plant and animal growth
3. Major land qualities related to natural product extraction and
4. Major land qualities related to practices in plant production and animal production or extractions.

3.2.2.4 Land use requirements

After the selection of the land utilization types, their requirements for their successful production are described. This may be obtained through empirical data, research results or inferred from the performance of LUT's in other areas with similar soil and climatic conditions. Land use requirements are the conditions of land necessary for successful and sustained practice of a given LUT (FAO, 1983). These are the set of

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land qualities that determine the production and management condition of a kind of land use (FAO, 1976) whilst limitations are land qualities, or their expressions by means of diagnostic criteria, which adversely affect a kind of land use. Thus limitations may be regarded as land qualities expressed in such a way as to show the extent to which the conditions of the land fall short of the requirements for a given use (FAO, 1976).

Each land use needs different environmental conditions to be practised sustainably and economically. Land use requirements and limitations indicate the types of data which are required for evaluation, and thus govern the conditions and the nature of the surveys needed (FAO, 1976).

There are three set of land use requirements, namely those related to crop performance, those related to management and those related to environmental conservation. An outline of these factors is presented here below:

Crop requirements and tolerances which include such aspects as:

Climate requirements and tolerances,

Soil requirements and tolerances,

Prevalence of pests, diseases and persistent weeds in the area.

Management requirements which include such aspects as:

Benefit: cost analysis,

Infrastructure,

Availability and distances to markets, processing and/or packaging facilities.

Cost of land clearing, land preparations, etc.

Irrigation systems and irrigation costs (e.g. pumping costs),

Drainage requirements and costs.

Environmental requirements which include such aspects as:

Erosion hazard (both water and wind erosion) – looking at both on-site and off-site impacts,

Pollution hazard especially off-site,

Threats to endangered species.

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3.2.2.5 Matching Process

Land use requirements are used in the matching process to determine what extent land qualities of a particular land unit would fit the requirements of the intended land use. Matching process will result in a suitability assessment or factor rating of the land to be evaluated. Matching is a complex process involving several steps in which land improvements, environmental impact, socio-economic analysis, reviews and field checks play a role. The end result is that land is evaluated for specific purpose and put into two orders of suitability i.e. suitable (S) and not suitable (N). In some instances, land may be conditionally suitable (Sc) giving rise to a sub-order for suitable (S).

3.2.2.6 Land suitability classifications

The FAO (1976) defines land suitability evaluation as the fitness of a given type of land (land mapping unit) for a defined use. According to the expanded definition of the FAO (1976), land suitability classification is an appraisal and grouping of specific types of land in terms of their absolute or relative suitability for a specified kind of use. Land suitability classification may be considered in its present condition or after improvements. Thus, land may be suitable, conditionally suitable or not suitable for a particular use under the management specified for that use, but suitable given that conditions are fulfilled (FAO, 1976), (Table 3.1)

Table 3.1 Description of suitability classes according to the FAO Framework for Land Evaluation (FAO, 1976)

Order	Class	Description
Suitable	S1 (Highly suitable)	Land having no or insignificant limitations to the given type of use.
	S2 (Moderately suitable)	Land having minor limitations to the given type of use.
	S3 (Marginally suitable)	Land having moderate limitations to the given type of use.
Not suitable	N1 (Currently not suitable)	Land having severe limitations that preclude the given type of use, but may be improved by specific management.

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Suitability of land is attributed to its physical conditions, but land can hardly produce anything without any improvement (FAO, 1976). Thus, the severity of a condition may render the land not fit for specific type of use. Such conditions may after some improvements become suitable.

The suitability of a given land-mapping unit (LMU) for a specified land utilization type (LUT) is the degree to which it satisfies the land use and can be expressed in various ways. It may be expressed on a continuous scale of "goodness" (e.g. 0-100%) or more commonly, as a set of discrete classes, which are conventionally numbered from class **I to IV** (Rossiter, 1990).

3.2.3 Land Capability Classification System for South Africa

Laker (2004) gives a comprehensive account of the development and evolution of land capability evaluation systems in South Africa. Land capability systems and subsequent modified systems were based on the USDA Land Capability Classification System for Agriculture (Kliengbel and Montgomery, 1961), both revisions made according to the original system in principle and structure making subsequent systems more of derivatives than locally based dynamic land suitability evaluation systems (Laker, 2004).

Land capability evaluation in South Africa was initially regionalized, resulting in different systems used in different regions in the country. These mainly served the needs of planners rather than the development of a national system. However, it became apparent that these individualistic systems led to confusion among users of soil information and data. There was a need for a uniform system for the interpretation of soil data in South Africa (Scotney *et al.*, 1987).

Soil scientists attempted to develop a land capability system for South Africa (Scotney, 1981; van Niekerk, 1983), but such initiatives were short of required strategies to the challenge of local land capability evaluation. In 1987, a team of specialists was mandated to develop a land capability evaluation system for the Republic of South Africa and then TBVC states (Transkei, Bophuthatswana, Venda and Ciskei) (Scotney, *et al.,* 1987). After reviewing various systems, the team concluded that a system similar to the USDA would be proper for South Africa and these states. An eight class deviation of the USDA system was developed for South Africa and the then TBVC

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(Transkei, Bophuthatswana, Venda and Ciskei) states. The system uses standardized sets of land capability evaluation criteria and fixed class limits.

In contrast to its objectives, the system could not resolve the realities of lack of modern technology; lack of resources, poor technical skills in the country, particularly in the TBVC states where the system was to be equally employed (Scotney *et al.*, 1987).

This system lacked consideration for the local people and the issues of importance regarding land use planning and land resource allocation. The system is very general and does not give guidelines for land suitability evaluation for different land utilization types (Laker, 2004). This system was designed for rainfed agriculture and did not address the requirements of land evaluation for irrigated agriculture in general and those of small-scale communal irrigation schemes, in particular. The system is further criticized for not addressing the complex interactions of suitabilities for specific crops (Ellis, 1994). Failure to recognize this interaction has mainly resulted in conflicting objectives and priorities between the soil scientists, agronomists, land use planners with conventional academic training in science and the community which has historical knowledge of soil, climatic and surface water resources (Laker, 1980, Nethononda, 1996).

An interdisciplinary approach is required for a meaningful and successful land suitability evaluation and for proper planning and decision making processes. A mere multidisciplinary approach may end-up as a "fragmented-report-pass-on" affair, where scientists make lone recommendations and pass the report to the next person who in most instances will perpetuate the action. This may result in making improper and misleading recommendations leading to poor decision-making and planning processes (Laker, 2004). The consequences of such actions are more costly. Laker (1978) illustrated how this approach has led to improper planning in the former homelands of Ciskei and Transkei in the Eastern Cape Province.

The then Soil and Irrigation Research Institute (now known as ARC-Institute for Soil Climate and Water) made a lot of effort to develop a soil suitability system for irrigation (Laker, 2004). Procedures for the assessment of land for irrigation development that are also good guidelines for irrigation development planning are given in Irrigation Planning Staff (1981) and Hensley and Laker (1981). A chapter by Turner and Scotney (1993) provided guidelines for the assessment of land suitability for irrigation based on

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important soil and land properties for irrigation, but did not provide class limits to be used to assess suitability class of land for irrigation or for given crops.

Though several attempts were made to develop land suitability evaluation system for South Africa, there is still no fixed system for land suitability evaluation system for irrigation in South Africa. Soil surveyors are continuing to use individualistic land capability classification systems and consequently different interpretations in different parts of the country depending on who did the work. There are also a very limited publications regarding land suitability evaluation and planning for irrigation in South Africa and such papers can only be described as approaches or broad guidelines rather than formal evaluation system (Laker, 2004). A paper by Laker (2004) suggested the development of a more dynamic "South Africanized" version of the FAO (1976) and guidelines for land evaluation for irrigated agriculture (FAO, 1985).

3.3 Indigenous soil knowledge and soil use perspectives

In recent years, there has been increased recognition of the importance of indigenous knowledge of soils and its role in soil survey and land use planning in most parts of the developing and developed countries (Ettema, 1994; Osunade 1988; 1992a&b; Barrera-Bassols and Zinck, 2003; Ryder, 2003; Birmingham, 2003; Mikkelsen and Langohr 2004; Macharia and Ng'ang'a, 2005; Barrera-Bassols *et al.,* 2006). There is an increasing consensus that local soil knowledge often forms a much better starting point for communication than the modern soil classification systems. Studies have shown that farmers in different parts of developing countries have over the years used this knowledge to produce crops for sustainable livelihoods (Osunade, 1988; Macharia and Ng'ang'a, 2005; Barrera-Bassols *et al.,* 2006). This knowledge is based on experiences of farmers with soil, land type and crop performance under prevailing soil and climatic conditions and available technology. Indigenous soil knowledge provides information on local nomenclature of soils and land types; their properties and uses; their location; agricultural uses and management practices associated with each soil type (Guarino, 1995).

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3.3.1 Principles and criteria used in indigenous soil classification systems

Barrera-Bassols and Zinck (2003) gave a full account of the principles, categories and classes used for soil and land classification by indigenous people. They conducted a comparative analysis of 62 ethnic groups in 25 countries in Africa, America and Asia. They found that visible and touchable characteristics of the soil namely, colour, texture, consistence, soil moisture, organic matter, stoniness were the most commonly used properties to describe and classify soils (Figure 3.1).

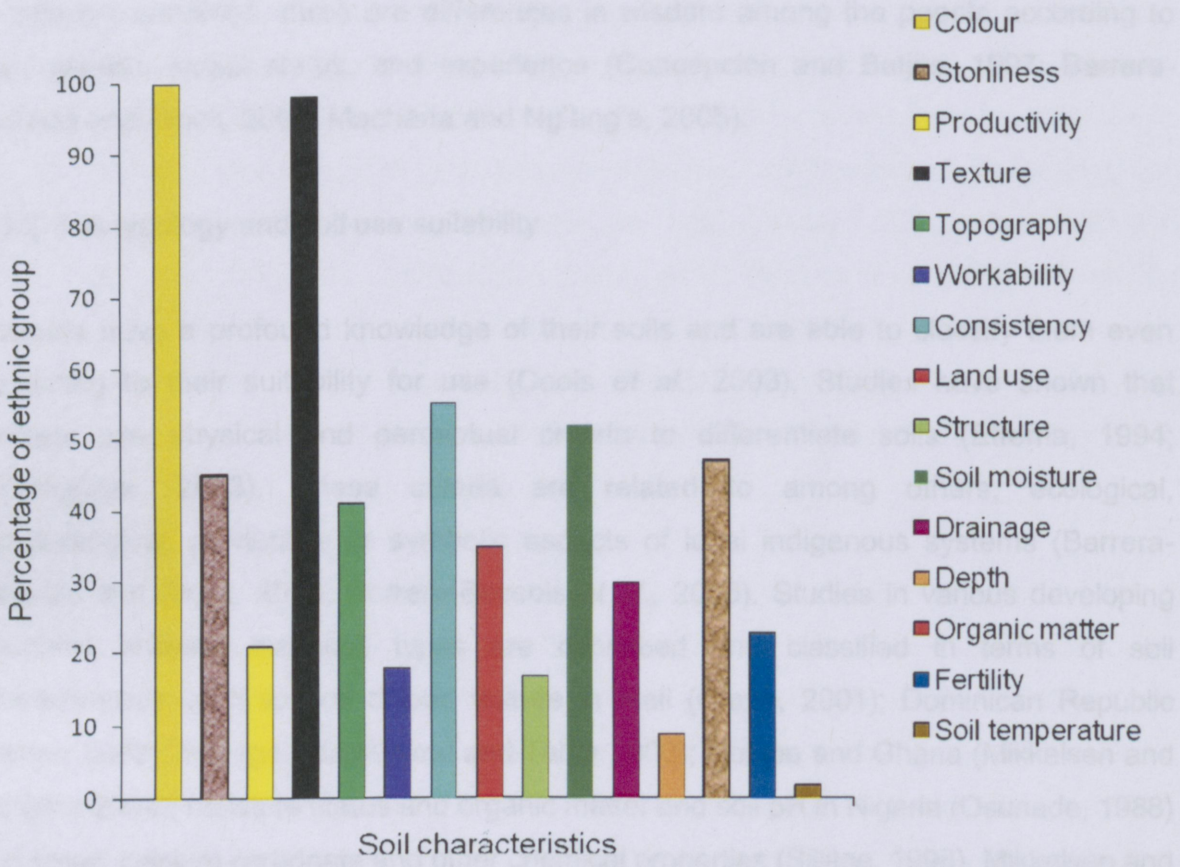


Figure 3.1 Characteristics and qualities used by local peoples to classify soils (Barrera-Bassols and Zinck, 2003)

They identified four general principles that are used by these indigenous peoples:

1. *The existence of complex systems of indigenous knowledge about hierarchical organization of the soil mantle;*
2. *The recognition of complex systems of indigenous knowledge about morphological attributes for soil classification, which are at the same time dynamic, utilitarian and symbolic;*

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3. *The use of similarities and differences between soil bodies for constructing multi-categorical classification systems; and*
4. *The existence of universal criteria in all ethnopedological classification systems.*

There is similarity in the principles used among local or indigenous folk taxonomy systems or soil classification systems (Barrera-Bassols and Zinck, 2003). These principles are intertwined with one another to build localized systems of soil classification which are understood and fit-for-purpose in different regions where they are used. Although there is such great commonality in principles and criteria used in indigenous soil classification in different countries, there are differences in wisdom among the people according to age, gender, social status, and experience (Concepcion and Batjes, 1997; Barrera-Bassols and Zinck, 2003; Macharia and Ng'ang'a, 2005).

3.3.2 Soil typology and soil use suitability

Farmers have a profound knowledge of their soils and are able to classify them even according to their suitability for use (Cools *et al.,* 2003). Studies have shown that farmers use physical and perceptual criteria to differentiate soils (Ettema, 1994; Birmingham, 2003). These criteria are related to among others, ecological, morphological, productive or symbolic aspects of local indigenous systems (Barrera-Bassols and Zinck, 2003; Barrera-Bassols *et al.,* 2006). Studies in various developing countries showed that soil types are described and classified in terms of soil characteristics such as soil colour, texture in Mali (Crane, 2001); Dominican Republic (Ryder, 2003); Senegal (Krasilnikov and Tabor 2003); Guinea and Ghana (Mikkelsen and Langohr 2004); moisture status and organic matter and soil pH in Nigeria (Osunade, 1988) and smell, calcium carbonate and other chemical properties (Sillitoe, 1998). Mikkelsen and Langohr (2004) found that the colour of the topsoil was a parameter of great importance to the farmers to distinguish soil types in Guinea Woodland Savannah in Ghana. Perceptual criteria include other properties other than soil physical characteristics and reflect the importance of local environment, distinctions and priorities (Ettema, 1994). Suitability of soil for use is based on soil characteristics and climatic conditions in relation to the use (Cools *et al.,* 2003; Barrera-Bassols *et al.,* 2006). Cools *et al.* (2003) indicated that the rating of soil suitability is based on its scope for the use that is considered to be the most important (valuable) for their livelihoods. Soil suitability should be considerate of the available technology and socio-cultural issues (Nethononda, 1996).

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3.3.3 Comparative analysis of indigenous soil classification systems and modern soil classification and land evaluation systems

Comparison of indigenous and modern soil classification systems is made very complex mainly because of the differences in conceptual basis of the classification. Studies have shown that indigenous soil classifications and soil suitability classifications are based on the visible and perceptual characteristics (Ettema, 1994; Barrera-Bassols and Zinck, 2003; Cools *et al.,* 2003; Payton *et al.,* 2003; Ryder, 2003). Indigenous systems use surface soil properties whilst modern or scientific systems use both surface and subsurface properties of the profile (Barrera-Bassols and Zinck, 2003; Macharia and Ng'ang'a, 2005). The common aspect of indigenous systems is that the nomenclature is self explanatory for the nature and properties of the soil be classified, for instance colour, texture, position in the toposequence and drainage (Osunade, 1992a&b; Barrera-Bassols and Zinck, 2003; Birmingham, 2003; Payton *et al.,* 2003). Scientific systems often use name of the place where the soil was identified for the first time e.g. Kroonstad in the taxonomic systems (Soil Classification Working Group, 1991); soil genesis, prevailing climatic conditions and additional laboratory tests (Soil Survey Staff, 1990).

Several studies have shown that indigenous systems are biased toward the intended use of the soil (Concepcion and Batjes, 1997; Osunade, 1988; Ryder, 2003; Macharia and Ng'ang'a, 2005) and the required management practices for a given use (Birmingham, 2003). Unlike the scientific soil classification systems, indigenous systems are based on criteria influencing the use and productivity of soils as well as tillage characteristics in relation to suitability for use under available physical, technological and economic conditions. Scientific and indigenous soil classifications vary greatly in their purpose and scale of use (Ettema, 1994). A paper by Krasilnikov and Tabor (2003) indicated that scientific systems are more complex than indigenous systems because they must address multiple purposes and be applied over large regions, even the world. Soil suitability in indigenous systems is based on soil characteristics important to local and cultural factors. It is important for any land evaluation system to consider the uniqueness of each community during land suitability assessment until the contrary is found (Laker, 1982). Thus, participation of the local people and a multidisciplinary approach is an important element for successful decision-making for project

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development (Copeland, 1993). In general, the contrast between indigenous and scientific soil classification systems should be expected because farmers and scientists pursue different objectives and use different approaches in soil classifications and soil use suitability.

3.4 Conclusions

Although, USDA land capability classification system has been widely adopted around the world, it is evident from the literature review that current land suitability and capability classification systems, guidelines and approaches fall short of addressing the needs of land suitability evaluation for small-scale communal irrigation schemes. There is a need to develop dynamic guidelines for land suitability evaluation for small-scale irrigation schemes. Such guidelines for land suitability should consider participation of the local people in land use planning to ensure sustainable agricultural development. The FAO guidelines are the most appropriated basis for the development of such guidelines.

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CHAPTER FOUR

SOIL AND CLIMATIC INFORMATION KNOWLEDGE-BASE USING PARTICIPATORY TECHNIQUES

Abstract

Farmers at Rambuḍa have been growing crops on a trial and error basis and consequently with no increase in yields. The objective of this chapter was to investigate indigenous knowledge on soil and climate of small-scale farmers using local ethnopedology, classification and participatory techniques at Rambuḍa irrigation scheme. Situation analysis was conducted followed by field surveys that included person-to-person interviews, and participatory soil mapping. Verification of participatory soil maps was achieved through soil profile description and classification. In general, famers knew the different types of soil found in the irrigation scheme according to their indigenous soil classification knowledge. Farmers identified and described four soil types namely, Tshilogo, Dzwabo, Sengeṭavha and Tshiṭavha using local nomenclature. Soil compaction, water-logging, crusting and rapid drying were identified as limiting soil factors to crop production. Sweet potato, maize and cabbage were major crops grown while Chinese spinach, sugar bean, beet root, onion, and wheat are alternative crops. Choice of crops was based on availability of planting material, adaptability, ease of growth, storage life-span and sales. The indigenous soil classification system is based on visible soil surface physical properties and classifies soil according to their properties. It is consistent with other systems used elsewhere around the world. Farmers could also identify climatic factors important for crop production and those limiting to crop performance. Hot, dry conditions during August to October and January months were limiting to crops, particularly sweet potato production. The results showed that indigenous soil and climate knowledge and participatory mapping provide reliable information and can be used together with the scientific systems during agricultural development planning and in the development of intermediate systems for South Africa.

4.1 Introduction

Local people know the land and the responses of crops in the area. In recent years, soil scientists have begun to take the issues of knowledge of soil and soil use by the local people as an integral part of soil studies for land use planning (Mikkelsen and Langohr, 2004). Although a soil study was conducted in 1997 at Rambuḍa irrigation scheme, farmers were not informed or asked to make contributions (Lutsinge Daniel, Personal communication, 2007). Farmers are using indigenous and empirical knowledge of crop responses to soil and climatic conditions to make production decisions.

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Sound planning of changes in land use requires a thorough knowledge of the natural resources, and a reliable estimate of their agricultural potential, so that reliable land use predictions and recommendations can be made (Aubert, 1981). Information on both physical and chemical properties of soils and their distribution is indispensable if sustainable development planning is to be made (Beek, 1977). Detailed soil survey is expensive and requires large amounts of resources that are not readily available in developing countries (Laker, 1982). Participation of the local people in soil studies reduces time and money spent on surveying areas with poor agricultural potential (Laker, 1982; Osunade, 1992b; Ryder, 2003).

There is increasing consensus on the invaluable contribution of local knowledge systems of traditional farmers in soil surveys, local taxonomies and land suitability evaluations around the world (Ettema, 1994; Crane, 2001; Barrera-Bassols and Zinck, 2003; Krasilnikov and Tabor, 2003; Ryder, 2003; Mikkelsen and Langohr, 2004). Knowledge of soil among farmers in developing countries is well-documented in South America (Barrera-Bassols and Zinck, 2003), Central America (Hecht, 1990; Sandor and Furbee, 1996), Africa (Osunade, 1988; Birmingham, 2003; Crane 2001), Asia (Sillitoe, 1995; 1998) and in the Caribbean islands (Ryder, 2003). These studies have demonstrated vast and invaluable knowledge of ethnopedology which can offer important guidelines for development planners (Ryder, 2003). Increasing evidence shows that soil surveyors can learn a great deal from indigenous farmers (Barrera-Bassols and Zinck, 2003; Oudewater and Martin, 2003).

Active participation of farmers in the planning process as opposed to mere consultation makes a difference in the potential success of an irrigation development (Copeland, 1993). Participation of land users in issues of soil surveys and land suitability evaluations is imperative to make decisions that are understandable to land users. A paper by Schuler *et al.* (2006) in participatory mapping in northern Thailand stated that the farmers' perception about soil fertility and soil suitability for cropping could be confirmed by analytical data. They concluded that integrating local knowledge, petrographic information and knowledge of local cropping practices allowed for rapid compilation of information for land evaluation purposes at watershed level and was the most efficient way to build a base for regional land-use planning. Participatory mapping has been used and reported to be popular among animal health workers and cattle keepers in Kenya (Minjauw *et al.*, 2002). Oudewater and Martin (2003) used participatory soil

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mapping in Tanzania and Uganda and found representative results with only minor differences in soil nomenclature between men and women.

In South Africa soil surveys, mapping and land use planning have always been conducted using a top-down approach using modern soil classification and land capability systems. Knowledge of soils and their properties is important in the management requirements and crop choices for an area and land suitability for given uses. Rambuḍa irrigation scheme is important for household livelihood and rural economy of Dzimauli village and surrounding communities. Farmers have been using their local soil knowledge and empirical crop responses to soil and climatic conditions of the area in making production decisions. During situation analysis, farmers indicated that they have observed variation in crop performance and yield both within the plot and across the irrigation scheme. Such decline in yields threatens household food security and income and may force farmers to seek alternative sources of income. It is therefore important for local irrigation scheme planning to take examples from other developing countries in regard to soil studies by promoting participation by local people who otherwise are more knowledgeable of soils and other aspects of natural resources in their area. Participatory soil mapping can provide information on the extent of local soil and climate knowledge of farmers and their implications for crop production.

The objective of this chapter was to investigate indigenous knowledge on soil and climate of small-scale farmers using local ethnopedology, classification and participatory techniques at Rambuḍa irrigation scheme.

4.2 Research procedures

The study involved three methods of data collection, namely situation analysis, interviews and participatory soil mapping to obtain information on soil and climatic conditions affecting crop production at Rambuḍa irrigation scheme.

4.2.1 Situation analysis

The study involved a preliminary situation analysis of the irrigation scheme. Information collected during the situation analysis was used to develop a theoretical framework that consists of the full set of soil and climatic factors known to influence crop performance

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and land suitability for crop production. The framework was used to compile a logically arranged checklist of issues to be explored during interviews with participants according to the principles described in the triple-A framework (Van Averbeke and Khosa, 2004).

4.2.2 Field surveys

Questionnaires were used during the contact interviews to acquire information on the range of crop production and soil issues in the area such as use of fertilizers; chemicals; organic manure; crop behaviour; soil types, drainage, soil problems and sources of planting materials (APPENDIX I). The questionnaire covered history, ownership, soil knowledge, soil problems and crop production and the entire process, from acquisition of seed to marketing of the produce. A total of 76 farmers who were found in their plots during the survey period were interviewed.

4.2.3 Participatory soil mapping

Participatory soil mapping was conducted with farmers who were asked to identify and describe soils and soil properties based on their knowledge and experience. Thirty-four (34) farmers who were present participated in the exercise. The purpose of the participatory mapping exercise was explained to the participants. Farmers were requested to present information according to the local knowledge and understanding of soil and climatic conditions. Farmers were asked to choose three group leaders and members were randomly allocated to each group. A 1:3 000 orthophoto map of the area was given to which group, each was then requested to draw soil boundaries and make a list of characteristics of each soil type based on their observations, local understanding and experience. Farmers were also requested to indicate and mark areas with soil problems such as slow infiltration rates, compaction, difficulty in ploughing; poor yields and frost-prone areas on the map. Groups were then combined to integrate results, resolve anomalies and validate participatory maps, soil characteristics and climatic information. Farmers were asked to list crops that have been grown in the past and presently grown and reasons for choosing such crops. They were also asked to list crops that they want to grow in the irrigation scheme. A list of forty (40) crops was compiled.

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Rating of severity of each climatic parameter and period of the year was conducted at a scale of 0 - 5. Participants were asked to indicate when rains fall, as well as cold, hot and dry months during the year. Rating for cold, hot and dry was achieved by marking stars as follows: 0 = no problem, 1 = slight, 2 = moderate, 3 = problem, 4 = severe and 5 = very severe. Rainfall was rated as follows: 0 = no rain, 1 = one day drizzle, 2 = two days good rain, 3 = 5 days good rain, 4 = a week of good rain, 5 more than two weeks of good rains. Groups were then combined to integrate and resolve anomalies in climatic knowledge.

The observations listed by farmers were collated and compared to the recorded climatic data of Tshiombo Weather Station situated (22°30'147" E and 30°48'145" S), ± 8 kilometres south east of the study area at 650 m above sea level to validate responses of plot holders (Table 2.1). Data from participatory ranking and rating was subjected to matrix scoring to assess the severity of each climatic variable in relation to recorded climatic data.

4.2.4 Data verification and consolidation

Fifteen (15) soil profile holes were dug on every area that displayed difference in soils and were classified according to Soil Classification: A taxonomic system for South Africa (Soil Classification Working Group, 1991) and procedures for describing soil profiles (Turner, 1991). A hand soil auger was used to drill observation points to delineate soil boundaries. The information obtained from soil profile holes and auger observations points was used to collate and enhance trustworthiness of participatory soil map and tables. Final participatory maps were drawn using ArcMap view 3.0 (ESRI, 2000) and care was taken not to change boundaries as originally drawn by farmers (Figures 4.1 & 4.2). Recorded climatic data (Table 2.1) were used to compare and validate responses of farmers on climatic conditions at Rambuḍa irrigation scheme.

4.3 Results and Discussion

This section presents the results of the participatory mapping of local soil, climatic knowledge, soil typology and use, and comparison of the principles of indigenous soils classification with the Soil Classification: a Taxonomic Systems for South Africa (Soil Classification Working Group, 1991).

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4.3.1 Soils of Rambuḍa irrigation scheme according to the farmers

In general, the response of the farmers indicated that the majority of farmers know the types of soils found in the irrigation scheme. Farmers were able to draw the soil map of different types of soil that are found in the irrigation scheme (Figure 4.1).

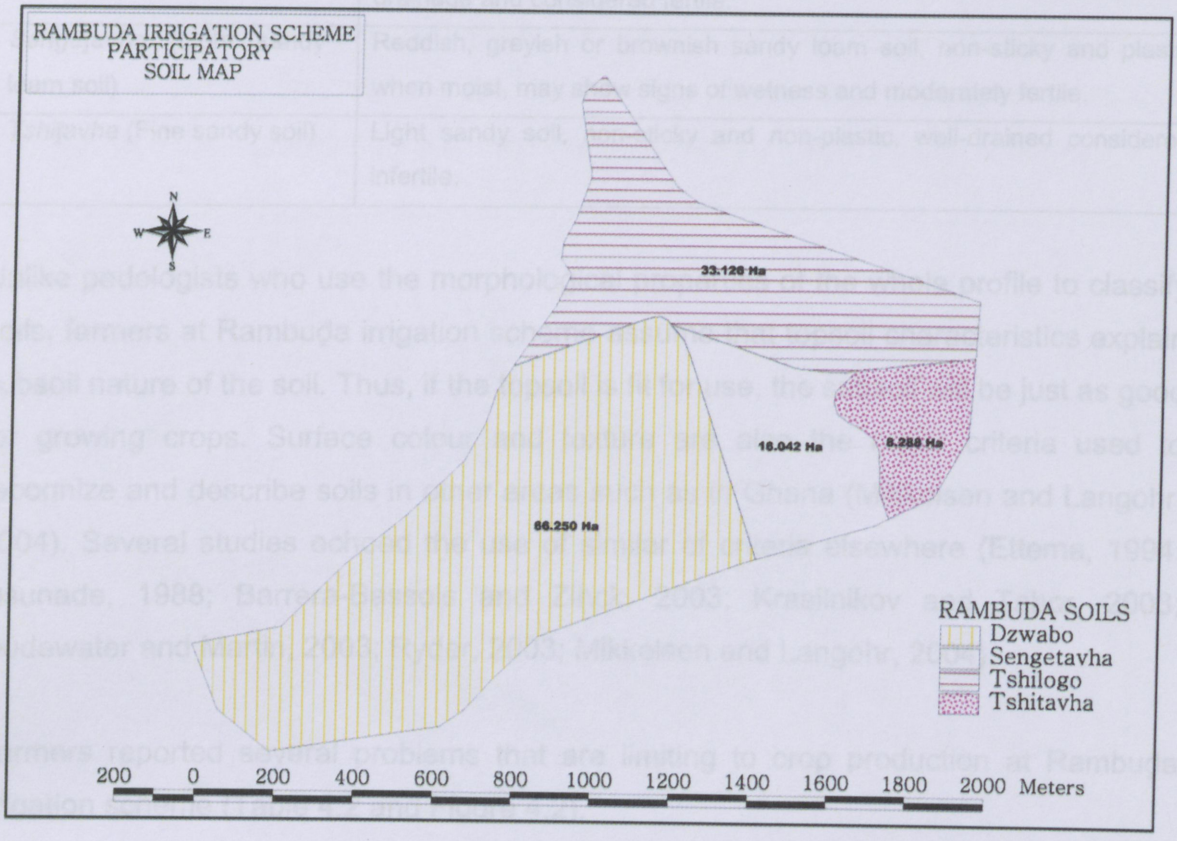


Figure 4.1 Participatory soil map of Rambuḍa Irrigation Scheme, Vhembe District

Farmers classified soils using local soil classification principles and nomenclature (Table 4.1). Farmers at Rambuḍa irrigation scheme classified and described soils in terms of observable topsoil characteristics and did not consider the subsoil characteristics. Soils were described and classified in terms of colour, texture, organic matter content and tendency to waterlogging. Dark brown, gray or black soils were associated with water-logging and high organic matter contents with high clay content.

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Table 4.1 Indigenous soil classification and description

Soil Classification	Description
Tshilogo (Dark brown/grey/black clay soil)	Soil may be dark brown, grey or dark in colour with high clay content, high plasticity and very sticky when moist, prone to waterlogging, rich in organic matter and is considered to be fertile.
Dzwabo (Red clay soil)	Reddish clay soil, slightly sticky to sticky and plastic when moist, good drainage and considered fertile.
Sengeṱavha (Light sandy loam soil)	Reddish, greyish or brownish sandy loam soil, non-sticky and plastic when moist, may show signs of wetness and moderately fertile.
Tshiṱavha (Fine sandy soil)	Light sandy soil, non-sticky and non-plastic, well-drained considered infertile.

Unlike pedologists who use the morphological properties of the whole profile to classify soils, farmers at Rambuḓa irrigation scheme assume that topsoil characteristics explain subsoil nature of the soil. Thus, if the topsoil is fit for use, the subsoil will be just as good for growing crops. Surface colour and texture are also the major criteria used to recognize and describe soils in other areas such as in Ghana (Mikkelsen and Langohr, 2004). Several studies echoed the use of similar of criteria elsewhere (Ettema, 1994; Osunade, 1988; Barrera-Bassols and Zinck, 2003; Krasilnikov and Tabor, 2003; Oudewater and Martin, 2003; Ryder, 2003; Mikkelsen and Langohr, 2004).

Farmers reported several problems that are limiting to crop production at Rambuḓa irrigation scheme (Table 4.2 and Figure 4.2).

Table 4.2 Soil problems listed by farmers at Rambuḓa Irrigation Scheme

Soil type	Problems
Tshilogo (brownish clayey)	Soil takes too long to dry; crusting soil compaction, difficult to plough when too dry or moist; larger clods during ploughing; water ponding and water logging.
Dzwabo (reddish clay to sandy clay loam)	Crusting, compaction and large clods during ploughing.
Sengeṱavha (reddish brown coarse sand)	Dries too quickly, poor crop stand; low yields.
Tshiṱavha (red fine sand)	Dries too quickly; poor crop stand; lowest yields.

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The responses showed that there was variation in soil properties within plots and across the irrigation scheme. Soils near the access roads were pointed out as having slow infiltration rate, being compacted and low yielding. *Sengeṭavha* and *Tshiṭavha* were listed by farmers as having good infiltration rate and usually being free from waterlogging. *Tshilogo* was listed as having lower water infiltration rate compared to *Dzwabo* (Figure 4.2). This can be attributed to the movement of people, vehicles and tractors turning circles during ploughing. Knowledge of the areas that are susceptible to soil compaction is important in decision-making concerning choices of cultivation methods and ripping programme to alleviate compaction in the irrigation scheme.

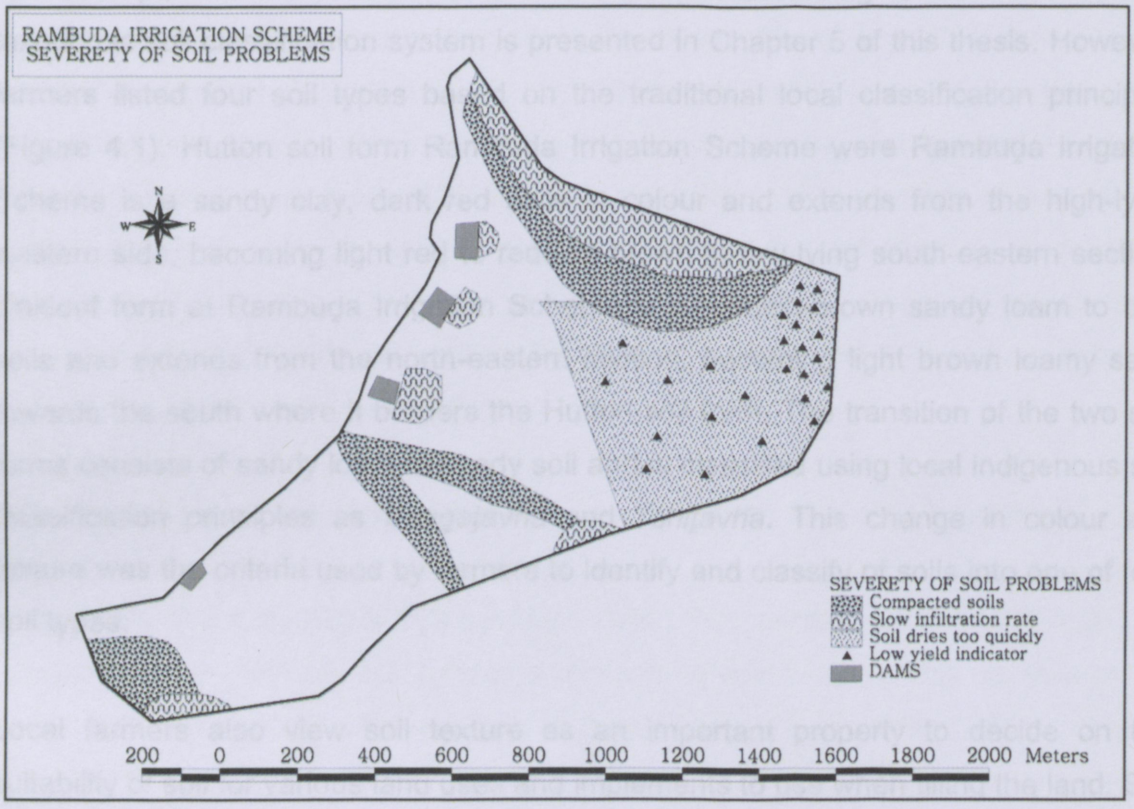


Figure 4.2 Participatory map of soil problems as perceived and observed by farmers

According to the group discussion, clayey *Tshilogo* and *Dzwabo* soils were reported as being difficult to plough and forming large clods during ploughing compared to other soil types. *Tshiṭavha* and *Sengeṭavha* soils were reported as being more suitable for sweet potato production although they must be frequently irrigated as they tend to dry quicker than *Tshilogo* and *Dzwabo*.

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Sweet potatoes planted in these soils yielded good tubers and were easier to harvest compared to those grown in *Dzwabo* and *Tshilogo* clayey soils. Cabbages, Chinese spinach and *muxe* (*Solanum scabrum; villosum*) performed better on *Tshilogo* and *Dzwabo* soils than on *Sengeṱavha* and *Tshiṱavha* soils.

