AN INTEGRATED APPROACH FOR THE DELINEATION OF ARABLE LAND AND ITS CROPPING SUITABILITY UNDER VARIABLE SOIL AND CLIMATIC CONDITIONS IN THE NKONKOBE MUNICIPALITY, EASTERN CAPE, SOUTH AFRICA

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DECLARATION

I, ALEN MANYEVERE, declare that this thesis is my own work and that views from other authors have been cited.

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ABSTRACT

Arable crop production in Nkonkobe Municipality is low due to abandonment of potentially productive land and low productivity of the cultivated land. Little attention has been given to farmers' perspectives with regards to crop production and land abandonment. Understanding the relationships of indigenous knowledge systems, where local approaches to soil classification, appraisal, use and management and land evaluation, and scientific approaches could be important for the effective use of available soil resources while avoiding those resources that are vulnerable to degradation. In addition, the interactions between soil factors and climate could be useful in understanding the erodibility of soils. The intergration of scientific research and indigenous knowledge systems could help in the identification and delineation of high potential land and on crop suitability evaluation. The objectives of the study were: (i) to determine farmers' perspectives with regards to land utilisation and abandonment, constraints on crop production and crop preferences, (ii) to integrate and compare indigenous knowledge systems with scientific approaches of soil classification and potential, (iii) to determine the effect of climate and soil factors on erodibilities of soils in the Municipality (iv) to delineate arable land and evaluate its suitability for maize, potato, sorghum and cowpea under rainfed agriculture.

Using semi-structured and open-ended interviews, information on limitations to crop production, cropping preferences, indigenous soil classifications, cropping potential ratings and erosion was captured. Descriptive and correlation statistics were used to analyse farmers' responses. The information was later used for a pilot participatory mapping and the determination of the agricultural potential of the soils in three selected villages of the Municipality. Field boundaries of soil texture, colour, depth, and slope position were captured using global positioning systems (GPS). The relationship between the degree of erosion and soil and slope factors was analysed by step-wise regression. Crop suitability for rainfed agriculture was done using the FAO guidelines for Land evaluation for rainfed agriculture. The spatially referenced crop suitability classes were produced by applying the Law of Limiting Combinationusing GIS Boolean Logic.

The major biophysical factors, affecting crop production and land utilisation were soil degradation and low and erratic rainfall, while other factors included lack of farming equipment and security concerns. Maize, spinach and cabbage were the main crops grown, with maize,

sorghum and wheat the most abandoned crops. While it was difficult to accurately correlate indigenous classification with international scientific classification, the importance of colour, texture and soil depth for both classification and soil potential, suggests that some form of correlation is possible which enabled communication and other extension information to be conveyed. The shallow and stony soil (*urhete)* correlated well with the Leptosols in World Reference Base (WRB) or Mispah and shallow Glenrosa soils in the South African system. The red structured clays (*umhlaba obomvu*) matched the Nitisols in WRB or Shortlands in the South African system. The non-swelling black clayey soils *(umhlaba omnyama)* matched soils with melanic A horizons in both the WRB and South African soil classification systems. The *dongwe* and *santi* soils developed in alluvial sediments belonged to the Dundee, Oakleaf or Augrabies soils in the South African classification system and fluvisols or Cambisols in the WRB system. There was good agreement between farmers' assessment of the cropping potential and scientific approaches but scientifically high potential red soils were rated lowly by the farmers due to difficulties in management caused by shortages of farm machinery, especially under dryland farming. Overall, the soil factors affecting erosion were influenced largely by climate, while parent material was also important. Climate had a dominant influence on soil factors most notably fine sand and very fine sand fractions and exchangeable sodium percentage being more important on soil forms occurring in arid and semi-arid climate and less in the sub-humid and humid areas, where clay mineralogy, particularly kaolinite and sesquioxide dominated. Dolerite derived soils were the most stable and should be given the highest priority for cropping development while mudstone and shale derived soils had a lower cropping potential. While slope gradient and length had some effect on soil erosion in arid and semi arid environments its influence was generally overshadowed by soil factors especially in humid zones.

Cow pea and sorghum were the most adapted crops in the region while potato and maize were marginally suitable under rainfed agriculture. The study revealed that most adapted crops were not necessarily the most preferred crops by the farmers. A small percentage of the land was delineated as arable and therefore optimisation of this available land should be prioritized.

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Ca	Calcium
CEC	Cation Exchange Capacity
EC	Electrical Conductivity
Fe	Iron
GIS	Geographic Information Systems
K	Potassium
Mg	Magnesium
Mn	Manganese
Na	Sodium
PGDP	Provincial Growth and Development Plan
UN	United Nations
MDG	Millennium Development Goals
IDP	Integrated Development Plan
GDP	Gross Domestic Product
DEMs	Digital elevation Models
TRCs	Transitional Rural Councils
TLCs	Transitional Local Councils
FAO	Food and Agriculture Organisation
GLASOD	Global Assessment of human- Induced Soildegradation
SDPM	Sediment Delivery Potential Map
BSI	Bare Soil Index
ESM	Erosion SusceptibilityMap
PWEM	Predicted Water Erosion Map
NRA	National Resources Auditing
ISRD	Integrated Sustainable Rural Development Strategy nodes
SANBI	South African National Biodiversity Institute
ESP	Exchangeable sodium percentage

MCDA	Multi-Criteria Decision Analysis
OPVs	Open pollinated varieties
TMUs	Terrain morphological units
WRB	World reference Base
ARC	Agricultural Research Council
GPS	Global positioning system

CHAPTER 1

GENERAL INTRODUCTION

1.1 Introduction

The Eastern Cape is one of the poorest provinces of South Africa, partly because of its historical background (Neil and Hill, 1998). A large proportion of the present day Eastern Cape occupies the then marginalised homelands of Transkei and Ciskei,which were created during Apartheid through forced displacement of natives from their original homes to marginal lands with little potential. The Provincial Government of the Eastern Cape, through the Provincial Growth and Development Plan (PGDP), has embarked on pilot projects to empower communities (PGDP Assessment, 2008) in line with the Millennium Development Goals (MDG) on food security, poverty alleviation and rural development (UN, 2004). Agricultural development and the optimisation of the use of land resources have been identified as an important step towards achieving these goals (Laker, 2004a; IDP, 2008).

One area where the optimisation of land has been targeted is the Nkonkobe Municipality in the former Ciskei homeland. Agriculture is currently underdeveloped, contributing only 17% of the Gross Domestic Product (GDP), while a growth target of 10% by 2011 was set by this Municipality (IDP, 2008). A recent visit to the Municipality offices revealed that not much has been done to achieve the 10% growth target set in the Intergrated Development (IDP) goals of the Municipality by 2013 ([1]K.C. Maneli. Nkonkobe Municipality, personal communication, 2013). However, the set target may only be achieved if proper identification and delineation of arable lands, the areal extent and cropping suitability are established. This information could be useful to the Department of Agriculture as a natural resource inventory for policy formulation of strategic national policies such as agricultural expansion and land reform. Currently, the Department of Agriculture is relying on the general land evaluation done in 1975([2]X. Dubasi. Departmant of Agriculture, personalcommunication, 2010).

[1]K.C. Maneli. Municipal Manager, Nkonkobe Municipality. Fort Beaufort.

[2]X. Dubasi, Department of Agriculture, Happyrest, Alice, 5700

The Nkonkobe Municipality covers parts of the Kat River and Keiskamma River Catchments, including Fort Beaufort, Alice, Middledrift and Hogsback towns between geographic co-ordinates 32^{o} $04^{'}$ and 32^{o} $55^{'}$ south and 26^{o} $24^{'}$ and 27^{o} $07^{'}$ east. Laker (2004a) identified three categories of land that have high potential for arable agriculture, in parts of the Municipality. These lands are (i) former "white" commercial farming areas that were bought out by the previous government during the 1970s and incorporated into the Ciskei as part of the homeland consolidation process, (ii) previously cultivated "native lands" that lie abandoned, for which the reasons for abandonment are yet to be established, and (iii) new high potential arable land that has never been cultivated.

The Lower Kat river area around Fort Beaufort and the Tyume Valley are important commercial citrus production areas in Nkonkobe. The present production areas are smaller than before, and in some cases, they have completely collapsed (Laker, 2004a). The sight of collapsed farms is also common in the Upper and Middle Kat river catchment where land was expropriated for the creation of Ciskei. In the former 'native' lands, there are still areas that can be cultivated especially those along river valleys and on stable dolerite parent material that have not been used to their full potential. All these could be revitalised, and even expanded to other areas if their potential is fully established. It is also important to establish ways of increasing production on presently cultivated areas that are under-utilised. The identification and delineation of such lands would require an integrated approach that integrates farmer indigenous knowledge and scientific approaches.

Active participation of local farmers in generating important crop production knowledge would provide information on the socio-economic, biophysical, and other challenges that affect crop production and their magnitude. Interviews with farmers could unlock knowledge on the agricultural potential of the land, and why farmers may prefer to use certain lower potential soils rather than those with higher potential (Laker, 1980), as well as why presently cultivated lands are under-utilised. It is, therefore, essential to understand farmers' perspectives to crop production, the major limiting factors to crop production and the agricultural potential of soils in the Municipality.

Land degradation, as a result of soil erosion, is a major problem threatening the sustainability of land resources in South Africa, with indications that over 70% of the country has been affected

(Le Roux *et al*., 2007). About 27% of cultivated lands in communal areas in the Eastern Cape had been irreversibly lost to erosion by 1988 (Kakembo and Rowntree, 2002). This was partly due to the incorrect demarcation of arable land as a result of the incorrect assessment of the erodibilities of soils (Laker, 1990; 2004b). In addition to the understanding of farmers' perspectives on the agricultural potential, soil erosion studies would also inform on the sustainable use of land in the Municipality (Mulibana, 2000). Previous soil erosion studies in the former Ciskei focused mainly on soil erosion controlling variables, such as overall soil texture and rainfall intensity and landuse activities and not much on other important soil factors such as the effect of the sand grades and silt content, until work by D'Huyvetter (1985) in arid and semi-arid areas covering the Middledrift, Mavuso and Keiskammahoek pedosystems of the former Ciskei.

D'Huyvetter (1985) established critical slope limits at which different soil forms in the area can be cultivated without causing severe erosion by studying the relationships between soil erosion and (i) texture (content of clay, sand fractions and silt), (ii) contents and ratios of magnesium, sodium and calcium (iii) soil depth – in the case of shallow soils, (iv) parent material and (v) slope gradient and length. However, the work did not include clay mineralogy and assumed a homogenous climate. Rapp (1988) included very stable and extremely unstable soil from the Tyume valley in the Nkonkobe district Municipality in his studies and reported that clay mineralogy and sequioxides were important factors influencing erosion in South Africa. Smith (1990) also observed that as the degree of weathering increases, due to high rainfall, the less stable smectites and micas break down forming more stable secondary minerals such as kaolonite and the end-point clay oxides. As such soil factors controlling soil erosion such as mineralogy could vary between low rainfall areas and subhumid to humid areas.

Generally, the Central Eastern Cape region is located in a semi-arid region with harsh climatic conditions (Weather SA, 2009). However, a detailed analysis of climate shows high variability in rainfall and temperature patterns, ranging from the humid mountainous Amatola regions to the very dry Keiskamma river valleys (Laker, 1978). As such, a better picture could be obtained from a study on the effect of climate variability on soil factors and their impact on soil erosion. Speculation on how soil variables could affect erosion as the climate changes from the drier regions to the more humid areas of the Municipality could be put to rest by providing empirical

evidence. There is, therefore, a need to examine the relationship between soil erosion and important soil variables such as clay mineralogy and chemical composition in different climatic units of Nkonkobe Municipal area. This is particularly important for lands that are considered to have high potential by local farmers.

The identification and demarcation of arable lands and agricultural potential assessments involve the use of a number of input indices that contribute to an overall rating, recommendations and/ or decision making. Crops have different requirements for heat units, rainfall and soils for optimum production (Schulze, 1997). It is, therefore, necessary that suitable crop recommendations based on environmental factors be formulated for maximum production. The process is often complex with the analyst having to deal with too many input datasets. A convenient way of dealing with this problem is the use of multi-criteria analysis. The technique ranges from the use of simple empirical models and flow charts (Dooley *et al*., 2009) to applications of GIS analytical tools (Prakash, 2003; Ebrahim, 2007; Hossain *et al*., 2007).

The multi-criteria analysis concept could be used to delineate arable lands and evaluate crop suitability in the Nkonkobe Municipal area by subjecting input data sources, such as soil maps, digital elevation models (DEMs) and climate maps to different GIS operations using sound land evaluation guidelines, such as the FAO framework for land evaluation (FAO, 1976) and its related frameworks including the Guidelines to land evaluation for rainfed agriculture (FAO, 1983).

1.2 Research problem

Arable crop production in former homeland areas and the surrounding commercial farms in the Nkonkobe Municipality is low. Large pieces of potentially productive land have been abandoned and the situation is more serious in the once highly productive commercial farms, as some of the farms have completely collapsed. The reasons for this have to be established. It is essential to include farmers' perspectives in establishing the reasons for the collapse of farms. Farmers' perspectives could be in form of interrogations of indigenous knowledge systems where local local approaches to soil classification, appraisal, use and management and land evaluation are explored.

Land degradation due to soil erosion is a common sight in the area. Little/ no attention has been given by researchers to the interaction between soil factors and climate when assessing soil erosion vulnerability (Kakembo and Rowtree, 2002). Soils in the area are highly erodible possibly due to high exchangeable sodium, clay-sized quartz and fine sand fractions. The effect of climate on soil properties needs to be evaluated against soil erosion to establish the best management practices suited to the soil types in the area. Depending on the erodibilities of the soils, land could be demarcated into those that can be sustainably cropped and those areas that have high erosion risks, with a view towards the implementation of differential land management strategies.

Previous crop suitability studies were generalized, used minimum datasets and did not include the variability of the climate in Nkonkobe (Laker, 1978, Verdoodt *et al*., 2003). The availability of important datasets, such as digital soil maps, DEMs and interpolated rainfall and temperature maps that cover every single point of the Nkonkobe Municipality allow for more comprehensive spatially referenced land suitability evaluations. Spatial analysis using GIS in the evaluation of crop suitability means that the areal extent of the different suitability classes and their geographical locations can be established for point to point spatial planning.