4.3.2 Relationship between farmers' knowledge of soil and pedological classification

Observations of transect walks and auger profiles revealed two soil forms, namely Hutton and Oakleaf (Soil Classification Working Group, 1991) (Figure 5.1). Detailed soil description and discussion of soil classification according to the South African taxonomic soil classification system is presented in Chapter 5 of this thesis. However, farmers listed four soil types based on the traditional local classification principles (Figure 4.1). Hutton soil form Rambuḓa Irrigation Scheme were Rambuḓa Irrigation Scheme is a sandy clay, dark red soils in colour and extends from the high-lying western side, becoming light red to reddish brown in low lying south-eastern section. Oakleaf form at Rambuḓa Irrigation Scheme is a reddish-brown sandy loam to clay soils and extends from the north-eastern section, becoming light brown loamy sand towards the south where it borders the Hutton soil form. The transition of the two soil forms consists of sandy loam to sandy soil and is classified using local indigenous soil classification principles as *Sengeṱavha* and *Tshiṱavha*. This change in colour and texture was the criteria used by farmers to identify and classify of soils into one of four soil types.

Local farmers also view soil texture as an important property to decide on the suitability of soil for various land uses and implements to use when tilling the land. Soil texture is also an important criterion for determining suitable crops and irrigation cycles (Table 9.3). Unlike in the indigenous soil classification systems, soil texture is not used as a differentiating criterion in the South African system (Soil Classification Working Group, 1991). Although soil texture is not used as a differentiating criterion, it should be used as a qualifier conjunction with soil forms and families e.g. Hutton fine sandy loam (Lambrechts and MacVicar (2004). This will be more explanatory to land users and will narrow subjective conclusions by different pedologists in different parts of the country. Both Hutton and Oakleaf may vary in soil texture and this determines their practical suitability for given land uses. Local system emphasizes the importance of

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soil texture in its classification and thus, soils may be red, but differ in texture hence their suitability for given uses.

Unlike the nomenclature used in the South African system, where soil forms and families use geographical names or features near where the soil was identified for the first time, local nomenclature classification of soils is based on soil properties distinguishable by land users. This conveys more detailed information on which decision regarding land use can be made. Lambrechts and MacVicar (2004) indicated that much is lost because a geographical name does not give indication about the horizons that are present or soil properties important for land suitability for given uses. Besides indicating the horizons present in the profile, the nomenclature system does not tell the textural class of horizon. In the practical situation, land users base their choices of land use for given soil on visible soil properties such as texture, depth, presence of hard layer, workability, moisture behaviour, vertic property of the soil, etc. Soil classification systems also need to recognize this fact for practical utilization by land users. The SA classification system is designed to recognize all of these properties. It does not state these in the soil names, but provides a scientific framework for practical interpretation.

4.3.3 Climatic conditions and implications on crop growth according to farmers

The results of the participatory exercise showed that farmers consider the area to be characterized by warm to hot summers with mild to cold winters. This observation was confirmed by long-term recorded climatic data (Table 2.1). Farmers indicated that the area receives summer rainfall. The wettest months were stated by plot holders as February, March, April, November and December with most rain falling during February and March (Figure 4.3). Recorded climatic data indicated that February (208.3 mm) was the wettest month with an aridity index of >0.65 for humid conditions (Table 2.1) confirming the observations made by the plot holders. December (126 mm) and March (154.7 mm) were both higher than November (103.4 mm) and April (39.9 mm) (Table 2.1). However, farmers gave contrasting impressions in comparison to the recorded data for January. According to the data, 178 mm rainfall was received during January. This is higher than rainfall received in March, April, November and December months (Table 2.1). Farmers reported January as one of the driest months (Figure 4.3). This

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response could be attributed to rainfall distribution or heavy rains falling for a short period during very hot period.

According to farmers, light frost is experienced during the months of June and July (Figure 4.3), but it is more prevalent in July. Farmers rated April, May, June and July as the coldest months. This observation is not entirely reflective of the climatic data as June and July are the coldest months. According to the climatic data, the coldest months are May (12.0°C) and June (9.4 °C). Recorded climatic data show little differences in temperatures between June (9.4 °C) and July (9.2 °C). It is possible that the temperature during July will on occasion drop below the freezing point, mainly because the irrigation scheme lies in the valley. Poor growth and yield is attributed to low soil and ambient temperatures which drop below the minimum root and shoot growth temperature of 10 °C (van der Berg and Laurie, 2004). The implications are that crops that are susceptible to frost cannot be planted during the above-mentioned months or that only crops that are frost tolerant can be planted. This may also limit the suitability of some crops for Rambuḍa irrigation scheme. These conditions provide an opportunity for introducing crops that were not previously grown in this irrigation scheme.

According to farmers, August was the windiest month compared to the other months of the year (Table 4.3 & Figure 4.3). Climatic data shows that the wind speed was highest during October followed by September and November, respectively (Table 2.1).

Table 4.3 Climatic challenges at listed by farmers at Rambuḍa Irrigation Scheme

Climatic condition	Period/months
Cold	June and July
Hot	August, September, October, January
Dryness	January, August, September
Wind	August
Hail	Not often, but occurs during December
Frost	July
Drought	After 11 years cycle
Flood	After 23 years cycle

Other months with high wind speed were December, January, February and August. Any observations made by farmers on wind were different and certainly not reflective of

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measured data. Farmers indicated January, September, October, November and December as the hottest months. Data showed that September (29.0 °C) was not as hot as January (30.0 °C) though farmers rated them as equal. Temperatures are likely to rise above 30 °C value during most days of January. The data show that September is not as hot as October, November and December. According to the recorded climatic data, August and September has the lowest relative humidity at 14h00 (30 and 32% respectively). This could be the reason that made farmers to rate September as equal to January. These months are characterized by high temperatures and low relative humidity at Rambuḍa Irrigation Scheme. The monthly rainfall during September to October was just above 20 mm and coupled with low afternoon (14h00) relative humidities of around 30% and maximum temperatures sometimes exceeding 30 °C (Table 2.1). The potential effects of the latter conditions are deleterious to the growth and development of young sweet potatoes.

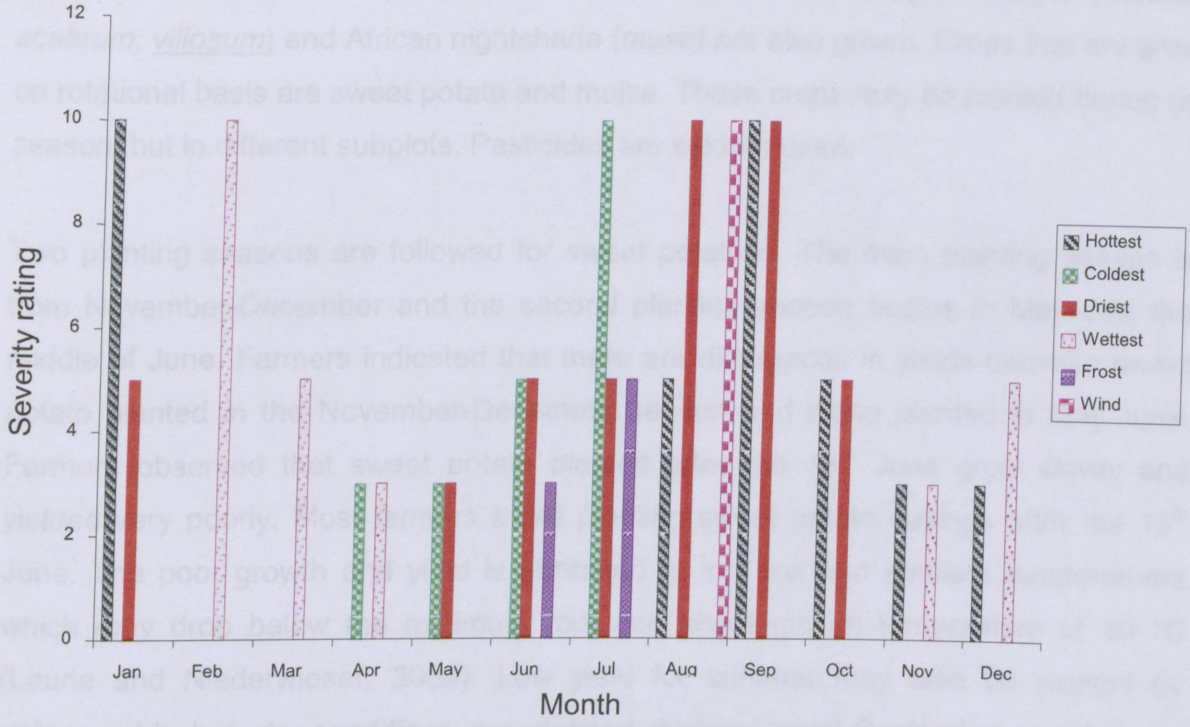


Figure 4. 3 Participatory rating of the severity of climatic problems

In general, hot, dry conditions were a major limiting factor to crops at Rambuḍa Irrigation Scheme. Hot, dry conditions were more severe during August to October according to the plot holders. This is a critical period for sweet potatoes because they have just produced early young spring sprouts of growth. The tender sprouts are sensitive to high temperatures and low humidity experienced during August, September and October. This

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is because they have not yet developed strong resistance mechanism in the form of a thick cuticle to counteract the loss of water through transpiration (Niederwieser, 2004). Farmers indicated that sweet potato and maize planted in August and September showed the symptoms of temporary wilting even after irrigation. This may be due to high atmospheric-evaporative demand and high temperature stress even when the soil is irrigated to field capacity, i.e. irrigation that is applied during September and October cannot make up for the water that is lost through transpiration to overcome the potential negative effects of the atmospheric evaporative demand during this period.

4.3.4 Crops currently grown on the irrigation scheme

Farmers listed the crops that are grown, sources of planting materials, varieties and reasons for choosing specific crop over the others (Tables 4.4 & 4.5). Sweet potato and maize are the main crops grown. Chinese spinach, cabbage, chillies, (*Solanum scabrum; villosum*) and African nightshade (*muxe)* are also grown. Crops that are grown on rotational basis are sweet potato and maize. These crops may be planted during one season, but in different subplots. Pesticides are seldom used.

Two planting seasons are followed for sweet potatoes. The main planting season is from November-December and the second planting season begins in May until the middle of June. Farmers indicated that there are differences in yields between sweet potato planted in the November-December season and those planted in May-June. Farmers observed that sweet potato planted after the 15th June grow slowly and yielded very poorly. Most farmers avoid planting sweet potato cuttings after the 15th June. The poor growth and yield is attributed to low soil and ambient temperatures which may drop below the minimum root and shoot growth temperature of 10 °C (Laurie and Niederwieser, 2004). Low yield for summer may also be caused by unfavourable hot, dry conditions experienced during August-September months and worsened by reduced water supply as the Tshala river flow rate is low during this period.

All maize cultivars listed in Table 4.4 are planted in summer except PNR 67 which is planted in winter because of its ability to survive low temperatures experienced in the irrigation scheme. Farmers indicated that this cultivar yielded better and provided good quality green cobs compared to the others when planted in winter.

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Table 4.4 Crops grown at Rambuḍa Irrigation Scheme and sources of planting materials

Crop	Cultivar/variety	Plant material	Source
Sweet potato	*Madivhatsiwana*	Cuttings	Self-cutting
	Thidziambi	Cuttings	Imported, self-cutting
	Blesbok	Cuttings	Self cutting
	Tshimboni	Cuttings	Self-cutting
		Cuttings	Self-cutting
	Magi	Cuttings	Self-cutting
Maize	ZM 521 (*Zuzavhusiwana*)	Seeds	Co-operative, Madzivhanḍila College of Agriculture, Local Seed Producer
	Obatamba	Seeds	Co-operative, Madzivhanḍila College of Agriculture, Local Seed Producer
	SNK 2147	Seeds	Co-operative
	PNR 67	Seeds	Co-operative
Sugar beans	Dwarf	Seeds	Self production, co-operative
Cabbage	Conquest	Seeds, seedlings	Co-operative, supermarket, Self-produced, fellow farmers
Chinese cabbage	*Ḍabaḍaba*	Seeds, seedlings	Self-produced, fellow farmers
	Murodishia (Rape)	Seeds, seedlings	Self-produced, fellow farmers
Night shade *(Muxe)*	Not known	Seeds, seedlings	Self-produced, fellow farmers
Chilli	Serrano	Seeds, seedlings	Self-produced; fellow farmers, co-operative
Onions	Texas Granno	Seed, seedlings	Co-operative, fellow farmers, nursery
Beetroot	Detroit dark red	Seeds, seedlings	Co-operative and supermarket, Self-produced
Butternut	Waltham	Seeds	Co-operative
Wheat	Not known	Seeds	Self-production

4.3.4.1 Sources of planting materials

According to farmers, planting materials are obtained from various sources which include self-production, co-operative and fellow farmers (Table 4.4). The results showed that most farmers prefer to buy seeds from the co-operative and then prepare a seedbed for seedlings in their plots because it is cheaper to produce their own seedlings than to buy them from external suppliers. Farmers indicated that sufficient

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seedlings are produced for planting and for sales to fellow farmers and surrounding community. Only a few farmers would prefer to buy seedlings from nurseries. Farmers use cuttings from sweet potato plants and also get new varieties from other places. Such variety as *Thidziambi* (literally meaning, do not mention it or keep it a secret) was brought from Mozambique by the farmer who visited that country. *Thidziambi* got its name from the fact that the importer did not want to tell anybody about it because it yielded better and bigger sweet potatoes than other varieties grown in the irrigation scheme.

4.3.4.2 Choice of crops and varieties

Crop such as sweet potatoes are grown throughout the year because of the history of the irrigation scheme. It is easy and cheap to grow them because planting materials are self-produced and readily available. Sweet potatoes require less labour for weeding and only require a few labourers during harvesting. Sweet potatoes have a long storage life compared to other crops and do not require sophisticated storage facilities.

4.3.5 Marketing of crops

According to farmers, crops are sold to local people and hawkers who come and carry sweet potatoes and vegetables from the plots as there is no central pack-house in the irrigation scheme. Dry beans are normally de-shelled at the farmers' homes and sold from home. Hawkers resell farm produce along the roads and in Mutale and Ṱhohoyandou towns. Chillies are sent to City Deep Market in Johannesburg.

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Table 4.5 Crops grown and reasons for crop choice at Rambuḍa Irrigation Scheme

Crop	Reasons for choosing the crop		
	Adaptability and availability	Yield	Sale
Sweet potato	Highly adapted, planting materials readily available and cheap to produce, farmers experienced in growing sweet potato and it provides food for family.	Good yield planted during November-January and before 15th June.	Easy to sell and no storage cost and has long shelf life.
Maize	Seeds readily available, easy to grow and provide household food security.	Good because high demand for green cobs.	Easy to sell and excess used for staple food.
Cabbage	Seeds readily available.	Good yields.	Sells very well if grown in good time.
Chinese spinach	Seeds readily available and easy to grow.	Good yields.	Sells easily among local people.
Nightshade *(Muxe)*	Easy to grow and no chemicals used.	Good yields.	Sells well among hawkers and local people.
Sugar beans	Readily available and easy to grow and easy to store.	Good yields.	Provide food for household and sells relatively easy.
Onion	Easily available and less diseases.	Crop rotation.	Sells poorly.
Beetroot	Readily available.	Good.	Sells poorly.
Chilli	New crop.	Good.	Sells well.
Wheat	Trial to see if it is feasible to produce.	Historically wheat did well in the scheme.	No information yet.

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4.4 Conclusions

In general, the results of this study showed that farmers do indeed know the types of soil that are found in the irrigation scheme and climatic conditions that are limiting to crop production as well as the months during which climatic conditions are critical. The results also showed that farmers have some correct and some incorrect perceptions regarding the prevailing climatic conditions and their trend in the irrigation scheme. The study showed that there is still a wide gap between perceptions and terms used by soil scientists/pedologists and farmers, particularly small-scale or subsistence farmers. Little work, if any, has been done in the field of ethnopedology in South Africa to bridge the gap between soil scientists and farmers. Farmers' participation in soil surveys provides information on criteria used by indigenous people to decide on soil suitability for a given crop and such criteria in land suitability evaluation for agricultural planning in less developed countries where recorded soil and climatic data are usually scarce. An intermediate practical user-friendly system of soil classification is increasingly becoming necessary for the new integrated farming society of South Africa. This will bridge communication gap between the indigenous soil knowledge and the taxonomical soil classification system of South Africa and land suitability evaluation for agricultural development planning. In general, participatory mapping promoted cooperation between the surveyors and farmers at the irrigation scheme providing basis for land users inclusive land suitability evaluation and land use planning.

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CHAPTER FIVE

SOILS OF THE IRRIGATION SCHEME

Abstract

Knowledge of soils and their distribution is important for making appropriate land use decisions and reliable predictions. There was no information on soils at Rambuḍa Irrigation Scheme. The objective of this chapter was to classify soils and to describe spatial distribution of soils across the irrigation scheme. Fifteen (15) soil profiles pits were dug at each soil area approximately 400 x 400 m apart. All soil profiles were georeferenced. Soil was classified according to the procedure in the taxonomic soil classification system of South Africa. Soil samples were collected from the A1 and B1 of each soil profile and were taken to the laboratory for analysis. Soil samples were analyzed for sand, silt, clay and organic carbon, extractable phosphorus, extractable potassium; calcium, magnesium and sodium. Soils of Rambuḍa Irrigation Scheme originated from colluvial deposition of material from sedimentary rock, diabase and sills. Soils belong to Suurbekom, Hayfield, and Ventersdorp families of the Hutton soil form and Dipene and Caledon of the Oakleaf soil form. In general, soils at Rambuḍa Irrigation Scheme were very low in P and K despite a long history of application of kraal manure. Application of phosphate and potash fertilizers is crucial for sustainable sweet potatoes and vegetable production at Rambuḍa Irrigation Scheme. This study produced a soil map and basis for crop choices and land suitability evaluation for Rambuḍa Irrigation Scheme.

5.1 Introduction

Sound planning of changes in land use requires a thorough knowledge and understanding of the natural resources, and a reliable estimate of their agricultural potential, so that reliable land use predictions and recommendations can be made (Aubert, 1981). Information on both physical and chemical properties of soils and their distribution is indispensable if sustainable development planning is to be made (Beek, 1977). Knowledge of the distribution, characteristics and qualities of the soil resources of an area is one of the basic requirements for correct agricultural development planning for an area (Laker, 1978). A high quality detailed soil map and accompanying report is an absolute prerequisite for development planning (Laker, 1982).

Information on natural biophysical resources of any area is indispensible for development planning of any agricultural project. It was stated in Chapter 1 of this thesis that no information on soil could be found either in the irrigation scheme or

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district office. There is no basis for crop choices and farmers at the irrigation scheme were using indigenous knowledge of soil and empirical observations of crop responses to various soils. Indigenous knowledge is not sufficient to make definite choices of suitable crops and land management decisions. Knowledge of soil and their distribution is necessary for making decisions on land use and management practices and, therefore a new soil survey was necessary for current and future planning of the irrigation scheme.

The objective of this study was to describe, classify and map the soils across the irrigation scheme for land suitability evaluation.

5.2 Materials and methods

5.2.1 Field survey and soil sampling

Orthophoto map 2230CD 4D with a map scale of 1:5 000 was digitized to generate a base map with map scale of 1:3 000. This base map was used during field soil survey. The geological map of Musina (2230) with a scale of 1:250 000 and Explanation Sheet 2230 (Brandl, 1981) were used to describe the geology of the study area and its influence on soil types.

Transect walks were conducted and a hand-held soil auger was used to identify soil boundaries during transect walks. Fifteen (15) soil profiles pits measuring 150 x 150 x 200 cm approximately 400 x 400 m apart were dug in each soil area showing a difference in regard to some soil property. Standard soil samples were collected from A1 and B1 horizons of each profile for laboratory analysis. All soil profile sites were georeferenced using a Garmin global positioning system. Soil profiles were classified and described according to the procedures described in the South African taxonomic soil classification system (Soil Classification Working Group, 1991). Diagnostic soil properties were measured in the field and recorded according to the procedure in Turner (1991). All soil boundaries were properly plotted on the base map.

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5.2.2 Laboratory analysis and soil mapping

Soil samples were prepared and analyzed according to the standard analytical methods (The Non-Affiliated Soil Analysis Committee, 1990). The following properties were measured: pH(H_2O) (1:2.5 soil/water suspension ratio); extractable phosphorus (Bray 1); calcium, magnesium and potassium (ammonium acetate); organic carbon (Walkley-Black) and soil texture (hydrometer method).

Final soil map was drawn using ArcMap view 3.0 (ESRI, 2000) and care was taken not to change boundaries as originally drawn by farmers (Figures 5.1).

5.3 Results and discussion

5.3.1 Soils of Rambuḍa Irrigations Scheme

Soils of Rambuḍa Irrigation Scheme originated from sedimentary rock through deposition of colluvium material from sandstone and diabase. In certain localities, the soil is influenced by the occurrence of diabase dykes and sills. Colluvium derived from these rocks covers the whole study area. The soils were dominantly red apedal with a small portion of the irrigation scheme comprised of dark brown clay to sandy loam soils. Topsoil horizons were dark reddish brown to dusky red and brown coloured overlying either light coloured reddish brown; dusty red; red or brownish sub-soil horizons. Dark coloured topsoil horizons were attributed to alterations brought about by application of organic matter in the form of kraal or chicken manure and compost from straws of crops grown in the irrigation scheme.

In general, soils were moderately to slightly acid. The topsoil and subsoil pH(H_2O) varied from 5.20-6.42 and 5.49-6.64, respectively. Soil pH at this irrigation scheme is good for sweet potato growth (van der Berg and Laurie, 2004) which is the major crop in this scheme and can be considered as desirable for most crops. However, the availability of some elements may be problematic at a pH lower than 5.5 and higher than 7.5 (FSSA, 2003). Liming may be necessary to keep pH at 5.5-6.5 range. This is a level at which essential elements become available (Tisdale *et al.*, 2005). Soil pH can

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greatly influence plant growth by affecting the composition of the soil solution and availability of essential and nonessential elements. At pH below 5.5 conditions favourable for Fe and Al solubility are created. Iron and aluminium in solution can fix P as Fe-P and Al-P, respectively, which are not available for plant use. Phosphorus availability is greatest in the pH range 6.0-6.5. Some micro-elements like Mn and others may become abundantly available low pH and consequently become toxic to crops (Tisdale *et al.,* 2005).

The amount of P ranged from 0.2-60.10 mg kg^{-1} soil and 0-20.6 mg kg^{-1} soil in the topsoil and subsoil horizons, respectively. The amount of extractable potassium varied from 6.77-240.32 mg kg^{-1} soil in the topsoil and 8.38-174 mg kg^{-1} soil in the subsoil, which is again too low for an old scheme where kraal and crop residues have been continually applied. Such low K values are rare for South African soils (FSSA, 2003). Solution K concentration is important for successful crop production. Although K deficiencies are rare for South African soils (FSSA, 2003), such low values are a concern with regard to the production of crops like cabbages and other vegetables and fruit crops that need high K levels. Potassium is not only necessary for high yields, but it is also important for good quality of the crops.

Availability of Ca and Mg in soil solution and their uptake by plants is largely influenced by their ratios with other cations (Prasad and Power, 1997). A Ca:(Ca+Mg+K) ratio of 0.1 to 0.2 is considered desirable for sufficient uptake of Ca (Prasad and Power, 1997). Excess Ca can negatively affect the uptake of Mg, and a Ca:Mg ratio of greater than 7:1 is not desirable (Tisdale *et al.,* 2005). The Ca:(Ca+Mg+K) at Rambuḍa Irrigation scheme was 0.7:1 for both top and subsoil. This is greater than 0.1 to 0.2 Ca:(Ca+Mg+K) ratio generally considered desirable for adequate Ca uptake. The average Ca:Mg ratios ranged from 2:1 to 5:1 for the topsoil and 3:1 to 6:1 for the subsoil. Magnesium may restrict the absorption of Ca by plants when Ca:Mg ratio is above 2:1 (Tisdale *et al.*, 2005). However, there is no certainty on the influence of Ca:Mg ratio on crops (McLean *et al.*, 1983; Sawyer, 2003).

5.3.1.1 Hutton soils

Soils with red to reddish brown surface and red subsurface horizons were found in the mid-section, extending to the western part of the irrigation scheme (Figure 5.1). The

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topsoil diagnostic horizons were red, sandy clay loam to sandy clay orthic A with friable to massive consistency and few common roots to the depth of 450 mm. Soil colour for the topsoil horizons varied from red, reddish brown to dark reddish brown (2.5YR 3/3; 4/3; 3/4; 4/4 and 5/6 dry). Subsoil diagnostic horizons were red, sandy clay to clay apedal B horizon with friable to slightly hard consistency. The subsoil horizons were red, dusky red to dark reddish brown (2.5YR 3/4; 3/6; 4/4; 4/6; 4/8; 5/6; 10R 3/6; 10 YR 4/4 moist).

The South African taxonomic soil classification uses two properties diagnostic for the soil families to distinguish soil families in Hutton soil form (Soil Classification Working Group, 1991), namely luvic properties and base status. Soils are considered to be luvic when:

1. The clay content of any part of the A or E horizons is 15% or less, the B1 horizon must contain at least 5% more clay than the A or E horizon; or the clay content of A or E horizons is more that 15% clay, the ratio of clay percentage of B1 horizon to that of A or E horizon must be 1.3 or greater.

2. The sum of exchangeable bases of Ca, Mg, K and Na expressed in cmol(+) kg^{-1} clay calculated by using the S-value and clay % using equation [cmol(+) kg^{-1} soil] × 100 ÷ % clay. According to the Soil Classification Working Group (1991), soil with low of base status of <5 is dystrophic, medium base status 5-15 mesotrophic and high base status >15 eutrophic (Soil Classification Working Group, 1991).

Soil profiles in Hutton soil form (Figure 5.1) had greater than 15% clay in the A1 horizon. Although, soil profiles R01, R03, R04 and R07 (Appendix II) had more than 15% clay in A1 horizon, the ratios of clay content in B1 to that in A1 horizon were less than 1.3 qualifying criterion for luvic families, thus qualifying them for the non-luvic soil families. The second criterion for distinguishing soil families is base saturation (leaching) in B1 horizon. The sum of exchangeable bases expressed in cmol(+) per kg clay for soil profiles R01, R03, R04 and R07 ranged from 8-15, thus qualifying them for mesotrophic families. The soils in these profiles were classified as belonging to the Hayfield soil family of the Hutton soil form (Rhodic *mesotrophic, haplic*, IUSS WRB, 2006). Soil profiles R02, R05, R06, and R08 had clay content greater than 15% in the A1 horizon. The ratio of clay content in B1 to A1 horizon ranged from 8-13, which falls within 5-15

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range for mesotrophic soil families. The soil profiles R02, R05, R06 and R10 were classified as belonging to the Suurbekom soil family of the Hutton soil from (Rhodic *mesotrophic, luvic*, IUSS WRB 2006). Soil profile R09 had 1.8 clay content ratio of B1 to A1 horizon thus qualifying it for the luvic families. The sum of exchangeable K, Ca, Mg and Na, expressed in cmol(+) per kg of soil was 19 and was greater than the 15 upper limit for mesotrophic horizon, qualifying it for the eutrophic families. The profile was classified as belonging to the Ventersdorp soil family of the Hutton soil form (Rhodic *eutrophic, luvic*, IUSS WRB, 2006).

5.3.1.2 Oakleaf soils

Soils with red to reddish brown surface and reddish brown subsurface horizons were found in the eastern part of the irrigation scheme (Figure 5.1). The topsoil diagnostic horizons were non-bleached brown to dark reddish brown (2.5YR 3/4; 4/3; 4/4 and 5YR 4/3 dry), loamy sand to sandy clay loam orthic A with friable to massive consistency and few common roots to the depth of 300 mm. Subsoil horizons were reddish-brown (2.5YR 4/4; 5/4 moist), loamy clay sandy clay with massive to blocky neocutanic B horizons (Appendix II). Subsoil horizons had 5-20% yellowish red, yellowish brown to reddish yellow distinct mottles. The soil was classified according to the South African taxonomic soil classification system as belonging to the Oakleaf soil form (Figure 5.1).

The South African taxonomic soil classification system uses the following properties diagnostic for distinguishing soil families for the Oakleaf soil form:

1. Whether A horizon is bleached in a dry state;
2. Whether B horizon is red or non-red or;
3. Whether B1 horizon is luvic (Soil Classification Working Group, 1991).

The A horizon for all soil profiles in the Oakleaf soil form were not bleached and had red B horizon, thus qualifying them for non-bleached A horizon, red B horizon families. Soil families in this form could further distinguished using the third criterion of the clay ratios of the B1 to A1 horizon. Soil profiles R11 and R12 had clay content greater than 15% in the A1 horizon (Appendix II). The ratios of clay content of B1 to A1 horizon for these profiles were 1.3 and 1.5, respectively, thus qualifying them for luvic families.

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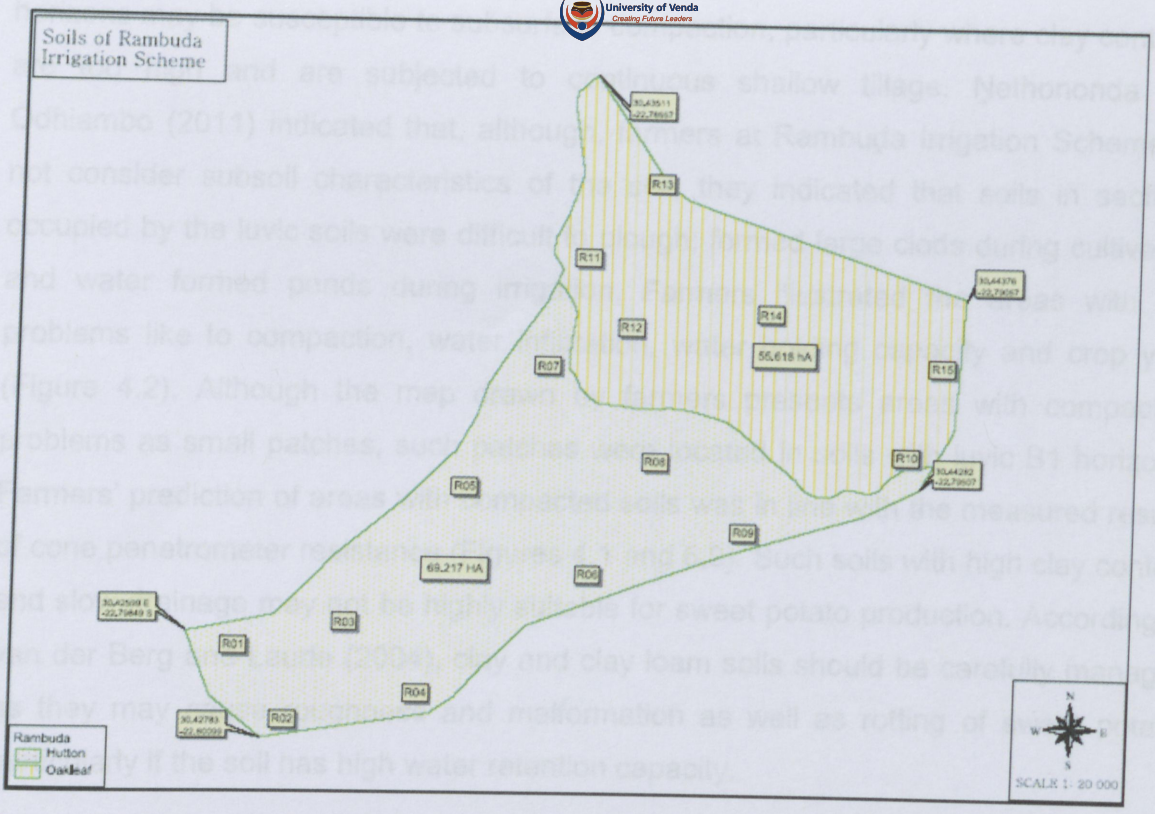


Figure 5.1 Soil map of Rambuḍa Irrigation Scheme

Soil profiles R13 and R14 had less than 15% clay content in the A1 horizon and the B1 horizon had an increase of more than 5%, thus qualifying them for the luvic families. Soil profiles R11, R12, R13, and R14 were classified as belonging to the Dipene soil family of the Oakleaf soil form (Neocutanic *chromic, rhodic, luvic*, IUSS WRB, 2006). Soil profile R15 had clay content greater than 15% in the A1, but the ratio of the B1 to A1 was 1, which is less than the 1.3 qualifying criterion for luvic families, thus qualifying it for the non-luvic families (Appendix II). Soil profile R15 was classified as belonging to the Caledon soil family of the Oakleaf soil form (Neocutanic *chromic, rhodic, haplic*, IUSS WRB, 2006). Soils where soil profile R15 were classified according to indigenous soil classification criteria as *Tshiṭavha* (fine sand) (Figure 4.1) (Nethononda and Odhiambo, 2011). They were described as quick drying and low-yield soils with fast water infiltration.

The luvic property of the soil may be attributed to eluviations (or many other reasons) of clay in suspension from surface horizons (Bridges, 1997). Subsoil horizons with high clay contents are susceptible to subsoil compaction (Spoor, 2006). In South Africa, sandy and fine sandy apedal soils are very susceptible to compaction when cultivated (Bennie and Krynauw, 1985; Bennie and van Antwerpen, 1988). Thus, soils with luvic B

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horizons may be susceptible to subsurface compaction, particularly where clay contents are too high and are subjected to continuous shallow tillage. Ṇethononda and Odhiambo (2011) indicated that, although, farmers at Rambuḍa Irrigation Scheme do not consider subsoil characteristics of the soil, they indicated that soils in sections occupied by the luvic soils were difficult to plough; formed large clods during cultivation and water formed ponds during irrigation. Farmers illustrated the areas with soil problems like to compaction, water infiltration, water holding capacity and crop yield (Figure 4.2). Although the map drawn by farmers presents areas with compaction problems as small patches, such patches were located in soils with luvic B1 horizons. Farmers' prediction of areas with compacted soils was in line with the measured results of cone penetrometer resistance (Figures 4.1 and 6.9). Such soils with high clay content and slow drainage may not be highly suitable for sweet potato production. According to van der Berg and Laurie (2004), clay and clay loam soils should be carefully managed as they may cause roughness and malformation as well as rotting of sweet potato, particularly if the soil has high water retention capacity.

5.3.2 Soil ecotopes

An ecotope is defined as an area of land, which the natural resources i.e. climate, topography and soil influence on yield are reasonably homogenous (MacVicar *et al.*, 1974). Four ecotopes were identified based on the principles by MacVicar *et al.* (1974). Management practicality of the irrigation scheme was also considered when delineating soil ecotopes and thus the luvic property was the most important soil property for crop production. Soils were delineated into Rambuḍa-Hutton luvic, Rambuḍa-Hutton non-luvic, Rambuḍa-Oakleaf-Luvic and Rambuḍa Oakleaf non-luvic (Figure 5.2).

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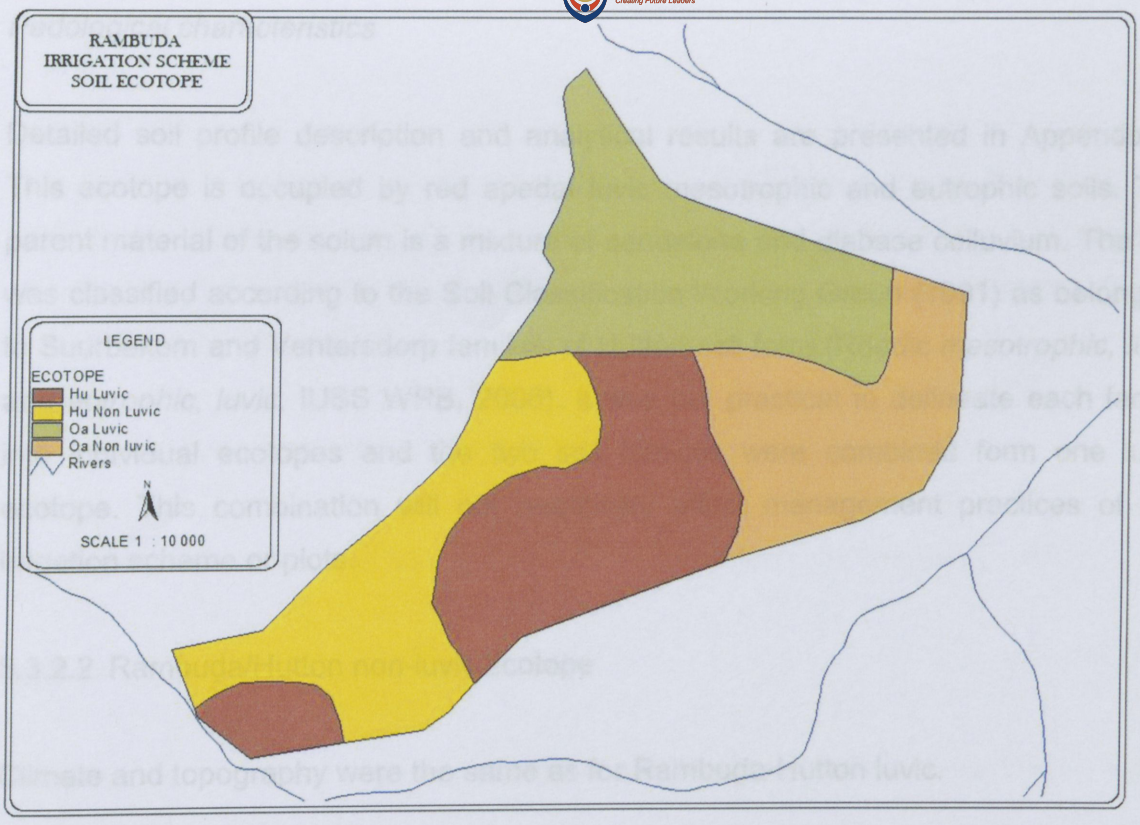


Figure 5.2 Soil ecotopes of Rambuḍa Irrigation Scheme

5.3.2.1. Rambuḍa/Hutton luvic ecotope

Climatic information

Long term climatic data for Tshiombo weather Station was used to describe the climatic conditions at Rambuḍa Irrigation Scheme. Tshiombo Weather station is located 8 km from Rambuḍa Irrigation Scheme. Summarized climatic data recorded for the period 1980-2010 are presented in Table 2.1.