1.3 Objectives

Main Objective

The main objective of this study was to use an integrated approach for the identification and delineation of high potential land for cropping under variable soil and climatic conditions in the NkonkobeDistrict Municipality

Specific objectives

1. To determine farmers' perspectives with regards to land utilisation and abandonment, constraints on crop production and crop preferences.
2. To determine the indigenous soil classification systems and soil potential evaluation of the Xhosa Speaking people compared with scientific approaches.
3. To determine the effect of climate and soil factors on erodibilities of soils in the Municipality.
4. To delineate arable land and evaluate its suitability formaize, potato, sorghum and cowpea under rainfed agriculture.

CHAPTER 2

LITERATURE REVIEW

2.0 Literature review

This section reviews, mainly, the important socio-econimic and biophysical factors affecting crop production. Firstly, the food security situation is briefly outlined and the history of the agricultural land that led to the abandonment of land is reviewed. The land degradation and erodibility problems prevalent in the Eastern Cape are also discussed. Finally, the steps that could be taken to correct these problems through land evaluation are highlighted.

2.1 The role of agriculture in food security

At national level, South Africa has adequate food reserves to cater for its population but, at household level, as much as 1400 000 households are food insecure due to disparities in income (Alber, 2009). Compared to other middle income countries, the country has extremely high levels of absolute poverty and achieving household food security is a critical component in reducing poverty levels (Altman *et al*., 2009). Household food supply could be improved through increasing the number of households that undertake productive agriculture for themselves and for trade. Such households could be empowered by increasing access to small scale irrigation systems, training of small scale farmers on sustainable technologies (Van Averbeke and Mohammed, 2006). The new technologies would enable them to produce food continuously even in lean times (Baipethi and Jacobs, 2009). In the Nkonkobe Municipality, located in the former Ciskei homeland, the food security situation is even worse, with a high dependency ratio of 0.67 (Stats SA, 2011) with people survive on government grants and pensions (Fraiser *et al*., 2003; Hebinck and Smith, 2007; Hebinck and Van Averbeke, 2007). The dependency ratio is a measure showing the number of dependents, aged 0-14 and over the age of 65 to the total population aged 15-64.

Agriculture in the Municipality is mainly dual, characterized by subsistence farming in the former native lands and commercial agriculture in the citrus farms around the Kat and Tyume river valleys (Hebinck and Lent, 2007). Farmers also grow vegetables for sale on small plots (Van Averbeke *et al*., 1998). However, low production, as low as 2 tonnes per hectare of maize has been reported in subsistence farms and small plot irrigation schemes (Monde *et al*., 2005). Commercial citrus farming has declined and collapsed in areas such as the Tyume Valley,

depriving the local people of jobs and income (Laker, 2004a). Reasons for the decline include uncertainities in land reform and the lack of proper training for new land owners (IDP, 2008). Laker (2004a) identified optimisation of land and water resources as important in alleviating food shortages and job creation. The Nkonkobe Municipality has also identified agriculture as vital for job creation and the economic empowerment of its inhabitants (IDP, 2008). It is, therefore, vital that those high potential lands that have been abandoned be revitalized and production be maximized in areas where there has been a decline or a total collapse.

2.2 Brief history of agricultural land and its use in the Nkonkobe Municipality

This section gives an insight into the possible types of agricultural land that the author is intending to identify and delineate. It is intended to highlight those aspects that are important in understanding the land use dynamics in the Eastern Cape and particulary Nkonkobe Municipality.

Creation of the Nkonkobe Municipality

The Nkonkobe Local Municipality was created through the amalgamation of the disestablished Alice, Fort Beaufort, Middledrift, Hogsback and Seymour Transitional Local Councils (TLCs) and the Victoria East, Fort Beaufort, Mpofu and Middledrift Transitional Rural Councils (TRCs) as per Municipality Demarcation Act of 1998 (IDP, 2008). The Municipality was once under the Ciskei government that was disbanded after the first democratic elections in 1994. There are two distinctly different types of land, viz: traditional native land and former 'white' commercial farms.

Traditional native land

Traditional 'native' land was created through a process of occupation by whites of European background on one hand and blacks of an African background on the other hand. During this period some land was handed to the Fingo (or Mfengu) people by the British rulers during the mid-1800s as rewards for helping the British in wars against the Xhosas, an example being land around Middledrift given to Chief Kamma and his people. Some black communities were displaced from their original homes to these native lands by the Europeans (Hebinck and Van Averbeke, 2007). The native homelands were then established mainly through the Bantu Authorities Act, No 68 of 1951 and The Promotion of the Bantu Self-Government Act, No 46 of 1959 (Malan and Hattingh, 1976).

As more people moved from their original homes to the native lands, pressure for agricultural land increased and the area under cultivation in those areas also increased (Hebinck and Van Averbeke, 2007). In addition, poor soil management practices led to soil degradation. In the former Ciskei, because of the over-reliance on research done outside the region such as the general slope classes inscribed in the then Soil Conservation Recommendation Act, cultivation could have even taken place on soils that were beyond acceptable slope thresholds (D' Huyvetter, 1985). Some of the areas were erroneously demarcated for cultivation during the Betterment scheme of the 1960s where general slope limits of up to 12% were recommended irrespective of the soil type (Laker, 2004b). Cultivation on steep slopes caused severe soil erosion, eventually resulting in gullies, and forcing people to abandon the lands (Kakembo and Rowntree, 2002). In his study, D'Huyvetter (1985), then, recommended varying slope limits for different soil types and that there be no blanket threshold limit for different soils. In the Central Eastern Cape region, another major problem that might have led to the abandonment of agriculture is the harsh climate that made crop production unattainable (Van Averbeke and Marais, 1991).

The role of agriculture diminished as the rural livelihoods shifted towards migratory labour, remittances and social grants and pensions (Hebinck and Van Averbeke, 2007; Shackleton *et al.*, 2013). Laker (2004a) also attributed underutilization of between 50 – 80% of the arable land in the Victoria East district around Alice to the preference by farmers for home gardens, which they found easier to manage. The above factors among others, might have led to abandonment of the native agricultural lands. Although the Native Trust and Land Act No. 18 of 1936 provided a legal framework for the reclamation of these lands, it did little to encourage people to use the abandoned lands. Today the former homeland of the Ciskei in the Central Eastern Cape region has vast tracts of such abandoned lands. The reasons for the decline represent the general trend from a South African perspective and may not only apply within the context of Nkonkobe Municipality. However, there are still areas that can be cultivated, especially those along river valleys and on stable dolerite parent material that have not been used to their full potential. It is these areas that will be identified and targeted for revitalization of crop production.

Former 'white' commercial farms

Former 'white' areas were bought out by the apartheid government during the 1970s and incorporated into the Ciskei as part of the homeland consolidation process. The intention was to compensate for land from which black people were removed in isolated 'black spots' elsewhere and incorporated into adjacent white owned territory that was assigned to the Africans in the 1936 Land Act but was never given to them (FPSF, 1981). The former white areas are found in the high potential citrus producing farms along the Tyume and Kat river valleys. According to figures from Lugg, Harrison and Associates (cited in Page, 1982) citrus production was once dominant in the Keiskamma River, Tyume River and the Kat River areas, where 205 000 citrus trees were planted on an area equivalent to some 730 ha of which 42% was within the Tyume sub-area, while the Keiskamma River and Kat River accounted for 30% and 28% respectively. Such figures suggest that ways to increase production ought to be found. If production was brought to full potential in collapsed farms the economy of the Municipality could improve, considering that 75%of the produce is exported ([3]Butler Keaton, Katco, personnal communication, 2013) and given the devaluation of the rand against other currencies which results in firming of export prices. Crop production in Tyume and Kat river valleys collapsed for a number of reasons, including errors made during land evaluation, inappropriate crop selection, poor irrigation management (IDP, 2008) and ownership uncertainties in the land reform process among farmers (Laker, 2004a). The reasons for decline in crop production are merely speculative, extrapolated from other similar areas in South Africa and sometimes based on single farmer interviews without any research backed by the use of acceptable qualitative and quantitative research methods. It is therefore necessary to validate such assertions using proper research.

2.3 Land use and degradation

Land use in the Municipality is dominated by vegetable and livestock production by small-scale farmers (IDP, 2008), commercial citrus production along the Kat River, forestry and tourism which include the rich cultural heritages of the University of Fort Hare where a number of former African leaders attended their university education, and site viewing at Hogsback (IDP, 2012). To the South of Middledrift and Alice towards Sheshegu and Breakfast vlei near Debe

[3] Katco Citrus Estate, 14 Fort Beaufort Street,Fort Beaufort

Nek (see Fig 3.1), the area is very dry, with shallow soils. It is used for extensive rangeland, with traditional peasant farming at Lower Sheshegu (Laker, 1978).

The latest land use data for the Municipality is not available. Awhite paper on spatial planning and land use management (SDFP, 2004) recommended that the different land uses and their spatial extent be quantified. In the absence of such quantitative information, this study would provide at least some quantitative estimates of arable soils the areal extents and locations suitable for growth of important crops such as maize, potato, sorghum and cowpea.

Large proportions of the land are suitable for the production of livestock, as an estimated 85% to 95% of the available land is not capable of supporting cultivation, mainly because of shallow and fragile soils (Laker, 2000) and steep slopes (Van Averbeke and Marais, 1991). Fragile soils are a result of very high dispersivity, caused by high levels of sodium and/or magnesium (Laker, 2004b), especially on soils derived from Beaufort sediments. These soils are made up of shale and mudstone, and have inherent soil physical problems. Other inherent soil physical problems are susceptibility to crusting and compaction, owing to the high fine sand and silt contents (D'Huyvetter, 1985). Some of the highly erodible land is currently under cultivation. Such land has to be identified and delineated first, and secondly, the exact reason for continued cultivation has to be established from farmers' perspective and be supported by scientific information. It is only after the above considerations have been taken into account that recommendations could be made.

2.4 Local soil classification and agricultural potential based on indigenous knowledge

Indigenous knowledge is defined as skills, knowledge and technology accumulated by local people, and derived from their direct interaction with the environment (Barrios and Trejo, 2003). The use of local knowledge is important in agricultural disciplines, such as pest and soil fertility management, agronomy (Derera *et al*., 2006; Rutto *et al*., 2006) and land use classification (Sicat *et al*., 2005) among others. Of note to this study is local knowledge on soils which Barrera-Bassols and Zinck (2003) termed ethnopedology. The study of ethnopedology was categorized into four main themes namely: (i) the formalization of local soil and land knowledge into classification schemes, (ii) the comparison of local and technical soil classifications, (iii) the

analyses of local land use evaluation systems and (iv) the assessment of agro-ecological management practices.

The need for better understanding of indigenous knowledge systems and the need for a paradigm shift from western knowledge and a search for local solutions to soil problems also ignited research in ethnopedology. Using indigenous knowledge in research allows scientists to conduct research that is aimed at developing technologies suited to local farmers (Birmingham, 2003). Research has shown that ignoring local knowledge through exclusion of local communities has led to failure of many development initiatives (FAO, 1997).

Over the past few decades there has been an increase in research on local soil knowledge with about 400 papers published worldwide by 2003 (Barrios and Trejo, 2003). Societies of Latin America, West Africa, the Sahel and East Africa were mainly studied because of their diversity in culture, ethnicity and language. South Africa, particularly the Eastern Cape, is lagging behind despite its wide cultural diversity. This has led to reliance solely on scientific approaches for land evaluation (Buthelezi, 2010). Reasons for the lack of information on indigenous soil knowledge are not known but they could include: fragmented/ grey literature that cannot be easily accessed and little emphasis on research in 'native' lands during apartheid where as most research was carried in the then South Africa.

Earlier studies on indigenous soil knowledge in Africa have concentrated on soil fertility, local soil classification and land degradation (Birmingham, 2003; Mowo *et al*., 2006). Mowo *et al*. (2006) initiated sustainable soil use based on farmers' perceptions of soil fertility in Northern Tanzania. Clements *et al*. (2010) gave farmers an opportunity to identify dominant soil types and the vulnerability of these to soil erosion. In their study, the farmers were able identify soil erosion hotspots, and the information was used for spatially targeted conservation measures. It is also important to note that some findings obtained in these studies did not meet scientific expectations. For example, Warren *et al*. (2003) investigated indigenous views on soil erosion in Niger and found that farmers did not view soil erosion as the main problem. Instead they perceived soil fertility, labour constraints and unpredictable rainfall as their problems, despite the fact that soil erosion was viewed by scientists as the main problem. They later concluded that the imposition of soil conservation measures might threaten the cohesion of the community and that open and productive debate between the scientific community, the State and farmers was

necessary to effectively combat soil erosion. The implications of the research by Warren *et al*. (2003) could be that scientific evidence may not yield the desired results during implementation unless they are backed by indigenous knowledge. Although most studies were conducted on soil fertility, key agricultural land potential variables such as dominant soil types, soil erosion hotspots and some socio-economic factors were captured in these studies. One notable study by Buthelezi (2010) evaluated the use of scientific and indigenous knowledge in agricultural land evaluation and soil fertility studies in some rural villages of Kwazulu-Natal in South Africa. In the Eastern Cape, Sobahle (1982) wrote a one page analysis of how Xhosa- speaking people classified their soils according to colour and texture. Apart from these studies, there appears to be no other research on the use of indigenous soil knowledge in delineating agricultural land potential in South Africa, especially on the Eastern Cape.

A study to determine farmers' indigenous knowledge on soil classification and potential for cropping on arable lands in the Nkonkobe Municipality is therefore essential. As such, this study could explore the following:

1. What are the soil related reasons for low crop production and land abandonment?
2. What are farmers' perspectives of the suitability classification of their soils and how do indigenous farmers classify their soil.
3. Why do farmers prefer to use certain unproductive land and not other land purported to have high cropping potential?