Topography

Topography of the ecotope is flat to gently sloping towards the south with south-east facing aspect. The slope varies between 0.5 - 2%. The slope is classified as level according to the slope gradient categorization in South Africa (Scotney *et al.*, 1987). These slopes are less than 8% threshold for irrigability (Turner and Scotney., 1993) and are regarded as suitable for irrigation.

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Pedological characteristics

Detailed soil profile description and analytical results are presented in Appendix II. This ecotope is occupied by red apedal luvic mesotrophic and eutrophic soils. The parent material of the solum is a mixture of sandstone and diabase colluvium. The soil was classified according to the Soil Classification Working Group (1991) as belonging to Suurbekom and Ventersdorp families of Hutton soil form (Rhodic *mesotrophic, luvic* and *eutrophic, luvic*, IUSS WRB, 2006). It was not practical to delineate each family into individual ecotopes and the two soil families were combined form one luvic ecotope. This combination will not negatively affect management practices of the irrigation scheme or plots.

5.3.2.2 Rambuḍa/Hutton non-luvic ecotope

Climate and topography were the same as for Rambuḍa-Hutton luvic.

Pedological characteristics

Detailed soil profile description and analytical results are presented in Appendix II. This ecotope is occupied by red apedal non-luvic mesotrophic soils. The parent material of the solum is a mixture of sandstone and diabase colluvium. The soil was classified according to the Soil Classification Working Group (1991) as belonging to Hayfield family of Hutton soil form (Rhodic *mesotrophic, haplic*, IUSS WRB, 2006).

5.3.2.3 Rambuḍa/Oakleaf luvic ecotope

Climatic information

Climatic conditions in this ecotope are similar to the Rambuḍa/Hutton ecotope.

Topography

Topography of the ecotope is flat to gently sloping towards the south with east facing slope aspect. The slope varies between 1.5% and 2%, and can be regarded as level and suitable for irrigation.

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Pedological characteristics

Detailed soil profile description and analytical results are presented in Appendix II. This ecotope is occupied by brown luvic soil with reddish neocutanic B horizon. The underlying material is unspecified without carbonate deposit at 120 cm depth. The soils belong to Dipene soil family of the Oakleaf form (Neocutanic *chromic, rhodic, luvic*, IUSS WRB, 2006).

5.3.2.4 Rambuḍa/Oakleaf non- luvic ecotope

Climatic conditions were similar as for Rambuḍa/Oakleaf luvic ecotope.

Topography

This ecotope is located in a gentle slope with slope gradient of 2% south-east facing slope aspect.

Pedological characteristics

Detailed soil profile description and analytical results are presented in Appendix II. This ecotope is occupied by brown non-luvic, rapid drying soils with reddish brown neocutanic B horizon. The underlying material is unspecified without carbonate deposit at 120 cm depth. There is no impeding layer for root development at the soil depth of 30 cm. The soils belong to Caledon soil family of the Oakleaf form (Neocutanic *chromic, rhodic, luvic*, IUSS WRB, 2006).

5.3 Conclusions

The results of this study showed that the soils at Rambuḍa Irrigation Scheme are deep with few, if any physical limitations to crop production. The soils were classified according to the taxonomic soil classification system of South Africa as belonging to Hutton and Oakleaf soil forms. The soil families for the Hutton soil form were Suurbekom, Hayfield and Ventersdorp. Oakleaf soil forms at Rambuḍa Irrigation Scheme were Dipene and Caledon. Soils in the irrigation scheme were predominantly luvic and soils may require slightly different management practices from the non-luvic

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soils, particularly in sections that have high subsoil clay content. This is important in land use and decisions on crops and agronomic practices required for sustainable crop production. The results indicated low levels of important macro-elements K and P which is a case of concern for the production of good quality vegetables. Topdressing of K fertilizers is necessary for vegetable production. These were spot samples taken from profile pits, which is normal in the case of soil surveys, and not representative samples as would be taken for analyses intended for fertilizer recommendations. It is thus possible that there could be variation in topsoil plant nutrient values. In general, soils at Rambuḍa Irrigation Scheme are considered to have high agricultural potential for crop production. Soil ecotopes are more useful in describing soil at a regional scale than at a detailed farm scale due to short-distance spatial variability of soil properties from detailed soil surveys. The soil information and the soil map from this study provide basis for crop choice and land suitability evaluation for Rambuḍa Irrigation Scheme.

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CHAPTER SIX

SPATIAL VARIABILITY OF SELECTED SOIL PHYSICAL PROPERTIES

Abstract

Knowledge of spatial variation of soil properties is important for selection of management practices and decisions relating to land suitability for specific crops. The objective of this chapter was to determine spatial variability of selected soil physical properties important for land suitability evaluation across the irrigation scheme. An aerial photograph was digitized. A 100 x 100 m grid was used to collect soil samples from 0-30 cm and 30-60 cm depths. Organic carbon and particle size distribution were analyzed using the Walkley-Black and hydrometer methods, respectively. In general, there was high spatial variability of soil properties across the irrigation scheme. Data were analyzed statistically and geostatistically. Coefficient of variation showed moderate to high variability of measured soil properties for both topsoil and subsoil layers. Exponential models gave the best fit for all the variables except the topsoil sand and clay, for which spherical models were used. Semivariograms exhibited moderate spatial dependence for sand, silt and clay and strong spatial dependence for organic carbon. Spatial maps showed high variability of soil properties for the topsoil in particular, indicating the effects of continuous shallow tillage and different agronomic practices used in the irrigation scheme. There was positional relationship between the top and subsoil properties indicating the interaction among soil properties. Nugget % showed moderated spatial structure for majority of properties except organic carbon and cone penetrometer resistance. Highest cone penetrometer resistance occurred below 22 cm soil depth. This was an indication of the presence of a compaction layer caused by continuous shallow mouldboard tillage. Geostatistics can be used to predict spatial distribution of soil properties across a communal irrigation area, thereby providing a basis for land suitability evaluation and land use decisions regarding site-specific management.

6.1 Introduction

Knowledge of soil spatial variability and interactions among soil properties is important for the evaluation of agricultural land suitability and management practices required for specific crop production. Spatial variability of soil properties has been reported both within and across the landscape and field (Iqbal *et al.*, 2005; Mzuku *et al.*, 2005). Spatial variability of soil properties is a direct result of soil forming factors (Jenny, 1941) and anthropogenic activities (Cambardella *et al.*, 1994; Sharma *et al.*, 2011). This variability affects crop suitability and input management requirements across the field (Mzuku *et al.*, 2005).

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Thus, an understanding of spatial variability of soil properties is important for appropriate management practices by farmers (Mzuku *et al.*, 2005; Sharma *et al.*, 2011).

Soil physical properties interact with one another and influence behaviour of one another as a result of natural processes and anthropogenic activities. Soil organic carbon variations are attributed to topographic variations or plant inputs, decomposition, soil texture, nutrients, water and/or soil carbon erosion and deposition (Haung *et al.,* 2005; Franzluebbers *et al.,* 2000). Sleutel *et al.* (2003) observed that the proportion of organic carbon in the silty and clay-sized soil fraction slightly increased with increasing silt and clay content. Organic carbon for instance, affects soil structure and other properties of the soil. The higher the organic carbon contents in the soil the better the porosity of the soil (Franzluebbers *et al.,* 2000). Silt and clay contents affect organic carbon stock in the soil. Loamy soils with low clay contents displayed low organic carbon values whereas silty clays and heavy clays displayed high organic carbon levels (Arrouays *et al.*, 2006). The most critical consequence of this interaction is its effect on the vulnerability of soils to compaction. Soil susceptibility to compaction is influenced by soil texture and the organic matter content of the soil. Soil texture influences consecutively the other soil properties. Susceptibility to compaction goes in the direction sandy < loamy sandy < sand loamy < loamy <clay loamy < loam clayey < clayey soils < clays (Panagos *et al.*, 2012).

Soil compaction is a particularly widespread and serious problem under intensive mechanised crop production in South Africa – both rainfed and irrigated (Mallet *et al.*, 1985; Mitchell and Berry, 2001). Tillage research in South Africa has shown that soils with less than 15% clay in the plough layer are very vulnerable to compaction (Mallet *et al.*, 1985; Mitchell & Berry, 2001). Studies in South Africa showed that sand grade is by far the most influential factor affecting compaction in most soils (Smith *et al.*, 1997). Soils with high fine sand and low clay contents are extremely vulnerable to compaction and such soils cover the large areas of various parts of the country. Particle size distribution and related factors such as sorting and the shape and smoothness of sand particles are by far the most important soil factors affecting the susceptibility of a soil to compaction.

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Soil compaction is serious in older communal irrigation schemes where resources for deep tillage are limited and wrong implements are often used to cultivate the soil. Laker (2005) observed that a disc plough was used instead of a mouldbourd plough for primary tillage in Dzindi small-farmer irrigation scheme near Thohoyandou, Limpopo Province. It was, furthermore, pulled by a small tractor resulting in wheel slip that aggravated the severe compaction. Soil compaction can be caused by plough-tractor mismatch where a small tractor is used to pull a large plough, which may result in wheel slip, especially in too moist clayey soils, which severely aggravates compaction. Laker (2005) observed a similar situation in Dzindi Irrigation Scheme where a small tractor was used to pull a big disc plough resulting in wheel slip as the small tried to pull a large weight plough. This is worsened by ploughing the soil when it is too wet. South Africa covered by soils with high fine sand and low clay contents to compaction and such soils cover the large areas of various parts of the country. Particle size distribution and related factors such as sorting and the shape and smoothness of particles are by far the most important soil factors affecting the susceptibility of a soil to compaction.

Continuous mouldboard tillage at the same depth densifies the soil, resulting in the formation of a plough pan (Kìlìç *et al*., 2004). During research comparing different cultivation strategies it was found that working with the tractor wheel in the open plough furrow, especially during mouldboard ploughing, gives more severe compaction and to greater depth (Mallett *et al*., 1985). Compacted soil forms a layer in the subsoil that impedes plant root growth, water percolation, nutrient availability, reduced soil workability and microbial activities in soils (Bennie and Laker, 1975; Laker, 2001; Spoor, 2006).

Soil compaction may occur in patches across the field causing variation in crop stand and yields (Tekeste *et al*., 2005; Batey, 2009). Raper *et al*. (2005) indicated that soil variability is a likely cause of extremely variable yields, particularly on highly weathered ultisols with deep sandy surface layers in south-eastern United States. It is therefore important to ascertain and map the sections of fields that are affected by soil compaction (Raper, *et al*., 2005). Site-specific tillage of compacted sections of the field will reduce energy requirement costs, compared with uniform tilling of the whole field (American Society of Agricultural Engineers, 1985; Raper *et al*., 2000; Raper *et al*., 2005, Mzuku *et al*., 2005). Site-specific management can be achieved by dividing the field into units known as management zones. They are sub-regions of a field with

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homogenous yield-limiting factors, for which a single rate of application of a specific crop input is appropriate (Doerge, 1999).

Penetrometers are widely used to measure the resistance of soil to penetration. Penetrometer resistance, simulating the mechanical resistance of a soil to the penetration of plant roots, was found to be the most efficient way to express soil compaction (Bennie and Burger, 1988; Rooney *et al.*, 2001; Tekeste *et al.*, 2005; Batey, 2009). A penetrometer imitates a plant root and the difference is that plant root is living, and much more delicate and smaller than the penetrometer (Rooney *et al.*, 2001). Root penetration decreases linearly with penetration resistance and plant roots are inhibited at 1500 kPa with roots of many plants stopping growing at 2500 kPa penetration resistance (Kees, 2005). Rooney *et al.* (2005) categorized penetrometer resistance into four classes, namely 0-1034 kPa as low; 1034-2038 kPa medium; 2038-3103 kPa heavy and >3103 kPa very heavy. Kìlìç *et al.* (2004) found that penetrometer resistance for clay loam was relatively lower than that of loamy soil and the coefficient of variation was higher in clayey soil than in loamy soil.

Geostatistics has become a very important tool to assess spatial variability of soil properties for decades (Webster and Burgess, 1980; Oliver, 1987; Oliver and Webster, 1991; Iqbal *et al.*, 2005; Mzuku, *et al.*, 2005). Unlike classical statistical methods that treat values of individual samples as though they were governed by chance, geostatistics takes into account the effects of sample location using semivariogram and kriging to estimate value of unsampled areas (Webster and Burgess, 1980). Thus, the values of neighbouring variables are more related than those far apart.

Knowledge and understanding of spatial variability of soil properties is indispensible for the delineation of a farm into site-specific management zones and soil mapping units for land suitability evaluation (Tekeste *et al.*, 2005). Farmers may either fertilize too much, thereby incurring high production costs as a result of over-application of fertilizers or too little, resulting in poor yields. Farmers at Rambuḍa Irrigation Scheme reported variation in crop stand both within the plots and across the irrigation scheme (Ṇethononda and Odhiambo, 2011). Lack of soil information may cause farmers at Rambuḍa Irrigation Scheme to guess how to manage the soil and inputs application, causing variations in crop stand and yields. Knowledge and understanding of soil and its properties will

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provide information for variable inputs management and land use management decisions as well as detection of areas with soil problems that affect crop production.

The objective of this chapter was to determine spatial variability of selected soil physical properties and soil organic carbon important for land suitability evaluation across the irrigation scheme.

6.2 Materials and methods

6.2.1 Field sampling and data collection

An aerial photograph 2230CD 4D was digitized to produce a base map of 1:3 000 with 100 x 100 m grid sampling points (Figure 6.1). Grid point sampling is useful when the goal of test results is to produce a more continuous surface map using interpolation techniques (Buscaglia and Varco, 2003). A total of 115 soil samples were collected at each node from the topsoil (0-30 cm) and subsoil (30-60 cm), using a soil auger. Cone penetrometer resistance was measured in the field according to techniques described in section 6.2.3. All sampling points were geo-referenced using a Garmin GPS.

6.2.2 Laboratory analysis

Soil samples were air dried and sieved using a 2 mm sieve according to the procedures described in the Handbook for Soil Testing for Advisory Purposes (The Non-Affiliated Soil Analysis Work Committee, 1990). Samples were analysed for sand (2 mm), silt (0.02 mm) and clay (0.0020) using hydrometer method and organic carbon by Walkley-Black methods, respectively.

6.2.3 Penetrometer measurements

Soil penetrability was measured using the static Rimik CP40II electronic penetrometer with integrated global positioning system and data logger. Penetrometer readings can be strongly influenced dependent on soil moisture content (Miller *et al.*, 2001; Vaz *et al.*, 2001), filed measurements were carried out in summer. Measurements were made on a 100 x 100 m grid across the irrigation scheme, using a digitized map with computer

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generated grid points three day after substantial rain when the soil was near field moisture capacity so that PR reading are least influenced by differences in soil moisture (American Society of Agricultural Engineering, 1999; 2000; Miller *et al.*, 2001). The study site map was pre-installed into the GPS that was used during field measurements, ensuring that measurement points were located properly within the irrigation scheme. The penetrometer was set at 25 mm intervals to minimize errors caused by jittering of CP40II by small pockets of air, stones, roots etc. and a 130 mm^2 cone was used (Rimik 2004). The maximum insertion speed was set at a minimum speed of 0.2 m/min and a maximum speed of 2 m/min to a depth of 750 mm where soil conditions allowed. Field measurements were uploaded to a computer using the Rimik CP40II Retrieval 6.0 software (Rimik 2004) for further analysis.

6.2.4 Statistical and geostatistical analysis

Data of measured soil properties were analysed for the following parameters: maximum, minimum, mean, skewness (Shapiro and Wilk, 1965), standard deviation and coefficient of variation of sand, clay, silt, organic carbon and cone penetrometer resistance for each soil layer (Table 6.2). SAS 9.0 (SAS Institute, 2010) was used to conduct statistical analysis. Non-normal distributions can be brought to near normal distributions by using either natural logarithm or square-root techniques (Trangmar, *et al.*, 1985; Cambardella *et al.*, 1994; Iqbal *et al.*, 2005). Non-normal data should be transformed to near normal before geostatistical analysis could be conducted (Robertson, 2008).

Geostatistics has been used to assess spatial variability of soil properties (Goovaerts, 1999; Webster, 1985; Webster and Oliver, 1990; Iqbal *et al.*, 2005; Mzuku *et al.*, 2005). Geostatistical analysis was performed to determine the spatial variability of sand, silt, clay, organic carbon and cone penetrometer resistance at the two depths (0-30 and 30-60 cm) using GS+ Version 9.0 Gammadesign (Robertson, 2008). The degree of spatial variability of each variable was ascertained by using semivariogram analysis (Goovaerts, 1997). A semivariogram summarizes all lag-distances of all paired values. A semivariogram is a graph of semivariance versus separation distance. Geostatistics uses three parameters of the semivariogram namely, nugget variance (C_0), the sill (C_0+C) and the range (a). Nugget variance is the variance at zero distance. A nugget variance represents two sources of variability, namely spatial variability at a scale

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smaller than the minimum lag distance as well as the experimental error caused by sampling error, also called human nugget. Thus, when semivariogram values are plotted for all h, the values are small for low values of h and they increase with increasing distance, and usually level off at a certain distance. When the values of the semivariograms remain constant, it implies that the variance between the values does not change with distance. Small values at short lags indicate that the data are spatially continuous while large values of lags indicate that the samples (data) are spatially discontinuous. Semivariance values tend to increase as the distance between sample pairs increases until the trend levels off, and the variogram value at which the plotted points level off is called the sill. The value of the sill is equivalent to traditional sample variance. The distance at which the values of variogram level off, is known as the range (Trangmar *et al.*, 1985). In simpler terms, the range is the average distance within which the samples remain spatially autocorrelated. Semivariances were estimated at lag distance h as follows (Goovaerts, 1997):

$$\gamma(h) = \frac{1}{2N(h)}\left\{\sum_{i=1}^{N(h)}[Z(x_i-h)-Z(x_i)]^2\right\} \qquad (6.1)$$

where z is the regionalized variables, $z(xi)$ and $z(xi+h)$ are the measured sample values at xi and $xi+h$ points. N is the number of pairs separated with distances h (lag space).

Spatial dependency of soil variables was defined by the percentage of nugget variance of the total semivariance according to spatial rates to describe distinctive spatial dependence of samples which are summarized in Table 6.1 (Cambardella *et al.*, 1994).

Table 6. 1 Spatial classification ratios expressed as percentage of nugget variance

Ratio <25%	Variables accepted as strongly spatially dependent.
Ratio between 25 and 75%	Variables considered moderately spatial dependent.
Ratio >75%	Variables considered weakly spatially dependent.

Ordinary kriging was conducted on the basis of weighted averages determined by the semivariogram and the geometric relationships between neighbouring points (Goovaerts, 1997). Kriging is a technique of making optimal, unbiased estimates of regionalized variables at unsampled locations using the structural properties of the

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semivariogram and the initial set of data values (Trangmar *et al.*, 1985). Ordinary kriging involves estimation of point values and assuming that the sample data are normally distributed. Non-normal distribution was normalized by transformation techniques before geostatistical analysis can be performed. Ordinary kriging is estimated as follows:

$$\hat{z}(x_0) = \sum_{I=1}^{N} \lambda_i(x_i) \qquad (6.2)$$

Where n is the number of neighbouring samples z (x_i) and λ_i are weights applied to each (z). The results of spatial values are presented in the form of spatial maps. Spatial maps were drawn from the ordinary kriged data using ArCGIS 9.3 (2009). The breaks between the classes were set at equal interval, so the range from minimum to maximum was just divided equally into six classes on the maps (Figures 6.2-6.5).

6.3 Results and discussions

6.3.1 Descriptive statistics

The results of descriptive statistical analysis of soil physical properties for two soil depths are presented in Table 6.2. Most measured soil variables were normally distributed except the subsoil cone penetrometer resistance (Table 6.2). Subsoil cone penetrometer was not normally distributed (Figure 6.1) because of the highest PR (>5000 kPa) in the north-eastern tip of the irrigation scheme (Figure 6.6). The Shapiro-Wilk (1965) test for skewness showed that the data for subsoil clay, silt and organic carbon and cone penetrometer resistance were positively skewed for both layers (*P*= 0.14-1.16). The data for sand and topsoil clay were negatively skewed and the skewness ranged from -0.005 to -0.23. The data for the subsoil PR was transformed using log-transformation before geostatistical analysis (Figure 6.1).

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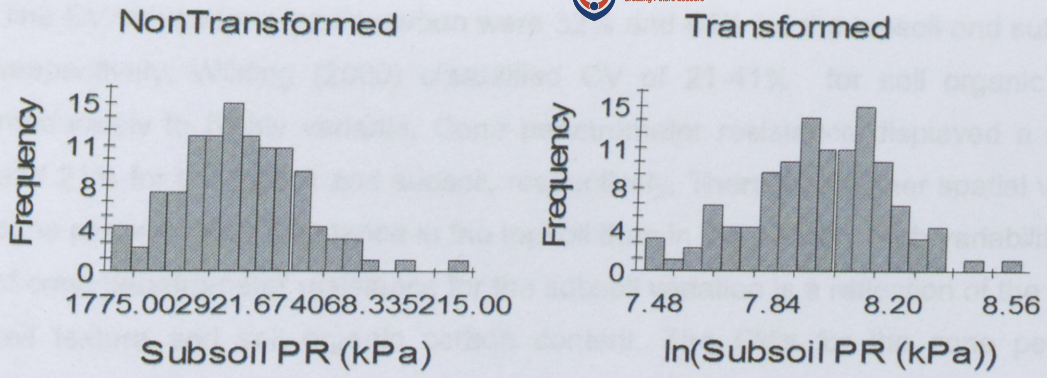


Figure 6.1 Frequency distribution non-transformed and log-transformed cone penetrometer resistance (kPa)

The values for coefficient of variation (CV) for clay, silt, organic carbon and topsoil cone penetrometer resistance were greater than 30% for both the topsoil and subsoil layers (Table 6.2). Sand content displayed a moderate spatial variability for both soil depths across the irrigation scheme. The CV was 14 and 17% for topsoil and subsoil, respectively. Clay content had 35 and 31% coefficient of variation for the topsoil and subsoil respectively across the irrigation scheme. Silt had the highest values, with a CV of 41 and 46% for the topsoil and subsoil as compared to other measured soil physical properties. According to Wilding, (2000) and Mulla & McBratney, (2000) these levels indicate high spatial varibility of clay across the irrigation scheme.

In general, organic carbon was very low across the irrigation scheme. Soils with high values for topsoil organic cabon were found in the low-lying areas. This finding was not expected for an irrigation scheme where different types of organic matter in the form of kraal manure and crop residues are applied.

Table 6. 2 Summary statistics of measured soil properties

Variable	Layer	Min	Max	Mean	SD	Skewness	CV
Sand (%)	Topsoil	46	90	69.983	9.405	-0.23	14
	Subsoil	36	82	62.435	10.118	-0.15	17
Clay (%)	Topsoil	8	46	24.122	8.158	-0.005	35
	Subsoil	2	52	31.791	8.759	0.23	31
Silt (%)	Topsoil	2	12	5.896	2.411	0.25	41
	Subsoil	12	14	5.696	2.644	1.16	46
Organic carbon (%)	Topsoil	0.202	1.665	0.899	0.290	0.122	32
	Subsoil	0.093	1.172	0.593	0.263	0.143	44
Cone resistance (kPa)	Topsoil	216	3824	1791.678	644.417	0.23	36
	Subsoil	1775	5215	2975.530	619.401	0.48	21

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The CV values for organic carbon were 32% and 44% for the topsoil and subsoil layers, reapectively. Wilding (2000) classsified CV of 21-41% for soil organic carbon as moderately to highly variable. Cone penetrometer resistance displayed a CV of 36% and 21% for the topsoil and subsoil, respectively. There was higher spatial variability of cone penetrometer resistance in the topsoil than in the subsoil. High variability of values of cone penetrometer resistance for the subsoil variation is a reflection of the variation in soil texture and soil organic carbon content. The CV's for the cone penetrometer resistance were between 20-61% which according to Wilding, (2000) are considered moderately to highly variable, respectively.

6.3.2 Soil penetrability

Cone penetrometer resistance showed an increasing trend as depth increased, from the mean value of 570.70 kPa to a maximum of 3163 kPa and then declined as the depth increased (Figure 6.1). Rooney *et al.* (2005) categorized PR into four classes namely, 0-1034 kPa low, 1034-2038 medium, 2038-3103 heavy and >3103 kPa as very heavy. This indicated that the soils at Rambuḍa Irrigation Scheme were compacted, particularly in the subsoil layers. Low mean value of 570.70 kPa cone penetrometer resistance in the top 0-50 mm may be attributed to loosening of the soil by continuous hand-hoe tillage during weeding and harvesting of crops such as ground nuts and sweet potatoes. The mean value ranged between 1137.36-2445.73 kPa within the top 200 mm. The mean PR values for the topsoil showed the presence of plough layer compaction which forms within the bottom part of the plough layer due to repeated secondary cultivation with shallow implements like disc ploughs and random tractor movement across the field (Bennie, 2003). This can be very severe in a small-scale communal irrigation scheme like Rambuḍa Irrigation Scheme. This is damaging, especially for a clayey soil when heavy implements are used to cultivate the soil when it is at its wet state and its strength is low (Hillel, 1982). Wheel slip and smearing of the plough shears create a plough pan just below the plough depth. This layer can be a very dense, so that it severely restricts root growth, water percolation and nutrient transport (Bennie and Laker, 1979; Laker, 2001).

Studies have shown different thresholds of soil strength that inhibit root growth. Kees (2005) indicated that root growth is inhibited above 1500 kPa and roots cease to grow at cone penetrometer resistance >2500 kPa. The levels of PR in the topsoil are not

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favourable for shallow-rooted crops like groundnuts, sweet potatoes and maize, which are main crops in the irrigation scheme.

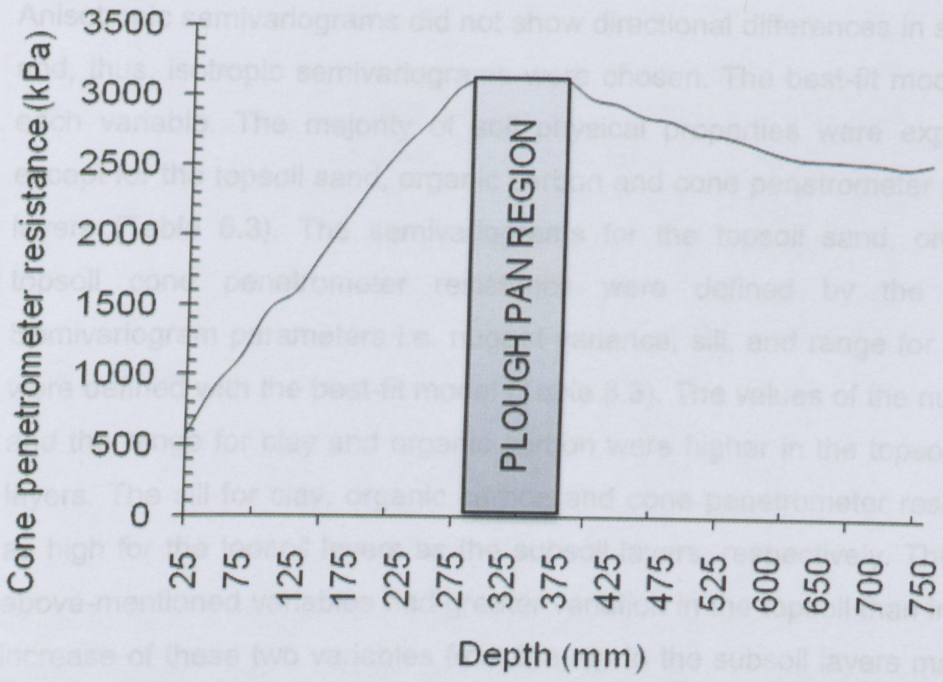


Figure 6.2 Mean field measured cone penetrometer resistance of the soil across the irrigation scheme

The impact of shallow tillage was evident just below 250 mm depth. Cone penetrometer resistance increased by between 3020 and 3163 kPa, forming a layer of very high compaction between 250 and 400 mm depths. According to Bennie (2003) this type of compaction is sub-plough layer compaction that can be a plough pan formed during primary cultivation with a mouldbourd plough due to pressure or smearing actions of the plough. Mouldbourd plough and disc ploughs are used for primary and secondary tillage respectively and often the other way round at Rambuḍa Irrigation Scheme. These implements till the soil to 250 mm depth, densifying packing of soil particles just below the 250 mm tillage depth (Kìliç *et al.*, 2004). These figures were higher than the threshold of 3038 kPa above which root growth of crops will cease. There was a decline in PR from 400 mm to 750 mm, the maximum depth of the instrument that was used to measure soil penetrability. However, the PR values remained above the threshold for the limitation of root growth for most crops.

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6.3.2 Spatial variability of soil properties

Anisotropic semivariograms did not show directional differences in spatial dependence and, thus, isotropic semivariograms were chosen. The best-fit model was defined for each variable. The majority of soil physical properties were exponentially defined except for the topsoil sand, organic carbon and cone penetrometer resistance for both layers (Table 6.3). The semivariograms for the topsoil sand, organic carbon and topsoil cone penetrometer resistance were defined by the spherical model. Semivariogram parameters i.e. nugget variance, sill, and range for each soil property were defined with the best-fit model (Table 6.3). The values of the nugget variance, sill and the range for clay and organic carbon were higher in the topsoil than the subsoil layers. The sill for clay, organic carbon and cone penetrometer resistance was twice as high for the topsoil layers as the subsoil layers, respectively. This implies that the above-mentioned variables had greater variation in the topsoil than in the subsoil. An increase of these two variables from the top to the subsoil layers may indicate higher structured variance nugget effect or random variability (Iqbal *et al.*, 2005). Such increase may be due to depositional events or a series of depositional events. In this case, continuous shallow tillage and variable application of organic manure may be the cause of high structured variance.

The ratios for defining distinctive classes of spatial dependence given in Table 6.1 state that if the ratio is <25%, the variable is considered to be strongly spatially dependent; if the ratio is 25-75%, the variable is considered to be moderately spatially dependent and if the ratio is >75%, the variable is considered weakly spatially dependent. Semivariograms of all soil physical properties showed moderate spatial dependence in both soil layers except organic carbon and topsoil cone penetrometer resistance (Table 6.3).

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Table 6. 3 Semivariograms of sand, clay, silt, organic carbon and cone penetrometer resistance

Variable	Layer	Model	Nugget variance	Sill	% Nugget	Spatial Class	Range
Sand	Topsoil	Spherical	0.02398	0.05556	43	Moderate	1264
	Subsoil	Exponential	66.80	167.70	40	Moderate	1316
Clay	Topsoil	Exponential	3.63	8.205	44	Moderate	1225
	Subsoil	Exponential	0.1382	0.2904	48	Moderate	682
Silt	Topsoil	Exponential	34.40	77.61	44	Moderate	1027
	Subsoil	Exponential	53.70	124.39	43	Moderate	1444
Organic carbon	Topsoil	Spherical	0.0112	0.882	13	Strong	88
	Subsoil	Spherical	0.0034	0.0665	5	Strong	84
Cone penetrometer resistance	Topsoil	Spherical	210000	4300000	5	Strong	169
	Subsoil	Exponential	18.03	36.07	50	Moderate	368

Organic carbon displayed a strong spatial dependence for the topsoil and the subsoil layers. Cone penetrometer exhibited strong spatial dependence for the topsoil and moderate spatial dependence for the subsoil layers. Cambardella *et al.* (1994) indicated that strongly spatially dependent properties may be controlled by intrinsic variation in soil characteristics such as texture and mineralogy. Soil texture may be the main cause of strong spatial dependence in topsoil cone penetrometer resistance at the irrigation scheme.

The values of range for sand, silt and cone penetrometer resistance for the topsoil layer were greater than those for the subsoil layers (Table 6.3). The range values for all soil physical properties were greater than the 100 m sampling distance, except for organic carbon. This indicates the presence of spatial structure beyond the sampling distance for soil physical properties >100 m. The range for topsoil organic carbon was 88 and 84 m for the subsoil layers. Semivariograms for organic carbon indicate the absence of spatial structure at 88 and 84 m for topsoil and subsoil layers, respectively. Range values for properties increased with soil depth except for clay and organic carbon. The ranges for the majority of soil properties were greater than 1 km, implying they were spatially correlated with each other at much greater distance than the sampling distance that was used in this study.

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6.3.3 Spatial distribution of soil properties across the irrigation scheme

Spatial maps can be used to interpolate spatial changes of soil properties of unsampled area based on their semivariograms (Goovaerts, 1997; Robertson, 2008). In general soils with highest values of 75.7-80.5% for topsoil sand were found in the eastern section which is a natural drainage area, extending from the north-western to the southeastern part of the irrigation scheme (Figure 6.3). There was positional relationship between Figure 6.3 and the observations by the farmers (Figure 4.1). However, their obesrvation contradicted with the measured sand content for the northern part of the eastern section of the irrigation scheme (Figure 4.1 and Figure 6.3). Soils with medium values of 72.7-75.5% for topsoil sand formed a small areas in the far eastern and part and the west of the midsection of the irrigation. The implications are that soills in these parts of the irrigation scheme are susceptible to compaction from tractor wheels causing subsoil traffic pans. Soils with low values of 55.1-66.7% for the topsoil sand extended from the northwestern part to the southeastern middle part of the irrigation scheme (Figure 6.3).

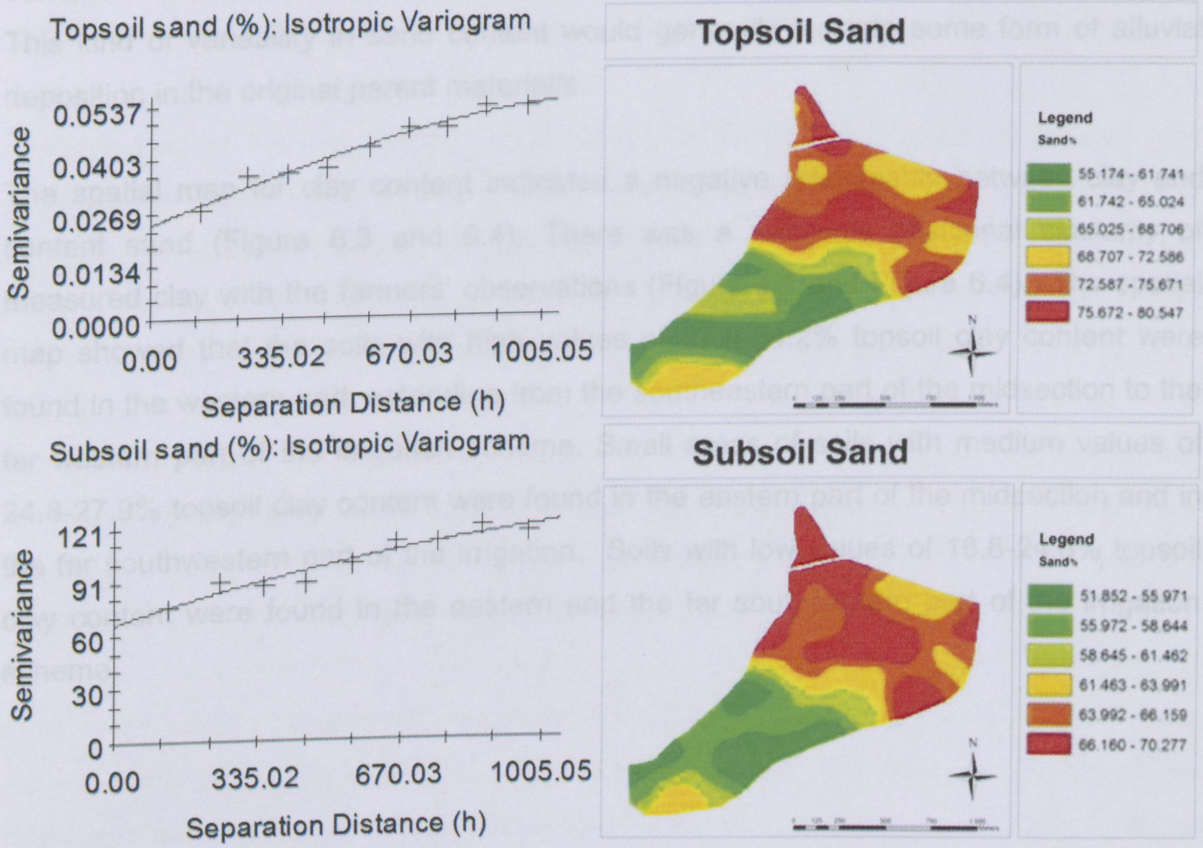


Figure 6. 3 Semivariograms and spatial maps of topsoil and subsoil sand

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Soils in these parts were dominated by medium sand. Sandy soils are more susceptible to compaction, particularly traffic compaction under wet conditions. Nortje *et al.* (2012) observed serious subsurface compaction due to vehicular traffic under moist conditions on soils with similar sand grade in northeastern Limpopo province. As already stated, farmers at Rambuḍa Irrigation Scheme would often have their plots ploughed quickly after rain in summer season for sweet potato and maize. This leads to ploughing the soil when it it still too wet and aggrevate severe subsoil compaction caused by tractor wheels.

Soils with values from 66.1-70.3% for sand content in subsoil layers were found in the eastern part which is a natural drainage area, extending from the southwestern part to the middle section of the eastern part of the irrigation scheme. Small areas of soils with medium values from 61.4-63.9% of sand content in the subsoil layers were found in the eastern and the far southwestern parts of the irrigation schme. The subsoil values for sand content of 51.8-61.4% were found on the western part of the irrigation scheme. There was positional relationship between the topsoil and the subsoil layer for the sand content which indicates some interaction between the topsoil and the subsoil layers. This kind of variability in sand content would generally indicate some form of alluvial deposition in the original parent material/s.

The spatial map for clay content indicated a negative relationship between clay and content sand (Figure 6.3 and 6.4). There was a relatively positional similarity of measured clay with the farmers' observations (Figure 4.1 and Figure 6.4). The spatial map showed that the soils with high values of 27.9-34.2% topsoil clay content were found in the western part, extending from the southeastern part of the midsection to the far western part of the irrigation scheme. Small areas of soils with medium values of 24.8-27.9% topsoil clay content were found in the eastern part of the midsection and in the far southwestern part of the irrigation. Soils with low values of 16.6-24.8% topsoil clay content were found in the eastern and the far southeastern part of the irrigation scheme.

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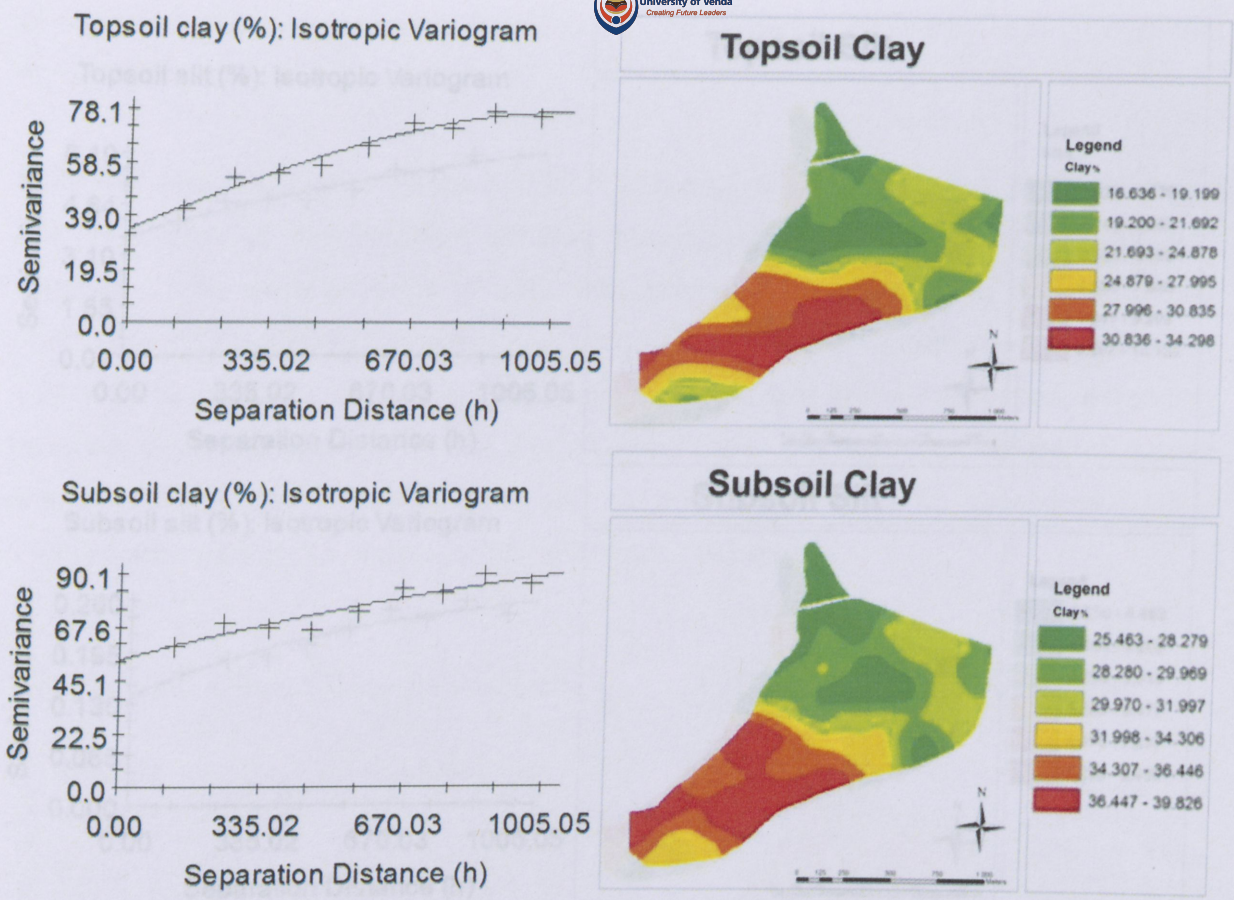


Figure 6. 4 Semivariograms and spatial maps of topsoil and subsoil clay

A small area of soil with slightly moderately low values of 34.3-39.8% subsoil clay occupied the western part, extending from the southeartern part of the midsection of the irrigation scheme. There was a postional relationship between the topsoil and the subsoil clay content. This indicates the some form of interaction between the two soil layers (Iqbal *et al.*, 2005; Sharma *et al.*, 2011). The clay content of the subsoil layer in the eastern part was 25.4-34.3% and small areas of 31.9-34.3% clay content were found in the east of the midsection and the far south part of the western section of the irrigation scheme. Soils in this section of the irrigation scheme are likely to suffer from plough pan compaction formed as a result of smearing by tillage implements, thereby compacting the subsoils, particularly if cultivation is done when the soil is too wet.

Soils of Rambuḍa Irrigation Scheme generally have moderately low silt content. Soils with relatively higher values of silt contnent were found in the low-lying section of the irrigation scheme (Figure 6.5). Small areas of soils with relatively higher topsoil values of 7.5-12.1% silt content were found in the western part, extending from the northwestern part of the midsection of the irrigation scheme.

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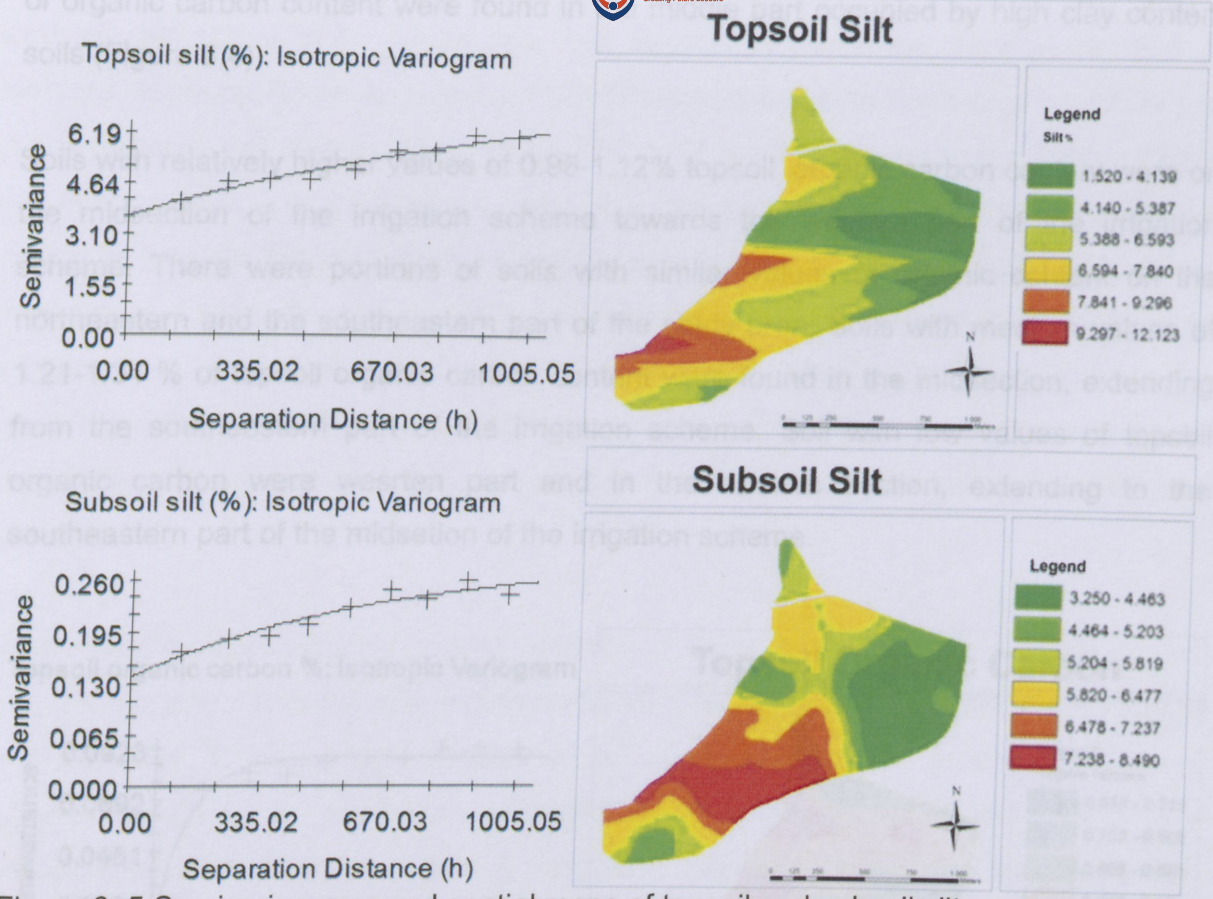


Figure 6. 5 Semivariograms and spatial maps of topsoil and subsoil silt

Soil with relatively higher topsoil values of 6.4-8.4% silt were found in the in the midsection extending from the northwestern part (Figure 6.5). Moderate values of 6.5-7.5% topsoil silt were found on soils in the northeastern tip and the midsection, extending to the south of the midsection. A small area of soils with similar values were found in the western part of the northeastern tip (Figure 6.5). Small areas of soils with moderate values of 5.8-6.4% subsoil silt content were found in the northeastern area, extending to the far southeastern part of the midsection of the irrigation scheme. Soils with low values of 3.2-5.8% subsoil silt content were found in similar positions as observed in the topsoil layers.

Spatial maps for organic carbon exhibited moderate varibility for both the topsoil and subsoil layer across the irrigation scheme (Figure 6.6). In general, soils at Rambuḍa Irrigation Scheme were very low in organic carbon. The topsoil layers displayed higher values of organic carbon content than the subsoil. The spatial maps for organic carbon showed that there was a positive positional relationship between clay content and soi organic carbon for both the topsoil and the subsoil. Consquently, soils with high values

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of organic carbon content were found in the middle part occupied by high clay content soils (Figure 6.4).

Soils with relatively higher values of 0.96-1.12% topsoil organic carbon content were on the midsection of the irrigation scheme towards the western part of the irrigation scheme. There were portions of soils with similar values of organic content on the northeastern and the southeastern part of the study area. Soils with medium values of 1.21-1.34 % of topsoil organic carbon content were found in the midsection, extending from the southeastern part of the irrigation scheme. Soil with low values of topsoil organic carbon were wesrten part and in the eastern section, extending to the southeastern part of the midsetion of the irrigation scheme.

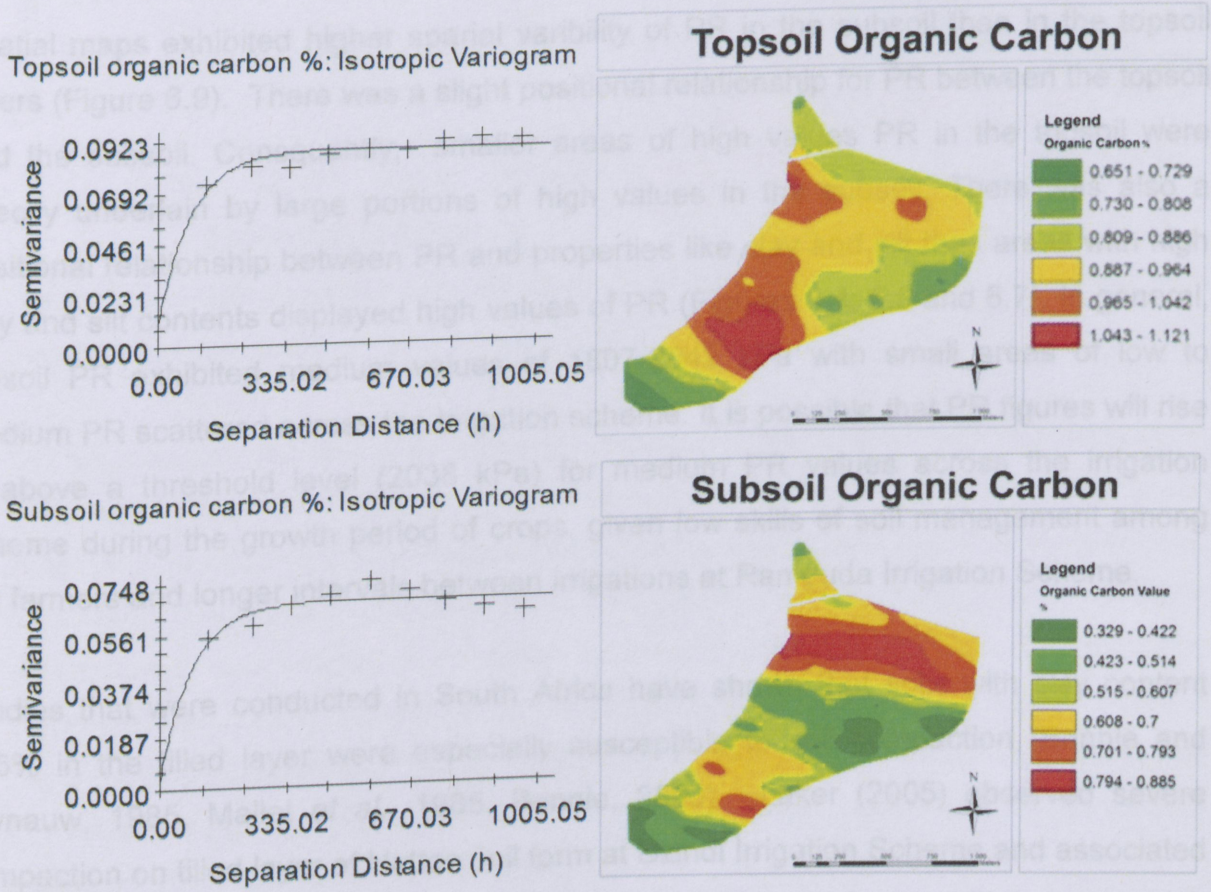


Figure 6. 6 Semivariograms and spatial maps of topsoil and subsoil organic carbon

Soils with high subsoil organic carbon values of 0.79-0.88 % occupied eastern part and small areas of similar values were found in the midsection section of the irrigation scheme. Spatial map exhibited low values of 0.32-0.60% in te far northern tip and the wetern part extending from the south eatern part of the irrigation scheme. Such low

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values of soil organic carbon contents normal for South African conditions, especially on sandy soils. Although, low carbon contents are normal, farmers at Rambuḍa Irrigation Scheme may not be sufficiently ploughing back crop residues into the soil to boost soil carbon stock. During the field survey and sampling, farmers were seen burning heaps of crop straw along the plot boundaries. Farmers had different reasons for burning the crop residues from lack of time to wait for the residues to decay before the next planting season and in some instances it was just lack of knowledge on the importance of crop residues in improving soil health and quality. There is a need to retrian agricultural advisors and farmers on good soil management practices for sustainable crop production, particularly the role of soil organic carbon in soil structure and soil fertility.

Spatial maps exhibited higher sparial varibility of PR in the subsoil than in the topsoil layers (Figure 6.9). There was a slight positional relationship for PR between the topsoil and the subsoil. Consquently, smaller areas of high values PR in the topsoil were directly underlain by large portions of high values in the subsoil. There was also a positional relationship between PR and properties like clay and silt thus areas with high clay and silt contents displayed high values of PR (Figures 6.4; 6.5 and 6.7). In general, topsoil PR exhibited medium values of 1807-2042 kPa with small areas of low to medium PR scattered across the irrigation scheme. It is possible that PR figures will rise to above a threshold level (2038 kPa) for medium PR values across the irrigation scheme during the growth period of crops, given low skills of soil management among the farmers and longer intervals between irrigations at Ramḍuda Irrigation Scheme.

Studies that were conducted in South Africa have shown that soils with clay content <15% in the tilled layer were especially susceptible to soil compaction (Bennie and Krynauw, 1985, Mallet *et al.*, 1985, Bennie, 2003). Laker (2005) observed severe compaction on tilled layer of Hutton soil form at Dzindi Irrigation Scheme and associated it with tractor-plough mismatch and ploughing the soil when it was still too wet which caused wheel slip, severe consenquetly compaction. This is a likely cause of such high PR values in this part of the Rambuḍa irrigation scheme. Disc plough has been used for a long time (more that 40 years) to plough the soil before secondary ridging and could be responsible for such severe compation in the topsoil as exhibiited by high PR values.

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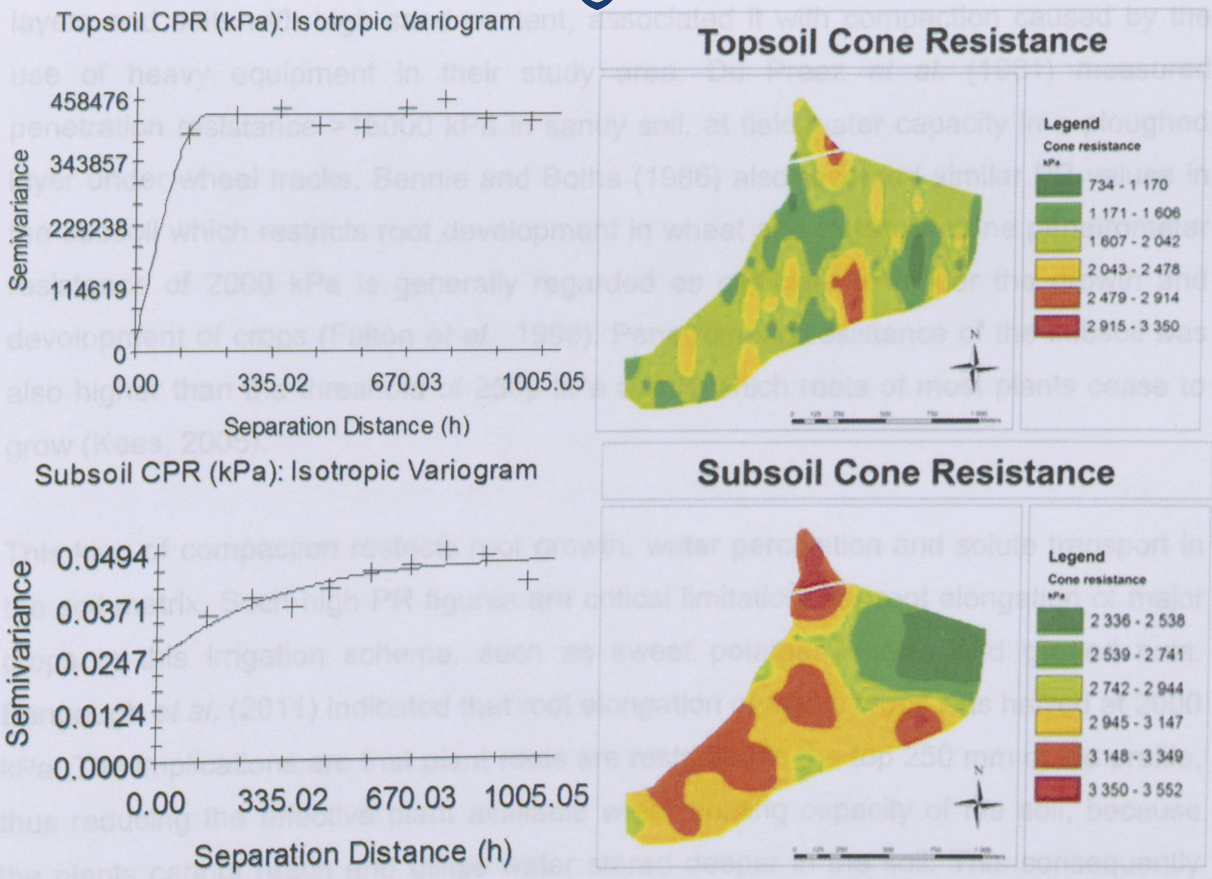


Figure 6. 7 Semivariograms and spatial maps of topsoil and subsoil cone penetrometer resistance

Spatial map showed that soils with high values of 2945-3552 kPa for the subsoil PR were largely found in the western part, extending from the northern tip of the irrigation scheme. The western part was occupied by sandy clay to clay red soils of Hutton soil form with clay content ranging from 31.9-39.9% (Figure 6.3). These soils are susceptible to sub-plough pan compaction caused by wheel slips or smearing of soil by implements such as disc plough if the soil is tilled while it is too wet. As already stated in the preceding paragraphs, farmers at Rambuḍa Irrigation Scheme have been using disc and mouldourd ploughs interchangeabley for primary tillage, often when the soil was too moist and tractor-plough size mismatch.

Spatial map showed medium values from 2945-3147 kPa PR were found in the southeastern part of the irrigation scheme (Figure 6.7). Although PR values in this part were not as high as those recorded in the western part, they were greater than the threshold value of 2038 kPa for medium compaction. Thus, the soils in this sandy area were heavily compacted. Iqbal *et al.* (2005) observed high bulk density in fine sandy

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layers and soils with high sand content, associated it with compaction caused by the use of heavy equipment in their study area. Du Preez *et al.* (1981) measured penetration resistance >15000 kPa in sandy soil, at field water capacity in a ploughed layer under wheel tracks. Bennie and Botha (1986) also recorded similar PR values in the subsoil which restricts root development in wheat and maize. A cone penetrometer resistance of 2000 kPa is generally regarded as sufficient to hinder the growth and development of crops (Fulton *et al.*, 1996). Penetrometer resistance of the subsoil was also higher than the threshold of 2500 kPa above which roots of most plants cease to grow (Kees, 2005).

This kind of compaction restricts root growth, water percolation and solute transport in the soil matrix. Such high PR figures are critical limitations for root elongation of major crops in this irrigation scheme, such as sweet potatoes, maize and ground nuts. Bengough *et al.* (2011) indicated that root elongation of maize crops was halved at 2000 kPa. The implications are that plant roots are restricted to the top 250 mm of the profile, thus reducing the effective plant available water holding capacity of the soil, because the plants cannot reach and utilise water stored deeper in the soil. This consequently leads to poor plant growth and uneven crop stands and low yields (Bengough *et al.*, 2011). Bengough *et al.* (2011) also stated that PR of 2000 kPa occurs even in many relatively moist soils at matric potential of -100 kPa to 200 kPa which is enough to inhibit root growth leading to poor plant growth and yields. Botha and Bennie (1982) reported up to 30% reduction in yield due to soil compaction in maize, while a reduction of 22% in potato was reported by Fulton *et al.* (1996). Such high values of PR may have unprecedented effects on plant growth and yields, particularly for Rambuḍa Irrigation Scheme were irrigation scheduling is poor. Soil compaction reduced the uptake of P and K by plants, causing stunted growth of plants in certain areas more than in others (Bennie and Laker, 1975). These nutrient elements are important for both the quality and yields of sweet potatoes and other vegetables that are grown in this irrigation scheme. During field measurements of soil penetrability, farmers indicated that the soil had not been ripped for over a ten (10) years. According to Ṇethononda and Odhiambo (2011), farmers indicated that yields have been going down over the years and there is uneven crop stand within a single plot and across the irrigation scheme. Soil compaction as exacerbated by poor irrigation management may be the main cause of spatial variation in crop stands and yield within the plots and across the irrigation scheme.

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The values of PR of the soils at Rambuḍa Irrigation Scheme were generally higher than the threshhold for the heavy PR categories defined by Rooney *et al.* (2005), implying that the soils were heavily compacted, particularly in the subsoil layers. There is an urgent need for deep tillage at Rambuḍa Irrigation Scheme to sustain good crop production. Subsoil compaction can be alleviated by deep ripping and controlling the wheel traffic of implements to fixed parallel lanes (Bennie and Botha, 1986; Nortjé *et al.*, 2012). This approach may be very effective for Rambuḍa Irrigation Scheme because crops are planted in parallel row ridges. Bennie (2003) indicated that on sandy soils with <8% clay, deep breaking of the soil with a ripper every time before planting is advisable. Deep tillage and controlled trafficking had proven to be an effective solution to compaction. Bennie and Botha (1986) showed that deep ripping and controlled traffic led to a significant increase in rooting depth, rooting density in the subsoil, water use efficiency reuslting in a 30% and 19% increase in yields for maize and wheat, respectively. The use of heavy machinery is not advisable for small-scale communal irrigation scheme due to their costs and impact on the soil. Denison and Wotshela (2009) reported a very useful system of soil cultivation in the Eastern Cape and ironically this system was also used in Vhembe District, but has been rapidly disappearing since the introduction of tractors and can now only be found among subsistence farmers under rainfed crop farming conditions, in paricular. Laker (2005) reported a positive practice used by a farmer at Dzindi irrigation scheme whose plot had no soil compaction. This farmer used a tractor in his first cultivation, followed up with an ox drawn plough tillage before planting. Laker suggested that any compated layer that might have formed during the first tractor plough cultivation was broken during the second ox drawn plough cultivation. This approach may be the appropriate solution to dealing with soil compaction problems in small-scale communal irrigation schemes.

However, site-specific tillage may be the appropriate cost-effective approach for the subsoils because compacted layer does not occur at uniform depth across an irrigation scheme. In comparing site-specific tillage and subsoilling of the entire field found a saving of almost 67% savings per hactare on fuel costs when using site-specific tillage (America Society of Agricultural Engineers, 1999).

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6.4 Conclusions

Results of spatial variability analysis of soil properties displayed presence of a moderate structure for most measured properties imprinted by soil forming factors and management practices such as different tillage practices caused by variation plough depths calibrations, tractor speeds, hand-hoeing during weed control and harvesting of sweet potatoes and different application rates and types of manure. The influence of soil forming factors was also evidenced by positional relationship of most properties. Spatial maps confirmed the moderate spatial structure for most properties except the topsoil PR which displayed lesser variability. Such lesser variability can be attributed to shallow conventional tillage using mould board and disc ploughs which only till the soil to 25 cm depth. Heavy subsoil PR indicated the effects of shallow tillage. The figures for topsoil PR were near 2000 kPa which is the threshold at which roots of most plants stop to grow. Heavy PR figures are expected to reach heavy PR during the growing period of the crops due to poor soil management skills and irrigation scheduling. Such heavy PR coupled with poor irrigation scheduling is not good for crop production. This necessitates introduction of soil management training programmes for agricultural advisors and agricultural technicians, particularly soil cultivation and irrigation scheduling. Quantification of spatialy variability in site-specific management zones of soil physical properties, particularly soil penetrability indicated that the topsoil layer at Rambuḍa Irrigation Scheme can be treated as one site-specific management zone during conventional tillage. Geostatistics can be used to predict predict soil properties of unsampled areas of the irrigation scheme allowing the implementation of site-specific management. Spatial maps can be used to predict boundaries of mapping units for land suitability evaluation.

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CHAPTER SEVEN

SPATIAL VARIABILITY OF SOIL pH, EXTRACTABLE PHOSPHORUS, POTASSIUM, CALCIUM AND MAGNESIUM

Abstract

Understanding of spatial distribution of chemical soil properties is necessary for proper nutrient management. The objective of this chapter was to determine the spatial variability of pH, P, K, Ca and Mg across a 120 ha communal irrigation scheme for land suitability evaluation. A total of 115 soil samples were collected from two soil depths (0-30 and 30-60 cm) on a 100 m grid. Soil samples were analyzed for pH, extractable P, K, Ca and Mg. Data were subjected to descriptive statistical analysis and geostatistical analysis using SAS 9.0 and GS+ 9, respectively. Soils showed high variability for all variables analyzed for topsoil and subsoil layers. Extractable P, K, Ca and Mg had high CV's (122 and 154, 67 and 84 and 70 and 66% respectively) for topsoil and subsoil layers. Soil pH showed a low CV (6.0%) for topsoil and subsoil layers. Most properties were analyzed with the exponential model except Ca and Mg that were fitted to a spherical and Gaussian model. All variables that were fitted with exponential model had strong spatial structure and those fitted to a spherical model had a moderate spatial structure. Spatial contour maps displayed a positional relationship between the topsoil and subsoil layers. Soils at Rambuḍa Irrigation Scheme were generally low in P, K, Ca and Mg mainly due to poor soil fertility management. Areas with low K and P can be delineated into separate management zones based on their requirements for these elements. These maps can be used to implement a variable-rate of input application strategy, thereby reducing variation in soil fertility status caused by application of different types and rates of manure and fertilizers. The results showed that there is a serious skills gap on soil fertility issues. Serious steps should be taken to address this gap to ensure sustainable crop production in this irrigation scheme and other communal irrigation schemes in the country. This will reduce costs of fertilization which would otherwise be incurred when using uniform applications of fertilizer across the irrigation scheme and thus ensure sustainable crop production.

7.1 Introduction

An understanding of the spatial variability of soil chemical properties at field and time scale is important for agricultural management practices for sustainable crop production (Cambardella *et al.*, 1994; Couto *et al.*, 1997; Kalivas *et al.*, 2002; Ayoubi *et al.*, 2007; Bai *et al.*, 2011; Sharma *et al.*, 2011). Spatial variability of soil nutrients is mainly attributed to fertilizer history of the individual farm, diversity of crop types and varieties (Jin and Jiang, 2002). A high degree of variability could be the result of previous fertilization history and this makes first-time mapping of soil test levels, difficult (Lauzon *et al.*, 2005). Crop production is affected by spatial variability of soil chemical properties

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within and across the field (Brouder, *et al.*, 2001; Kalivas *et al.*, 2002). Khosla *et al.* (1999) indicated that uniform application of inputs such as fertilizers often results in over- and under application in various parts of the field due to in-field variability. Sen *et al.* (2007) indicated that the variability of soil nutrients under small-scale operations was more related to the history of fertilizer application, crop variety and field management.

Knowledge of spatial variability of soil chemical properties is useful in the assessment of the fertility status of mapping units. Recently, an approach of combining portions of the field with homogenous yield-limiting factors, for which a single rate of a specific crop input is appropriate into management zones (Doerge, 1999) has been adopted in agriculture (Khosla *et al.*, 2002). The principles used to delineate management zones are similar to those recommended by in the FAO (1976; 1985). Site-specific management zones were delineated according to variability in colour of bare soil imagery of tilled land, farmers' perceptions of field topography and farm knowledge of past production practices (Khosla *et al.*, 2002; Fleming *et al.*, 2000). This approach can be successfully used in the first stage land evaluation, but care must be taken in assessment of soil fertility requirements after varied fertilizer and manure applications.

Studies on spatial variability of soil chemical properties focused on physical properties, topography, and yields (Kalivas *et al.*, 2002) under good management practices. Farmers at Rambuḍa irrigation scheme do not have information on fertility status and their spatial distribution. Farmers reported variation in crop stand within individual plots and across the irrigation scheme as reported in Chapter 4 of this thesis. Such variation may be caused by in-field variability of soil fertility status (Khosla et al., 1999). Farmers at Rambuḍa Irrigation scheme only guess the type and amounts of manure and fertilizers to be applied in their plots as they do not send soil samples for laboratory tests of fertility status of their plots. This means that they may be applying too much or too little to the soil as they apply uniformly across the plot. Knowledge of the spatial variability of nutrients in the soil can be useful in the assessment of required land improvements of a mapping unit during land suitability evaluation.

The objective of this chapter was to determine spatial variability of selected soil chemical properties important for plant growth across the irrigation scheme.

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7.2 Materials and methods

7.2.1 Sampling and laboratory analysis

Soil sampling distance is dependent on the extent of research area (Sun *et al.*, 2003). Soil samples were collected from 0-30 cm and 30-60 cm depths on a 100 x 100 m grid over 120 ha. A total of 115 soil samples were collected from both depths. All sampling sites were georeferenced with a geographic information system. Soil samples were taken to the laboratory for analysis of soil pH, extractable P, K, Ca and Mg. Samples were prepared and analyzed according to the procedure described in the Handbook of Standard Soil Testing Methods for Advisory Purposes (The Non-Affiliated Soil Analysis Work Committee, 1990). Soil pH (H_2O) was determined using 1:2.5 soil/water suspension ratio, extractable P (Bray 1), and extractable K, Ca and Mg using 1 mol l^{-1} NH_4Ac.

7.2.2 Statistical and geostatistical analysis

Data were subjected to descriptive statistical analysis for minimum, maximum, mean, standard deviation, skewness (Shapiro-Wilk, 1965) and coefficient of variation for the two soil depths using SAS 9.0 (2010). Most measured variables displayed non-normal distributions for both the topsoil and subsoil layers, except soil pH for both depths and topsoil Mg which showed normal distributions (Figures 7.1-7.4). Skewed distributions should be transformed to near normal distributions using either log-transformation or square-root-transformation before geostatistical analysis (Robertson, 2008). Data with non-normal distributions may lead to high fluctuation in variograms and reduce the reliability of the analytical results (Isaacks and Srivastava, 1989, Özgöz et al., 2012). Non-normal data were transformed to near normal using log-transformation or square-root techniques and, where necessary, back-transformation was done using the weighted technique (Robertson, 2008).

GS+ 9.0 Gamma Designs (Robertson, 2008) software was used to analyze the spatial structure of the data and to describe the semivariograms (Trangmar *et al.*, 1985; Cambardella *et al.*, 1994). The models were fitted to the semivariogram data Oliver,

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1987, Isaacks and Srivastava, 1989). The semivariogram was calculated using the following equation (Goovaerts, 1997):

$$\gamma(h) = \frac{1}{2N(h)}\left\{\sum_{i=1}^{N(h)}[Z(x_i-h)-Z(x_i)]^2\right\} \quad (7.1)$$

where (h) is the semivariance for interval class h, $N(h)$ is the number of pairs separated by lag distance where the distance between samples = 100 m, $Z(x_i)$ is the measured variable at spatial location i, $Z(x_i+h)$ is the measured variable at spatial distance location $i+h$.

There are three parameters which describe the spatial structure of a semivariogram, namely nugget effect (C_0), the sill (C_0+C) and the range (Robertson, 2008). The semivariogram increases with distance between sampling locations, rising to a more or less constant value called the sill at a given separation distance called the range of spatial dependence (Trangmar *et al.*, 1985). The range is the maximum separation distance beyond which there is no longer spatial dependence between the measured variables (Goovaerts, 1997).

Ordinary kriging was used to interpolate each measured soil pH, P, K, Ca and Mg to prepare spatial maps at each soil depth (Isaacks and Srivastava, 1989). Interval breaks to describe spatial maps for each measured soil property were according to the reference values of interpretation of soil analysis presented in the Fertilizer Handbook (FSSA, 2003) using respective semivariograms. Spatial maps for each measured soil property were drawn using ArCGIS 9.0 (ESRI, 2006). This was done to make spatial maps user-friendly.

7.3 Results and discussion

The data for subsoil pH, P, K, Ca and subsoil Mg exhibited non-normal distributions and only the topsoil pH and Mg displayed normal distributions. All the non-normal distributions were positively skewed and this indicated that most outliers were to the right of the distributions (Figures 7.1-7.4). The non-normal distributions for topsoil P, K and subsoil Mg were transformed to near normal distributions. The topsoil P remained non-normal after attempting transformation techniques and the distribution only looked better, but not normal, after square-root transformation (Figure 7.1) The same trend

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was observed for the topsoil and subsoil Ca and subsoil K after log-transformation (Figure 7.2 and 7.3). Cambardella *et al.* 1994 reported a similar trend, where many variables remained non-normal after log-transformation. The Shapiro-Wilk (1965) test for normality of the data showed that all measured variables were greater than $P>0.05$ and significantly skewed (Table 7.1).

All measured variables showed higher values in the topsoil than the subsoil layers (Table 7.1). Soil pH displayed moderate variability for both topsoil and subsoil layers (Table 7.1). The minimum and maximum values for pH in the topsoil and subsoil were 5.20 and 7.40 and 5.00 and 7.20, respectively. The mean values for pH in the topsoil and subsoil were 6.12 and 6.16, respectively (Table 7.1).