2.5 Determination of the relationship between soil erosion and selected soil variables

Soil erosion is an environmental problem that has reached alarming proportions in many parts of South Africa with severe forms of erosion common in the former 'homelands' (Kakembo and Rowntree, 2002). Before the 1980s, few studies on soil erosion were conducted in South Africa but there was a significant increase in the late 80s and 90s as reviewed by Mulibana (2000) and Laker (2004b). Le Roux *et al*. (2008) also reviewed a series of soil erosion studies that were undertaken in South Africa (Table 1.1). These studies, however, were carried out mainly on regional scales and may not be suitable for detailed soil erosion inferences. Weaver (1989) compared soil erosion estimates from data obtained from regional and local studies and

concluded that regional soil loss estimates can be misleading when applied to localized catchments. Laker (2004b) also reported that using soil estimates derived from regional studies is not recommended because some parameters used elsewhere may be irrevalent to the local context and suggested that local class limits be used. Soil erosion studies at local scales are therefore important,

Table 2.1: Summary of regional erosion studies done in South Africa since 1990

Abbreviation	**Name**	**Developed by**	**Aim**	**Area and scale**
GLASOD	Global Assessment of human-Induced Soil Degradation	International Soil Reference and information Centre (ISRIC) (Oldeman *et al.*, 1991)	Actual soil erosion based on distributed point data obtained from various experts. Soil erosion areas were delineated according to their judgment.	Global Expert/subjective delineations
SDPM	Sediment Delivery Potential Map	Water Research Commission (WRC) (Rooseboom *et al*., 1992)	To provide spatial data on sediment yield by gathering sediment data and relevant geographical Information which influences sediment yield values of catchments	Southern Africa Catchments 14 to 60 000 km2
BSI	Bare Soil Index	Agricultural Research Council – Institute for Soil, Climate and Water (ARCISCW) (Pretorius and Bezuidenhout, 1994)	To detect bare soil and the status of extensive eroded areas on a national scale with Landsat Thematic Mapper (TM) data.	South Africa 30 m resolution
ESM	Erosion Susceptibility Map	Agricultural Research Council – Institute for Soil, Climate and Water (ARCISCW) (Pretorius, 1995)	To investigate the use of remote sensing and GIS in soil degradation management by integrating a green vegetation cover map produced from NOAA AVHRR satellite data with the sediment yield map.	South Africa 1:2.5 million
PWEM	Predicted Water Erosion Map	Agricultural Research Council – Institute for Soil, Climate and Water (ARCISCW) (Pretorius, 1998)	Map erosion by integrating the main erosion contributing factors of the USLE in a GIS including the rainfall erosivity map of Smithen and Schulze (1982), the sediment yield map and green vegetation cover map to account for rainfall, soil-slope and vegetation factors.	South Africa 1: 2.5 million
NRA	Natural Resources	Agricultural Research Council – Institute for Soil,	Map erosion by regional application of RUSLE in a GIS. Soil and topography factors	Mpumalanga & Gauteng provinces

	Auditing	Climate and Water (ARCISCW) (Wessels *et al*., 2001a) (Wessels *et al*., 2001b)	were, for the first time, separately facilitated by: Applicationof digital elevation models with a resolution of 75 m for the topography factor; and Soil maps (Soil Survey Staff, 1973-1987) were used to link erodibility values to correspondingsoil series in the Land Type Inventories on a scale of 1:250 000 (Land Type Survey Staff, 1972-2006).	1: 250 000
ISRDS nodes	Integrated Sustainable Rural Development Strategy nodes	Agricultural Research Council – Institute for Soil, Climate and Water (ARCISCW) (Ströhmenger *et al*., 2004)	As above	OR Tambo and Umkhanyakude nodes in Eastern Cape and Kwa-Zulu-Natal 1: 250 000
SANBI land degradation review	South African National Biodiversity Institute land degradation review	SANBI (Garland *et al*., 2000)	series of maps illustrating the type andseverity of soil degradation between different land-use types, using qualitative information obtained from 400 extension workers throughout SA during 1997 and 1998.	South Africa Magisterial Districts

(Souce: Le Roux *et al.*, 2008)

A number of studies were also carried out on local scales in the Eastern Cape. These studies include the determination of maximum permissible slope limits for the identification of arable lands (D'Huyvetter, 1985), the modeling of soil erosion (Weaver, 1988). Weaver (1988) developed soil erosion relationships based on soil texture, rainfall intensity/ erosivity, terrain attributes, parent material and vegetation. However, the models did not give a detailed account of important soil variables as controlled by rainfall and the degree of weathering such as iron oxide content, clay mineralogy and chemical composition, such as Mg content. Weaver (1989) reported a decrease in erosion severity with increased rainfall and concluded that this did not make sense. However, such an observation could have been purely the effect of increased rainfall resulting in higher degrees of pedogenesis and more stable soils, thus, overriding the effect of rainfall erosivity (Laker, 1990; 2004b). From such observations, a study to determine how soil

variables could affect erosion as climate changes from drier regions to more humid areas of the Municipality was inititated. Previous erosion studies conducted in South Africa on a regional scale have disregarded important erosion factors and have overvalued less important ones (Le Roux *et al*., 2007)**.** Clay mineralogy is one of the variables that has been disregarded (Mulibana, 2000; Laker, 2004b). D'Huyvetter (1985) defined acceptable maximum slopes at which different soils in the area can be cultivated without causing erosion based on physical and chemical soil characteristics. D'Huyvetter's study included the unstable soils derived from the Beaufort mudstone of the Mavuso and Middledrift pedosystems, which dominate these areas, but also extremely stable soils derived from dolerite. The main findings were that there was no single threshold slope limits for cultivation, and that different soils have different slope limits and that mudstone and shale derived soils were highly degradable while the dolerite derived soils were stable. The reasons for the absence of a single threshold slope limit for different soils could be the differences in clay mineralogy as affected by the degree of weathering, the particle size fractions and chemical composition of the soils.

The soil variables used in D'Huyvetter's models consisted of a small number of easily measurable soil characteristics such as ESP and texture. It would be worthwhile to refine these models to include other important soil properties such as clay mineralogy. Stern (1990) and Rapp (1988), who included very stable soil from the Tyume valley in the Nkonkobe district Municipality and extremely unstable soil from the Eastern Cape amongst the soils in their studies, reported that clay mineralogy was an important factor influencing erosion in South Africa. In the Eastern Cape, illite and kaolinite form dominant minerals governing crusting (Levy, 1988; Mulibana, 2000). Illite and smectites were found to be responsible for serious erosion while kaolinite was responsible for stability of the soils. However, the presence of some smectite together with kaolinite caused soil dispersion (Stern, 1990). Organic matter was found to stabilize smectites and was therefore the overriding factor in the erosion of smectitic clays (Wakindiki and Ben-Hur, 2002). Compared to global research, many South African soils have large quantities of quartz in the clay fraction, which is usually absent in other soils around the world (Buhmann *et al*., 1996; Laker, 2004b; Buhmann *et al*., 2006). In a Municipality such as Nkonkobe where rainfall gradually increases from South to North of the Municipality it would be important to determine the influence of climate on clay mineralogy and erosion.

Iron oxides and chemical balance of bases including exchangeable sodium percentage (ESP) play contrasting roles in soil stabilization and dispersion, respectively (Stern, 1990; Rapp, 1998; Laker, 2000; Laker, 2004b). Singer and Shainberg (2004) reported that citrate bicarbonate dithionite extractable iron > 3% was enough to bring stability to soils. However, this may depend on other interacting factors, such as clay mineralogy, ESP and texture. Soils high in kaolinite have been reported to withstand ESP > 40% (Thompson 1986). Levy (1988) reported that there was no single threshold ESP value and that this value is different between soil types and is dependent on other interacting soil factors.

Kakembo (2000) highlighted the need to examine a range of soil erosion controlling variables giving due attention to soil characteristics. Kakembo and Rowtree (2002) studied the relationship between land use and soil erosion in the communal lands near Peddie using a series of aerial photographs taken between 1938 and 1988. Their research provoked thoughts regarding both the causes for land abandonment and the reasons for the vulnerability of such land to erosion. The observed land degradation was seen as the result of a complex interaction of social, economic and environmental factors which led to soil erosion and land abandonment.

Little research on soil erosion is currently going on in the Eastern Cape save for extension activities carried out by the Provincial Department of Agriculture and land degradation studies along the Kat and Great Fish River Basins undertaken by Rhodes University Catchment Research Group. Their research sought to understand how land degradation is influenced by physical and anthropogenic factors and how in turn it influences the choices made by rural people in their farming (http://www.ru.ac.za/static/departments/geography/body_crgr.php). The studies by this group also overlooked the role of specific soil properties on soil erosion and land degradation. However, there could be isolated and undocumented studies carried out by individuals that may not have been accessed. From this literature review there seems to be a lack of appreciation on the role of interaction of soil factors and climate on erosion. This study could reveal the complex interaction between soil variables and climate and their effect on erosion.

2.6 Delineation of arable land and land suitability evaluation

The aim of the section is to review land evaluation process within the context of the Eastern Cape; the main land characteristics, land qualities and the soci-economic variables in the Province with regards to local conditions are given more attention.The review sets the tone for creation of a land evaluation framework for the Eastern Cape. General land evaluation has been reviewed in detail in many studies (FAO, 1976; 1983; Mbatani, 2000; Weldergorius, 2000; Ebrahim, 2007). Land evaluation is formally defined as the assessment of land performance when used for a specified purpose, and involves the execution and interpretation of surveys and studies of land forms, soils, vegetation, climate and other aspects of land in order to identify and make a comparison of promising kinds of land use in terms applicable to the objectives of the evaluation (FAO, 2007). According to Weldegiorgis (2000), any land evaluation should answer the following questions; (i) how is the land presently managed and what could happen if present management practices are changed (ii) which possible improvements can be done to the land (iii) what other land uses are physically possible and economically and socially acceptable (iv) which of the uses offer possibilities of sustained production or other benefits (v) what negative effects are associated with each of the uses (vi) what corrective measure can be taken to improve production and reduce the negative effects (vii) what are the benefits of each land use.

Because of the high erodibility of the Eastern Cape soils, soil erosion assumes a higher precedence over other land evaluation factors. In a study using aerial photographs taken from 1949 to 1996, erosion was seen to be developing rapidly even on flat terrain (Kakembo and Rowntree, 2002) with gully development increasing by over 66% (Hebinck and Lent, 2007). During the Betterment planning, errors were made in assuming that all soils could be used as long as the slope was < 12% leading to serious erosion and subsequent abandonment of the land (Laker, 2004b). The Betterment Scheme was a policy statement made in 1936 to combat erosion, conserve the environment and develop agriculture in the homelands and be able to cut down on urbanization and labour migration to urban areas (De Wet, 1989). Farmers could not appreciate the primary role of soil erosion which led to its failure, and this underlines the need to prioritise soil erosion in land evalution in the Eastern Cape. The failure of the Betterment Scheme triggered a series of research studies to determine the erodibilities of different soils. Studies by D'Huyvetter (1985) to determine the maximum permissible slope limits for sustainable

cultivation of crops were carried out (reviewed earlier). Follow-up studies by Rapp (1998) and Mulibana (2000) on the erodibilities of different soils were done and the findings backed up earlier assertions that soil erosion was a major problem that could hinder crop production. Maswana (2001) dedicated her study to combating soil erosion in the Province. Any land evaluation exercise should first identify and delineate those soils that are arable and discard those that cannot sustain long term cultivation. Soils forms such as the Glenrosa, Escourt and Swartland have traditionally been avoided for cultivation (Laker, 2004b). Verdoodt *et al*. (2003) used the psedoduplex Valsrivier soils in their maize, sorghum and sunflower trials and managed to get a reasonable yield. In the short-term, the soils could give a reasonable yield but long term use is questionable considering the high erodibilities. These soils need evalution to ascertain if they could be used for long term agriculture. The most recent land evaluation exercise in the area was done in 1975 (Laker, 1978) and there is need for a modified land evaluation that takes into account work done after the 1975, such as the permissible slope limits (D'Huyvetter, 1985).

In arid and semi-arid regions such as the Eastern Cape, stored soil moisture is very pivotal in determining the planting opportunity and water deficits. Studies by Van Averbeke and Marais (1991) revealed that certain soil types store soil moisture better than others. They reported a significantly higher maize yield on Oakleaf soils than onthe Hutton because of higher effective soil moisture reserves, more favourable effective depth and lower clay content. Verdoodt *et al*. (2003) reported that in dry areas rainfall is normally insufficient to replenish available water reserves in soils with large total available water (i.e deep soils with high clay content). In lower rainfall areas, soils with high clay content are less likely to be maintained at an optimum available moisture status (Smith, 1997). Land evaluation procedures in the Eastern Cape should seriously consider stored soil moisture (FAO, 1976).

Soil fertility is normally very important in the determination of land evaluation. Previous studies in the region reported low phosphorus and zinc status in the Ciskeian soils (Mandiringana *et al*., 2005). The dystrophic soils in higher rainfall areas of the Amatola Mountains are likely to experience more serious soil fertility problems than the eutrophic soils of the South of the Municipality. In higher rainfall areas, the bases, nitrogen and zinc are leached while phosphorus is highly fixed by sesquioxides of the extensively weathered soils (Havlin *et al*., 2005). The correction of soil fertility deficiencies would likely receive some priority during land evauation.

Climate is another important factor in crop production and land evalution. Van Averbeke and Marais (1991) reported that rainfed crop production in the Eastern Cape is almost impossible. However, Laker (1978) suggested that few areas (those in the Amatola Mountains and parts of the Amatola Basin) in the the former Ciskei recorded water surpluses. The areas to the south of the Municipality are very dry and unsuitable for the majority of crops. However, a few crops such as sorghum and cowpeas could be grown in such dry areas. Laker (1978) also suggested that the occurrence of severe hailstorms and the scorching 'berg winds' may cause damage to crops but these cover a relatively small area.

While water deficits are the main climatic drawbacks, Burger (1983) in his summary on temperature suitability using the Ehlers System reported that the majority of the Ciskei falls within the 67/ 25 zone which is suitable for many crops. The Ehlers temperature system was developed for South African conditions. The first two digits (67) represent the sum of summer month's average temperature from November to February and the last two (25) represent the sum of winter month's average temperature from June to August (Zuma-Netshiukhwi and Walker, 2009). Its main advantage is that the database contains temperature specifications for > 400 crops grown in South Africa hence it gives farmers a wide range of crops to choose from. The Municipality falls within 4 basic Ehlers zone units, namely the 67/25, which comprises the largest fraction including the semi-arid region, 46/14, 46/15 and 57/25 comprising mainly the cooler Amatola Mountains and its surrounding areas and zone 77/35 falling mainly within the arid climate (Burger, 1983). To put this into perspective, navel oranges grown in the Municipality are temperature sensitive and achieve optimum growth in 67/25 Ehlers zones. It is in such temperature zones where navel orange production should be prioritised. Maize crop achieves marginal yield in 46/14 and 46/15 and therefore such zones should be avoided (Zuma-Netshiukhwi and Walker, 2009).