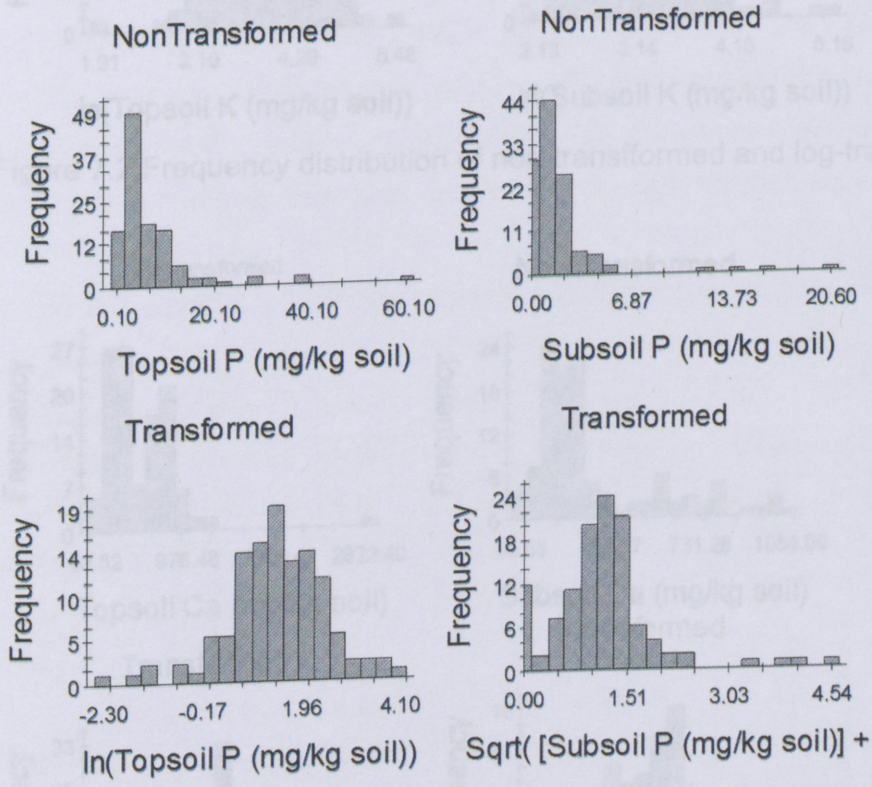


Figure 7.1Frequency distribution of non-transfformed and square-root-transformed soil P

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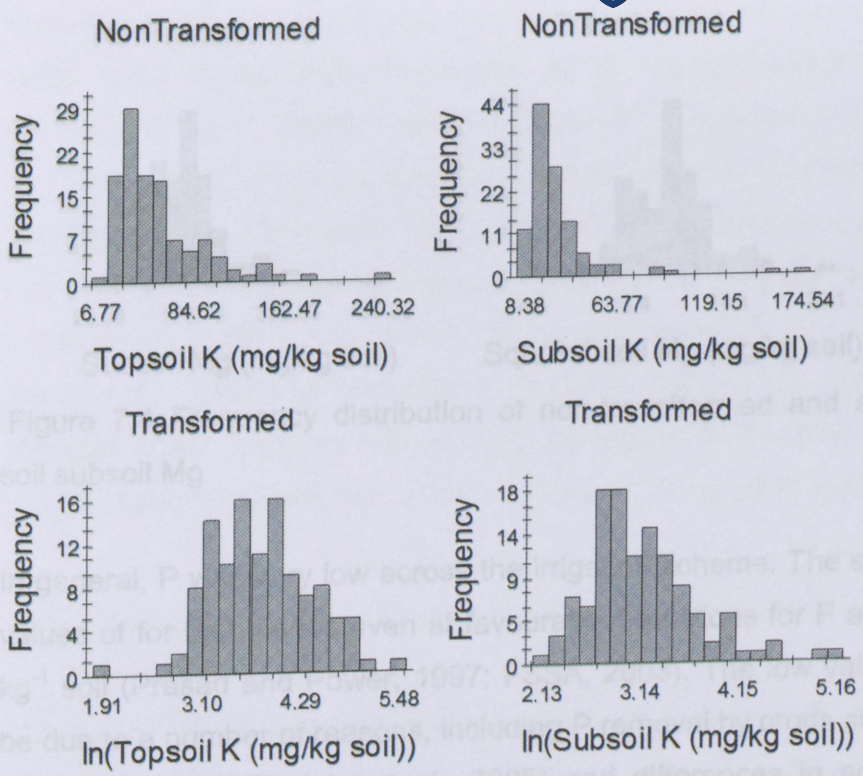


Figure 7.2 Frequency distribution of non-transfformed and log-transformed soil K

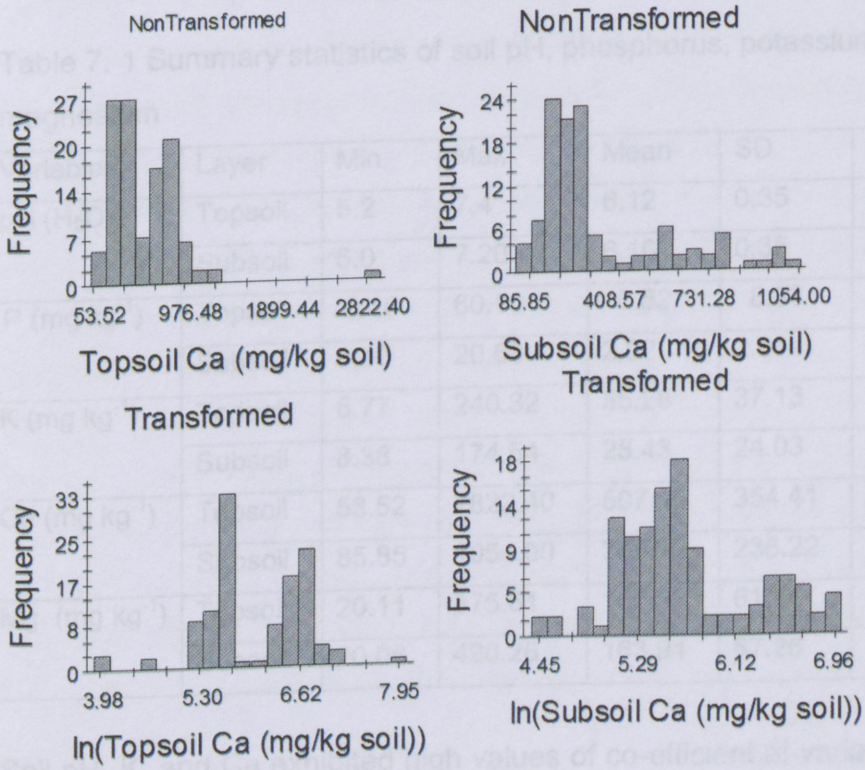


Figure7.3 Frequency distribution of non-transfformed and log-transformed soil Ca

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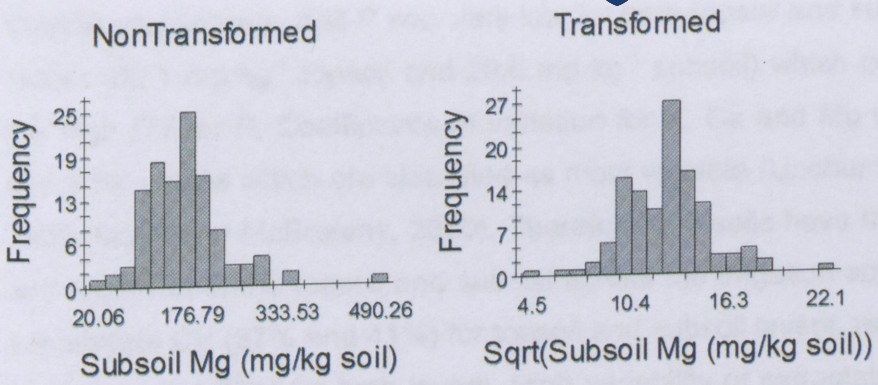


Figure 7.4 Frequency distribution of non-transfformed and square-root-transformed soil subsoil Mg

In general, P was very low across the irrigation scheme. The soil P contents gave low values of for both layers even at favourable conditions for P availability of 5.5-6.8 mg kg^{-1} soil (Prasad and Power, 1997; FSSA, 2003). The low values for the topsoil may be due to a number of reasons, including P removal by crops such as maize which has high P demand (Tisdale *et al.*, 2005) and differences in agronomic practices like fertilization and treatment such as burning of crop residues after harvest.

Table 7. 1 Summary statistics of soil pH, phosphorus, potassium, calcium and magnesium

Variables	Layer	Min	Max	Mean	SD	Skewness	CV
pH (H_2O)	Topsoil	5.2	7.4	6.12	0.35	0.430	6
	Subsoil	5.0	7.20	6.16	0.35	-0.390	6
P (mg kg^{-1})	Topsoil	0.10	60.10	6.82	8.33	3.510	122
	Subsoil	0.10	20.60	2.02	2.91	4.410	154
K (mg kg^{-1})	Topsoil	6.77	240.32	55.28	37.13	1.950	67
	Subsoil	8.38	174.54	28.43	24.03	3.790	84
Ca (mg kg^{-1})	Topsoil	53.52	2822.40	507.35	354.41	2.610	70
	Subsoil	85.85	1054.00	355.72	236.22	1.370	66
Mg (mg kg^{-1})	Topsoil	20.11	375.61	167.63	61.36	0.560	37
	Subsoil	20.06	490.26	163.94	67.26	1.390	41

Soil pH, K, and Ca exhibited high values of co-efficient of variation for both the topsoil and subsoil layers, while Mg displayed moderate co-efficient of variation (Table 7.1). Soil pH displayed low variability with coefficient of variation values of 6% for both topsoil and subsoil. Phosphorus displayed CV of 122% and 154% for the topsoil and

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subsoil respectively. Soil P was very low for both topsoil and subsoil, but there was an outlier (60.1 mg kg^{-1} topsoil and 20.6 mg kg^{-1} subsoil) which could be responsible for the high CV for P. Coefficients of variation for K, Ca and Mg were greater than 30% and 31% values which are classified as most variable (Upchurch *et al.*, 1988; Wilding, 2000; Mulla and McBrateny, 2000). Therefore, the soils have high variability for K, Ca and Mg for both the topsoil and subsoil across the irrigation scheme. Magnesium has a moderate CV (37% and 41%) for topsoil and subsoil layers, respectively. Soil pH has the lowest CV (6%) for both layers. High variability of extractable P, K, Ca and Mg at this communal irrigation scheme may be due to differences in application rates and type of manure or fertilizers used by individual farmers in the irrigation scheme.

7.3.1 Spatial variability of pH, extractable P, K, Ca and Mg

The results of semivariance analysis for pH, P, K, Ca and Mg for the two soil layers (0-30 and 30-60 cm) are presented in Table 7.2. The data did not show any trend, therefore detrending was not necessary for these data. There was no evidence of anisotropy in the directional semivariograms for all measured soil properties. Thus, isotropic models were the best-fit to describe the semivariograms for all soil properties. Semivariogram parameters for soil pH, topsoil P and K were defined by the exponential model while Ca and topsoil Mg were defined by a spherical model. The best-fit model to define the semivariogram for the subsoil P was a Gaussian model. The nugget variance and the sill for pH, P and Mg were higher for the topsoil layers than the subsoil layers (Table 7.2), implying greater variation. Such variation may be attributed to differences in types and rates of fertilizers and manure applied to the soil. Sen *et al.* (2007) attribute the high spatial variability of soil P content to differences in P application rate between farmers. The nugget, sill, nugget % and range for K and Ca increased with depth. This indicated high structured variance, nugget effect or random variability (Trangmar *et al.*, 1985). Such small nugget variances for topsoil K and Ca (0.001) were close to zero. This may indicate the presence of variability of K and Ca at distances smaller than the typical sample space used in this study (Trangmar *et al.*, 1985, Robertson, 2008).

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Table 7. 2 Semivariograms of soil pH, phosphorus, potassium, calcium and magnesium

Variable	Layer	Model	Nugget variance	Sill	% Nugget	Spatial class	Range
pH(H_2O)	Topsoil	Exponential	0.0192	0.133	14	Strong	264
	Subsoil	Exponential	0.0078	0.124	6	Strong	9
P (mg kg^{-1})	Topsoil	Exponential	0.105	1.157	9	Strong	276
	Subsoil	Gaussian	0.033	0.355	9	Strong	276
K (mg kg^{-1})	Topsoil	Exponential	0.001	0.332	0.2	Strong	114
	Subsoil	Exponential	0.192	0.615	31	Moderate	6615
Ca (mg kg^{-1})	Topsoil	Spherical	0.001	0.441	0.2	Strong	1028
	Subsoil	Spherical	0.235	0.520	45	Moderate	1439
Mg (mg kg^{-1})	Topsoil	Spherical	2247	4495	50	Moderate	943
	Subsoil	Spherical	3.69	7.738	48	Moderate	1028

Comparison of the relative sizes of the nugget effect among soil properties can be made by expressing nugget semivariance as percentage of total semivariance (Trangmar *et al.*, 1985). Cambardella *et al.* (1994) used this ratio to define distinct spatial dependence of soil properties as follows: the variable is considered to be strongly dependent when the ratio is ≤25%, moderately dependent when the ratio is between 25% and 75% and weakly dependent when the ratio is >75%. The percentage of nugget to sill ratio showed a strong spatial dependence for pH, extractable P, topsoil K, and Ca (Table 7.2). This might be attributed to intrinsic factors like the parent material of the soil (Section 2.3) or extrinsic such as leaching of bases in this high rainfall area (Table 2.1) and poor soil fertility management. Subsoil K and Mg was moderately spatially dependent which might be attributed to extrinsic factors. The range of influence is the distance beyond which observations are not spatially dependent (Trangmar *et al.*, 1985). The range for the majority of the measured soil chemical properties and pH were >100 m, except for the subsoil pH (Table 7.2), implying that spatial relatedness extended over several soil mapping units for these variables (Cambardella *et al.*, 1994).

7.3.2 Spatial distribution of soil pH, P, K, Ca and Mg across the irrigation scheme

Soil pH displayed moderate variability for both the topsoil and the subsoil layers across the irrigation scheme, and can be considered suitable for most crops (Landon, 1991). Soils with slightly acid pH values (6.0-6.7) for the topsoil and subsoil layers were spread across the irrigation scheme (Figure 7.5). This implies that the irrigation scheme can be

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managed as a single site-specific management zone for soil pH allowing a uniform liming programme for the whole irrigation scheme. Small areas of soils with very strongly (4.0-5.0) and strongly (5.0-5.5) acid pH values were scattered across the irrigation scheme for both the topsoil and the subsoil layers. Such low pH results in excessive availability of Ac, Mn and Fe which may reach toxic levels (Prasad and Power, 1997). However, the pH of these small areas may over time of good liming be increased to optimum levels for most crops. Spatial maps displayed a similar trend for soils with a moderately and neutral pH values of 6.0-6.7 and 6.8-7.2, respectively for both layers (Figure 7.5). There was a positional relationship between the topsoil pH and the subsoil pH across the irrigation scheme, indicating some interaction between these layers of the soil. In general, the subsoil pH at Rambuḍa Irrigation Scheme was very low (Figure 7.5).

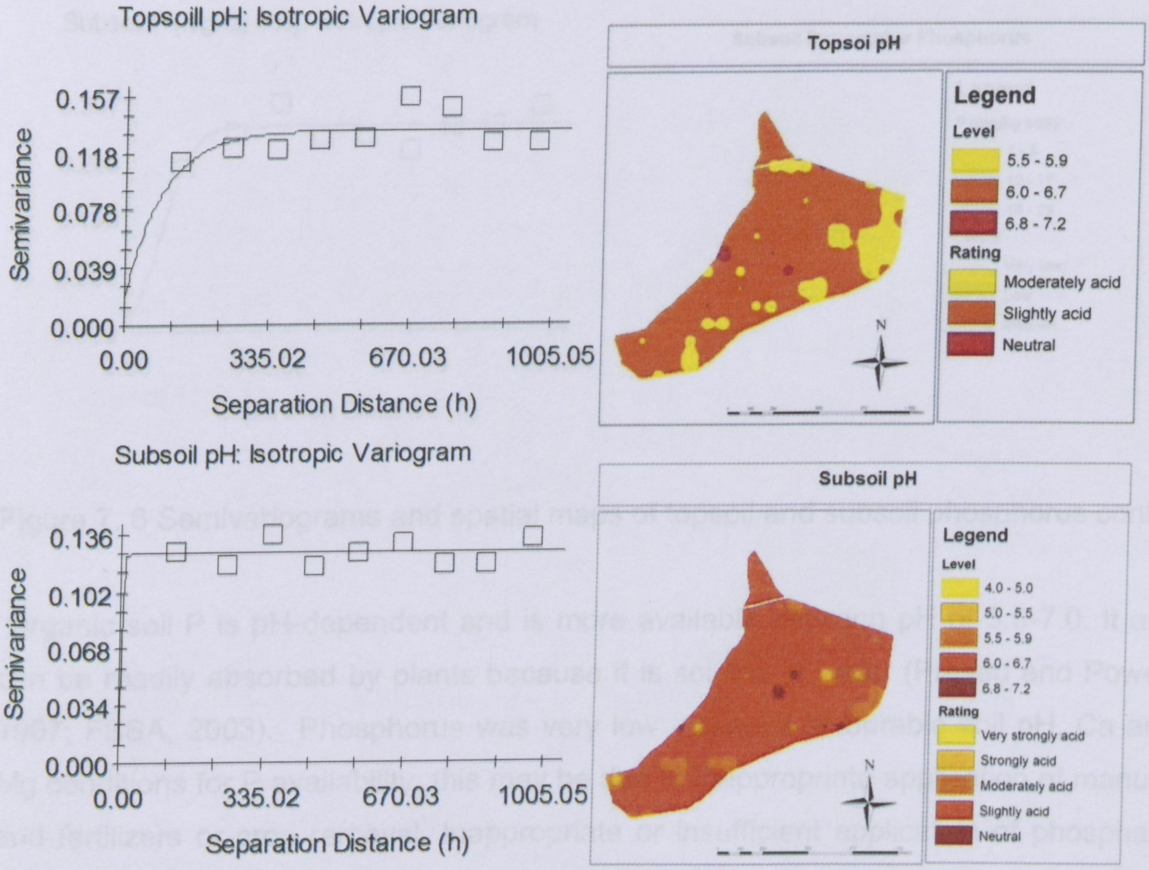


Figure 7. 5 Semivariograms and spatial maps of topsoil and subsoil pH

Spatial maps for P exhibited high variability in topsoil layers when compared with the subsoil P variability (Figure 7.6). The maps showed that soils at Rambuḍa Irrigation Scheme were very low in P, in general. The spatial maps showed that the soil with

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medium (18-25 mg kg^{-1} soil) soil P were scattered in the southeastern part and in the midsection, extending from the northwestern to the southeastern part of the midsection of the irrigation scheme. Soil P content (1.0-9.0 mg kg^{-1} soil) was very low for both the topsoil and the subsoil layers across the irrigation scheme, in general.

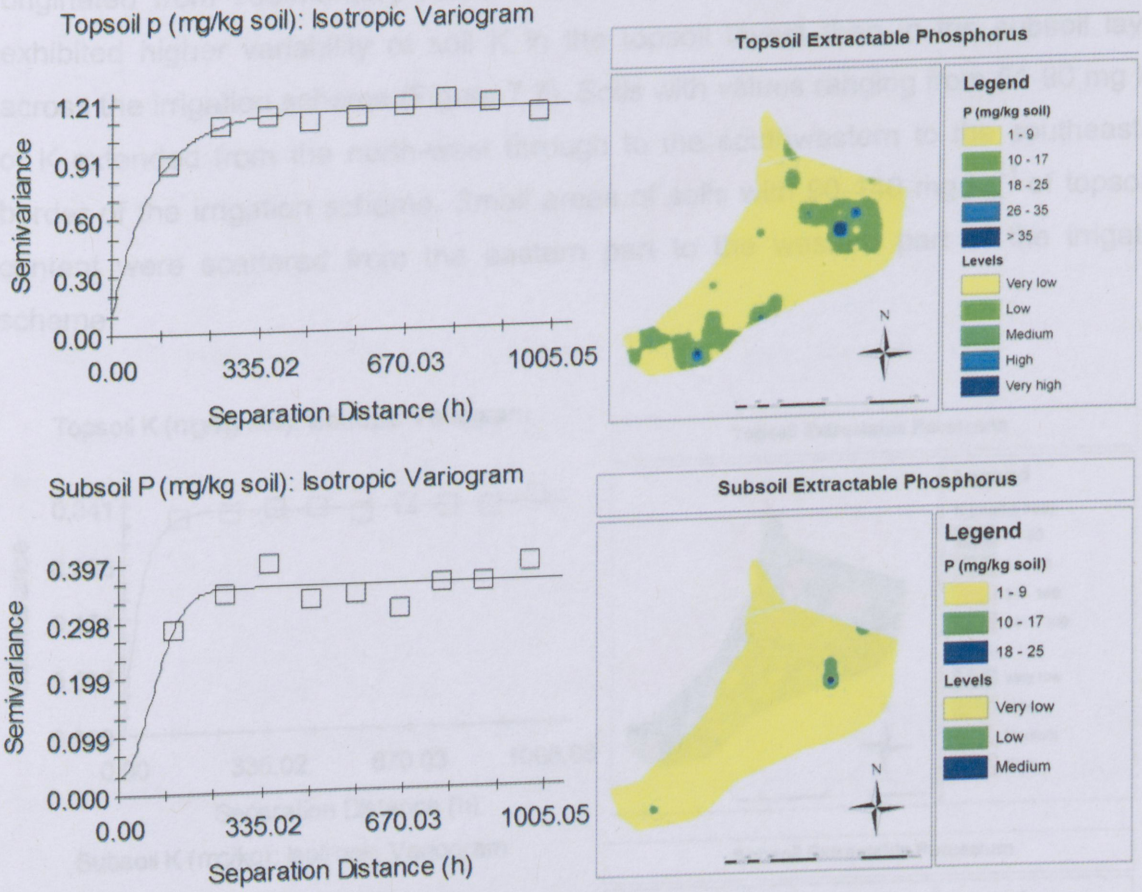


Figure 7. 6 Semivariograms and spatial maps of topsoil and subsoil phosphorus content

Organic soil P is pH-dependent and is more available between pH of 5.5-7.0. It and can be readily absorbed by plants because it is soluble in water (Prasad and Power, 1997; FSSA, 2003). Phosphorus was very low despite favourable soil pH, Ca and Mg conditions for P availability, this may be due to inappropriate application of manure and fertilizers or crop removal. Inappropriate or insufficient application of phosphate fertilizers was probably caused by lack of information on nutrient status of the soil as farmers do not send their soils to laboratories for testing for fertility status, due to a lack of knowledge or funds.

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Soils at Rambuḍa Irrigation were generally very low in soil potassium in both the topsoil and the subsoil (Figure 7.7). Sparks (2000) indicated that igneous rocks contain more K than sedimentary rocks. This coupled with poor fertilization might be the cause of such low K content in this irrigation scheme as soils in this area have mainly originated from sedimentary rocks. Soil K is also highly leachable. Spatial maps exhibited higher variability of soil K in the topsoil layers than in the subsoil layers across the irrigation scheme (Figure 7.7). Soils with values ranging from 51-90 mg kg^{-1} of K extended from the north-west through to the southwestern to the southeastern border of the irrigation scheme. Small areas of soils with 90-140 mg kg^{-1} of topsoil K content were scattered from the eastern part to the western part of the irrigation scheme.

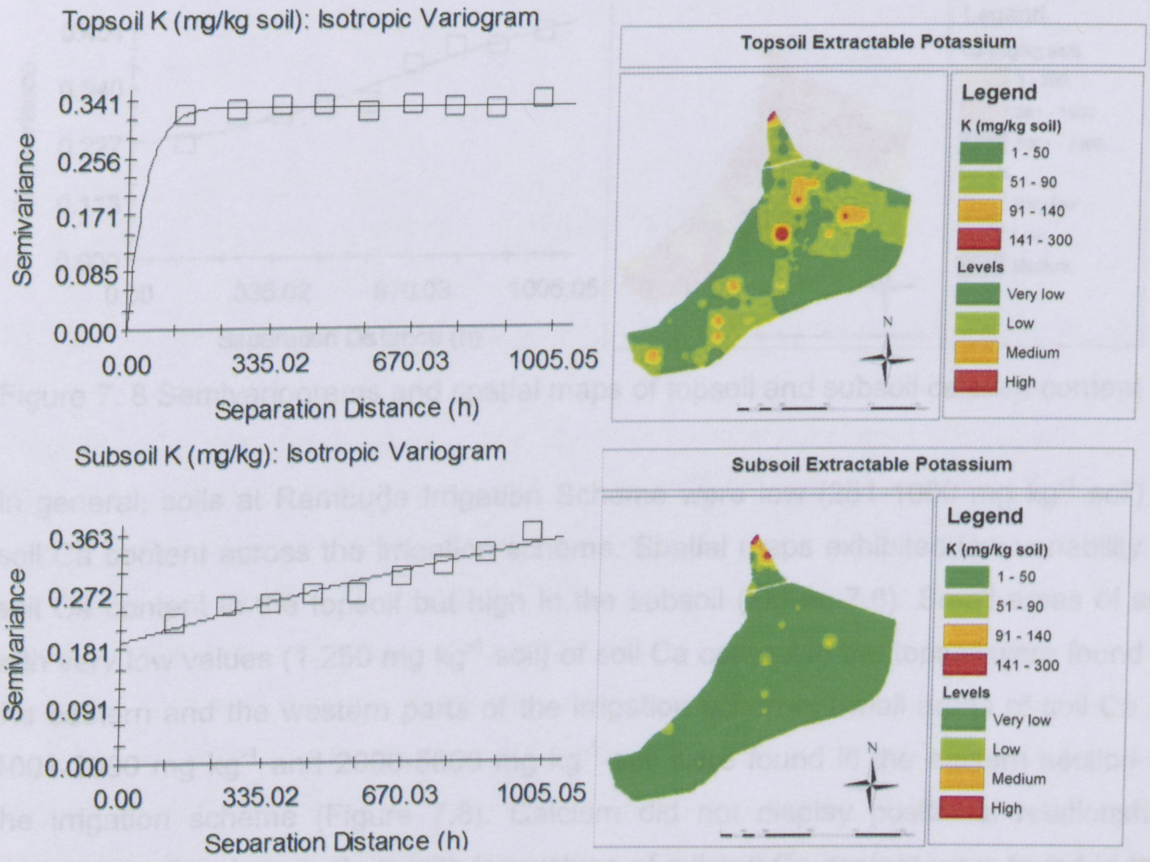


Figure 7. 7 Semivariograms and spatial maps of topsoil and subsoil potassium content

The spatial map for the subsoil showed soils with very low values of soil K (1-50 mg kg^{-1}) found across the irrigation scheme as well as small areas scattered across the irrigation scheme (Figure 7.7). A small area of soil with medium and high values (91-

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140 mg kg^{-1} 141-300 mg kg^{-1} soil), respectively of soil K were found in the far eastern part of the northern tip of the irrigation scheme.

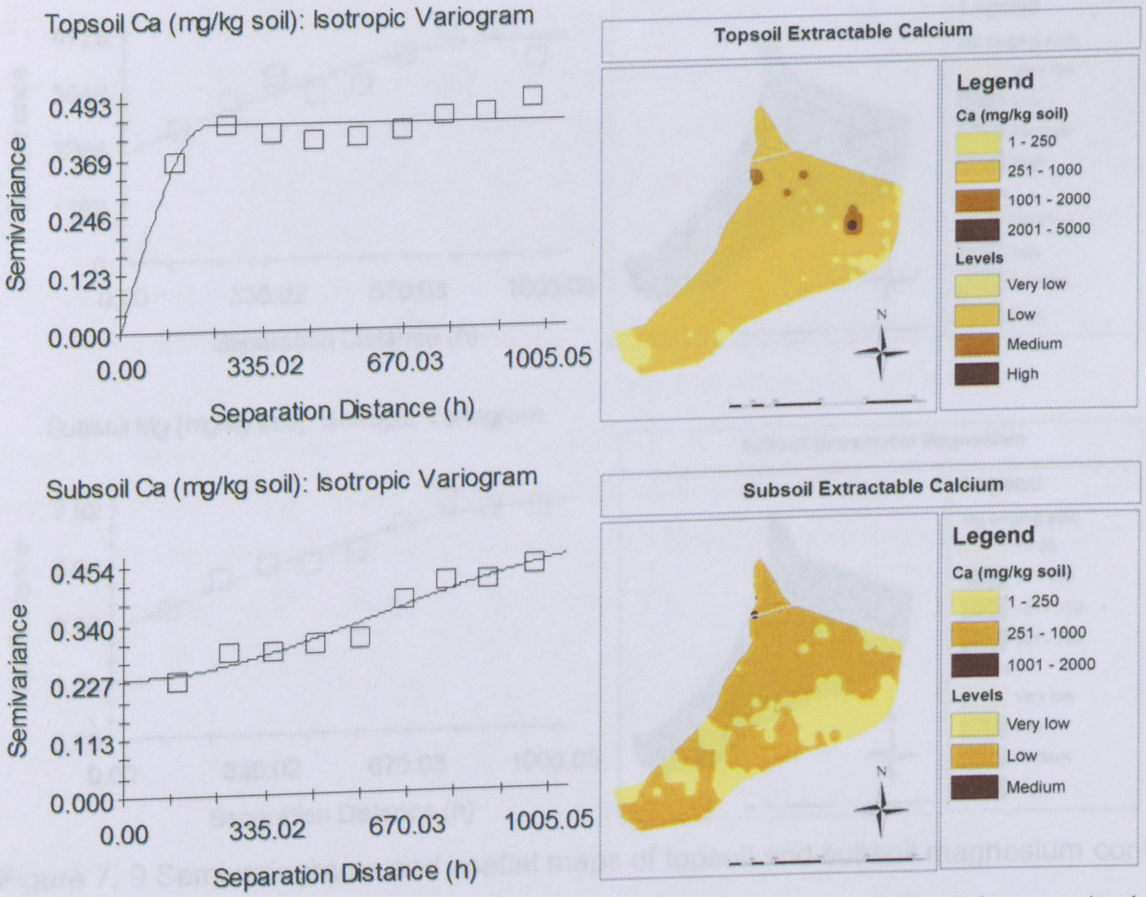


Figure 7. 8 Semivariograms and spatial maps of topsoil and subsoil calcium content

In general, soils at Rambuḍa Irrigation Scheme were low (251-1000 mg kg^{-1} soil) in soil Ca content across the irrigation scheme. Spatial maps exhibited low variability of soil Ca content in the topsoil but high in the subsoil (Figure 7.8). Small areas of soil with very low values (1-250 mg kg^{-1} soil) of soil Ca content in the topsoil were found in the eastern and the western parts of the irrigation scheme. Small areas of soil Ca of 1001-2000 mg kg^{-1} and 2000-5000 mg kg^{-1} soil were found in the eastern section of the irrigation scheme (Figure 7.8). Calcium did not display positional relationship between the two layers. Soils with low values of subsoil Ca content were found in the far southeastern part, extending from the southern part through to the far northwestern part of the irrigation scheme. The Ca of the soil in the northeastern and the midsection through to the far southwestern parts of the irrigation scheme was 2250-1000 mg kg^{-1} soil in the subsoil layers.

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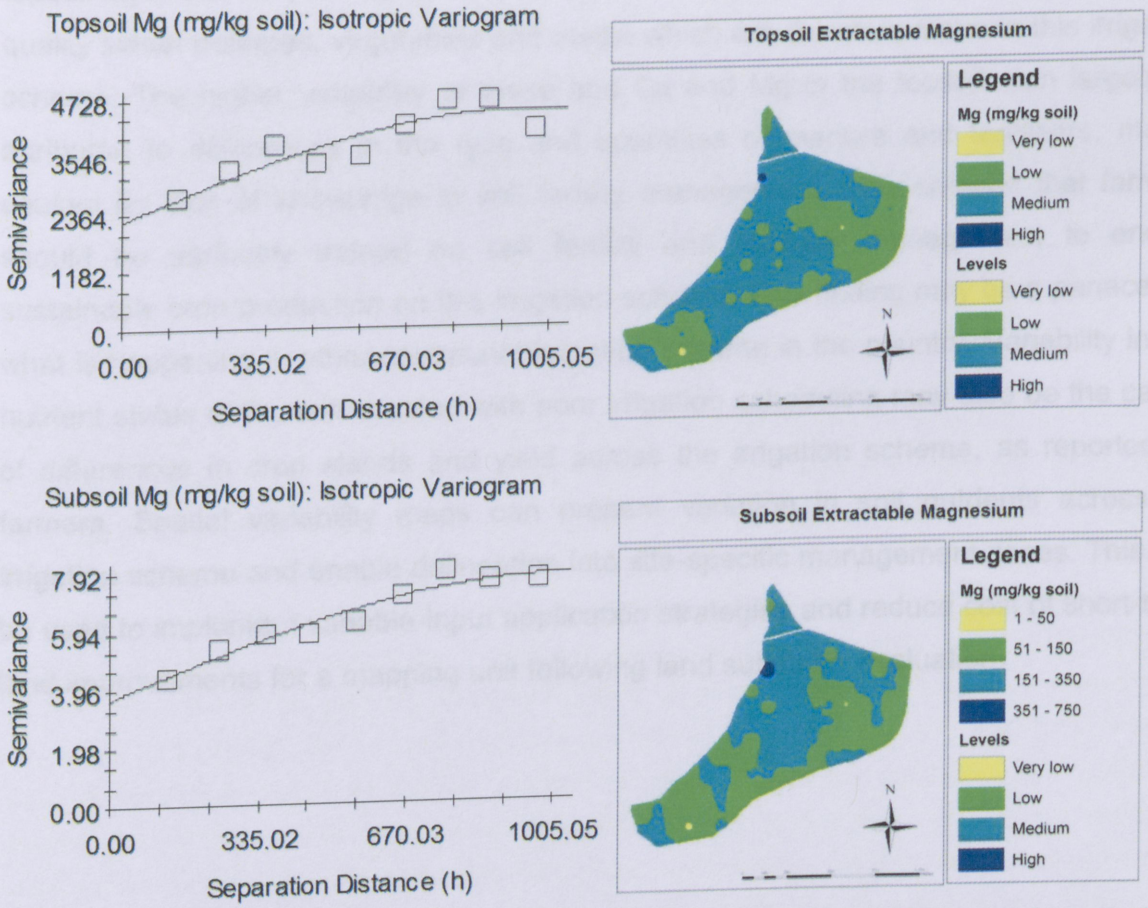


Figure 7. 9 Semivariograms and spatial maps of topsoil and subsoil magnesium content

Subsoil layers displayed higher variability of soil Mg content than the topsoil (Figure 7.8). In general, soils exhibited medium values (151-350 mg kg^{-1} soil) of soil Mg in the topsoil and the subsoil layers. There was positional relationship between the topsoil and the subsoil layers. The spatial map showed that the soils with 151-350 mg $^{kg-1}$ soil extended from the northeastern part to the middle part of the irrigation scheme and a portion of soils with similar values was found in the far western part. Soil Mg content displayed a similar trend in the subsoil layers. Low values of soil Mg were found in the southeastern part, extending to the far western part of the irrigation scheme and a small area of soil with similar values was found in the western part of the northern tips of the irrigation scheme.

7.4 Conclusions

The results showed that soils at Rambuḍa Irrigation Scheme were very low in plant nutrients. In general, soil exhibited higher variability for extractable P and K in the

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topsoil layer than in the subsoil. These elements are critical for the production of good quality sweet potatoes, vegetables and maize which are the main crops in this irrigation scheme. The higher variability of these and Ca and Mg in the topsoil, can largely be attributed to differences in the type and quantities of manure and fertilizers, mainly caused by lack of knowledge in soil fertility management. This showed that farmers should be seriously trained on soil fertility and fertilizer management to ensure sustainable crop production on this irrigation scheme. This finding may be a panacea of what is happening in other communal irrigation scheme in the country. Variability in the nutrient status of the soil coupled with poor irrigation scheduling may also be the cause of differences in crop stands and yield across the irrigation scheme, as reported by farmers. Spatial variability maps can present variation in soil nutrients across an irrigation scheme and enable delineation into site-specific management zones. This can be used to implement variable-input application strategies and reduce cost of short-term land improvements for a mapping unit following land suitability evaluation.

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CHAPTER EIGHT

DEVELOPMENT OF DYNAMIC LAND SUITABILITY EVALUATION GUIDELINES FOR SMALL-SCALE IRRIGATION SCHEMES

Abstract

The objective of this study was to develop dynamic land suitability evaluation guidelines for small-scale irrigation schemes in Vhembe District, Limpopo Province using the principles of the FAO guidelines for land suitability evaluation. These guidelines are land-user oriented and evaluation process is concluded with the rating of suitability of every mapping unit for crops in the crop range. The initial step is consultations at community leadership and land users representative level. Specific or prospective land users list the crops that they would like to grow in the area. It is always important to gather information on land resources information because such information is not always readily available in rural areas. Such information includes soil, climate, river flow rates and criteria used to assess soil suitability for particular crops. A team of soil scientists, agronomists, horticulturalists, economists, sociologists, etc can be put together to deal with specific uses during the evaluation process. Soil and crop scientists decide on additional criteria that should be used during field survey and additional properties that affect suitability of a mapping unit can be recorded during field survey. The guidelines have two levels; firstly, broad evaluation of biophysical resources for irrigated agriculture and secondly specific evaluation of land use requirements and tolerances against land characteristic or land qualities using decision tree approach so that the end result is the suitability rating, assessing land either as suitable (S) or not suitable (NS) and specifically evaluated as well suited (W), suitable (S), marginally suitable (MS) and not suitable (NS). Explanation for downgrading or up grading accompanies suitability evaluation. These guidelines not only provide a simplified and dynamic process, but produce land suitability class rating for each mapping unit for a particular crop or group of crops. The non-static and flexible approach of the guidelines makes them versatile for use under different socio-economic and cultural conditions.