Burger (1983) reported that the influence of temperature in the Ehlers zones 46/14, 46/15 and 57/25 was very similar and because of this, these Ehlers temperature zones were grouped to form one land unit during test crop temperature suitability classification. The crops need to be evaluated for their suitabilities to different temperature regimes in the Province.

Socio-economic and agronomic practices

The main cultural and socio-economic variables affecting crop production in the Eastern Cape were cited by Hebinck and Monde (2007) as access and control of land, shortage of labour and tractors and absentee farmers. They highlighted that most of the land is owned by old people and this had a negative influence on production as young and able bodied aspiring farmers could not access land. Those who managed to access land did so through sharecropping arrangements. Under such arrangements the landlord provided land to the aspiring farmers and they shared the produce. Such arrangements made farming unprofitable at times, due to unrealistic share demands by landlords.

Monde *et al*. (2005) reported that shortage of tractors was another major hinderance to crop production. Few farmers owned tractors and where farmers were provided with tractors by the government, they were often abused by political leaders. Farmers resorted to hiring tractors at huge cost and taking turns to cultivate their fields. Labour is mostly provided by women who have other household chores to take care of. Shortages of labour and tractors led to late planting or to the missing of the planting opportunity altogether, resulting in significant yield reduction (Burger, 1983; Mbatani, 2000).

Poor agronomic practices, such as incorrect plant density, weed control problems, also contributed to the decline in crop production (Van Averbeke, 1991; Fanadzo *et al.*, 2007). Mbatani (2000) suggested that a correct balance between correct plant populations, with climate and yield projection, was needed to achieve the best plant populations in a given area. For example, lower plant populations with low yield would be better under semi-arid conditions than higher plant population with no yield at all. Van Averbeke (1991) also recommended different maize plant populations in the Eastern Cape for different yield potentials; an optimum plant density of 22 000 plants/ ha was required for yield of 3 tonnes/ ha; plant populations were 11 100 plants/ ha for yield potential of 1 tonne/ ha while low plant populations yielded 0.5 tonnes/ ha in low potential areas.

Cultural issues sometimes influenced farmers' choices of the fields to cultivate. Farmers chose to grow crops on low potential and highly degradable soils than high potential red soils because the

later were reserved for residential areas and graveyards simply because they are more stable ([4].Chief Mabandla, personnal communication, 2011).

In land evaluation, the changes in socio-economic and agronomic practices call for dynamism of the land evaluation exercises so that they are within the local context. A land suitability evaluation exercise based on biophysical conditions only assumes that the agronomic and social–economic conditions are not liming, which is often not true (Laker, 2004b). The socio-economic challenges in Nkonkobe or other former homelands are far different from other parts of the world and play a greater role in land suitability evaluation. An exampleis the total abandonment of sorghum crop caused by shortage of labour and general lack of interest, which overrides the favourable biophysical conditions in the Municipality.

2.7 Multicriteria Analysis in land suitability studies

Decision-making is often subjective, as perceptions regarding a problem differ from one person to another (Prakash, 2003). Subjectivity becomes even more complex when variables under consideration increase as is the case in agricultural potential decision making. In cases that involve many stakeholders, decision making using traditional methods is often complex (Dooley *et al*., 2009). To address this problem, multi-criteria decision analysis and GIS can be integrated to solve spatial problems and make important agricultural decisions (Prakash, 2003). Multiple criteria decision analysis (MCDA) provides a formal, quantitative and qualitative means of evaluating agricultural decisions taking into account all input variables needed to make those decisions (Malczewski, 1999).

Multi-criteria decision analysis constitutes a tool that helps evaluate the relative importance of all criteria involved and reflects on their importance during project management and decision making (Prakash, 2003). It offers a process that leads to rational, justifiable and explainable decisions. Unlike some models that need testing and calibration first, MCDA is flexible, and accommodates the participation of multiple experts and stakeholders. It also deals with mixed data sets both quantitative and qualitative, including expert knowledge (Malczeswki, 1999). Multi-criteria decision analysis has found applications in the business sciences (Kaisler, 2009), policy analysis (McDaniels and Thomas, 1999) and the natural sciences. Mendoza and Martins

[4]Chief Mabandla, Ncera Village, Alice

(2006) reviewed situations in natural resource management where MCDA has been applied, including forest management and planning (Pukkala, 1998), environmental conflict analysis (Malczewski *et al*., 1997), land suitability analysis (Jiang and Eastman, 2000; Sicat *et al*., 2005) and watershed management (Prato, 2000). Similarly, complex interactions between qualitative and quantitative variables influencing land suitability evalution in Nkonkobe Municipality such as soil, climate and socio-economic factors could be best better explained using MCDA.

Early studies in MCDA were done using conventional empirical models, but recently, focus has shifted to the use of powerful GIS based models that allow for the creation of maps (Pereira and Duckstein, 1993). Geographical Information System based MCDA has found widespread use in land suitability classification and related studies (Wandahwa and Ranst, 1996; Ghebremeskel, 2003). Wandahwa and Ranst (1996) integrated GIS, Automated Land Evaluation Systems (Ales) and expert knowledge to assess their suitability for pyrethrum cultivation in Kenya while Ghebremeskel (2003) used GIS spatial information to identify areas suitable for specific crops in Kwazulu-Natal, South Africa. Hossain *et al*. (2007) used GIS based MCDA to identify suitable sites for tilapia farming in Bangladesh. Ceballos-Silva and Lopez-Blanco (2003) used a multi-criteria approach to evaluate the roles of different variables in the identification of areas suitable for oat production in Central Mexico. The Multi criteria decision analysis in GIS involves the integration of spatial operations that are logically defined. The GIS operations may include fuzzy membership (Sicat *et al*., 2005), Boolean Logic and Weighted Linear Combinations (Jiang and Eastman, 2000). However, which ever operations are used, the objective of using MCDA models is to find solutions to decision making problems characterized by multiple alternatives (Jankowski *et al*., 2001).

In most decision making situations where multiple variables are involved confusion often arises if there is no logical and well structured decision-making process in place. Flow charts offer a mechanism to illustrate a logical overview of the sequence of steps and a framework of the research approach for spatial MCDA (Prakash, 2003). It is normally followed by a hierarchical organisation that presents a common criterion where main variables can be distinguished and further decomposed at lower levels. The variables are also weighted according to their relative importance (Sicat *et al*., 2005; Hossain *et al*., 2007). The hierarchical order normally follows a set of logical rules created by the analyst in accordance with his expert knowledge of the subject

and other recognised procedures such as the FAO land evaluation framework. For land evaluation, the rules could be set using the FAO Land evaluation framework (FAO, 1976). The requirements for land suitability set in the FAO framework such as rainfall amount, nutrients, soil and topography could then be manipulated in GIS MCDA using spatial analysis (Ebrahim, 2007).

The land suitability evaluation for Nkonkobe Municipality done in 1975 does not provide the platform for spatial overlay of the different sources of data. The use of GIS MCDA could give a better flexibility for manipulation of different data layers using different GIS operations such as Boolean Logic and Weighted Linear Combinations. The data could be manipulated to show how different crops could be suited to the different biophysical conditions. Thus, data layers including soil maps, climate maps, and digital elevation models can be manipulated to determine land suitability without any need for validation.

2.8 Conclusions

The literature review revealed that there are vast tracts of abandoned lands in Nkonkobe Municipality. The reasons for land abandonment given in literature reflect a broader view within the South Afrcan context and using them to formulate policy in Nkonkobe Municipality could be speculative. The reasons given in literature include land degradation, migration of labour and lack of understanding of the farmers' priorities with regards to agriculture. This justified the need for research on farmers' perspectives to arable crop production and the reasons for land abandonment in Nkonkobe Municipality. The review also showed that there are knowledge gaps between scientific research and indigenous knowledge and that scientific work alone may not yield the desired results during implementation unless they are backed by indigenous knowledge. Such revelations necessitated a participatory ethnographic study integrating indigenous knowledge and scientific knowledge to unlock the farmers' perspectives with regards to arable cropping and understanding of their soils and how they have shaped cropland agriculture.

The reviews revealed that many soil erosion studies have not properly established the role of climate and soil factors on soil erosion. The role of climate on soil erosion especially rainfall has mainly been interpreted in terms of rainfall erosivity and not in terms of how they affect pedogenesis and soil variables such clay mineralogy. This has led to contradictory results on the

effect of the amount of rainfall on soil erosion where some findings reported that high amount of rainfall were responsible for increased erosion with some concluding that high rainfall led to more stable soils. The inconclusive findings motivated for a study on the role of climate on soil factors affecting soil erosion.

There are revelations that the land evaluation exercise done in 1975 was generalized, based on research from other regions and did not prioritise the unique biophysical challenges such as highly degradable soils and socio-economic variables. From such literature review a study to formulate land suitability evaluation for the Eastern Cape was proposed.

CHAPTER 3

FARMERS' PERSPECTIVES WITH REGARD TO ARABLE CROP PRODUCTION: AN ANALYSIS OF NKONKOBE MUNICIPALITY, SOUTH AFRICA

3.1 Introduction

Many agricultural projects have failed because of a lack of knowledge of the biophysical, cultural and socio-economic variables affecting agriculture and rural livelihoods (FAO, 1997). The situation is pronounced in former homelands of South Africa, including the Transkei and Ciskei in the Eastern Cape Province, where there has been a general decline in agricultural production (Hebinck and Van Averbeke, 2007). Reasons for this decline in crop production in former homelands include crop diseases; adverse climate and water deficits; lack of assets for agricultural production; diminishing farm sizes; changes to government support for irrigated agriculture after the regime change in 1994; poor health and education (Vink and Van Rooyen, 2009, Baiphethi and Jacobs, 2009); limited availability of land suitable for crop production (Van Averbeke and Marais, 1991; Van Averbeke and Bunnet, 2007; Shackleton *et al.*, 2013); able-bodied young men being away as migrant labourers and increased dependency on government grants since 1994 (Hebinck and Van Averbeke, 2007). Expenditure on food has consequently risen to between 60 – 80% of the total income for low-income households (Baphethi and Jacobs, 2009). Identification and development of appropriate intervention measures to stimulate food production and reduce reliance on purchased food are therefore necessary.

A reconnaissance of Nkonkobe Municipality showed that large areas of previously cultivated land have been abandoned. According to an unpublished report by Van Averbeke in 2003, quoted by Laker (2004a), a survey of four rural villages in the Tyume valley in Nkonkobe Municipality found that 50 – 80% of the cultivated areas had been abandoned. Large scale abandonment of cultivated fields is also found in other parts of the world. A study on changes in land use patterns in West Bahia district of Brazil found that between 1985 and 2000 about 1.6 million ha land were cleared and brought into cultivation (Batistella and Valladares, 2009). During the same period about 320 000 ha that were cultivated in 1985 were abandoned, i.e. about 20% as much land was abandoned as was brought under new cultivation during that period. In contrast the proportion of abandoned fields in the Wild Coast region of the former Transkei

homeland in the Eastern Cape was almost insignificant, being only 1.5% in 1961 and 6.9% in 2009 (Shackleton *et al.,* 2013). The difference is that the latter has higher annual rainfall (800 to 1 000 mm) and much more stable high quality soils than the problem areas in Nkonkobe Municipality.

Many of the abandoned cultivated fields in Nkonkobe Municipality show very severe gully erosion (D'Huyvetter, 1985). In a 1998 unpublished document, Kakembo, quoted by Laker (2004b), even refers to abandoned cultivated fields in this region as gully erosion "hot spots". There are, however, also many abandoned fields that do not show any signs of erosion. It would be very important to determine why such fields were abandoned and which of them could be recommended for cultivation again.

In Nkonkobe Municipality, government services and employment is the biggest contributor to the GDP, contributing 44% of the gross domestic product (GDP), with agriculture the second largest contributor, with a market share of 17% (IDP, 2008). There is some tourism potential, but no mining potential and industrial potential is very limited. It is therefore necessary that the productivity of available agricultural land be maximised to increase the contribution of agriculture to the GDP. There are three categories of land that need optimisation, i.e. (i) the previously highly productive white commercial farms, which were bought out by the apartheid government during the late 1970s and incorporated into the then Ciskei as part of the homeland consolidation process, but are presently abandoned and unproductive, (ii) some of the previous cultivated native lands that lie abandoned for which the reasons are yet to be established that may have cropping potential and (iii) high potential land that has never been cultivated. To optimise the use of such land resources, Aliber and Hart (2009) called for greater support of local farmers and an understanding of their thinking. Participatory studies could determine what the local farmers view as serious threats to crop production; reasons for land abandonment; and how best current agricultural production could be intensified to reduce pressure on marginal lands (Baphethi and Jacobs, 2009). Currently grown and future crops also need to be investigated. This information could pave the way for evaluation of alternative crops in order to determine if they could be grown successfully in this region.

The aim of this chapter was to determine local farmers' perspectives with regard to crop production as a basis for agricultural development in Nkonkobe Municipality.

The specific objectives were (i) to determine farmer perspectives with regards to constraints on crop production and optimum land utilisation; (ii) to identify reasons for abandonment of croplands and (iii) to determine farmer perspectives on their past, present and future cropping preferences.

3.2. Materials and methods

3.2.1 Study area

The Nkonkobe Municipality is situated in the Amathole District of the Eastern Cape province, South Africa, between 32^{o} $21^{'}$ and 33^{o} $07^{'}$ South and 26^{o} $24^{'}$ and 27^{o} $13^{'}$ East (Figure 1). It has a total land area of 3 725 km^2 and a population of 133 434 (Stats SA, 2001). The Municipality is characterised by high levels of unemployment, estimated at over 85% of the indigent population (IDP, 2008). Official figures revealed that the economy was able to create jobs for only 3.5% of the economically active population (Stats SA, 2001). For their livelihood, the population depended on public sector employment, which contributes to the bulk of their income, government grants, agriculture and migratory labour (Hebinck and Van Averbeke, 2007). Small-scale agriculture is dominated by vegetable and livestock production in projects that are mainly funded by the Department of Agriculture. Other economic activities include tourism, forestry and sheep and wool production (IDP, 2008).

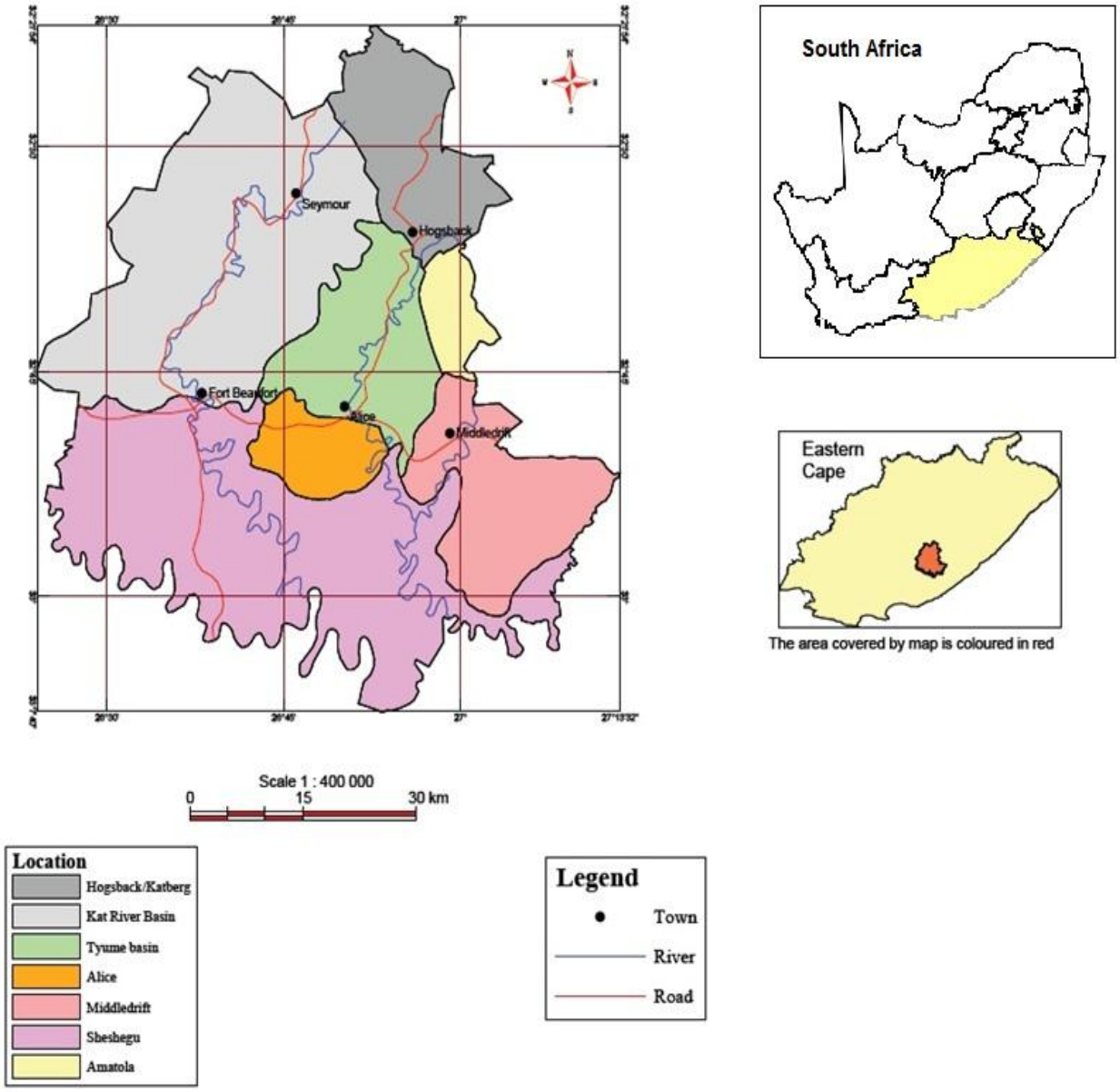

Fig. 3.1: Map of the Nkonkobe Local Municipality showing the biophysical units

In this study the municipality was divided into seven units, based on geomorphology, climate and soils (Laker, 1978). The Hogsback/ Katberg unit is a high rainfall mountainous area, with tourism and forestry as main enterprises and very limited cropping. The Alice and Sheshegu units are characterised by low rainfall and poor quality soils and are thus used almost exclusively for extensive grazing. The Amatola unit has significant cropping potential, but is a small isolated

unit surrounded by steep mountains. Thus, this study was carried out in the Kat River, Tyume River and Middledrift catchments, where most of the agricultural activities in the Municipality take place. The three catchments are described below:

1. The Kat River catchment consists of two main units, namely the sub-humid upper catchment and the semi-arid middle catchment around Fort Beaufort, with annual rainfall approximately 800 mm and 500 mm, respectively. Farming in the Kat River catchment is mainly commercial; comprising both fully fledged commercial farmers and emerging farmers on highly developed former white commercial farms, which were incorporated into the Ciskei as part of the homeland consolidation programme in the late 1970s. The latter include some former highly productive irrigated farms, mainly citrus, on which most of the cropping has been abandoned.

2. The semi-arid Tyume River catchment lies between the escarpment of the Amatola Mountains and Alice, with rainfall between 580 mm at Lovedale near Alice and 611 mm at Pleasant View closer to the mountains (Laker, 1978). Farming activities includes both traditional small-scale farming areas and former commercial farms, including some former highly productive citrus farms that have collapsed. Alluviums are found on terraces along the Tyume river and on floodplains of seasonal streams, where most cultivation is carried out. Doleritic intrusions are also found on higher ground, especially in the east (Laker, 1978).

3. The Middledrift unit consists of two parts. One is along the Keiskamma River around Middledrift, which is made up of a combination of river valleys that are dry (annual rainfall < 390 mm), with high agricultural potential only under irrigation, and semi-arid hills with poor quality soils (Laker, 1978). The other is a large section on the Eastern boundary of the Municipality, South of the road from Middledrift to Debe Nek, with limited cropping potential. Mean annual precipitation at Middledrift is about 500 mm with high potential evapotranspiration (> 2 000 mm) in January, causing a severe mid-summer drought (Laker, 1978). Parent material on the river terraces is alluvium, with mudstones, shales and dolerite intrusions dominating in the land away from alluvial terraces.

3.2.2 Farmer interviews

Information on farmers' perspectives was obtained through semi-structured and open-ended interviews. To reduce the response error and clarify unclear questions a pilot test of a draft questionnaire was run with 15 selected farmers from each of the Kat, Tyume and Keiskamma Catchments. A final questionnaire was then produced to use for interviewing farmers. Because the survey was confined to mainly traditional rural setting where croplands are allocated by tribal authorities to some individuals, no statistical records distinguishing between total households and active farmers were available. It was, therefore, impossible to accurately establish the farmer population size. In this scenario, all farmers who attended the induction meetings at which the research objectives were explained were afterwards included for individual interviews. One hundred and seventy-five farmers selected from communal farmers and consisting of 69 from the Tyume, 52 from the Kat and 54 from the Middledrift unit were interviewed. Communal farmers in this study refer to the small-scale subsistence and semi-subsistence farmers mainly found in the mainly native communal areas. A snap survey was also carried out on 27 commercial and emerging farming units. Commercial farmers in this study refer to established farmers who are farming profitable on commercial basis while emerging farmers were black farmers who were allocated previously white-owned commercial agricultural land under the government land reform programme, including those who received land during the Ciskei homeland consolidation process in the 1970s. Views from established commercial farmers were also used in addition to those provided by the emerging commercial farmers. The informants gave background history regarding the farms, management practices and soil fertility problems faced by the farmers. The information collected also included demographic, using the defined criteria used in census (Stats SA, 2001); proportion of land not in use and reasons for land abandonment; factors limiting crop production; and current and future crops.

3.2.3 Data analysis

For the purposes of this study an active farmer- communal, commercial and emerging - was defined as the unit of analysis. No household information was captured because from the pilot study the size of the family, gender and income did not feature prominently and were therefore assumed not important. Since 85% of the farmers were indigent, an assumption was made that the farmers (excluding the commercial farmers) were resource poor, and below the poverty datum line (Monde *et al*., 2005).

The quantitative data was summarised and analysed using Microsoft Excel and SPSS (SPSS, 2008) software. The descriptive statistics was used to generate frequency tables and the unit of analysis was defined. The literacy rate was obtained by assuming that any person who had completed at least grade 7 was literate (SDFP, 2004; Stats SA, 2001). Four levels of land abandonment namely, < 25%, 25% – 50%, 50% - 75% and > 75% were correlated against the main drivers of land abandonment namely; high temperatures, low rainfall, soil degradation, farm machinery, security and migration were performed to establish the main factors leading to land abandonment.

The order of importance of crops grown and limitations to crop production in the area were ranked by weighting the factors. A weighted average was calculated for each factor by multiplying the item frequency by the numerical rating (Azar, 1999). Limitations to crop production were weighted by summing up the product of the degree of limitation and the frequency of occurrence of the factor, using the formula:

$$WF = ((H1F1) + (H2F2) + (H3F3))/ 100$$

Where H is the degree of limitation on a scale of 1–3, representing low, moderate and high respectively; F is the frequency.

Crop rankings to establish farmers' cropping preference were also weighted using the formula

$$WF= ((R1F1) + (R2F2) + \ldots + (R5F5))/ 100$$

Where R is the ranking of the crop on a scale of 1–5.

3.3 Results

3.3.1 Demographic characteristics of the farming community

Of the smallholder communal farmers in the Tyume catchment, 37%, 27% and 34% were in 30–54, 55–64 and ≥ 65 age groups, respectively, while in Middledrift, these age groups constituted 30%, 27% and 40%, respectively. In the Kat River catchment, 27%, 24% and 30% of the farmers were in age groups 30–54, 55–64 and greater than 65, respectively (Table 3.1).

The farmers had reasonable experience, with at least 73% of the respondents in the three areas having more than 5 years' experience, while about 25%, 34% and 36% of the farmers in Tyume, Middledrift and Kat River, respectively had more than 20 years of farming experience.

Literacy levels were low on smallholder farms, with 51%, 41% and 49% of the interviewed farmers at Tyume, Middledrift and Kat being illiterate. Very few farmers had tertiary education, with 7% (mostly retired teachers) at Tyume and Middledrift, but none in the Kat River valley. Twenty seven percent of the farmers in Middledrift, 24% in Kat and 17% in Tyume, had completed a senior certificate.

Of the smallholder communal farmers, in the Tyume catchment, Middledrift and Kat catchment, 29%, 52% and 30%, respectively, were part-time farmers and were employed elsewhere to supplement their income. Part-time farmers are mostly those who have other sources of income, such as remittances from relatives working in towns and recipients of government grants in the form of old age pensions, child support and disability grants. The remainder of the farmers were farming on a full-time basis (Table 3.1).

Table 3.1: Demographic data of farmers at Nkonkobe Municipality

Demographic category	Communal farmers			Commercial farmers (%) n = 27
	Tyume River catchment (%) n= 69	Middledrift (%) n= 54	Kat River catchment (%) n = 52	
Age of farmers				
24–29	2	2	12	8
30–54	37	30	27	43
55–64	27	27	24	29
> 65	34	40	30	20
Farming experience (years)				
< 5	19	27	27	
5–10	22	18	15	28
11–20	34	21	15	51
> 20	25	34	36	21
Levels of education				
Primary education (Grade 7)	51	41	49	-
Grades 8–10	25	25	21	-
Senior certificate (Grade 12)	17	27	24	43
Tertiary	7	7	0	57
Status of farmers				
Part-time	29	52	30	54
Full-time	71	48	70	46

3.3.2 Land utilisation for crop production

Ninety-five percent of the smallholder communal farmers in the Tyume valley do not fully utilise their land for crop production, with 46% of them indicating that more than half of their land had been abandoned. Correlation results showed that the amount of abandoned land was strongly influenced by lack of farm machinery (0.550), soil degradation (0.467), shortage of inputs (0.326) and low rainfall (0.357) (Table 3.2).

Table 3.2: Correlations between land abandonment and factors influencing land abandonment

Driving factors	Land abandonment		
	Tyume	Middledrift	Kat
Temperature	0.289**	0.017	0.147
Low rainfall	0.357**	0.360**	0.035
Labour shortages	0.184*	0.10	0.088
Lack of interest	0.0194*	0.109	0.073
Theft	0.084	0.184*	0.051
Shortage of farm machinery	0.550**	0.346**	0.267**
Poor infrastructure	0.089	0.003	
Disease prevalence	0.0128	0.073	0.176*
Soil degradation	0.467**	0.262**	0.236**
Shortage of inputs	0.326**	0.107	0.380**

***. Correlation is significant at the 0.01 level.*

** Correlation is significant at the 0.05 level.*

In the Middledrift area, 10% of the farmers indicated that they fully utilised their land, with at least 61% using less than three quarters of the previously cultivated land. The amount of abandoned land was influenced mainly by low rainfall (r=0.360), shortage of farm machinery (r=0.346) and soil degradation (r=0.262)

In the Kat River catchment, 62% of the farmers use only about 25% of the available land and 39% of the farmers had completely abandoned the available arable land. Shortages of inputs (r=380), farm machinery (0.267) and soil degradation (r=0.236) were the major factors that led to increased land abandonment.

3.3.3 Limitations to crop production

The main limiting factors to crop production, as ranked by smallholder communal farmers in the Tyume River catchment were soil degradation, farming equipment, low and erratic rainfall, lack of security and shortage of fertiliser and seed (Table 3.3). The farmers mentioned that soil erosion, poor soil fertility and compaction were the main soil-related problems experienced in the area. In Middledrift, the order of importance was similar to Tyume, but low rainfall was the

second most important factor after soil degradation. In the Kat catchment, farmers cited soil degradation and pests and disease as the most important factors limiting crop production, with erratic rainfall and lack of security being less important than in the Tyume and Middledrift catchments. Other factors of less importance in the three communal farming areas were labour shortages, limited land and lack of farming interest and expertise.