8.1 Introduction

Small scale irrigation schemes play an important role in local livelihood in rural areas of South Africa. Systems approaches that are used in South Africa are the derivatives of the USDA land capability classification system (Laker, 2004). The USDA land capability system and its derivatives have often been criticized for being risk oriented (van Niekerk, 1983); being too static and inflexible (Smyth, 1981); not addressing the complex interactions of suitabilities for specific crops (Ellis, 1994); its negative approach cannot incorporate the varying needs of different land uses (Davidson, 1982); and of

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being inconsiderate of the interaction of land, land use and land user (Laker, 1982). The system was designed for a system which is virtually fixed by using large mechanized farming, high management levels, good infrastructure, uniform cropping system and management practices (Laker, 2004). Such systems do not suit the needs of small-scale farmer, particularly in a communal irrigation scheme where technological transformation – both modern and traditional land use operate side-by-side sometimes linked by a land use characterized by intermediate technologies (Beek, 1977).

Land evaluation for land use planning embraces land, land use and land users (Hewitt and van Wambeke, 1982). Land suitability evaluation in developing countries in particular requires simple dynamic land suitability evaluation guidelines that cater for the needs of different specific land uses and recognize the interaction between land, land use and land users. Irrigation farming in rural areas is very complex as farmers do not only deal with crops and irrigation, but with many other issues within the rural setting and social system. Thus, an interdisciplinary approach is necessary to deal with land and land use issues under rural setting. The FAO (1976; 1983; 1985) guidelines can be used to develop dynamic land suitability guidelines for small-scale irrigation schemes.

The objective of this chapter was to develop dynamic land suitability evaluation guidelines for small-scale communal irrigation schemes.

8.2 Structure and principles of the dynamic land suitability evaluation guidelines

The essence of the dynamic land suitability evaluation guidelines is to provide simple, technically sound and dynamic guidelines that respond to the needs of small-scale communal irrigation schemes in Vhembe District. The guidelines are flexible and may be applicable for other regions of the province. Dynamic land suitability evaluation guidelines use a step-by-step process diagrammatically presented in Figure 8.1.

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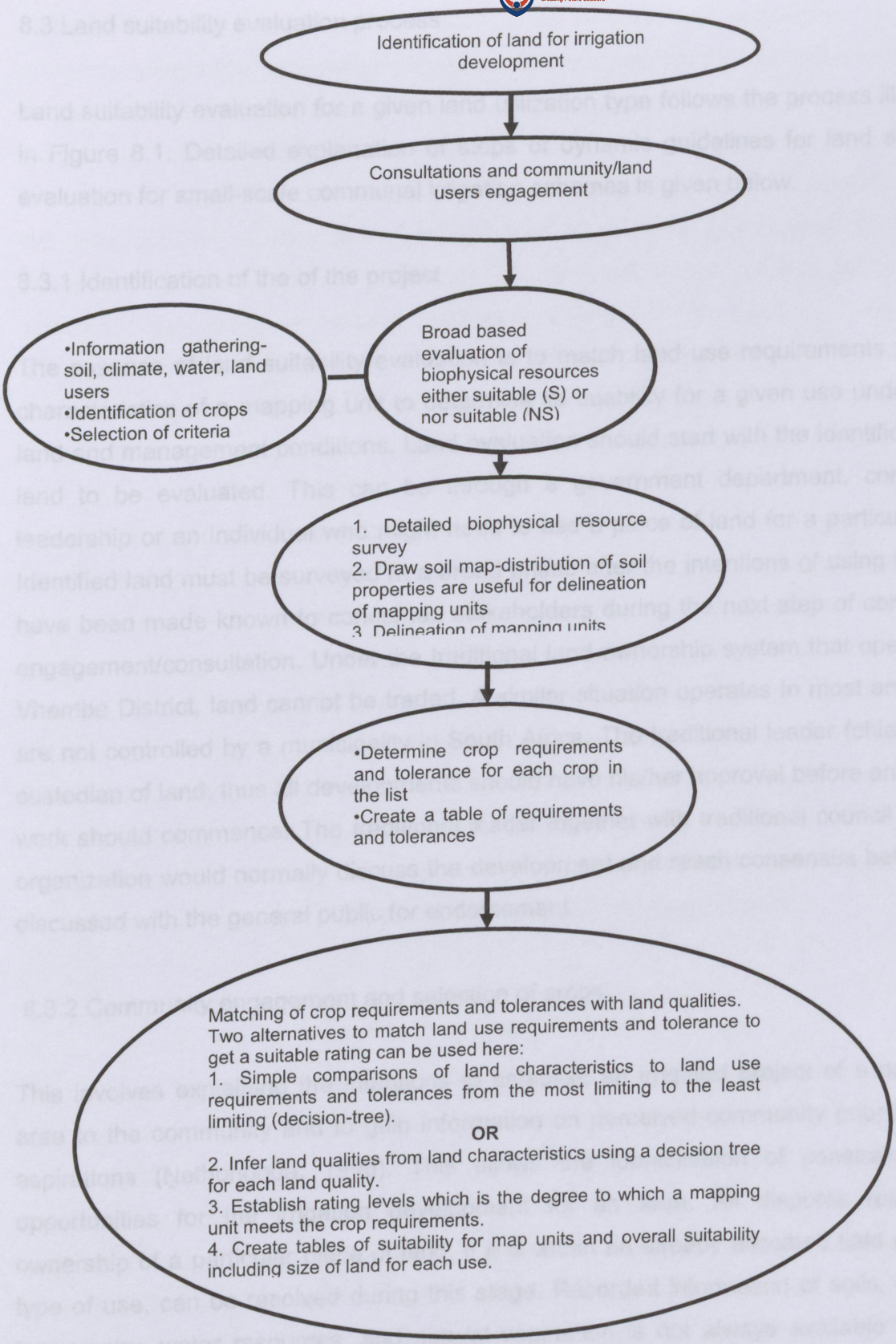


Figure 8. 1 Structure of dynamic land suitability evaluation guidelines for small-scale communal irrigation scheme

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8.3 Land suitability evaluation process

Land suitability evaluation for a given land utilization type follows the process illustrated in Figure 8.1. Detailed explanation of steps of dynamic guidelines for land suitability evaluation for small-scale communal irrigation schemes is given below.

8.3.1 Identification of the of the project

The essence of land suitability evaluation is to match land use requirements with the characteristics of a mapping unit to determine its suability for a given use under given land and management conditions. Land evaluation should start with the identification of land to be evaluated. This can be through a government department, community leadership or an individual who might need to use a piece of land for a particular use. Identified land must be surveyed at a broad phase after the intentions of using the land have been made known to concerned stakeholders during the next step of community engagement/consultation. Under the traditional land ownership system that operates in Vhembe District, land cannot be traded. A similar situation operates in most areas that are not controlled by a municipality in South Africa. The traditional leader (chief) is the custodian of land, thus all developments should have his/her approval before any actual work should commence. The traditional leader together with traditional council or civic organization would normally discuss the development and reach consensus before it is discussed with the general public for endorsement.

8.3.2 Community engagement and selection of crops

This involves explaining the intentions to establish an irrigated project of a particular area to the community and to gain information on perceived community priorities and aspirations (Nethononda, 1996). This allows the identification of constraints and opportunities for the irrigation development for an area. All disputes related to ownership of a particular piece of land, if it is within an already allocated field or other type of use, can be resolved during this stage. Recorded information of soils, climate, topography, water resources, and natural vegetation is not always available in rural areas. Local people often have useful information about biophysical resources that has been acquired through experience and has been orally passed on from one generation to another. Information on accessibility of the area; topography, rainfall and temperature

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patterns; river flow, soil information and places of socio-cultural/religious importance and other factors that may prevent land use. If it is a new land, prospective farmers can be identified. Prospective farmers should be asked to list crops that they would like to grow in the irrigation scheme. An extension officer may facilitate a meeting with land users where they list crops they envisage to grow in the area under available technologies. The function of the extension officer is not to guide land users, but to assist them to draw a list of crops. He can also add to the list that farmers have provided. Farmers can be asked to list important indigenous criteria used to decide soil suitability for different crops in the area. The soil scientist/pedologist can use some of the criteria together with the criteria obtained from the literature and specialists like agronomists and horticulturalists to delineate mapping units during field survey.

The list of crops should then be presented to the soil scientists, agronomists and horticulturalists, who will generate characteristics that are important for optimal growth of each crop in the list. This interdisciplinary team should then decide on specific mappable soil properties that affect crop growth. Such characteristics may include rooting patterns, vegetative growth pattern and botanical family group. Rooting characteristics are helpful to soil scientists/pedologists to note additional soil properties which can be used during land suitability evaluation of soil mapping unit for specific crops. Vegetative growth pattern and family group help to identify crops that have similar pests and diseases that may otherwise not be planted during one season. A list of crops may be grouped into crop ranges for land suitability evaluation.

8.3.3. Evaluation of biophysical resources for irrigated agriculture

First level of suitability evaluation is to conduct broad classification of biophysical agricultural resources such as climate, soil, water (hydrology) and current land use. This is done to ascertain the quality of biophysical resources for irrigated agriculture. This step provides a guide by means of which different mapping units should be evaluated for specific land utilization types. A key objective is elimination of areas that are clearly not suitable for irrigated agriculture. This is a broad suitability evaluation and does not indicate the suitability of specific land utilization type for mapping unit. The land is classified into two broad ratings namely, suitable (S) or not suitable (N) for irrigated agriculture. This is achieved by asking simple questions as illustrated in Figure 8.2.

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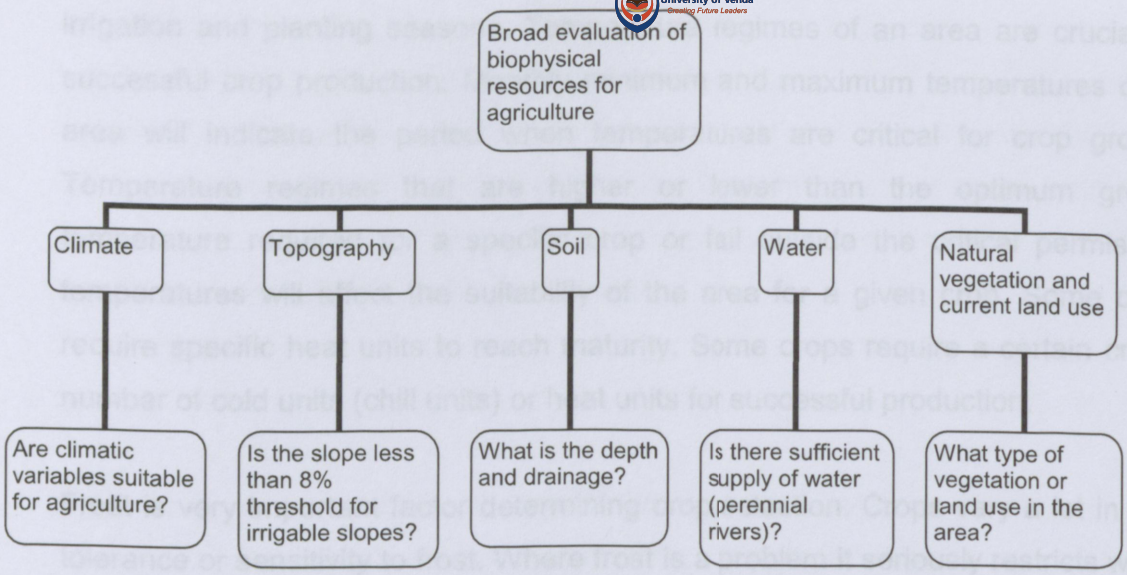


Figure 8.2 Evaluation of biophysical resources for irrigated agriculture

8.3.4 Detailed survey of biophysical resources

Land resource surveys for land suitability evaluation are required to ascertain the climate, soil, topography, water, natural vegetation and current land use in the area (Hensley and Laker 1981; Laker, 1982; Turner and Scotney, 1993; Nethononda, 1996). This is a preliminary evaluation of the biophysical resources of an area. This includes review of existing information on soil, climate, physiographic, water resources, natural and current land uses. Other non-technical information on socio-economic status, infrastructure, political aspects can also be included at this level though most information could have been obtained during community engagement. It is important to verify all information that was obtained through word-of-mouth. Areas that are not accessible can be eliminated and areas that need detailed investigation can be identified.

1. Climatic conditions

Recorded climatic data can be obtained from the weather stations, Weather Bureau or the Agricultural Research Council-Institute for Soil, Climate and Water. In places where there is no weather station, such information can be inferred from nearby weather stations (FAO, 1976; Laker, 2004). Climatic information of an area provides an indication of the critical climatic conditions during the growing season of the crops. These influence management decisions such as crop choices,

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irrigation and planting seasons. Temperature regimes of an area are crucial for successful crop production. Monthly minimum and maximum temperatures of an area will indicate the period when temperatures are critical for crop growth. Temperature regimes that are higher or lower than the optimum growth temperature required for a specific crop or fall outside the critical permissible temperatures will affect the suitability of the area for a given crop. Some crops require specific heat units to reach maturity. Some crops require a certain critical number of cold units (chill units) or heat units for successful production.

Frost is very important factor determining crop selection. Crops vary a lot in their tolerance or sensitivity to frost. Where frost is a problem it seriously restricts winter season crop choices compared with frost-free areas. Length of the frost period is important. In areas with long frost periods the growing periods of summer crops are reduced so that knowledge of the frost start and end dates for a specific area is very important.

The relation between rainfall and reference evapotranspiration (ET_{ref}) during the growing season determines the irrigation requirements for a crop. This can be determined by the aridity index (See 2.5.5). The lower the rainfall during the growing season of the crop, the higher the evapotranspiration of the crop (Et_c) and the higher the irrigation requirement. A crop may have a high irrigation requirement even when it is grown in an area with a high average annual rainfall, if it is grown outside the rainy season of the area. Examples are a winter crop grown in a summer rainfall area or a summer crop grown in a winter rainfall area.

Low relative humidities during the critical growth stages of a crop can cause serious damage to some crops. On the other hand, very high relative humidities during critical periods can also be harmful, e.g. due to increased disease incidence. Day length plays an important role for flowering, fruit initiation and ripening in certain crops. Areas with shorter or longer day length than required for these processes to properly occur in photoperiod sensitive crops will dictate crop suitability.

Hail is an important factor in some areas, including its frequency, severity and seasonal distribution. The importance of wind in crop production is often

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underestimated. Wind plays an important role in crop production in areas where strong winds prevail. Some important aspects include wind speed, direction of prevailing winds, sites exposure to harmful winds and seasonal distribution of wind. Wind has several negative effects, including sandblast of crops, wind-throw of trees and scorching of crops by hot, dry winds. These should be considered during the land suitability evaluation process.

2. Topography

Topography is extremely important in land suitability evaluation for irrigated crop production. The most important factors of topography for irrigated agriculture are slope gradient, slope aspect and the elevation of the land relative to the elevation of the water source.

Slope determines the choice of appropriate farming system and management techniques for the area. Turner and Scotney (1993) stressed that slope is a parameter that should be always be incorporated in the assessments for irrigation. The authors further stated that slope gradients less than approximately 8% are generally considered to be suitable for irrigation development and any slope greater than this would require specialized irrigation systems and conservation measures. These involve large capital investments, the cost of which may be higher than the returns rendering the area unsuitable or lowly rated for irrigated agriculture. According to Scotney *et al.* (1987) slope gradients in South Africa are grouped into four classes as presented in Table 8.1.

Table 8. 1 Classes of slope gradients in South Africa

Slope classes (%)	Description
0-2	Level
2-5	Gently sloping
5-8	Moderately sloping
8-15	Strongly sloping

Slope aspect is important both for crop growth and management. In the southern hemisphere, north-facing and west-facing slopes are warmer and drier than the southerly and easterly slopes. Nethononda (1994) observed that tea plants

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growing on the north and west facing slopes suffered the effect of hot, dry conditions more severely than their counterparts growing on the south- and east-facing slope aspects.

3. Soils

A detailed soil survey is a necessity for at least every arable agricultural project development. During soil surveys, soils are delineated into mapping units according to their observed properties. Each mapping unit may be comprised of single soil form or more depending on the general description and limitations of soils under consideration. It is important to describe in detail all the properties that may affect the envisaged land utilization types for the mapping unit.

Such properties as slope, type of soil (i.e. infiltration rate, internal and external drainage), soil depth (especially effective rooting depth), texture, water infiltration rate, drainage and water holding capacity are important for irrigated crop production. Chemical properties of the soil must be determined by collecting representative samples for laboratory analysis of soil pH, electrical conductivity, fertility status, salinity, and micronutrients. New technology like a geographic information system (GIS) is available to interpolate soil properties of unsampled areas of the field/ land particularly where variable-input management strategy is to be introduced or followed. These properties can be presented in the form of maps and/or tables with extended relevant legend of soil properties and characteristics (Table 8.2).

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Table 8.2 List of soil properties and reasons for their choice

Soil property	Reasons for choosing
Texture	Influences choice of irrigation system, root penetration and growth, aeration, workability, management practices.
Effective depth	Affects root penetration and growth, water availability.
Soil type	Duplex soils are susceptible to soil erosion even at gentle slopes. An exchangeable sodium percentage (ESP) of 15% is usually considered to be the limit above which serious dispersion problems occur, irrigation suitability.
Drainage	Workability, aeration, irrigation management and cost.
Compaction and crusting	Seed germination, root penetration, yield of rooting crops, choice of irrigation system, water infiltration and pest and disease infection on certain crops, workability of the soil.
pH	Crops have their pH preferences for optimum growth. Affects availability of nutrient and toxicities, disease infection and cost of liming requirements.
Salinity	Crops have their salt tolerance levels above which yields are adversely affected and special management requirements such as leaching and appropriate irrigation method are applicable.
Base status	The cost of bringing soil fertility level to favourable for optimum crop production without causing negative impacts on the environment.

Areas with properties that require similar management inputs can be delineated into a single mapping unit based on their properties. A taxonomic classification of the soils should also be given for soils in each mapping unit. This information is useful in explaining the reasons for down-grading the suitability rating of the mapping unit for a given land utilization type during the matching process. Other relevant properties can be selected from the literature and from personal experience in a specific area as these vary from place to place and crop to crop.

4. Water resource

Water is an important resource for irrigated agriculture, both in terms of quantity and quality. Good quantitative information is often not available in developing areas. Knowledge of seasonal patterns of water availability, especially of regular

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periods of water shortage, is important where water is abstracted from rivers/streams by means of weirs or pumping and is not supplied from larger storage dams. Information obtained from local farmers or the community is useful to provide possible state of sources of surface water in the area and their seasonal trends (Laker, 2004).

Water quality (especially dissolved salts content), is critical in the evaluation of the suitability of water for irrigation. Water quality concerns salinity, alkalinity, pH, and concentration of dissolved metals. These properties may affect the crop performance and quality, soil quality and choice of irrigation system and irrigation scheduling. Different crops have different tolerances and sensitivities to different levels of salinity.

5. Vegetation and land use

Natural vegetation, particularly the type and species of vegetation found in the area provides information such as extent of drainage and water table, soil and climatic adaptability of certain crops. Some grass and tree species prefer to grow in less fertile soil, shallow soils or soils with certain textural classes. Knowledge of the relationship between natural vegetation species and environmental factors is critical. It can provide guidance on the suitability of an area for certain crops.

Performance of crops planted or growing as "volunteer plants" in the area under evaluation of adjacent areas is useful. This can be used for suitability and performance inferences for the crops that are considered. Empirical records of observed crop performances and views of farmers; agronomists, extension officers of crops listed can provide a basis for suitability evaluation where technically researched information is unavailable.

The cost of land clearing must be considered as these may be too high and offset any expected "Net Increment Irrigation Benefits" and thus may make the development of irrigation scheme unfavourable (FAO, 1985). The costs of land clearing vary with the type and size of vegetation, local labour costs, removal and dumping of cut trees, available equipment in the area and the place that is being evaluated. In areas where there is dense bush, forest or plantation vegetation, large machinery may be required for cutting and removing trees. It is important for

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the land evaluator to understand the implications of the method that will be used to clear the land and impacts associated with each method of land clearing.

The cost of removing big trees may be too high. The cost of hired labour may be excessive in South Africa compared to bulldozers where the vegetation is thick and consists of large trees. In the rural areas where firewood is in demand, land clearing costs can be substantially reduced by inviting the community to fell trees for firewood. This may however, take longer than anticipated unless timelines are set. However, mechanical equipment will be required for the removal of tree stumps. The evaluator should weigh the most cost-effective method under given situation and provide necessary advice.

Large machinery is seldom available in the rural areas and may have to be outsourced from the urban areas, resulting in escalation of cost for land clearing. In areas with few trees and bushes, it is advisable to use chainsaws and manual labour to remove vegetation and tree stumps depending on the costs associated with this method. Large machinery may not only be expensive to hire, but often compacts the soil, particularly clays and leaves large holes and root-balls in places where trees were removed. Land grading or levelling is necessary regardless of the type of irrigation method to be used (FAO, 1985).

8.3.5 Suitability evaluation of mapping units for specific land utilization type

This evaluation is conducted on the land that was rated as suitable during the evaluation of biophysical resources for irrigated agriculture (Section 8.2.3). Crop requirements and tolerances are matched with land qualities/characteristics of each soil mapping unit to generate suitability ratings. Such requirements include climatic, soil and management requirements of each mapping unit necessary for successful crop production. Crop requirements and tolerances, include among other things climate requirements and tolerances; soil requirements and tolerances; prevalence of pests, diseases and persistent weeds. A decision tree can be constructed from the most limiting land characteristic to the least limiting one to generate suitability rating. When land qualities are used, a decision tree can be constructed using the most critical land characteristics that influence land use to generate a suitability rating (Figure 8.2). Management requirement, including cost-benefit analysis; infrastructure; availability and distances to markets; processing/packing facilities; cost of land clearing, land

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preparations, etc; climate and soil requirements of different, irrigation systems; irrigation costs; drainage requirements and costs. Establishment of an irrigation scheme will impact on the environment and land evaluation should consider aspects related to erosion hazards either onsite or offsite; pollution hazard – especially off-site; threats to endangered species; new animal and plant species and disease incidences like malaria.

Available data and expert knowledge are important for the decision tree approach were land qualities are used or a simple approach which is more deterministic where land use requirements and tolerances are matched with the land characteristics of a mapping unit to generate suitability rating (Rossiter, 1996). An example of decision tree is illustrated in Figure 8.3. Tables of the requirements and tolerances can be constructed for each crop or group of crops. These requirements can be obtained from the existing literature. Crop requirements include climatic, soil and tolerances for each crop. Often, information in the literature particularly, on soil requirements for a given crop is insufficient and too subjective to be useful for suitability evaluation. Local people can provide useful information on adaptability of some crops that are either growing as volunteer crops or planted in homes or as hedge crops between the plots boundaries. The steps used by van Lanen *et al.* (1992) (although in their situation they used a computerized program) were found to be more relevant to these guidelines, and are as follows:

1. Determining land use requirements and tolerances derived from the land use types.
2. Selecting relevant land characteristics that characterize the land resources of a mapping unit.
3. Defining land qualities and inferring these from land characteristics using a decision tree for each land quality; ratings or severity levels of land qualities were established for each mapping unit, for no moderate or severe restrictions, to which a mapping unit meets the requirements and tolerances of specific crop range.
4. Combining land qualities/land characteristics using a decision tree to deduce overall suitability of specific crop range.

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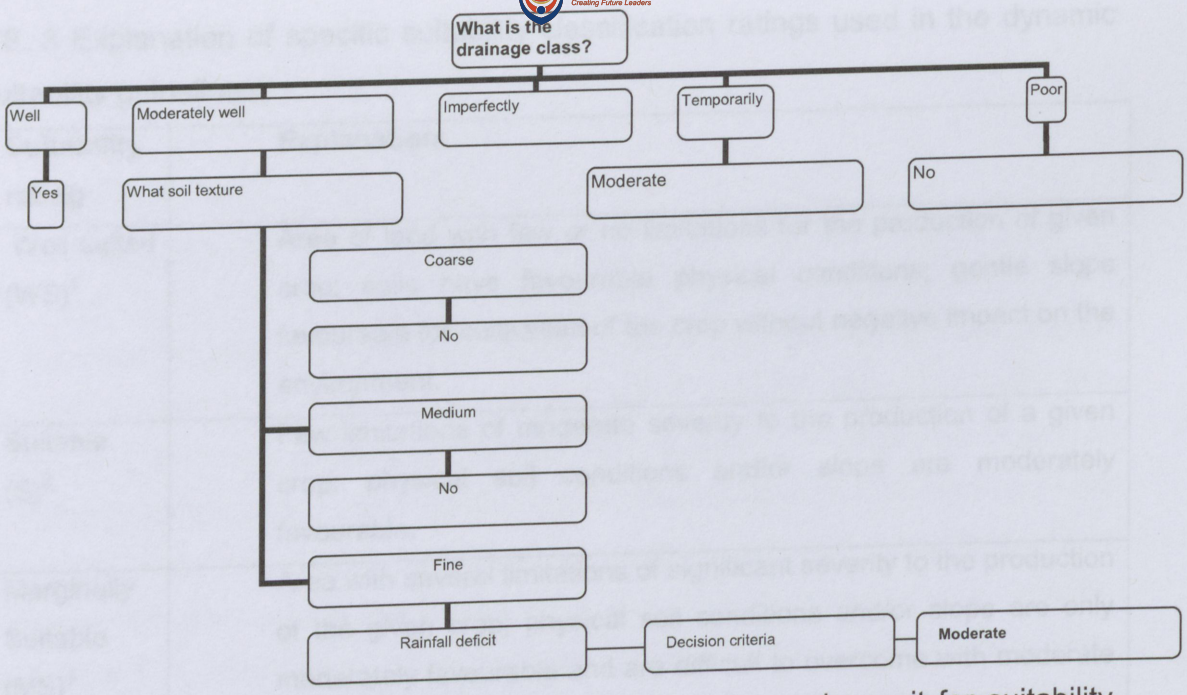


Figure 8.3 Decision tree for land suitability evaluation of mapping unit for suitability rating

Rating is based on best management under given technology available in the area, taking into consideration the management capabilities and experience of the land users or prospective land users. Suitability assessment is done on the crops listed by land users or prospective land users. Rating is based on qualitative information since quantitative information on yield and performance of crops that are listed by land users are usually not available under small-scale communal irrigation schemes. Ratings may improve as and when new technology becomes available to alleviate the limiting factors and/or the management capabilities of land users improve. A mapping unit may be rated as well suited (WS), suited (S), and marginally suited (MS) or not suited (NS) for a particular land utilization type based on the data and expert knowledge to reach a decision (Table 8.3). Where suitability rating is less than well suited (WS), a reason or reasons for down-grading is provided to inform the report user or planner of the basis of evaluation to enable informed decision-making process.

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Table 8. 3 Explanation of specific suitability classification ratings used in the dynamic land suitability guidelines

Suitability rating	Explanation
Well suited (WS)[1]	Area of land with few or no limitations for the production of given crop; soils have favourable physical conditions; gentle slope favourable for cultivation of the crop without negative impact on the environment.
Suitable (S)[2]	Few limitations of moderate severity to the production of a given crop; physical soil conditions and/or slope are moderately favourable.
Marginally Suitable (MS)[3]	Area with several limitations of significant severity to the production of the given crop; physical soil conditions and/or slope are only moderately favourable and are difficult to overcome with moderate management; high management inputs are required for the a given crop.
Not Suitable (NS)[4]	Soils have severe limitations for the production of the given crop; physical soil conditions and/or slope are not favourable such that it is not feasible without the implementation of significantly high levels of management.

Limitations that cause downgrading of the suitability of specific mapping unit(s) for a given land utilization type and the extent of the limitation can be indicated by lower case suffixes after the rating, such as $S^{**}_{e(n)}$, $MS^{***}_{d,e,s(vs)}$, etc. where:

Symbol	Meaning
e	Erosion hazard
d	Depth restriction
s	Slope steepness limitation

Other limitations that are not listed must be indicated in the land suitability report to inform the user. The letter(s) in brackets indicate the severity of the limitation according to the following classification:

[1] FAO equivalent Class S; Optimal
[2] FAO equivalent Class S2; Suboptimal
[3] FAO equivalent Class S3; Marginal
[4] FAO equivalent Class N; Not suited

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Symbol	Meaning
n	Minor
m	Medium
s	Severe
vs	Very severe

Finally, a table of the suitability ratings may be generated for soil and climate of each mapping unit for each crop. The overall suitability rating table for all mapping units with total size of crop suitability for various mapping units is given. Tables are preferable as they are simple to follow and understand. Concise explanations and discussion of the rationale behind the rating (thus upgrading or downgrading) and recommendations should be given in the land suitability evaluation report to enable users make informed decisions. This gives meaning to otherwise dead tables and ratings and communicates precise information on the rationale behind evaluations and objectives of the evaluations to the user as this is the main purpose of land suitability evaluation. Any future improvement in technology and management skills that can reduce the impact of current limitation on land use will result in upgrading of the suitability rating.

8.3.6 Management requirements

All management aspects are to be considered during the evaluation process. Such include management requirements related to soil fertility, cultivation, soil erosion and more importantly irrigation. Land suitability for irrigation must consider the suitability of specific irrigation system for a particular soil of soil mapping unit. It is important to consider soil suitability for a specific irrigation system before making large investments on the system that has high running costs or may cause soil degradation i.e. compaction, erosion.

Soil crusting, is for example a huge problem to consider when looking at sprinkler irrigation. Some soils in Swaziland and Eastern Cape Province are not suitable for drip or micro-sprinkler irrigation and only furrow irrigation can be used on them (Laker, M.C, Personal communication, 2009). Studies have shown that most soils are prone to crusting even on red soils that traditionally were viewed as highly suitable for overhead irrigation have displayed problems of crusting (Laker and D'Huynenter, 1988; Laker and

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Vannasche, 2001). The large contributor to the problem of crusting was switching from surface irrigation systems to overhead or micro-irrigation systems.

8.3.7 Alternative scenarios

Other considerations should be given to the impacts of land utilization type on the environment and socio-cultural setting of the area. The extent of the impacts must be ascertained and possible ameliorations be outlined. The last aspect is to determine the cost versus benefits with and without land utilization to the local people through cost:benefit analysis. Costs of LUT must be less than the benefits of having the LUT in a given land i.e. economic, social and environmental benefits to the people living in the land. Any LUT that will result in negative impacts should be down-graded.

1. Environmental Impacts

   Agricultural land use or other alternative land use must not result in environmental degradation of the area. Proper weighing of scenarios is important to assess which ones among many are environmentally risky. Any land use that may over a short or long term period result in pollution excessive levels or erosion must be classified as not suitable.

2. Socio-cultural Impacts

   In developing countries, land management may be in conflict with beliefs, myths requiring evaluation to bring acceptability or LUT. Settlement destabilization – graves, movement/homesteads/ social acceptability is difficult to rate. Area used for religious activities may be considered unsuitable for any other use depending on the view and history of the people living in the land (Nethononda, 1996).

FAO (1985) stresses the importance of ascertaining the attitude of the intended beneficiaries (or whole community) towards irrigated agriculture. They may not even want it. The attitude of farmers towards irrigation varies between projects and from area to area. This may be due to resistance to change caused by fear associated with costs, technology and regulations accompanying the introduction of irrigation. In an area where farmers have been using a particular method of

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irrigation e.g. furrow irrigation, introduction of overhead irrigation or drip may not be acceptable to the local community due to acquaintance and empirical knowledge and means of dealing with problems of furrow irrigation. However, such fears may over sometime be overcome through training and active extension services.

3. Cost: benefit Considerations

The benefits may be tangible (crop production) or intangible such as job creation. Tangible benefits are assessed in physical terms e.g. volume of production while intangible benefits are difficult to quantify (FAO, 1976). These may just be the satisfaction of social needs or a political agenda. Assessment of intangible benefits is made in terms of negative or positive effects.

The FAO (1985) gives emphasis on the determination of the "Nett Incremental Irrigation Benefit" (NIIB) of land. Net Incremental Irrigation Benefit is a measure of the potential increase in productivity of a unit area of land when developed under a specified plan, expressed in economic value i.e. its benefit relative to the original or an alternative land use, e.g. rainfed cropping. This is ascertained by comparing the costs of irrigation with benefits (profits) of irrigation. Development of a new irrigation project involves debushing and removal of rocks; land levelling, contouring and other activities related to soil fertility. The cost of any of these activities determines whether the land is suitable or not for irrigation in a broad suitability evaluation of bio-physical agricultural resources. It is important to also consider the comparative advantage of irrigation with rainfed agriculture in the area. Sometimes the value is negative, i.e. the net income (profit) from irrigated agriculture is less than from the alternative – usually due to high development costs of irrigation infrastructure, irrigation systems, etc.

Benefits of irrigation should not only be considered in monetary value, but also in terms of environmental and socio-cultural benefits. Areas which are susceptible to damage due to any of the activities necessary for preparing the land for irrigation or is a habitat for red data (near extinct) plant or animal species must be indicated. Irrigation development may require moving of graves or other socio-cultural sites

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to make way for a new irrigation project and this may not be acceptable to local community, thus making a specific land not suitable for irrigation development.

Land suitability rating is made in consideration of the common projects costs and area-specific land development costs. These are integrated into Net Incremental Irrigation Benefit (FAO, 1985), which is calculated as follows:-

Net Incremental Farm Income (i.e. net farm income with project less net farm income without project derived from the budgets). This is normally assessed for the full year of development;

Less (B) Annual Equivalent Value of Common Costs

Annual Equivalent Value of Area-specific Land Development Costs.

Suitability rating is decided on the assumptions that if (A) less (C) is less than (B), the land in question is "Not Suitable" for irrigation development thus N1 or N2 (FAO, 1985). The Annual Equivalent Value of Common Costs (B) represents the cut-off value for required net incremental farm income i.e. after the payment of area-specific costs. It must be clear that (A) less (B) is equivalent to the maximum permissible amount which can be spent on Area-specific Land development (C), expressed in annual equivalent values. Suitability ratings can then be set based on the range of NIIB between the cut-off point (NIIB = 0) and the maximum obtainable in the project area. The FAO, (1985) shows the convenience of using a nomograph to determine class ratings based on the calculation of NIIB.

8.3 Conclusions

The principles of the FAO guidelines were successfully used to develop the dynamic land suitability evaluation guidelines for small-scale communal irrigation schemes. The purpose of land evaluation is to inform the user of the report of land assessment about suitability of land utilization types for sustainable crop production. The developed guidelines considered a multi-disciplinary approach, participation of land users and consideration of their aspirations and inputs. In essence, the guidelines employ bottom-up approach and promote cooperation between land user and use planners. Land suitability assessment results in suitability rating of a mapping unit for the production of a specific crop and economists can assess economic profitability of a

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crop or combinations of crops for a final land use plan. The dynamic land suitability evaluation guidelines for small-scale communal irrigation schemes are simple to understand and reasons for downgrading or upgrading suitability rating are provided for the user of the report to understand basis of each rating. The dynamic land suitability evaluation guidelines for small-scale communal irrigation schemes provide a comprehensive, dynamic and versatile approach. The beacon of dynamic land suitability evaluation guidelines is a non-static approach, recognition of the interaction between land, land user and land use and suitability rating for each mapping unit for a given land utilization type. This enables the guidelines to be adapted under various communal land use systems without compromising sustainability of natural biophysical resources for agriculture. The dynamic land suitability evaluation guidelines provide basis for the future development of a land suitability system for irrigated agriculture for South Africa.

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CHAPTER NINE

LAND SUITABILITY EVALUATION FOR SPECIFIC CROP RANGES USING THE DEVELOPED DYNAMIC LAND SUITABILITY EVALUATION GUIDELINES FOR SMALL-SCALE COMMUNAL IRRIGATION SCHEMES

Abstract

Small-scale communal irrigation schemes that are not top-down managed comprise an important agricultural activity in many deep rural areas of South Africa. Farmers in these irrigation schemes rely on basic indigenous knowledge of soil, climate and empirical observations of crop performance to make crop production decisions. Such knowledge is not sufficient to make appropriate land use decisions on crop suitability. Land suitability evaluation systems and approaches used in South Africa are often geared to commercial skilled farmers with better knowledge and technological resources for crop production. The objective of the study was to assess land suitability for specific crop ranges at Rambuḍa irrigation scheme using dynamic land suitability guidelines for small-scale irrigation schemes. The first step in these guidelines is community engagement through consultation to ensure community participation in land utilization choices. This is followed by a detailed survey of biophysical resources and assessment by matching land utilization type requirements and tolerances against land characteristics or qualities of each mapping unit to generate suitability ratings. Results showed that majority of mapping units were well suited (WS) and suited (S) for the majority of specific crop ranges and only mapping unit Ao was marginally suited (MS) for citrus because of crusting, susceptibility to compaction, crusting and moderate drainage. Dynamic land suitability evaluation guidelines were successful for assessing land suitability for specific crop ranges at Rambuḍa Irrigation Scheme and will have to be tested in other irrigation schemes under different socio-cultural and biophysical conditions.

9.1 Introduction

Small scale irrigation schemes play an important role in the betterment of peoples' livelihood in rural areas of South Africa (van Averbeke and Mohamed, 2006). Proper planning of land resource development is paramount for sustainable crop production in these irrigation schemes. Ṇethononda and Odhiambo, (2011) reported that there was no land resource information or basis for crop choices at Rambuḍa irrigation scheme and farmers were growing crops on a trial and error basis resulting in low yields and crop loses. Such low yields and crop loses negatively affect livelihood of the people in

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rural areas (Bembridge, 2000). Land suitability evaluation is important information for land use and development planning (Rossiter, 1996).

The objective of this chapter was to assess land suitability for specific crop ranges for Rambuḍa Irrigation Scheme using dynamic land suitability evaluation guidelines for small-scale communal irrigation schemes in Vhembe District, Limpopo Province.