Table 3.3: Limitations to crop production, as identified by smallholder farmers

Factor	Tyume River catchment		Middledrift		Kat River catchment	
	Score	Rank	Score	Rank	Score	Rank
Soil-related problems	1.64	1	1.75	1	1.56	1
Low and erratic rainfall and extreme temperatures	1.53	3	1.67	2	1.24	4
Farming equipment	1.54	2	1.27	3	1.42	3
Pests and disease	1.41	4	1.05	4	1.54	2
Security	0.75	5	0.98	5	0.24	7
Shortage of inputs	0.69	6	0.57	6	0.64	5
Labour shortages	0.32	7	0.50	7	0.61	6
Limited land	0.12	8	0.16	9	0.06	9
Lack of farming interest	0.09	9	0.32	8	0.12	8
Lack of expertise	-	10	-		0.07	10

3.3.4 Types of crops grown

Maize was ranked as the most common crop grown by smallholder farmers in the three communal areas. The other important crops grown by the smallholder farmers included potatoes, cabbage, spinach and onions in Tyume; and spinach, cabbage, potatoes and beans in Middledrift. In the Kat catchment, the crops are cabbage, spinach, potatoes and butternut (Table 3.4). The minor crops grown by smallholder farmers in the three communal areas were pumpkin, beetroot and carrots.

Table 3.4: Main crops grown by smallholder farmers in Nkonkobe Municipality

Crop	Tyume River catchment			Middledrift			Kat River catchment		
	*Score	Rank	[1]Reason	Score	Rank	[1]Reason	Score	Rank	[1]Reason
Maize	2.29	2	2	2.75	1	2	2.18	1	2
Potatoes	2.31	1	2	1.54	4	2	1.56	4	2
Cabbage	1.87	3	2	1.76	3	3	1.91	2	2
Spinach	1.34	4	3	1.84	2	3	1.63	3	3
Onions	0.46	5	3	0.78	7	2	0.69	8	3
Pumpkin	0.90	6	2	0.98	6	2	0.70	7	2
Butternut	1.19	7	3	0.73	8	3	0.94	5	2
Beans	1.16	8	3	1.11	5	2	0.46	9	3
Beetroot	1.09	9	3	0.57	10	2	0.40	10	3
Carrots	0.46	10	2	0.73	8	3	0.76	6	3

[1]*1 = commercial; 2 = subsistence; 3 = both commercial and subsistence*

** Score means the weighted average*

On the smallholder farms, maize, potatoes, pumpkin and onions were grown mainly for subsistence, while spinach, cabbage and beans were grown for consumption and sale. Butternut, beetroot and carrots (minor crops) were grown primarily for family consumption. Apart from maize, no other cereal crop was grown, and beans were the only leguminous crop grown to supplement protein intake. In the Tyume catchment, crops that were last grown 10 years ago by the farmers but have now been abandoned (termed formerly grown crops in this study) namely wheat, maize, sorghum, beans and pumpkin were cited by about 25%, 24%, 22%, 19% and 15% of the respondents (Table 3.5). The farmers mentioned loss of interest and shortage of farming machinery as reasons for not growing wheat and sorghum, while low rainfall, lack of security and soil degradation were given as reasons for not growing maize, beans and pumpkin, respectively. In the Middledrift region, wheat (36%), sorghum (30%), maize and beans (25%) and peas (16%) were the most excluded crops. Shortages of farm machinery were the major reason for not growing wheat, maize and sorghum. Soil degradation and low rainfall were cited as reasons for abandoning bean crops, while loss of interest was the main reason for not growing peas. Smallholder farmers in the Kat River catchment indicated that the most excluded crops

were also maize, wheat and sorghum, potatoes and beans. Labour shortages, loss of interest, due to preference of processed food from shops, and insecurity due to crop destruction by animals were listed as major reasons for not growing maize, wheat and sorghum. Low rainfall and pests and disease were the main reasons for not growing beans and potatoes respectively in the Kat catchment (Table 3.5).

Table 3.5: Formerly grown crops most excluded by smallholder farmers in Nkonkobe Municipality

Crop	Tyume River valley		Middledrift		Kat River Valley	
	*Frequency (%) n = 69	[2]Reason	*Frequency (%) n = 54	[2]Reason	*Frequency (%) n = 52	[a]Reason
Wheat	22	4	36	10	18	3, 8
Maize	24	2	25	10, 11, 12	21	4, 11
Sorghum	22	4, 10	30	10	18	3, 4
Beans	19	11	25	2,5	12	2
Peas	-		16	4, 8, 9	-	-
Pumpkin	15	5	-	-	-	-
Potatoes	-	-	-	-	15	2, 12

**Farmers were asked to give 5 reasons each, hence the total frequency may exceed 100%.[a]2 = low rainfall; 3 = labour shortages; 4 = lack of interest; 5 = soil degradation; 8 = theft; 9 = limited land; 10 = farm machinery; 11 = fencing; 12 = pests and disease; 13 = inputs*

Farmers in Tyume catchment expressed interest in growing cabbage (25%), butternut (25%), tomatoes (29%), peas and carrots (19%) and maize (15%) in the future, citing emerging local markets in the nearby town of Alice for cabbage, butternut, tomatoes and carrots, while maize and peas were intended for family consumption (Table 3.6). About 14% and 12% of the respondents indicated that they would in future want to grow sorghum and wheat, respectively. Sorghum would be used for brewing traditional beer, while wheat would be preferred for food security.

Table 3.6: Crops that smallholder farmers in Nkonkobe Municipality show an interest in growing in future

	Tyume River valley		Middledrift		Kat River Valley	
Crop	*Frequency (%) n = 69	[1]Reason	*Frequency (%) n = 54	[1]Reason	*Frequency (%) n =52	[1]Reason
Peas	19	2	27	2	12	2
Cabbages	25	1	14	1	15	1
Potatoes	-		23	2	12	1
Tomatoes	20	1			21	1
Butternut	25	1	14	1	12	1
Carrots	19	1	16	1, 2		
Maize	15	2	15	2	9	2
Sorghum	12	2	16	2	6	2
Wheat	14	2	-	2	7	2
Beans	-	-	18	1,2	18	1

[1]*Reason: 1 = sale; 2 = consumption*

Peas (27%), potatoes (23%), beans (18%), carrots and sorghum (16%) and maize (15%) were the most preferred crops for future cultivation in Middledrift. Farmers want to grow peas, potatoes, maize, sorghum and wheat for food security, while butternut, carrots and beans would be grown for sale. Tomatoes (21%), beans (18%), cabbage (15%) and peas (12%) were the most preferred future crops in the Kat catchment, with the first three crops being grown for sale and the later for consumption. A low percentage of farmers (10–15% in Tyume and Middledrift and < 10% in Kat) cited cereal food crops, maize, wheat and sorghum as their future crops.

Commercial farms

The main findings on commercial farms indicated that more than half of the previously highly productive orange farms, acquired for crop production in the 1970s and mid-90s were completely abandoned. The reasons were poor management of finances (43%), farmers who do not live on their farms (54%), who sometimes employ ‘farm managers’ with no tertiary education and simplyact as watchmen. On a positive note, 57% of the farmers/ farm managers had tertiary qualification.

3.4 Discussion

3.4.1 Demographic characteristics of the farming community

The large proportion of ageing smallholder farmers between 55-64 years and >65 years could be the main reason for labour shortages on the farms. This suggests that there would be fewer able-bodied farmers if no new farmers emerged in the near future as the older farmers retire. The low proportion of able-bodied young farmers could be attributed to migration to cities (Lattif, 2000) and mines. This trend is supported by national household surveys conducted country-wide (Stats SA, 2007; Aliber, 2009), which also reported a larger proportion of old farmers in the country. Old age removes the incentive to engage in crop production (Hebinck and Monde, 2007), thus, the higher proportion of farmers over 65 years of age in the Middledrift could have led to the high percentage of part-time farmers.

Old age could have contributed to low land utilisation, as most of the aged farmers still retain the land, which they cannot fully utilise. In the Kat, Middledrift and Tyume catchments, shortage of land was among the five most important reasons for inefficient land utilisation by the smallholder farmers. This was the case despite the vast tracts of underutilised land and could be because land is sometimes in the hands of people who are working in towns (Monde *et al*., 2005). Fewer farmers in Tyume cited land shortage as a major problem mainly because a large proportion of the farmers in the area have been absorbed into cooperatives such as the AgriPark initiated recently by University of Fort Hare and, as a result, do not need additional land outside these schemes. Such initiatives could be adopted in Middledrift and Kat to provide land to willing farmers who do not own land. Owing to the present land tenure legislation, whereby chiefs allocate land under the Permission to Occupy (PTO) land tenure system, transfer of land from old people to the youth, women and the able-bodied is difficult. Land tenure legislation should give able-bodied men and women, who wish to farm, full rights to the land. However, such legislation threatens to legally remove the powers that traditional leaders still have over land and would, therefore, be opposed (Claasens, 2003; [5]Mufundo Kalawe, personnal communication, 2010). In similar work done in Wild Coast of South Africa, Shackleton *et al.* (2013) reported that farmers did not want to part with their land even if it is not cultivated due to

[5] Mufundo Kalawe, Zanyokwe Irrigation Scheme, Middledrift, Eastern Cape, South Africa

a strong sense of entitlement. Farming could present a good employment opportunity for the youth in Nkonkobe, where 41% of the population is unemployed (Stats, SA, 2001). The high unemployment figure is partly attributed to an absence of a strong economic base, which can absorb only 3.5% of the economically active group, and the dominance of subsistence-related activities, with little surplus being produced for profit (SDFP, 2004). Consequently, the youth should be given an opportunity to venture into farming. Findings from this study suggest that the unemployed youth are not involved in farming because of limited land in Middledrift and Kat or lack of interest, in all areas, possibly due to dependency on guardians' government grants (Hebinck and Monde, 2007). Concerted efforts are therefore necessary to lure the youth into agriculture by providing them with land rights.

The effects of shortage of labour due to high proportion of the aged and non-involvement of the youths in agriculture could have been worsened by low literacy rates leading to more land abandonment. The low literacy rate of the farmers is a concern as it creates difficulties in promoting new farming ideas through extension services. The low literacy rate is reflected, firstly, in the overall population census figures for Nkonkobe Municipality, where between 42% and 67% in Kat and about 40% in Middledrift and Tyume are illiterate (Stats SA, 2001). The low literacy rate could be because the youth who have obtained senior certificates might have left for towns in search of employment, instead of staying on the farms and in the villages (SDFP, 2004; Hebinck and Monde, 2007). The lack of expertise that emerged as one of the reasons for low land utilisation, suggest that there is a need for strong capacity building in extension services as earlier recommended by Laker (2004a).

3.4.2 Land utilisation for arable crop production

The overall low land utilisation in Nkonkobe was also reported by Verdoodt *et al*. (2003), who indicated that more than 70% of what is perceived as potentially productive fields was left uncultivated in Nkonkobe, and that only about one-third of such land in the former homelands was being cultivated at any one time while Shackleton *et al.* (2013) observed a similar trend in the Wild Coast of South Africa, where they found land cover in the fields to have decreased from 12.5% in 1961 to 2.7% in 2007.

On of the the major driving factors for land abandonment in this study was shortages of farm machinery. This could be attributed to a decline in animal draught power at household and

community levels due to decreased livestock farming (Fraiser *et al*., 2003; Shackleton *et al.*, 2013). Correlations were stronger in Tyume because of the prevalence of the red soils with very hard dry consistency making it difficult to till using small implements. To increase draught power there is need for government support in livestock production. Hiring of tractors for tillage would be a problem, especially during peak farming periods as farmers share and could miss critical planting periods (Monde *et al*., 2005). The Animal Traction Centre at the University of Fort Hare is currently conducting research on the use of animal draught power for production of vegetables, and preliminary results in terms of cost reduction and yield increase are encouraging (Joubert, 2010). The animal traction technology is less labour-intensive and could serve other purposes, including bulk transportation, ripping, ploughing, planting and weeding (Joubert, 2010). Fewer farmers in Kat catchment indicated that farm machinery contributed to low land utilisation probably because the government had provided these farmers with tractors at some point.

While land abandonment was strongly correlated with shortage of inputs in the Tyume and Kat, the projects carried out by the University of Fort Hare (AgriPark and ARDRI) have provided considerable support through the provision of seed and fertilizers. Chimonyo (2012) recommended the use of improved open pollinated varieties (OPVs) as a viable option to reduce seed costs. With these (OPVs), farmers can retain seed for future seasons for themselves and other farmers by harvesting, treating and packaging the seed. Under low-input smallholder farmer conditions, locally derived "land races" are often better adapted and perform better than hybrids (Mendes *et al*., 1985).

Traditionally, kraal manure is widely used in the Eastern Cape particularly in home gardens to alleviate fertiliser shortages (Mandiringana *et al*., 2005). There is also need to develop fertiliser use efficient strategies, such as the use of leguminous green manure cover crops and kraal manure to reduce the requirement for inorganic fertilisers for the farmers who cannot afford them (Musunda, 2010).

Strong correlations found between land abandonment with low rainfall and soil degradation in Tyume and Middledrift concurred with reconnaissance studies carried out in the area indicating that 85 to 95% of the available land is not capable of supporting cultivation, mainly because of low and erratic rainfall, shallow soils and high erodibility (Van Averbeke and Marais, 1991;

Laker, 2000). The high sodium content and high fine sand fraction in these soils caused high crusting and erodibilities (Laker, 2004b). The insignificant correlation between land abandonment and low rainfall in the Kat was due to the provision of irrigation services in some farms. To mitigate the low and erratic rainfall farmers could consider drought tolerant crops like sorghum, sunflower and cowpea in all the three smallholder areas.

However, studies carried out over many years in the Municipality reported that the average yield of maize was higher at Guquka, which had more favourable conditions than Koloni, but the proportion of the field area planted to crops turned out to be equally low in both cases (Verdoodt *et al*., 2003), suggesting that biophysical conditions were not the only factors for the low land utilisation. Apart from shortages of farm machinery, low rainfall, soil degradation and shortages of inputs which generally showed a strong relationship with land abandonment other factors influencing low production were lack of security (crop theft), labour and land shortages. The later is anomalous in view of the vast tracts of unused abandoned land. The problem of theft could have been caused by the dense population in the Kat and Tyume catchments where criminals from Alice and Fort Beaufort wreck havoc. The above statement is supported by data from Alice and Fort Beaufort police stations ([6]SAPS, 2009; unpublished report). Theft may cease to be a major problem if farming becomes an attractive business to the youth.

Labour shortages were also major reasons for crop production in Tyume and Kat, probably because of migration to the nearby towns of Alice and Fort Beaufort, and also to commercial farms in the case of the Kat River catchment. As discussed earlier, migration, lack of farming interest, government grants and old age constitute some of the major reasons for shortage of labour in communal areas. Family labour is also mostly provided by women, who usually have other household chores to take care of (Monde *et al*., 2005). In addition, Aliber (2009) argued that in over 60% of the households in former homelands, family labour is provided by one member of the family. During peak periods, farmers form labour co-operatives, which help to alleviate the labour shortages (Hebinck and Monde, 2007). Hiring of labour is costly and most resource-poor farmers cannot afford it (Van Averbeke & Mohamed, 2006). Research needs to

[6] South African Police Service, 1 Bell Street, Alice, 5700

focus on identification of labour-saving technologies, such as animal draught power (Joubert, 2010; Fanadzo *et al.*, 2010).

There are several areas in the Nkonkobe Municipality with moderate to high cropping potential that have never been cultivated or have never been used to their full potential. This is despite the fact that many other people, especially the youth, are landless, while some active farmers cultivate on less suitable lands (Mbuti, 2000). A significant number of farmers in Middledrift and Kat catchment cited land shortages and expressed concerns that they were leasing land from the older farmers, partially in exchange for their produce. This group of people need help to secure land rights. A land reform policy that is designed to transfer productive land to potential young farmers with the will and energy to venture into farming should be put in place without creating land conflicts.

3.4.3 Types of crops grown

Maize was the most common crop grown by smallholder communal farmers in Tyume River catchment, Middledrift and Kat River catchment. However, the role of traditional cereal food crops is slowly diminishing, as indicated by the high proportion of farmers who no longer grow maize, wheat and/ or sorghum. At one time, some parts of the Eastern Cape near Peddie (which borders Nkonkobe Municipality to the South) were big suppliers of wheat in the Province but now production has almost ceased ([7]Laker, personnal communication, 2012). Since wheat and sorghum are labour intensive, their decline in production could be due to labour shortages and an ageing population. The decline could also have been caused by a shift by farmers from fields to smaller home gardens as a result of security concerns. Beans and butternut are also common in Middledrift and the Kat catchment. These findings are supported by information from a review on subsistence farming in South Africa, conducted by Baiphethi and Jacobs (2009), which reported that 92% of the consumers in former homelands buy their basic staple food needs from food chain stores, which has increased food expenditure to between 60–80% of the total household income for low-income earners. Shackleton *et al.* (2013) also reported that maize production decreased because of the increased preference to rice which is normally purchased

[7]Laker,M.C, 477 Rodericks Road, Lynnwood 0081, Pretoria, South Africa

from food chains. The abandonment of cereal food crops is a threat to food security in the Municipality and ways to revitalize these excluded food crops should be sought.

While cereal crop production in the Municipality has been declining, production of vegetable crops such as potatoes, cabbage and spinach has increased. The farmers were more willing to continue growing cabbage, potatoes and beans in the future for sale. Though the general impression of homeland agriculture that emerges from literature is that farming is practised on a small scale and that produce is mainly for home consumption (Lahiff, 2000), findings from this study reflect encouraging signs of a shift towards commercial agriculture. This was evident among people around Upper Ncera village, in Tyume, under Chief Mabandla, who have been producing mainly cabbage and spinach on a commercial basis. Farmers have acknowledged that they want to grow crops mainly for sale and therefore efforts are needed to help these farmers achieve this goal.

There has been a shift in farmers' preference towards production of cowpeas and dry beans in the Municipality. The two crops are important for daily consumption and are a very good source of protein (Adeyemi *et al*., 2012). Dry beans, mixed with samp are a popular food in the former Transkei and Ciskei. The mixture is known as *umngqusho* (gnush). The legumes have also been used as intercrops with maize and fertility improvement crops, both in the Eastern Cape and Limpopo provinces, owing to their high biomass and N-fixation capacity (Musunda, 2010; Odhiambo and Nemadodzi, 2007). Tomato, another emerging crop, was grown for sale to the nearby town markets of Alice and Fort Beaufort. However, all these crops should be grown only after crop suitability studies have been carried out. Future studies should focus on evaluation of current, forgotten and future crops to determine their potential in these regions.

Commercial farms

Literacy levels among the commercial farmers were higher, a situation which could make training of such farmers easier. In the Kat River region, the established farmers provide on-farm training to emerging farmers. Laker (2004a) also emphasised the importance of such mentorship programmes and highlighted that they could be successful if conducted in a spirit of good faith between the emerging and established farmers. While high levels of education are normally a positive development in any society, it should be noted that more than half of the emerging farmers – mostly with tertiary education – are 'absentee farmers' who have employed 'farm

managers'; and in most cases the later do not have relevant agricultural qualifications or experience. This challenge has serious implications for land ownership and maximisation of efficient use of land resources. A land audit could be required to determine the number of absentee farmers and the amount of land they occupy in order to formulate meaningful land reform policies.

In the emerging commercial farming sector of Kat River catchment, financial indiscipline was highlighted as a major factor for reduced land utilisation and crop production. Some farmers claimed that at times loans were not used for their intended purposes and, ultimately, farmers fail to service them. Other common problems, such as lack of farming machinery and inputs, were also cited as a manifestation of financial indiscipline. Emerging farmers get technical advice from nearby established farmers on farm management, and marketing is done by an organised commodity chain, which is supported by farmer cooperatives, although the farmers complained that middlemen normally swindle them.

3.5 Conclusions

The major constraint to crop production study was shortages of farm machinery. Demographic discrepancies such as old farmers, low levels of education, absentee farmers and labour shortages have contributed to a decline in crop production. Soil degradation and low rainfall were strongly correlated with increased land abandonment. Maize, cabbage and potato were the main crops grown, while sorghum and cow-peas were identified as future crops. The decline in cereal crop production in the Municipality has been compensated by an increase in production of vegetable crops such as potatoes, cabbage and spinach.

Government support in terms training, marketing of crops and outreach programmes to sensitise youth on importance of agriculture could be used. With > 60% of the farmers not fully utilising their land and > 75% of the land having been abandoned in some areas, increased government support in cattle restocking and provision of tractors to improve draught power could be adopted. Amendment of the Land Tenure Act to include repossession of unused land could also increase area under crop production. The Department of Agriculture could also adopt soil and water conservation programmes to combat soil degradation and alleviate the effects of low and erratic rainfall. The crops grown need to be evaluated for their suitability in the Municipality to

formulate a cropping programme that could be used in the province. Collapsed orange farms need resuscitation through sound management and provision of irrigation services.

There is need to use indigenous soil knowledge on classification and potential to complement scientific approaches and to evaluate the soils for their suitability for the current and future crops.

CHAPTER 4

THE USE OF INDIGENOUS KNOWLEDGE SYSTEMS IN SOIL CLASSIFICATION, MAPPING AND LAND EVALUATION FOR CROPPING POTENTIAL IN NKONKOBE MUNICIPALITY, SOUTH AFRICA

4.1 Introduction

Increasing attention has been given to local soil knowledge in recent years as a result of a greater recognition that experiences of people interacting with their soils for a long time could offer insights on sustainable management, assessment for different uses (FAO, 1997; Sicat *et al*., 2005) and development of technologies that are useful to farmers (Birmingham, 2003). Ethnopedology is defined as local soil knowledge accumulated by people, constructed through trial and error and derived from people's direct interaction with their soils and the environment (Barrios and Trejo, 2003). The main goal of ethnopedology is to understand local approaches to soil perspectives, classification, appraisal, use and management and land evaluation (Barrera-Bassols and Zinck, 2003).

Local people and small-scale farmers possess a good knowledge of their lands and soil characteristics that remain largely uknown to the scientific community (Clemens *et al.*, 2010). While it is normal for small-scale farmers to take instructions from scientific community, it is also important for researchers to understand farmers' knowledge of soil and its management. Important aspects of indigenous knowledge such as the cultural and the social dynamics of the farmers are often ignored by researchers and yet they are crucial during the implementation of soil management strategies (Mowo *et al.,* 2006). Research on local soil knowledge has evolved over a number years with a huge increase in world literature noted in the last few decades (Barrera-Bassols and Zinck, 2003). There are, however, few documented studies on local soil knowledge in South Africa (Buthelezi, 2010).

The previous chapter showed that increasing abandonment of land as a result of soil degradation was a major cause for the decline in crop production in Nkonkobe Municipality. An understanding of indigenous knowledge of soils in the Municipality could help identify the soil factors causing soil degradation and could help form a basis for designating good areas for arable crop production and community-based soil resource management. Laker (1980) established that

certain productive soils were not cultivated by farmers, who preferred less productive soils because high potential areas were only viable under mechanization. In this chapter, indigenous knowledge systems were used to identify, classify and rate the soil and give the farmers' perspectives of the soil factors that are responsible for land degradation.

It is hoped that this study could give an insight on indigenous soil classification approaches of the people of South Africa. The Municipality is inhabited by the Xhosa speaking people found mainly in the Eastern Cape Province but also fairly distributed across the country. The Xhosa tribe is one of the largest tribes comprising about 8 million people of South Africa's population (Stats SA, 2011). Presently, Xhosa is South Africa's second most common home language, after Zulu, to which Xhosa is closely related. Such a demographic set-up could give a fair understanding of the natives' perspectives of the South African soils. Indigenous knowledge systems in the Municipality seek to establish (i) how farmers classify their soil and their perspectives on land evaluation; (ii) the reasons for farmers' preferences to use certain unproductive land and not other land purported to have high cropping potential and (iii) soil factors that caused land abandonment.

Unlike indigenous knowledge systems which are based on qualitative data on cultural and social perspectives, scientific approaches are based on hypothetical facts and quantitative experimental data. Integrating the two approaches could help offset the shortcomings of either of the approaches. Integration of indigenous and scientific soil knowledge could also help in spatial planning of soil resource through participatory mapping approaches (Chapin and Threlkeld, 2001) combined with geographic information systems (PGIS) (McCall, 2003; Oudwater and Martin, 2003; Payton *et al*., 2003; Minang and McCall, 2006). This way soil potential and land suitability maps could be contructed and used for soil and land management purposes. Similarly, the two systems could be used in the Municipality to give a better understanding of the soils, their classification and susceptibility to degradation.

The main objectives of this study were to (i) determine the indigenous soil classification systems of the Xhosa Speaking people (ii) integrate and compare indigenous knowledge systems and scientific approaches of soil classification, agricultural potential and soils'susceptibility to degradation in Nkonkobe Municipality.

4.2 Materials and Methods

4.2.1 Indigenous soil classification and cropping potential ratings

This study was carried out on selected arable lands in the Kat River catchment, the Tyume River catchment and the Middledrift area in Nkonkobe Municipality described in Chapter 3. In the previous chapter, respondents were interviewed on their demographic characteristics; proportion of land not in use and reasons for land abandonment; factors limiting crop production; and current and future crops. This chapter is a continuation of the interviews where the same respondents gave information on farmers' indigenous soil classifications, soil potential ratings and erosion hotspots. Information on local soil names, their colour, texture, slope position and soil erodibility were recorded (Appendix 3.1). The farmers' determinants of their classification and soil productivity and erosion control methods were also captured. Topsoil and sub-soil samples were collected from the corresponding soil classes that were identified by the farmers for laboratory analyses. The samples were analysed for texture, organic carbon, phosphorus and exchangeable bases. The scientific data was later used for comparisons with ethnopedological information to aid in the possible correlation of the indigenous names with the South African classification system (Soil Classification Working Group, 1991) and the World Reference Base classification system (FAO, 2006).

Data Analysis

The information on indigenous knowledge was captured and coded in Microsoft Excel and SPSS (IBM SPSS Statistics 19) software. The descriptive analysis Toolpaks in SPSS was used to generate frequency tables for soil potential and erosion ratings. The unit of analysis was an individual farmer.

Assessment of factors influencing soil classification (determinants of soil classification) was done by ranking them using the weighting formula:

$WF = ((S1F1) + \ldots\ldots + (S3F3))/100$

Where WF is the weighted factor of the soil determinants i.e. texture, colour, depth and slope position

S is the soil potential ranking of the factor on scale 1 – 3; 1= high; 2 = moderate and 3 = low

F is the frequency corresponding to the soil potential ranking

Correlation tests between the two levels of soil productivity (high and low) and the main soil determinants affecting soil productivity (soil fertility, erosion, soil crusting/ moisture content, surface stoniness) were performed to establish the main determinants of soil productivity.

4.2.2 Participatory soil mapping for maize suitability

After obtaining the soil ethnographic information captured in section 4.2.1, the next phase, participatory soil mapping, was restricted to farms in 3 selected villages (each with an area < 100 hectares). One village was selected from each of the Tyume and Kat catchments and the Middledrift. The respective villages were Upper Ncera, Blinkwater and Mbizana. Upper Ncera had mainly the droughty red soils; Blinkwater had the most productive soils while the Mbizana had the most erodible soils. From each of the 3 villages, 6 experienced farmers, irrespective of gender, undertook a transect walk and subsequent participatory mapping of their fields. Only the farmers who have been farming consistently for over 10 years were selected as they were assumed to have sound historical knowledge of their land and its soil resources. During the transect walk, the boundaries of the different soils in the fields were identified. The co-ordinates at the soil boundaries were captured using a Global Positioning System (Garmin GPS 76). Participatory mapping was done using maize as a test crop since this crop was identified as the main crop across the three catchments (Chapter 3).

Due to the small size of the field each farmer possessed, the soil variability was captured at short intervals (normally < 50m). At least 117, 89 and 79 observation points were made at Ncera, Blinkwater and Mbizana, respectively. The farmers described their soils using soil colour, texture, soil depth, and slope position. These attributes were identified as the main determinants for soil classification from the main farmers' interviews in section 4.2.1 of this chapter. At the same time, scientific field verifications of the same attributes were done using available soil maps obtained from the Institute for Soil, Climate and Water of the Agricultural Research Council (ARC-ISCW). These soil maps had information on site and soil profile descriptions. Topsoil and sub-soil samples were also collected the same mapping units where indigenous information was collected for laboratory analyses.