9.2 Materials and Methods

9.2.1 Description of study site

Detailed description of the study area was given in Chapter 2, however, for convenience a concise description is presented below. The total area of the irrigation scheme is 120 ha, demarcated into 104 terraced plots of 0.24 to 1.28 hectares lying between 635-665 m above sea level. The main land utilization types are sweet potatoes and maize planted on ridges under furrow irrigation method with limited use of inputs such as pesticides and inorganic fertilizers. The topography of the study area is level to undulating with gentle slopes with 0.5-2% gradient.

9.2.2 Identification of the irrigation scheme

Rambuḍa irrigation scheme was selected during the training needs assessment survey by the author. It was realized that crops then being grown in the irrigation scheme were not growing properly. The extension officer was asked if there was a report of land suitability assessment for the crops that are grown. Realizing that there was no information in the irrigation scheme, a few farmers were asked how they decide on the crops that they were growing. Farmers indicated that they were just growing whatever crops were simple to grow, irrespective of their suitability. It was then decided to carry out a detailed investigation on the project which led to the current study.

9.2.3 Consultation and community engagement

An initial visit to the irrigation scheme was conducted to discuss an overview of the irrigation scheme and prevailing production problems. The extension officer then organized a meeting with farmers as well as the tribal chief. A follow-up meeting was

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held with a group of farmers to get the general overview and perspectives on land use at Rambuḍa irrigation scheme to pave the way forward for this research. These were followed by surveys presented in Chapters 4, 5, 6 and 7 of this thesis to obtain extensive information on soils and their properties for land suitability evaluation.

9.2.3.1 Soil criteria used by farmers for land suitability for specific uses

Criteria used by indigenous people to assess land suitability for given uses include slope, texture, organic matter content, depth, drainage, climate and socio-cultural issues (Table 9.1). Organic matter and clay content of the soil are considered as the main determinants of soil fertility (Ṇethononda and Odhiambo, 2011) and soil with lower clay or organic content is considered less fertile. Clay content is considered the most important indication of soil fertility status. Land characteristics used by indigenous people were not different from those used in modern land suitability systems used elsewhere. The most important climatic variable is rainfall, particularly pattern and distribution. Cultural norms are considered equally important and are complex because of myths around certain crops e.g. bambara/jugo beans cannot be planted at the beginning of rainy season because it is believed to inhibit rainfall (Ṇethononda, 1996). There are no quantitative limits to determine land suitability for given crop and without quantitative limits of each factor, the systems are more subjective on land suitability assessments. Suitability is based on long term empirical observations of crop performance in a specific area. Land suitability assessment using these criteria is simple and subjective.

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Table 9. 1 Criteria used in indigenous soil suitability for crop production

Criteria	Meaning	Crop suitability
Colour	Dark soils considered fertile and having good moisture-holding capacity whereas light soil considered less fertile, low moisture-holding capacity.	Dark soils - maize, *nawa* (beans), pumpkins. Light soils - millet.
Texture	Coarse sandy soil less fertile while fine clayey soil fertile.	Millet, bambara beans, sorghum, water melon.
Depth	Soils on steep slopes considered shallow and also soils with lot of stones.	Millet.
Stoniness	Soil with stones associated with shallow depth and difficult to work (*lukwara* or *lukwalanganda*).	Millet.
Drainage	Poor drainage associated with soils in flat low lying areas, in wetland or near rivers (*mụtanga*).	*Nawa*, sweet sorghum.
Fertility	Soils under trees, dark coloured, clayey, soils near termite mounds or with earthworms are considered fertile.	Maize, *nawa*, pumpkins groundnuts.
Organic matter content	High organic matter content indicates highly fertile, good moisture-holding soils and soils found under trees and low lying wetland areas.	Maize, *nawa*, pumpkins.
Moisture content	Associated with soils with clay or high organic matter content, normally soils under trees or in wetlands.	Maize, *nawa*, pumpkins.
Wetness	Low lying flat areas with high organic matter consistent with wetlands.	Maize, *nawa*, pumpkins.
Slope	This include direction and gradient – west facing slopes considered drier and less fertile while east facing slopes less dry and fertile. Steep slopes considered shallow, less fertile, prone to erosion and difficult to work.	Millet west slope and maize east slope.
Flora and fauna	Trees and grass are used as indicators of fertility or drainage. Earthworms and termite mounds are indication of fertility of the soil.	Associated with moist areas, and wetlands for maize, *nawa*.
Socio-cultural issues	Soils in religious groves are considered sacred and not suitable for any other use except religious purposes.	Not suitable.

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9.2.4 Selection of crops and generation of specific crop ranges for land suitability evaluation

Firstly, famers decided on the crops that they aspire to grow in the irrigation scheme irrespective of their suitability. Farmers at Rambuḍa Irrigation Scheme listed forty crops that they want to grow in the irrigation scheme. The list of crops that was drawn up by farmers was used to generate ten specific crop ranges (Table 9.2). Crop ranges were grouped according to their growth requirements such as rooting patterns and growth characteristics, following the approach of Protz (1981).

Table 9. 2 Crop ranges generated from crops listed by farmers

Range	**Crops in specific range**
I. Alliums range	Onion, garlic, spring onion
II. Root range	Sweet potato, beetroot, carrot, potato
III. Leaf vegetable range	Cabbage, spinach, Chinese cabbage, *muxe* (African nightshade)
IV. Tomato range	Tomato, chilli, green/red pepper
V. Oil range	Ground nuts, sunflower
VI. Pulses range	Green beans, dry beans, peas, cowpea, okra
VII. Cereals range	Maize, wheat
VIII. Cucurbit range	Gem squash, sweet melon, baby marrow, watermelon, pumpkin
XI. Fruit range	Mango, banana, avocado, litchi
X. Citrus range	Lemon, orange, naartjies

9.2.5 Detailed biophysical resource survey and delineation of mapping units

Detailed survey of biophysical resources was conducted and was presented in Chapters 2, 5, 6 and 7.

9.2.5.1 Climatic conditions

The rainfall at Rambuḍa irrigation scheme is above 900 mm per annum (Table 2.1; and Table 9.3) and falls within high rainfall climatic zone. No frequent hail has been recorded in the area except for occasional light hailstorms and the area is considered hail-free. Hot, dry conditions during August-September months necessitate supplementary irrigation during this period. The area has dry, cool winters coupled with

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low afternoon relative humidities ranging from 32-34% and low mean monthly rainfall from 9-21 mm. Such low relative humidities and low temperatures are less conducive to pests and diseases, particularly fungal diseases. Climatic conditions of Rambuḍa irrigation scheme are suitable (S) for crops like tomatoes and potatoes that are sensitive to fungal infections.

Table 9. 3 Mean monthly climatic conditions at Rambuḍa Irrigation Scheme (ARC-ISCW, 2010)

Climate	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall (mm)	178.39	208.33	154.73	39.94	15.72	20.71	17.16	8.89	21.3	61.55	103.44	126.04
Daily maximum temperature °C	29.96	29.14	28.53	27.21	25.62	23.48	23.07	25	27.4	28.04	29.17	29.73
Daily minimum temperature °C	19.59	19.61	18.53	15.77	12.03	9.38	9.23	10.86	13.73	15.96	17.76	18.99
Mean temperature °C	24.78	24.38	23.53	21.49	18.82	16.44	16.16	17.93	20.56	22	23.46	24.36
Wind run km/day	108.3	104.1	90.77	78.12	75.04	79.54	88.89	100.22	115.76	121.58	113.08	104.99
A-Pan Evaporation (mm)	197.83	160.79	163.08	131.07	122.59	100.36	111.35	143.22	175.06	191.2	203.52	195.81
Maximum daily relative humidity	84.66	84	87.24	86.47	87.81	87.05	86.54	84.17	84.06	81.3	83.26	84.02
Minimum daily relative humidity	40.47	41.42	42.84	38.54	34.97	32.44	32.15	30.08	32.67	35.67	38.88	39.25
Sunshine hours	7.06	7.03	6.65	7.07	7.63	6.99	7.35	7.76	7.54	6.86	6.8	6.86
Aridity index	1.2	1.6	1.2	0.4	0.2	0.3	0.2	0.08	0.2	0.4	0.7	0.8

9.2.5.2 Soils of Rambuḍa Irrigation Scheme

Soils were classified according to the taxonomic classification system for South Africa as belonging to Hutton and Oakleaf forms (Ṋethononda and Odhiambo, 2011). A detailed account on soils was presented in Chapters 5, 6 and 7. Summary of soil description is presented in Table 9.4.

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Table 9. 4 Brief descriptions of soils of Rambuda Irrigation Scheme

Soil form	Soil family	B1 clay	Limitations
Hutton	Hayfield 2100	Non-luvic	Soil is fine to medium sand and has low water holding capacity, fine sands may be prone to compaction.
	Suurbekom 2200	Luvic	High subsoil clay content may be difficult to till when dry; where there is high content of fine sand and silt soil susceptible to compaction.
	Ventersdorp 3200	Luvic	High subsoil clay content may be difficult to till when dry; where there is high content of fine sand and silt soil susceptible to crusting.
Oakleaf	Caledon 1210	Non-luvic	Low water holding capacity; subsoil susceptible to crusting and subsoil compaction.
	Dipene 1220	Luvic	Prone to crusting, subsoil compaction moderate drainage and difficult to till when dry.

9.2.5.3 Soil mapping units of Rambuḍa Irrigation Scheme

Map units were delineated by using spatial maps of mappable soil properties (Figures 6.3-6.7) that influence crop production and other agronomic practices. The irrigation scheme was delineated into six soil mapping units (Figure 9.1). A summary of the characteristics of each mapping unit are presented in Table 9.5. The area is considered flat and thus, topography was not used in the delineation of the soil mapping units.

A list of soil characteristics important to crop growth was generated and each mapping unit was evaluated in terms of its suitability for the production of each crop in the ten specific crop ranges (Table 9.2) that might be grown in the irrigation scheme.

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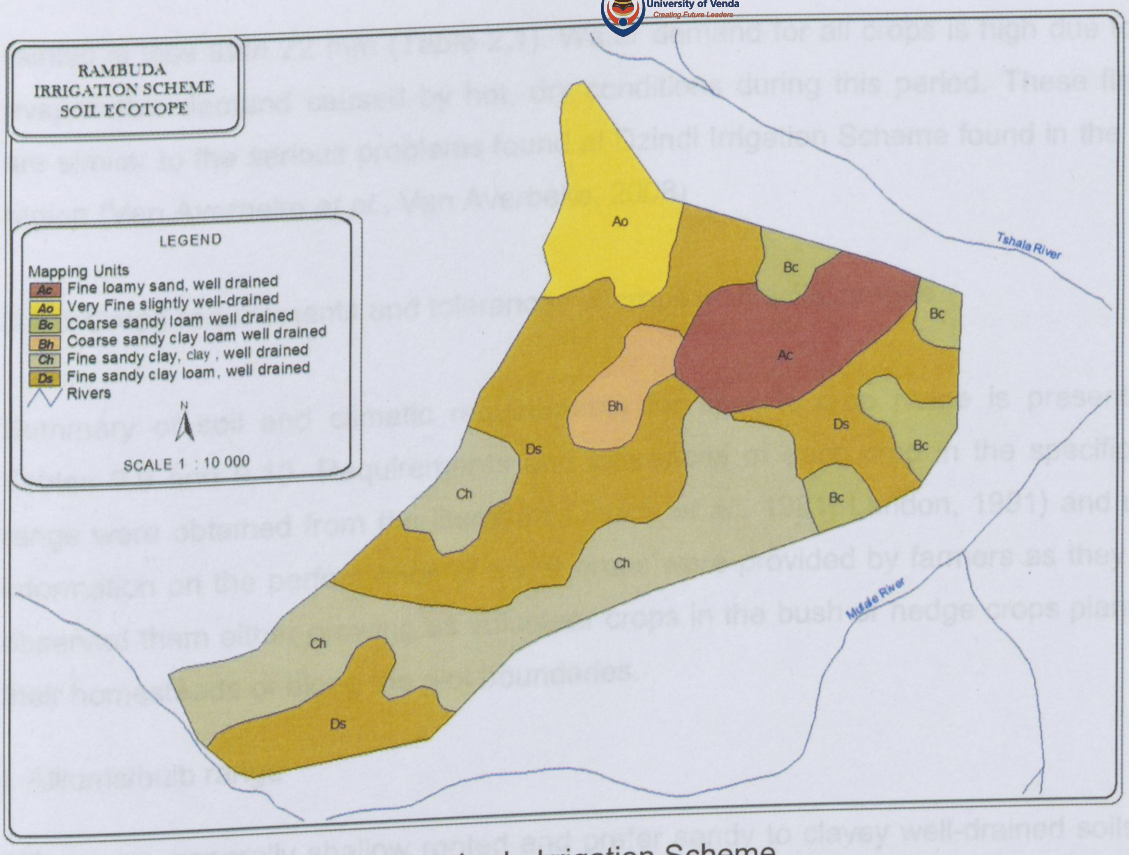


Figure 9.1 Mapping units of Rambuḍa Irrigation Scheme

Table 9.5 Brief description of mapping units of Rambuḍa Irrigation Scheme

Map Unit	Topsoil clay content (%)	Effective soil depth (cm)	Slope (%)	Limitations
Ao	18-36	>120	0.5-1	Soil prone to surface sealing and subsoil compaction and surface sealing (infiltration rate), moderate drainage.
Ac	12-32	>120	1-2	Low water-holding capacity; prone compaction.
Bc	12	>120	0.5	Low water-holding capacity; prone compaction.
Bh		>120	0	No limitations.
Ch		>120	0.5-2	Very few limitations, small patches that may be susceptible to subsoil compaction particularly in the low lying areas.
Ds	36	>120	0—1	Few limitations, if any. Deep slightly friable soil. Moderate drainage with restrictive layer at lower depths.

9.2.5.4 Water resources

There is no quantitative data on water resources for Tshala River (Figure 2.1). Empirical information on flow pattern of the river was obtained from the local people. Farmers indicated that the river flow is high during and just after the rainy months but subsides in dry season. The river flow is very low during June to October, when mean monthly

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rainfall is less than 22 mm (Table 2.1). Water demand for all crops is high due to high evaporative demand caused by hot, dry conditions during this period. These findings are similar to the serious problems found at Dzindi Irrigation Scheme found in the same region (Van Averbeke *et al.*, Van Averbeke, 2008)

9.2.6 Crops requirements and tolerances of crops in specific ranges

Summary of soil and climatic requirements for specific crop range is presented in Tables 9.9 and 9.10. Requirements and tolerances of each crop in the specific crop range were obtained from the literature (Janick *et al.*, 1981; Landon, 1991) and useful information on the performance of some crops were provided by farmers as they have observed them either growing as volunteer crops in the bush or hedge crops planted in their homesteads or along the plot boundaries.

I. Alliums/bulb range

Alliums are generally shallow rooted and prefer sandy to clayey well-drained soils with minimum depth of 45-60 cm, but can be successfully grown on soils with 30 cm depth. The optimum soil pH (H_2O) 5.0-6.0 is required for crop growth. The optimum growth temperature is 12-24°C, with mean monthly temperatures between 7-29°C (Landon, 1991; Brewster, 1994; Niederwieser, 2004; Stork and Potgieter, 2004).

II. Root range

Well-drained soils with <35% clay and minimum depth of 50 cm are desirable for this crop range. Crops in this range grow well at pH(H_2O) 5.0-6.1, but potatoes can withstand pH(H_2O) ranging from 4.3-6.1. Growth can be seriously affected at temperatures below 5°C and above 29°C. Sweet potatoes in particular require hot days and warm nights and mean monthly temperatures 21-29°C. The optimum growth temperature for crops in this crop range is 15-18°C. They are sensitive to frost (Landon, 1991; Steyn, 2003; Steyn and du Plessis, 2003; van der Berg and Laurie, 2004).

III. Leaf vegetable range

Vegetables are shallow rooted crops and can do well on soils with sandy to clay texture and a minimum depth of 45 cm, provided they are well drained. Most vegetables can be

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grown on soils with pH(H_2O) ranges of 5.0-6.0. The optimum temperature for this crop range is 15-24°C. Temperatures below 7°C and above 27°C negatively affect plant growth (Landon, 1991; Ryder, 1999).

IV. Tomato range

Deep well-drained sandy loam to clay soils free from compaction, with clay contents from 15-35% and an effective rooting depth of 60 cm are suitable. Sandy soils create conditions favourable for nematode infestation. Optimum soil pH(H_2O) ranges from 5.5-6.8. Temperatures below 12°C and above 35°C are detrimental to plants. The average daily mean temperatures for optimum growth, yield and fruit quality are from 22-24°C (Landon, 1991; Bosland and Votava, 1999). Crops in this range are sensitive to frost.

V. Oil range

Crops in this range grow well on deep, well-drained sandy loam to clay soils which are not prone to compaction. Crops in this range are sensitive to soil compaction and waterlogging. A soil pH(H_2O) of 5.6 is desirable for optimum crop growth. Groundnuts can be grown on soils with at least <20% clay in the topsoil. Although groundnut is a fairly shallow rooted crop, a depth of at least 90-120 cm is desirable (DAFF, 2010; Landon, 1991). Sunflower has a taproot that can grow as deep as 2.0 m. Warm temperatures are desirable for crops in this range. They grow well on temperatures from 18-33°C and growth and yields are adversely affected at temperatures above or below this range (DAFF, 2010, Citrus Research International, 1997).

VI. Pulses range

Pulses can be grown on wide range of soils, but sandy to loamy well-drained soils with >40 cm depth and not prone to crusting are preferred. The optimum soil pH(H_2O) of 5.3-6.0 is desirable for pulses. Crops in this range grow well at temperatures between 15-21°C and the mean monthly temperature should be between 10-27°C. Temperatures <12°C and above 35 °C are not desirable as they negatively affect fruits and their quality (Landon, 1991; ARC-Grain Crops Institute, 2002).

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VII. Cereals range

Most cereal crops can be grown on relatively shallow soils, however, a minimum depth of 60 cm is considered ideal for irrigated cereals. A soil pH(H_2O) from 5.5-7.5 is desirable for optimum plant growths. Although large-scale maize production does take place on soils with a clay content of less than 10% (sandy soils) or in excess of 30% (clay and clay-loam soils), the texture classes between 10 and 30% clay have air and moisture regimes that are optimal for healthy maize production (Landon, 1991). Maize is a warm weather crop and the optimum growth temperature of 19-23°C. Although, the minimum temperature for germination is 10°C, germination will be faster and less variable at soil temperatures of 16 to 18°C. At 20°C, maize should emerge within five to six days. The critical temperature detrimentally affecting yield is approximately >32°C. Wheat thrives well under warm temperatures from 22-34°C for spring wheat and 5-25°C for winter wheat. Frost can damage maize at all growth stages and a frost-free period is required (DAFF, 2010 Landon, 1991)).

VIII. Cucurbit (squash and melons) range

Cucurbits require relatively deep well drained soils with 45-100 cm depth. The optimum pH(H_2O) for cucurbit is 6.0-7.0. They are warm season crops and very sensitive to frost and low temperatures. Optimum temperatures for growth are 18-30°C, with mean monthly mean temperatures ranging between 20-32°C (Landon, 1991; DAFF, 2011,).

XI. Fruit range

Crops in this range are well adapted to moderately deep to deep well-drained sandy to loamy soils with 15-25% clay and pH(H_2O) of 5.6-7.2, but can grow on soils with 50% clay. The optimum growth temperatures from 20-30°C are favourable. Banana growth ceases at 14°C and lower, (Landon, 1991; Robinson, 1996; Wolstenholme, 2002).

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X. Citrus range

Citrus requires well-drained soils with at least 50-100 cm depth and no salts at 50 cm topsoil depth. Sandy to clay soils not prone to crusting are preferable, but heavy clays soils are marginally preferable for citrus. The optimum pH(H_2O) 6.5-7.5 is desirable for citrus production. Temperature between 14-32°C are preferable (Landon, 1991; Citrus Research International, 1997), but citrus is also successfully grown in areas with temperatures as high as 40°C in South Africa (Tshipise near Musina), but the optimum growth temperature is 20-27°C (Landon, 1991; Citrus Research International, 1997).

9.2.3 Management requirements for Rambuḍa irrigation scheme

Land evaluation will be done on agronomic aspects as well as management requirements for soil fertility, irrigation, tillage practices, conservations measures and costs of land improvements. Land improvement costs relating to land clearing were not considered because this suitability evaluation was conducted on an existing irrigation scheme, but for new land, costs of land clearing should be considered during the evaluation process. Socio-economic factors were also not separately considered during the land suitability evaluation process and will be briefly discussed because the objective of this study was to assess physical land suitability of the existing irrigation scheme for specific crop ranges. Management requirements that were considered at Rambuḍa irrigation scheme are explained below.

9.2.3.1 Irrigation management requirements

The most critical aspects of irrigation are the choice of appropriate irrigation method for each soil type and its adaptation to the specific soil. Any inappropriate selection of irrigation method can result in high running costs, direct and indirect loss of soil quality through erosion or crusting. Three irrigation methods were considered based on what farmers suggested as the most preferred methods of irrigation. Class-determining factors relating to management and costs or each irrigation method were used to decide suitability different soil mapping units for rating of each irrigation system according to their irrigation requirements. A summary of some important soil requirements for each irrigation method is presented in Table 9.6.

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Table 9. 6 Soil requirements for suitability classification of irrigation systems

Irrigation method	Soil requirements
Drip	Drip irrigation cannot be used on coarse textured (sandy) soils due to excessively fast infiltration which promotes vertical percolation of water, leading to poor lateral distribution. Thus, only a small area below the dripper is wetted which is insufficient to support the crop. Another limiting factor is the clogging of emitters by sand particles resulting in some areas of the field not being irrigated. This method cannot be used on soils that are prone to surface crusting. Surface crust prevents water percolation resulting in water ponding below the dripper instead of reaching the roots of the crop.
Sprinkler	Sprinkler irrigation can used on sandy soils however, soils should not be prone to surface crusting or located on slopes >8%. Care should be taken even on soil with 5% slopes to prevent soil loss through erosion, particularly under annual cropping. Sprinkler irrigation can be used on loamy clay to clay soil provided they are not susceptible to surface crusting.
Furrow	Furrow irrigation cannot be used on coarse textured (sandy) soils as it is difficult to prevent water from eroding the furrows. It is most suitable for soil with crusting problems as the irrigation water flows in the furrows preventing crusting effects on seed germination and the crops planted on ridges between furrows that are not affected by crusting.

9.2.4 Evaluation of suitabilities of soil mapping units for specific crop ranges

This section presents procedures for land suitability evaluation of each mapping unit for specific crop ranges for Rambuḍa Irrigation Scheme. The results of evaluation are presented in Section 9.3. Rambuḍa Irrigation Scheme is an existing irrigation scheme and thus, class-determining factors relating to management, land development, conservation and socio-economic conditions of the area did not have an adverse influence on land suitability for irrigation. Matching is choosing of crop or group of crops that closely match the conditions of the land (FAO, 1985) through the comparison between the land qualities or characteristics, and the requirements or tolerances of the land utilization type to give factor ratings. After consideration of class-determining factors for irrigated agriculture, the suitability rating was carried out on the basis of the agronomic aspects related to rooting conditions, aeration and water quantity (Table 9.7). Suitability ratings relating to salinity sensitivity were not included, since this area falls within a high rainfall area, where salinity is not found. The water quality is considered to be good and there is no chance of developing salinity problems in the area.

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Table 9.7 Class-determining factors and land characteristics for consideration in setting critical limits

Agronomic	**Relevant land characteristics**
Rooting conditions	Effective depth
	Root space
	Penetration resistance
Aeration	Period without sufficient aeration during the growing season of the crop
	Rainfall pattern
Water quantity	Stream flow
	Rainfall pattern

Figure 9.2 is illustrates the process of the evaluation of mapping units that was used to assess suitability ratings for different mapping units for specific crop ranges. Evaluation starts from the least limiting factor to the most limiting factor. If the factor is not limiting for a specific crop or groups of crop (specific crop ranges in this regard), it is indicated with a "No" and if it is limiting it is indicated with a "Yes" and the further assessed until a suitability rating decision is made. This is an example of how mapping units **Ao** and **Ac** were evaluated for the citrus crop range using a decision-tree approach reach to the suitability rating decision.

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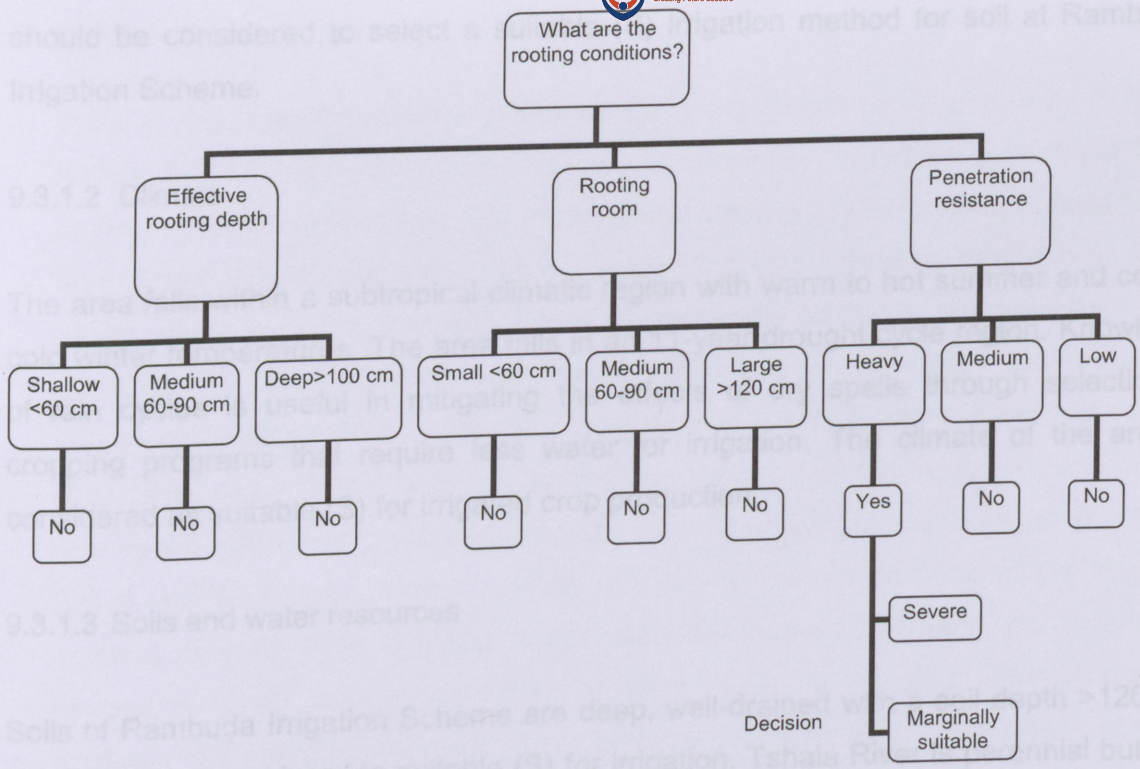


Figure 9.2 Class-determining rooting conditions for citrus using decision tree

9.3 Results and Discussion

9.3.1 Evaluation of bio-physical resources for irrigated crop production

This section presents the results of land suitability evaluation for irrigated crop production for Rambuḍa Irrigation Scheme using dynamic land suitability evaluation guidelines for small-scale communal irrigation scheme that were developed in this study.

9.3.1.1 Topography

The area is considered flat with gentle undulating slopes ranging from 0.5-2%. According to Turner and Scotney (1993), slopes less than approximately 8% are in general considered suitable for irrigation development. The slopes of all mapping units at Rambuḍa Irrigation Scheme are less than the threshold slope of 8% for irrigable land (Turner and Scotney, 1993) and thus, the area is classified as suitable for irrigation. However, selection of an appropriate irrigation method for a given soil type

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should be considered to select a suitable (S) irrigation method for soil at Rambuḍa Irrigation Scheme.

9.3.1.2 Climate

The area falls within a subtropical climatic region with warm to hot summer and cool to cold winter temperatures. The area falls in an 11-year drought cycle region. Knowledge of rain cycles is useful in mitigating the effects of dry spells through selection of cropping programs that require less water for irrigation. The climate of the area is considered as suitable (S) for irrigated crop production.

9.3.1.3 Soils and water resources

Soils of Rambuḍa Irrigation Scheme are deep, well-drained with a soil depth >120 cm. The soils are considered to suitable (S) for irrigation. Tshala River is perennial but with low flows during the June to October when the rainfall is low; however the water quantity is sufficient to irrigate 120 hectares of land. The water flow can be increased through the construction of diversion weir upstream and water flows to the secondary canals through the pipeline, thus, reducing wastage and increasing amount of water available for irrigation. In general, biophysical resources for agriculture at Rambuḍa Irrigation Scheme cab be classified as suitable (S) for irrigated agriculture.

9.3.2 Land suitability evaluation for irrigated crop production

Land suitability evaluation was conducted on ten (10) specific crop ranges generated from forty (40) crops that were listed by farmers of Rambuḍa Irrigation Scheme (Table 9.2).

9.3.2.1 Management requirements

Management aspects relating to soil fertility, cultivation, soil conservation measures, irrigation and costs involved in crop production were considered. These issues determine suitability of specific crops for an area.

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I. Soil fertility management

Soils of Rambuḍa Irrigation Scheme are generally, either moderately acid (5.5-5.9), slightly 6.0-6.7) or neutral (6.8-7.2). This is considered optimum growth pH for all crops in specific crop ranges for the irrigation scheme. A liming programme should be followed to keep soil pH at optimal levels for crop production. Phosphorus status of the soil is very low and application of phosphate fertilizers is crucial to raise P status of the soil. Phosphorus deficiency was observed on maize during the field survey and was particularly severe on sandy loam soils (Figure 7.2 and Figure 9.1). Quantities of fertilizers will be guided by the norms for various crops. Over-fertilization with P is sometimes found and should be guarded against (Ellof and Laker, 1978). Potassium was low to very low in certain sections of the irrigation scheme (Figure 7.3). It is an important plant nutrient element, particularly for vegetable, sweet potatoes and fruits in terms of quality and taste. Management of nutrients like nitrogen (N) may be a challenge under small-scale irrigation scheme due to leaching. Slit application of N and K through top-dressing is the appropriate strategy to deal with such a challenge to ensure constant supply of these nutrients elements during different stages of crop growth (Van Averbeke *et al.*, 2007). Proper management strategy of these elements is imperative to ensure production of good quality crops. Mzuku *et al.* (2005) stated that P and K can be managed together in site-specific management zone. Fertilizers and pesticides can be purchased from the co-operative which is found in the irrigation scheme if enabling financial resources are available to farmers.

Soil fertility management is a great challenge among farmers at Rambuḍa Irrigation Scheme mainly due to the lack of financial resources to purchase fertilizers and lack of training in soil fertility management. The majority of farmers have resorted to the use of kraal manure and fresh chicken manure which may cause temporary imbalances in the soil C:N ratio and bring in new weed species. Another critical aspect of soil fertility is the Ca:Mg ratio. This was explained in detail in Section 5.3.1. The average Ca:Mg ratio of the soils at Rambuḍa Irrigation Scheme was 3.3 and 2.4 for the topsoil and subsoil, respectively.

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Farmers do not have tractors and tillage implements. They rely on individuals who own old tractors for tillage. Individual tractor owners do not have implements for deep tillage and they thus use disc, mouldbourd ploughs and "skofel" to till and prepare the soil for planting. These implements only till the top 22 cm of the soil resulting in compaction of soil just below the tillage depth. Subsoil horizons are highly compacted. Subsoil compaction is difficult to detect (Spoor, 2006) and may lead to substantial yield loss, particularly, in the eastern part of the irrigation scheme.

Mapping units ***Ao, Bc, Bh*** and ***Ch*** have very high subsoil compaction potential and may require periodical deep tillage to prevent subsoil compaction (Figures 6.7 & 9.1). Figure 6.7 shows that soil compaction does not occur uniformly across the field, its distribution varies with soil physical properties, particularly texture and soil organic carbon content, volume of traffic, and other agronomical practices (Kees, 2005). Mapping units (***Ao, Bc, Bh*** and ***Ch***) found in areas that farmers indicated as compacted, are difficult to till and give low yields (Section 4.3.1 & Figure 4.2). Soils in mapping unit **Ao** in particular are prone to compaction and should not be tilled when the soil is too moist; large machinery should be used cautiously to avoid soil compaction problems. In general, ripping is urgently necessary and a deep tillage program is needed for soils at Rambuḍa Irrigation Scheme. The use of appropriate tractor-plough sizes is important to avoid wheel slip, which seriously aggravates compaction and, furthermore, using a systems of controlled traffic over the fields is of paramount importance. Soil compaction is also a very serious problem at Dzindi Irrigation Scheme, basically due to the use of a tractor with inadequate power to pull the plough. One old farmers successfully overcame the problem by using a final cultivation by means of ox-drawn implements after the last cultivation by tractor and planting only thereafter (Laker, 2012, Personal communication, June 20, 2012 Emeritus-Professor of Soil Science, University of Pretoria).

Farmers indicated that the soil has not been ripped since the Department of Agriculture took away tractors and ripping implements form the local government co-operative to Polokwane more than ten years ago. They complain that it was wrong of the Department to take away the implements as they do not have financial resources to buy or hire deep tillage implements to rip the soil from private contractors.

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Although, there are efforts through Micro Agricultural Financial Institutional Scheme of South Africa scheme (MAFISA) to enable individuals to purchase agricultural implements, these endeavours are usually not suitable for resource-poor small-scale farmers in communal irrigation schemes. Further investigations are needed on the feasibility of such schemes for the communal farming under specific socio-cultural and economic conditions.

III. Irrigation system management and soil suitability ratings

Farmers suggested three irrigation systems namely, drip, sprinkler (dragline) and furrow irrigation. Soils in the eastern and south-eastern part of the irrigation scheme are susceptible to crusting. Mapping unit ***Ao*** is susceptible to surface sealing/crusting and ***Bc*** has coarse texture which is problematic for drip irrigation method. Thus, drip irrigation is not suitable for soils in ***Ao*** mapping unit and is marginally suitable (MS) for soil in ***Bc*** mapping unit because of their excessively fast infiltration rate. Management is crucial as drippers require constant monitoring of blockages of emitters at all times. Any blockage can result in crops not being irrigated. During a NERISA (Network on Irrigation Research and Extension in Small-scale Agriculture) workshop at Port St. Johns in the Eastern Cape a case was seen where a farmer was growing tomatoes successfully, with one part being under furrow and the other under drip irrigation. The part under furrow irrigation was excellent, but water could not be applied due to problems with the system (Laker, 2005). The problem seemed to be drippers clogged as a result of the silt content of the water and lack of infrastructure to ensure proper maintenance. Such situation may also pose a serious problem for small-holder farmers at Rambuḍa Irrigation Scheme who do not have resources to employ labourers, but perform all tasks themselves except if a family member is available. The majority of plot-holders are women who are involved in family chores and require a system that will allow them to perform other tasks while irrigating.

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Table 9.8 Summary of soil suitability rating of mapping units for irrigation systems

Mapping unit	Soil type	Irrigation system suitability rating for map unit		
		Furrow	**Drip**	**Sprinkler**
Ao	Very fine sandy loam to clay	WS	MS	$MS_{c,m}$
Ac	Fine loamy sand	S	S	WS
Bc	Coarse sandy loam	$MS_{m,e}$	$MS_{i,m}$	WS
Bh	Coarse sandy clay loam	WS	WS	WS
Ch	Fine sandy clay to clay	WS	WS	WS
Ds	Fine sandy clay loam	WS	WS	WS

e Erosion; m Management difficulties; i Infiltration too fast and vertical and not effective for roots; c Soil susceptible to compaction and/or crusting.

The majority of mapping units at Rambuḍa Irrigation Scheme are not susceptible to crusting except soils in mapping unit ***Ao***. In general, soils at Rambuḍa are well suited (WS) for sprinkler irrigation except mapping unit ***Ao*** which is marginally suitable (MS) for sprinkler irrigation. Another aspect of management is the cost, both for establishment and running of the system during crop production period, particularly pumping costs in this regard. Furrow irrigation method is well suited (WS) for all mapping units except ***Bs*** and ***Bc*** which are marginally (MS) suited for furrow irrigation because of their coarse texture. Farmers at the irrigation scheme are more experienced in working with furrow irrigation and have gained lot of experience to manage and resolve problems of furrow irrigation. The system is low in running costs as the water flows from the weir through balancing dams to the plots by natural gravity.

IV. Soil conservation

Topography of the all mapping units is considered flat with gentle undulating slopes (0.5-2.5%) that require minimum conservation in the form of terracing. All plots are correctly demarcated on terraces and any change in land use such as overhead irrigation, management practices or technology must not disregard the existing conservation measures. It is recommended that terraces be protected, as any disturbance may result in severe problems through erosion and extreme costs of reconstructing terraces which are by now fully stabilized.

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9.3.2.2 Climatic suitabilities of mapping units for specific crop ranges

The results of climatic suitability are summarized in Table 9.9. The most critical climatic variable for crop production is temperature. Temperatures at Rambuḍa Irrigation Scheme are within the ranges for all specific crop ranges selected for the irrigation scheme (Table 2.1 and 9.1). Therefore, climatic conditions are considered well suited (WS) for majority of crops in specific crop ranges for Rambuḍa Irrigation Scheme. Hot, dry conditions experienced from the months of August to October may be limiting, particularly for mapping units ***Ac*** and ***Bh*** which are characterized by coarse textured soils. These mapping units fall within the area that was reported by farmers to have soils that dry out too quickly (Section 4.3.1 & Figure 4.2). The water flow can be increased through construction of a diversion weir upstream and water flows to the secondary canals through the pipeline, thus, reducing wastage and increasing amount of water available for irrigation. In general, biophysical resources for agriculture at Rambuḍa Irrigation Scheme are classified as suitable (S) for irrigated crop production in the low-lying parts, mapping units ***Ao, Ac, Bc*** and ***Ds*** are prone to light winter frost (Figure 9.1), particularly in the months of June-July. The eastern parts of mapping units ***Ao, Ac, Ds*** and ***Bc*** towards Tshala River (Figure 9.1) are prone to light frost. The southern parts of mapping units ***Ch*** and ***Ds*** as well as mapping unit ***Bc*** are prone to frost. Citrus fruits are sensitive to frost and may suffer leaf damage. Relative humidity of an area is critical for crop growth and plant health. Rambuḍa Irrigation Scheme has high morning relative humidity levels (>80%) throughout the year. Such high RH values coupled with warm temperatures are ideal for fungal disease infections. However, a proper spraying programme should be followed to eliminate chances of fungal infection.

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Table 9. 9 Summary of crop requirements for [illegible] climatic suitability for specific ranges

Crop range	Temperature tolerance limits (°C)	Optimum growth temperature (°C)	Climatic rating of mapping unit					
			Ao	Ac	Bc	Bh	Ch	Ds
Alliums	7-29	12-24	WS	WS	WS	WS	WS	WS
Root	5-29	5-18	WS	WS	WS	WS	WS	WS
Leaf vegetables	7-27	15-24	WS	WS	WS	WS	WS	WS
Tomato	12-35	22-24	WS	WS	WS	WS	WS	WS
Oil	12-25	15-21	WS	WS	WS	WS	WS	WS
Pulse	8-34	19-20	WS	WS	WS	WS	WS	WS
Cereals	32	18-30	WS	WS	WS	WS	WS	WS
Cucurbits	12-35	18-33	WS	WS	WS	WS	WS	WS
Fruit	14-29	24-27	S_f	S_f	S_f	WS	S_f	WS
Citrus	14-32(40)	21-27	S_f	S_f	S_f	WS	S_f	

WS = well suited, S = suited

Low-lying parts of mapping units ***Ao, Ac, Bc, Bh, Ch*** and ***Ds*** are prone to light frost during June-July and fruit trees are likely to suffer leaf damage.

9.3.2.3 Suitabilities of soil mapping units for specific crop ranges

Each soil mapping unit was assessed as to its suitability for the production of each crop in the specific range. Land suitability evaluation was conducted on specific crop ranges to determine the suitability rating for each crop range through the matching process. Tables 9.10 and 9.11 present summary of suitability ratings for different mapping units for specific crop ranges.

Mapping unit ***Ac*** was well suited (WS) for most crop ranges, suited (S) for Alliums and Oil crop range. Mapping unit ***Ac*** was suitable for Oil range because of high clay content and crusting which are not favourable for the crops in this range and is marginally suited (MS) for Citrus range because of crusting, subsoil compaction and drainage.

Mapping unit ***Bc*** is well suited (WS) for all ten specific crop ranges. Mapping unit ***Ao*** which is well suited (WS) for most crop ranges, suited (S) for root range and oil range, but marginally suited (MS) for Citrus range. Its susceptibility to compaction down-graded it to suited for Root range and Oil range which are sensitive to compaction and such soils may cause deformation of sweet potato tubers. Citrus trees are sensitive to compaction layers and poor drainage. This mapping unit has a moderate drainage

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which may be a problem for irrigated projects considering poor irrigation management by farmers. Prolonged soil wetness may be due to subsoil compaction. Soil compaction reduces pore spaces thereby increasing tortuosity of water flow leading to decreased water movement in the soil, consequently water logging and anaerobic conditions in the compacted land overlying layers, particularly in lands under irrigation (Bennie and Burger, 1979).

Mapping unit ***Ds*** was well suited (WS) for all crop ranges and suited (S) for root range and Oil range because of high clay content and susceptibility to compaction. Oil range sunflower, in particular is sensitive to compaction due to the deep rooting system. Mapping unit ***Bh*** is well suited (WS) for all crop ranges and suited (S) for Leaf Vegetables and Cucurbits crop range because of low moisture holding capacity. This mapping unit was reported to have soils that dry too quickly after irrigation and/or rains (Nethononda and Odhiambo, 2011).

Mapping unit ***Ch*** is well suited for most crop ranges and suited (S) to Alliums, Fruit; Oil and Root crop ranges because of high clay content and susceptibility to subsoil compaction. However, this mapping unit may be well suited for all crop ranges should a periodic deep tillage programme can be designed and strictly implemented.

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Table 9.10 Summary of crop requirements used in assessing the soil suitability for specific crop ranges

Specific Crop range	Rooting depth (cm)	Texture	Clay content %	Drainage	pH	Workability	Tolerance				
							Water-logging	**Drought**	**Clayey texture**	**Acidity**	**Salinity**
I. Alliums	30-60	Sandy to clay loam	<35	Well-drained	5.0-6.8	No restriction layers allowed	Low	Low	Medium	Low	Sensitive
II.Root	25-40	Sandy to loam ;exclude clays and poor structures	<35	Well-drained	5.6-6.6	No restriction layers allowed	Medium	Low	Low	High	Sensitive
III. Leaf vegetables	45-60	Sandy to clay	>15%	Well-drained to imperfectly drained	5.5-6.8	No restriction layers allowed	Low	Low	Moderate	Moderate	Moderate
IV. Tomato	45-60	Sandy loam to clay	<20	Well-drained	5.5.6.8	No restriction layers allowed	Low	Low	Moderate	Moderate	Sensitive
V. Oil	30-60	Sandy to loam; exclude sands and heavy clays	<20	Well-drained	5.3-6.0	No restriction layers allowed	Low	Moderate	Moderate	Moderate	Moderate
VI. Pulse	45-100	Sandy to clay loam	10-35%	Well-drained	5.5-7.5	No restriction layers allowed	Moderate	Moderate	Low	Low	Sensitive
VII. Cereals	90-120	Loamy to clay; exclude sands	10-80	Well-drained	6.0-7.0	No restriction layers allowed	Low	Moderate	Low	Low	Moderate
VIII. Cucurbits	90	Sandy loam to clay	15-35	Well-drained	5.5-6.8	No restriction layers allowed	Low	Low	Moderate	Low	Sensitive
IX. Fruit	90-120	Sandy, loamy-clay	15-25	Well-drained	5.6-7.2	No restriction layers allowed	Moderate	Moderate	Moderate	Moderate	Sensitive
X.Citrus	90-120	Sandy to clay ;exclude heavy clays	<30	Well-drained	6.5-7.5	No restriction layers allowed	Low	Low	Moderate	Moderate	Sensitive

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Table 9. 11 Suitability rating for each mapping unit

Mapping unit	Size	Suitability rating for each crop range									
		I Alliums range	II Root range	III Leaf vegetable range	IV Oil range	V Pulse range	VI Cereals range	VII Cucurbit range	VIII Fruit range	IX Citrus range	X Tomato range
Ao	10.928	WS	$S_{d,c}$	WS	S_c	WS	WS	WS	WS	$MS_{d,i,c}$	WS
Ac	13.416	WS	WS	WS	WS	WS	WS	WS	WS	$MS_{d,i,c}$	WS
Bc	8.863	WS	WS	WS	WS	WS	WS	WS	WS	S_c	WS
Bh	4.462	WS	WS	S_m	WS	WS	WS	S_m	WS	WS	WS
Ch	41.049	S_d	S_c	Ws	S_c	WS	WS	WS	S_c	WS	WS
Ds	41.497	S_d	S_c	WS	S_c	WS	WS	WS	WS	WS	WS

Notes: WS: Well Suited; S*: Suited $_{m=}$ moisture availability; $_{d=}$ drainage and $_{c=}$ susceptibility to soil compaction; severe.

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Table 9. 12 Summary of land suitability and total area for specific crop ranges for Rambuḍa Irrigation Scheme

Suitability rating	Suitability for specific crop range and total area for each rating (ha)									
	I Alliums range	II Root range	III Leaf vegetable range	IV Oil range	V Pulse range	VI Cereals range	VII Cucurbit range	VIII Fruit range	IX Citrus range	X Tomato range
Well suited (MS)	37.669	26.741	115.753	93.474	120.215	120.215	115.753	79.166	87.008	120.215
Suited (S)	82.546	93.474	4.462	26.741	0	0	4.462	41.049	8.863	0
Marginally suited (MS)	0	0	0	0	0	0	0	0	24.344	0
Not suited (N)	0	0	0	0	0	0	0	0	0	0

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9.4 Conclusions

The guidelines showed that Rambuḍa Irrigation Scheme was well suited for most crops in the specific ranges. The furrow irrigation system was generally, the most appropriate and economical method of irrigation. Dynamic guidelines for land suitability evaluation for small-scale irrigation scheme can be used under different conditions. These guidelines are not static and can be adapted to different conditions so that the end results will produce reliable suitability ratings that are easy to follow and understand. The dynamic land suitability evaluation guidelines were able to assess the suitability of crops in the specific ranges and the information required to make land use decisions at Rambuḍa Irrigation Scheme. The guidelines are a good basis for the development of a uniform land suitability evaluation system for small-scale irrigation schemes in South Africa and they should also be tested under commercial farming conditions for further refinement.

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CHAPTER TEN

GENERAL CONCLUSIONS AND RECOMMENDATIONS

10.1 Conclusions

The soils at Rambuḍa Irrigation Scheme have high potential for crop production. However, soils have not been fully exploited due to lack of information and these farmers have not entirely grown crops that are suitable for the area. Soil management, soil fertility and deep tillage in particular are big challenges for farmers as a result of lack of soil information which is the basis for crop production. Farmers can provide invaluable information on biophysical natural resources important for agricultural development of an area. Local knowledge of soil and crop performance under prevailing climatic conditions is a starting point to understand soil distribution and criteria used by local people to select suitable land use for an area given available technology, skills and socio-cultural issues that affect land use.

Farmers at Rambuḍa Irrigation Scheme could classify; describe and map soil types and their distribution across the irrigation scheme using indigenous knowledge of soils. They also identified climatic conditions and how they affect crop performance. The results showed that indigenous soil classification uses visible topsoil properties to classify soils and soil classification is made in terms of properties that influence soil use. Thus, criteria used to decide on soil suitability for a particular use are soil properties that affect crop performance under given management practices. Soil properties used for soil classification include soil texture, colour, organic matter and drainage. Criteria used to determine soil suitability for use are texture, depth, drainage, stoniness, workability, slope and climatic factors, which are not different from criteria used in scientific land suitability evaluation systems. This undocumented knowledge can provide invaluable information in situations where there is no recorded data on climate and hydrograph on stream flow. Participatory soil survey can save time and costs of conducting detailed soil survey by providing information on accessibility and where high or low agricultural potential soils are found in an area. This is fundamental information for land suitability evaluation for any area. Participatory soil survey is

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consultative and information on aspirations, local skills and education, demography of land user, concerns, socio-cultural issues that may affect land use are discussed and resolved, allowing a smooth and inclusive land suitability process and ownership of the outcome by the land users.

The detailed soil survey showed that soil at Rambuḍa Irrigation Scheme varied over short distances in both soil physical and chemical properties. Such variation in soil properties resulted from inherent processes and anthropogenic activities. Sand, silt, clay and organic carbon showed a moderate spatial variability in the topsoil than in the subsoil layers. Such a moderate variability in the topsoil layers indicated the impact of continuous mixing of soil due to shallow ploughing of the soil and a little influence of application of organic manure into the soil by farmers due to high soil temperatures experienced in the area. On the other hand, continuous shallow tillage of the soil loosens the topsoil to plough depth and causes a compacted layer in the soil below tillage depth. The results of the study showed variation in soil compaction which was very high in some parts of the irrigation scheme. Soils that are prone to compaction require different management from those that are not and site-specific management of such areas will save costs of deep tillage. There is a need for further assessments of the extent of soil compaction and its impact on crop production in all communal irrigation schemes in Vhembe district and South Africa in general. This will provide vital information for designing soil compaction amelioration strategies to improve soil quality in communal irrigation schemes and improved yields to be obtained and household food security to be increased.

Spatial distribution of sand, silt and clay is important in the delineation of soil mapping units which are the basic elements of land suitability evaluation. Soil physical properties together with topography, soil depths and climate determine crop production potential of a particular portion of land. The ecotope is described by topography, soil and climatic factors that have similar influence yield of the crop. Detailed soil surveys usually provide more information on soil properties and greater variability over short distances and time scale resulting in very small units to be delineated as ecotopes. Thus, the results also showed that the soil ecotope concept can be useful to for land suitability at both a regional scale and at a local detailed scale or farm level.

The results of this study showed moderate to high spatial variability in pH, P, K, Ca and Mg for both the topsoil and subsoil horizons across the irrigation scheme. Such

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variability in extractable P, K, Ca and Mg may be attributed to varying agronomic practices such as differences in types and application rates of manure and fertilizers into the soil and variation in removal of nutrients from the soil by crops. Knowledge of this variability may be used to implement variable rate of input application for each part of the irrigation scheme. Soils were very low in K and P, and this is a concern for production of good quality sweet potatoes and vegetables. Potassium and phosphorus can be managed together by combining areas with similar requirements into site specific management zones. Studies cited in this thesis showed that site-specific management can save costs of fertilizing the soil. This strategy may be equally applied under resource-poor irrigation schemes, particularly when coupled with extensive training of both farmers and extension officers.

Spatial variability and distribution of physical soil properties are important in delineation of areas of land into mapping units which are elements of land suitability evaluation. Areas with relatively similar properties require similar management practices and such areas can be delineated into mapping units. The dynamic guidelines for land suitability evaluation for small-scale communal irrigation schemes consider the interaction among land, land use and land use and are flexible to accommodate the uniqueness of specific community where they are used. Land users are consulted to acquire land and land use information and socio-cultural issues that affect land use. Good guidelines for land resources assessment for irrigation planning in South Africa do not provide suitability ratings for mapping units for specific crops or irrigation methods. The dynamic land suitability guidelines assess suitability of each map unit and provide its suitability rating for a specific crop and irrigation method. Reasons for down-grading are also provided to inform the report user on the basis for suitability rating or recommendations. This is important when there is improvement in technology, management skill or any factor that during the evaluation process caused down-grading of suitability rating of a given mapping unit. The results of suitability evaluation can be presented to economists to provide profitability assessments for each crop. Alternative crop combinations could be assessed to ascertain most profitable crop combinations under prevailing market conditions.

In determining a suitable irrigation method for soils at Rambuda Irrigation Scheme, the furrow irrigation method was well suited. Results of land suitability evaluation for specific crop range showed that the dynamic guidelines for land suitability evaluation were appropriate for this small-scale communal irrigation scheme. The principles used

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in the guidelines are flexible and consider the uniqueness of each community and perceptions of the local people on land use planning.

10.2 Research Recommendations

The study showed there is a need for further research on the following issues:-

1. Detailed studies of biophysical resources for agriculture are needed on all communal irrigation schemes, to provide basis for appropriate crop choices, management practices and re-planning where it may be needed.
2. There is need for soil scientists (pedologists) to investigate and match indigenous soil knowledge and knowledge systems to scientific information to find areas that can be integrated into either of the system to provide tested information on local soil and climatic conditions, and their implications on crop production. This will enable the use of these systems separately or complementarily by planners or land users.
3. Research on soil compaction under resource-poor irrigation scheme is imperative to ascertain the extent of this problem in Vhembe District and elsewhere in the country. Such information is necessary to provide policy guidelines, norms and standards to policy makers on combating soil compaction.
4. Further research on soil fertility management and site-specific management or variable-input-application strategy under communal irrigation scheme will provide information on the appropriateness of this approach to resource-poor farmers in communal irrigation scheme.
5. The local municipality or provincial Department of Agriculture should seriously consider for re-training of agricultural advisors on soil fertility management; tillage practices and irrigation scheduling. Local municipality should establish farmer forums to discuss causes and possible solutions to problems related to soil and crop production in communal irrigation schemes in Vhembe District.
6. Government's intervention in the form of subsidized deep tillage through re-establishment of government co-operatives to assist resource-poor farmer in communal irrigation schemes is urgently required for sustainable crop production in these irrigation schemes.

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7. Researchers, particularly from the University of Venda and the Agricultural Research Council are well-positioned to spear-head further and detailed investigations on soil compaction under resource-poor communal irrigation schemes in Vhembe District. Results from such studies should not only be academic, but should be useful to farmers in communal irrigation schemes. Thus, dissemination through establishment of study groups will cauntiatize and provide a discussion platform for both academics, extension officers and farmers and this will ensure effective adoption of the research results hence improve crop production.
8. Dynamic guidelines for land suitability evaluation for schemes that were developed in this study need to be tested and applied elsewhere in South Africa.

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APPENDICES

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APPENDIX I

QUESTIONNAIRE FOR CLIMATE, SOILS, AGRICULTURAL PRACTICES AND CROPS AT RAMBUḐA IRRIGATION SCHEME

Farmer :.....

Position :.....

Contact No: .....

PART I IRRIGATION SCHEME AND SOIL INFORMATION

1. When was Rambuḑa irrigation scheme established:.....
2. How many years have you been farming?..... from 19.....
3. What is the size of your plot and are you satisfied with the size .....ha

Yes	No

4. Do you have extra plots?:

Yes	No

5. Do you know the type of soil in your plot?:

Yes	No

If you answered Yes, please state the soil type:.....

..

6. Which crops did you plant over the past 5-10 years ago:

Crop	Mark	Year	Planted area	Season
Sweet potato				
Maize				
Beans				
Cabbage				
African shade bush				
Chinese spinach				
Pepper				

Other crops not mentioned.....

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7. Mark agronomical practices that you practice here in your plot?

Practice	Mark	Reasons
Ripping		
Irrigation		
Apply Kraal/ chicken manure		
Apply chemical fertilizers		
Hoeing		
Apply pesticides		
Others		

8. Do you have soil map for the irrigation scheme? | Yes | No |

9. Do you know the soil in the irrigation scheme? | Yes | No |

If, Yes fill below:

Type	Colour and other properties

10. What is the rate of water percolation of your soil? Please mark below:

Fast	Slow	Medium	Form ponds

11. Soil forms clods during cultivation? | Yes | No |

12. Is the soil workable?

Difficult	Easy	Hard underneath

13. Other crops that you wish to plant?.....

.....

.....

.....

PART II CLIMATE INFORMATION

2.1 Do you know how much rainfall is received in this area per year? | Yes | No | Not sure |

2.1.1 If yes state how much.....mm

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2.2 Which years did you receive more rain? **(Mark)**

1995	1996	1997	1998	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007

2.3 During which month does rain starts?

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

2. 4 Which are the driest months in this area?

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

2.5 According to your experience after how many years does drought period occur here? .....and which years did you experience drought.....

2.6 Which are the hottest months in this area?

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

2.7 Which are the coldest months in this area?

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

2.8 Do you experience frost in this area if yes during which month?

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

2.9 Which side of the scheme experience snow and which side has most snow?.....

.....

2.10 Do you experience strong winds in this area and if yes during which months?

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

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2.11 Which climatic condition is more limiting for the following crops?

Parameter	Mark if applicable	Severity rating**
Rainfall		
Temperature		
Frost		
Hot, dry conditions		
Wind		
Other		

** 5= Most severe, 3= Severe, 2= Moderately severe, 1= Not severe, 0= Not a problem

2.12 Do you think cropping season affect yield in your crops

Yes	No	Not sure

2.12.1 If yes which crops have been adversely affected also state which climatic condition was responsible?

Crop	Climatic conditions
Sweet potato	
Maize	
Dry beans	
Cabbage	
Onion/garlic	
Chilli	
Other:	

2.12.2 Which crops yield best during the following planting seasons?

Season	Worse	Poor	Good	Very Good
Summer				
Autumn				
Winter				
Spring				

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2.13 During which months do you grow the following crops and state the reason?

Poor	Good
Sweet potato	
Maize	
Dry beans	
Cabbage	
Onion/garlic	
Chilli	
Other:	

2.14 How can you avoid yield loses due to climatic conditions?.....

.....

.....

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RO LIVHUWA, NDAA!!!

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APPENDIX II

SOIL PROFILE DESCRIPTION AND CHEMICAL ANALYSIS

Profile No : R 01
Latitude : 22°47′919″
Longitude : 30°25′690″
Soil Form : Hutton
Soil Family : Hayfield
Altitude : 657.80
Terrain unit : Midslope
Slope : 0%
Slope shape : Straight
Aspect : South-east

Soil Particle Analysis

Profile No. R 01	Depth	Particle Fraction		
	mm	Sand	Silt	Clay
A1	350	60	8	32
B1	1450	58	6	36

Chemical Analysis

Sample No. R 01	Organic Carbon	Extractable cations				pH		P
		K	Ca	Mg	Na	H_2O	KCl	
	%	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}			mg kg^{-1}
A1	0.18	20.81	189.69	172.26	20.61	5.24	4.56	2.2
B1	1.23	60.90	142.6	552.7	18.27	5.06	4.56	0.7

Pedological characteristics

Horizon	Depth (mm)	Description	Diagnostic horizons
A1	350	Dry; dark reddish brown 2.5YR 3/4; sandy clay loam; massive; slightly hard; few pores; few roots common. gradual smooth transition;	Orthic
B1	1450	Moist red 2.5YR 4/8; sandy clay; massive; soft; friable; few common roots.	Red apedal

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Profile No : R 02
Latitude : 22°47′033″
Longitude : 30°25′788″
Soil Form : Hutton
Soil Family : Ventersdorp
Altitude : 648.68
Terrain unit : Footslope
Slope : 1.5%
Slope shape : Concave
Aspect : South east

Soil Particle Analysis

Profile No. R 02	Depth	Particle Fraction		
	mm	Sand	Silt	Clay
A1	350	70	4	26
B1	1200	48	6	46

Chemical Analysis

Sample No. R 02	Organic Carbon	Extractable cations				pH		P
		K	Ca	Mg	Na	H_2O	KCl	
	%	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}			mg kg^{-1}
A1	0.52	4.98	108.64	45.05	13.98	4.88	4.45	0.6
B1	0.98	208.10	417.38	597.72	26.24	4.88	4.15	1.7

Pedological characteristics

Horizon	Depth (mm)	Description	Diagnostic material
A1	350	Dry dark reddish brown 2.5YR 3/4; sandy clay loam; slightly hard; gradual smooth transition; many common roots.	Orthic
B1	1200	Moist dark red 10R 3/6; sandy clay; massive; soft, friable; few common roots.	Red apedal

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Profile No : R 03

Latitude : 22°47′887″

Longitude : 30°25′910″

Soil Form : Hutton

Soil Family : Hayfield

Altitude : 658.6

Terrain unit : Midslope

Slope : 1.5 %

Slope shape : Straight

Aspect : South-east

Soil Particle Analysis

Profile No. R 03	Depth	Particle Fraction		
	mm	Sand	Silt	Clay
A1	350	56	8	36
B1	1450	46	10	40

Chemical Analysis

Sample No. R 03	Organic Carbon	Extractable cations				pH		P
		K	Ca	Mg	Na	H_2O	KCl	
	%	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}			mg kg^{-1}
A1	1.82	106.82	595.1	115.37	21.15	5.61	5.01	7.5
B2	0.78	26.66	526.3	228.95	21.09	5.62	5.07	0.9

Pedological characteristics

Horizon	Depth (mm)	Description	Diagnostic material
A1	350	Dry dark reddish brown 2.5YR 3/3; sandy clay; massive; gradual smooth transition; slightly hard; few common roots.	Orthic
B1	1450	Moist dark reddish brown 2.5YR 3/4; sandy clay; massive; soft and friable; few common roots.	Red apedal

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Profile No : R 04
Latitude : 22°47′793″
Latitude : 30°26′811″
Soil Form : Hutton
Soil Family : Hayfield
Altitude : 654.80
Terrain unit : Midslope
Slope : 0-0.5%
Slope shape : Straight
Aspect : South

Soil Particle Analysis

Profile No. R 04	Depth	Particle Fraction		
	mm	Sand	Silt	Clay
A1	340	54	12	34
B1	1200	44	10	40

Chemical Analysis

Sample No. R 04	Organic Carbon	Extractable cations				pH		P
		K	Ca	Mg	Na	H_2O	KCl	
	%	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}			mg kg^{-1}
A1	1.29	505.47	530.3	125.89	21.11	5.77	5.25	0.9
B1	0.66	292.65	127.03	409.81	22.22	5.32	4.62	0.8

Pedological characteristics

Horizon	Depth (mm)	Description	Diagnostic material
A1	340	Dry dark reddish brown 2.5YR 3/4; sandy clay loam; massive; gradual smooth transition; slightly hard; few common roots.	Orthic
B1	1200	Moist dusky red 10YR 3/4; clay; massive; soft; friable; few common roots.	Red apedal

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Profile No : R 05
Latitude : 22°47′776″
Longitude : 30°26′019″
Soil Form : Hutton
Soil Family : Stella
Altitude : 652.20
Terrain unit : Midslope
Slope : 0-1.5%
Slope shape : Convex
Aspect : South west

Soil Particle Analysis

Profile No. R 05	Depth	Particle Fraction		
	mm	Sand	Silt	Clay
A1	350	52	12	36
B1	1350	42	4	54

Chemical Analysis

Sample No. R 05	Organic Carbon	Extractable cations				pH		P
		K	Ca	Mg	Na	H_2O	KCl	
	%	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}			mg kg^{-1}
A1	1.7	103.71	299.56	122.7	17.31	5.55	4.90	2.8
B1	0.75	145.55	646.14	617.31	26.32	5.56	5.35	0.5

Pedological characteristics

Horizon	Depth (mm)	Description	Diagnostic material
A1	350	Dry dark reddish brown 2.5YR 3/4; sandy clay; massive; gradual smooth transition; slightly hard; few common roots.	Orthic
B1	1350	Moist reddish brown 2.5YR 4/4; clay; massive; soft friable; few common roots.	Red apedal

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Profile No : R 06
Latitude : 22°47′795″
Longitude : 30°26′252″
Soil Form : Hutton
Soil Family : Suuurbekom
Altitude : 643.30
Terrain unit : Midslope
Slope : 0-1.5%
Slope shape : Straight
Aspect : South-east

Soil Particle Analysis

Profile No. R 06	Depth	Particle Fraction		
	mm	Sand	Silt	Clay
A1	450	66	4	30
B1	1230	48	4	48

Chemical Analysis

Sample No. R 06	Organic Carbon	Extractable cations				pH		P
		K	Ca	Mg	Na	H_2O	KCl	
	%	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}			mg kg^{-1}
A1	1.28	49.06	313.34	132.47	21.34	5.55	4.92	2.2
B1	0.69	12.7	287.99	127.58	16.5	5.74	5.14	0.8

Pedological characteristics

Horizon	Depth (mm)		Diagnostic material
A1	450	Dry dark reddish brown 2.5YR 3/4; sandy clay loam; massive; slightly hard; gradual transition; few common roots.	Orthic
B1	1230	Moist red 2.5YR 4/6; sandy clay; massive; soft; friable; few common roots.	Red apedal

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Profile No : R 07
Latitude : 22°47′623″
Longitude : 30°26′031″
Soil Form : Hutton
Soil Family : Suurbekom
Altitude : 657.90
Terrain unit : Midslope
Slope : 0-0.5%
Slope shape : Convex
Aspect : South west

Soil Particle Analysis

Profile No. R 07	Depth	Particle Fraction		
	mm	Sand	Silt	Clay
A1	350	66	8	26
B1	1450	60	10	30

Chemical Analysis

Sample No. R 07	Organic Carbon	Extractable cations				pH		P
		K	Ca	Mg	Na	H_2O	KCl	
	%	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}			mg kg^{-1}
A1	0.9	43.77	286.36	123.71	19.23	5.56	4.98	1.6
B1	0.7	7.38	428.43	203.83	11.93	5.01	4.64	0.5

Pedological characteristics

Horizon	Depth (mm)	Description	Diagnostic material
A1	350	Dry reddish brown 2.5YR 4/4; sandy clay loam; gradual smooth transition; few common roots	Orthic
B1	1450	Moist red 2.5YR 4/6; sandy clay loam; massive; soft; friable; few common roots.	Red apedal

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Profile No : R 08
Latitude : 22°47′597″
Longitude : 30°26′196″
Soil Form : Hutton
Soil Family : Suurbekom
Altitude : 654.20
Terrain unit : Footslope
Slope : 0-2
Slope shape : Convex
Aspect : South-west

Soil Particle Analysis

Profile No. R 08	Depth	Particle Fraction		
	mm	Sand	Silt	Clay
A1	350	70	6	24
B1	1250	56	4	40

Chemical Analysis

Sample No. R 08	Organic Carbon	Extractable cations				pH		P
		K	Ca	Mg	Na	H_2O	KCl	
	%	mg kg-1	mg kg-1	mg kg-1	mg kg-1			mg kg-1
A1	1.27	122.39	312.85	138.81	15.78	5.58	5.26	2.2
B1	0.73	64.57	249.94	116.69	18.68	5.47	5.12	0.7

Pedological characteristics

Horizon	Depth (mm)	Description	Diagnostic material
A1	350	Dry reddish brown 2.5YR 4/3; sandy clay loam; gradual smooth transition; few common roots.	Orthic
B1	1250	Moist red 2.5YR 4/6; sandy clay; massive; friable; few common roots.	Red apedal

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Profile No : R 09
Latitude : 22°47′331″
Longitude : 30°26′615″
Soil Form : Hutton
Soil Family : Suurbekom
Altitude : 647.90
Terrain unit : Footslope
Slope : 1-2
Slope shape : Convex
Aspect : South-west

Soil Particle Analysis

Profile No. R 09	Depth	Particle Fraction		
	mm	Sand	Silt	Clay
A1	350	70	4	26
B1	1350	50	4	46

Chemical Analysis

Sample No. R 09	Organic Carbon	Extractable cations				pH		P
		K	Ca	Mg	Na	H_2O	KCl	
	%	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}			mg kg^{-1}
A1	1.56	110.13	609.3	197.05	12.2	5.66	5.33	3.5
B1	0.69	119.51	266.29	125.96	18.24	5.6	5.23	0.7

Pedological characteristics

Horizon	Depth (mm)	Description	Diagnostic horizon
A1	350	Dry dark reddish brown 2.5YR 3/4; sandy clay loam; gradual smooth transition; few common roots.	Orthic
B1	1350	Moist red 2.5YR 5/6; sandy clay; massive; soft; friable; few common roots	Red apedal

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Profile No : R 10
Latitude : 22°47′729″
Longitude : 30°26′469″
Soil Form : Hutton
Soil Family : Suurbekom
Altitude : 639.10
Terrain unit : Footslope
Slope : 1-2
Slope shape : Concave
Aspect : South-west

Soil Particle Analysis

Profile No. R 10	Depth	Particle Fraction		
	mm	Sand	Silt	Clay
A1	300	76	6	18
B1	1050	64	4	32

Chemical Analysis

Sample No. R 10	Organic Carbon	Extractable cations				pH		Pp
		K	Ca	Mg	Na	H2O	KCl	
	%	mg kg-1	mg kg-1	mg kg-1	mg kg-1			mg kg-1
A1	0.61	6.67	134.64	58.69	11.47	4.94	4.43	0.6
B1	1.09	21.24	185.55	71.37	10.46	4.97	4.38	2.1

Pedological characteristics

Horizon	Depth (mm)	Description
A1	300	Moist reddish brown 2.5YR 4/4; sandy loam; massive; gradual transition few common roots.
B1	1050	Moist red 2.5YR 4/6; sandy clay loam; massive; soft; friable; few common roots.

Diagnostic material
Orthic
Red apedal

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Profile No : R 11
Latitude : 22°47′509″
Longitude : 30°26′612″
Soil Form : Hutton
Soil Family : Suurbekom
Altitude : 637.60
Terrain unit : Footslope
Slope : 0-2
Slope shape : Concave
Aspect : South-west

Soil Particle Analysis

Profile No. R 11	Depth	Particle Fraction		
	mm	Sand	Silt	Clay
A1	350	72	2	26
B1	1250	56	4	40

Chemical Analysis

Sample No. R 11	Organic Carbon	Extractable cations				pH		P
		K	Ca	Mg	Na	H_2O	KCl	
	%	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}			mg kg^{-1}
A1	1.11	23.46	235.9	89.21	15.67	5.15	4.37	1.8
B1	0.73	7.13	265.17	84.22	15.8	5.4	4.87	0.6

Pedological characteristics

Horizon	Depth (mm)	Description	Diagnostic material
A1	350	Moist dark reddish brown 2.5YR 3/4; sandy clay loam, massive; gradual smooth transition; few common roots.	Orthic
B1	1250	Moist reddish brown 2.5YR 5/4; sandy clay; massive; soft; friable; few common roots, few yellowish-red mottles.	Neocutanic

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Profile No : R 12
Latitude : 22°47′544″
Longitude : 30°26′396″
Soil Form : Hutton
Soil Family : Suurbekom
Altitude : 643.30
Terrain unit : Midslope
Slope : 0
Slope shape : Straight
Aspect : South east

Soil Particle Analysis

Profile No. R 12	Depth	Particle Fraction		
	mm	Sand	Silt	Clay
A1	350	70	2	28
B1	1450	56	8	36

Chemical Analysis

Sample No. R 12	Organic Carbon	Extractable cations				pH		P
		K	Ca	Mg	Na	H_2O	KCl	
	%	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}			mg kg^{-1}
A1	1.13	22.62	208.56	119.11	12.34	5.05	4.31	2
B1	0.77	12.15	183.12	95.63	12.42	5.16	4.76	0.7

Pedological characteristics

Horizon	Depth (mm)	Description	Diagnostic material
A1	350	Dry reddish brown 2.5YR 4/4; sand clay loam; massive; gradual smooth transition; many roots	Orthic
B1	1450	Moist reddish brown 2.5YR 4/4; sandy clay; soft; friable, few common roots, yellow-brown mottles, red; yellowish-red mottles.	Neocutanic

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Profile No : R 13
Latitude : 22°47′453″
Longitude : 30°26′217″
Soil Form : Hutton
Soil Family : Suurbekom
Altitude : 650.2
Terrain unit : Midslope
Slope : Straight
Slope shape : Convex
Aspect : South-west

Soil Particle Analysis

Profile No. R 13	Depth	Particle Fraction		
	mm	Sand	Silt	Clay
A1	450	84	4	12
B1	1450	56	4	40

Chemical Analysis

Sample No. R 13	Organic Carbon	Extractable cations				pH		P
		K	Ca	Mg	Na	H_2O	KCl	
	%	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}			mg kg^{-1}
A1	1.31	83.04	798.8	112.14	15.08	5.73	5.30	4.4
B1	0.6	43.55	268.19	115.42	15.75	5.31	5.03	1.1

Pedological characteristics

Horizon	Depth (mm)	Description	Diagnostic material
A1	450	Dry reddish brown; 5YR 4/3; loamy sand, massive; gradual smooth transition; few common roots.	Orthic
B1	1450	Moist reddish brown; 2.5YR 5/4; sandy clay; friable; few common root, with distinct yellowish-red mottles.	Neocutanic

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Profile No : R 14
Latitude : 22°47′506″
Longitude : 30°26′619″
Soil Form : Oakleaf
Soil Family : Dipene
Altitude : 638.0
Terrain unit : Lower midslope
Slope : 0-1%
Slope shape : Convex
Aspect : South-east

Soil Particle Analysis

Profile No. R 14	Depth	Particle Fraction		
	mm	Sand	Silt	Clay
A1	450	60	8	32
B1	1550	42	22	36

Chemical Analysis

Sample No. R 14	Organic Carbon	Extractable cations				pH		P
		K	Ca	Mg	Na	H_2O	KCl	
	%	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}			mg kg^{-1}
A1	1.04	22.97	201.92	87.72	12.7	5.41	4.98	1.7
B1	0.78	12.26	800.5	122.98	14.34	5.25	4.46	0.7

Pedological characteristics

Horizon	Depth (mm)	Description	Diagnostic material
A1	450	Dry reddish brown 2.5YR 4/3; sandy clay loam; gradual smooth transition; few common roots.	Orthic
B1	1550	Moist reddish-brown 2.5 YR 4/4; clay loam; massive; luvic; soft; friable; yellowish-red cutans; brownish red mottles.	Neocutanic

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Profile No : R 15
Latitude : 22°47′290″
Longitude : 30°26′179″
Soil Form : Oakleaf
Soil Family : Caledon
Altitude : 654.8
Terrain unit : Lower midslope
Slope : 0-1%
Slope shape : Convex
Aspect : South-east

Soil Particle Analysis

Profile No. R 15	Depth	Particle Fraction		
	mm	Sand	Silt	Clay
A1	350	54	10	36
B1	1550	42	22	36

Chemical Analysis

Sample No. R 15	Organic Carbon	Extractable cations				pH		P
		K	Ca	Mg	Na	H_2O	KCl	
	%	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}			mg kg^{-1}
A1	0.77	54.11	817.3	120.38	13.07	5.43	4.87	16
B1	0.83	21.02	1049	29.25	17.91	5.52	5.20	1.8

Pedological characteristics

Horizon	Depth (mm)	Description	Diagnostic material
A1	350	Dry reddish brown 2.5YR 5/3; sandy clay, massive; gradual smooth transition; few common roots.	Orthic
B1	1550	Moist reddish brown 2.5YR 5/4; sandy clay; massive; luvic; firm; black, yellowish red mottles.	Neocutanic

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