A spreadsheet with the co-ordinates and attribute data of these factors was created in MS Excel and exported to ArcGIS 10 for spatial mapping. The database was projected to WGS 1984 ellipsoid and Hartebeesthoek 1994 datum and converted to the vector point system. The

distribution of the geographic location of the observation points in the 3 villages were displayed in ArcMap10 (Fig. 3.1- 3.3).

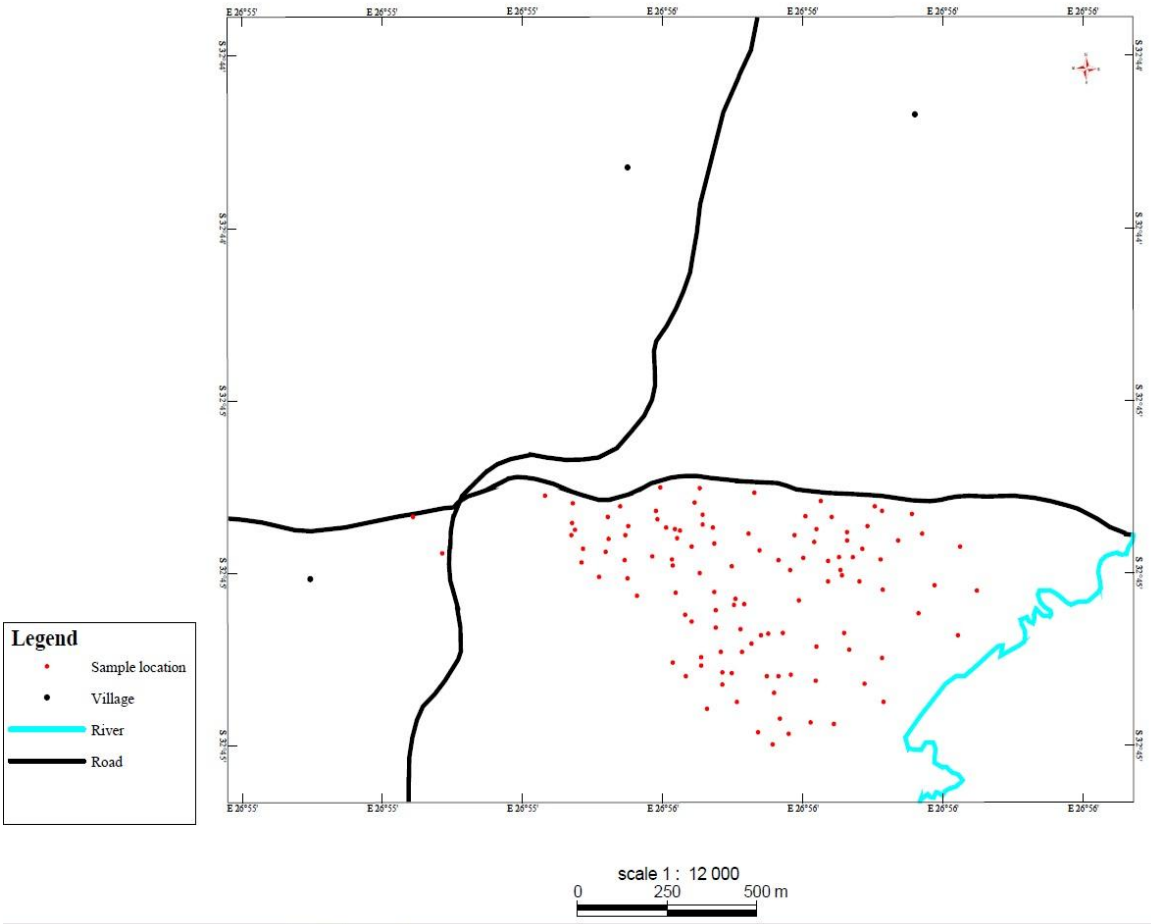

Fig. 4.1: Distribution of the observation points at Upper Ncera Village

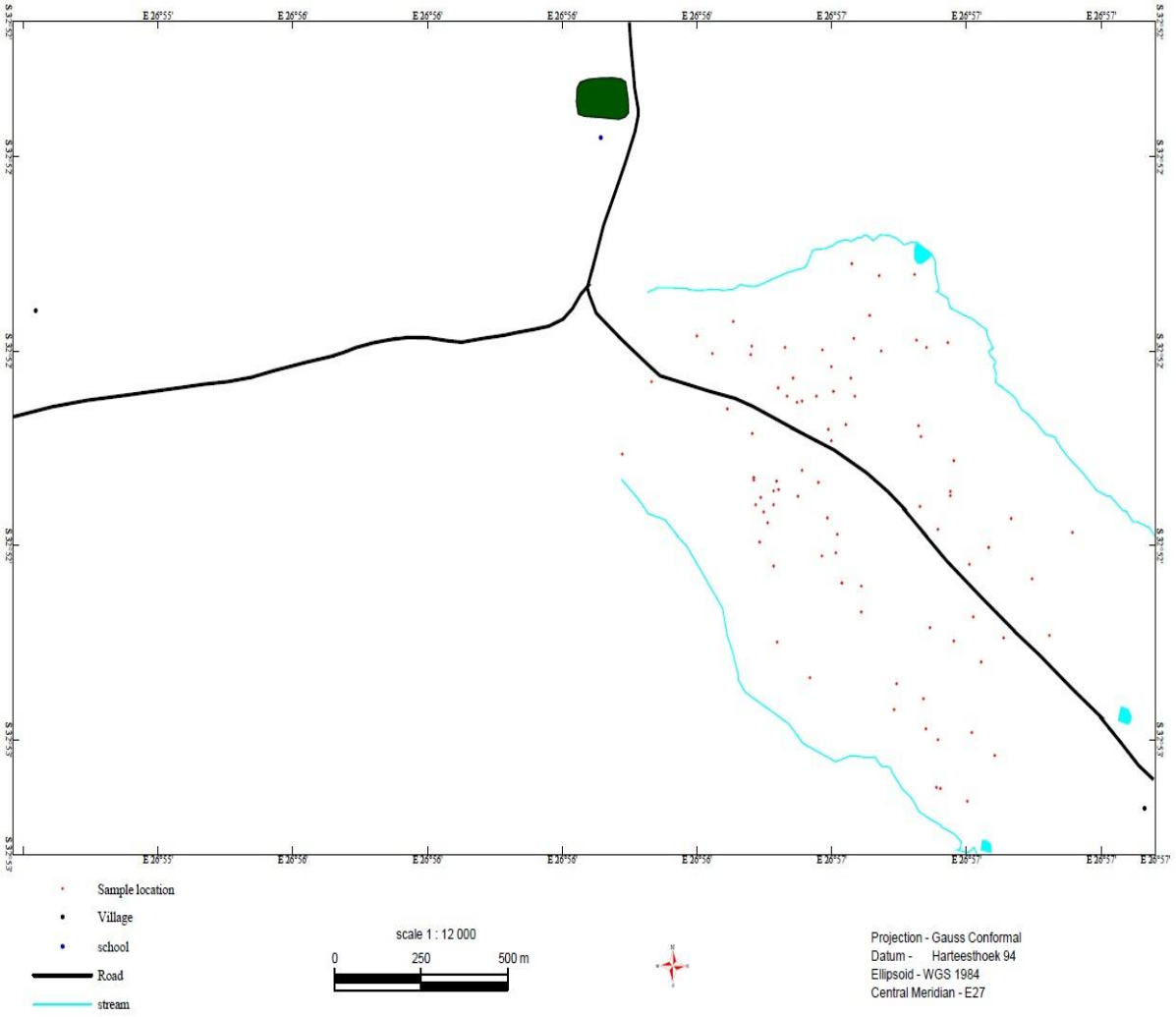

Fig. 4.2: Distribution of the observation points at Mbizana village

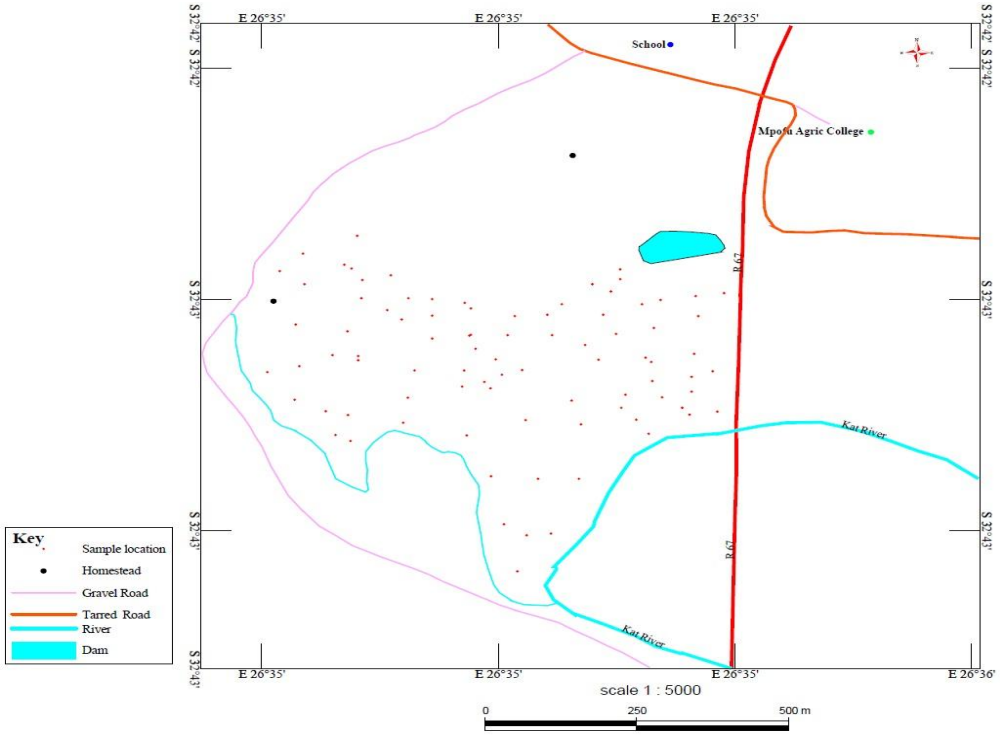

Fig. 4.3: Distribution of the observation points at Blinkwater

A set of rules and arbitrary values between 0.01 and 0.99 were created by assigning values to different soils according to their perceived productivities, using information obtained from the farmers' responses. These values were kriged to produce a continuous surface and later reclassified using the original allocated arbitrary values.

Soil depth arbitrary values of 0.01, 0.25, 0.5, 0.75 and 0.99 corresponding to four categories identified by the farmers namely; very shallow, shallow, moderately shallow, deep and very deep. Using auger holes, it was estimated that respective depths were < 20, 20 -50, 50 – 80, 80 – 150 and > 150 cm.

Topographic position was classified as upper slope, midslope and lower slope with values 0.01, 0.5 and 0.99 assigned to the respective terrain mapping units (TMUs). Texture was assigned three distinct grades, namely coarse, fine and medium textures with arbitrary values 0.01, 0.5 and 0.99, respectively. According to the farmers, soils with medium textures were better to till and less draughty than those with fine textures. Sands and loamy sands were described as coarse textured, sandy loam and sandy clay loam were graded as medium textured while sandy clay and clay were graded as fine textured. The grading of soil colour was based on farmers' perspectives,

where the farmers classified the soils in their order of increasing relative productivity with arbitrary values of 0.01 (red), 0.25 (dark), 0.5 ('white'), 0.75 (brown) and 0.99 (black) assigned. Because the points captured during the transect walk were fairly distributed over short spatial distances, the ordinary kriging method was used to model the perceptual data and to generate surface maps for texture, soil colour, slope position and soil depth. Attribute data showing the different arbitrary values for soil texture, depth, colour and slope position were entered as the Z values with the coordinates entered as X;Y values. The vector point data was then surface modelled by kriging to produce interpolated continuous surfaces using the Geostatistical Spatial Extension Analyst in ArcGIS 9.2. Semivariogram modelling was done to determine the line of best fit and the most suitable model. For all the soil determinants, the spherical model produced the best result as indicated by low standard deviation. Using the algebraic operation MULTIPLY in GIS and weighting factors calculated from farmers' responses (Table 4.5), soil potential maps for maize crop were produced for the three areas using the following equations respectively:

Mbizana: Soils' maize potential = 3.247C X 2.945D X 3.365T X 2.664S

Upper Ncera: Soils' maize potential = 2.779C X 3.321D X 3.236T X 2.948S

Blinkwater: Soils' maize potential = 3.064C X 2.741D X 2.996T X 2.800S

Where:

C is the raster surface for soil colour;

D is theraster surface for soil depth;

T is the map for soil texture;

S is the map for slope position.

The maps were reclassified using limits at infliction points of the cumulative frequency distribution graphs of the algebraic MULTIPLY model in ArcGIS 10, a similar approach described by Sicat *et al*. (2005) (Table 4.1).

Table 4.1: Reclassification limits of the soils' potential for maize production

	Agricultural potential limits		
	low	Moderate	High
Upper Ncera (Tyume)	< 6	6 – 12	>12
Mbizana (Middledrift)	< 6	6 – 12	>12
*Blinkwater (Kat)	-	-	> 22

*The soil potential at Blinkwater was high for the whole scheme

The farmers described soil potential relative to their normal yield, i.e. any soil giving their normal yearly yield (2 tonnes/ hectare maize) was described as moderate, yield above their normal was described as high and yield below their normal was described as low.

An accuracy check/ validation was done by spatially comparing the areal extent of the generated maps to the available 1:5 000 soil maps (Hill *et al*., 1977) to obtain the coefficient of areal association (Taylor, 1977, cited in Sicat *et al*., 2005).

4.2.3 Soil laboratory analyses

Soil pH and electrical conductivity (EC) were determined in 1:2.5 soil/ water (w/v) ratio using a pH meter (pH meter 330 SET-1, 82362). Exchangeable bases (Ca, Mg, K, and Na) were extracted in 1.0 *M* ammonium acetate (pH 7) and determined using the Atomic Absorption Spectrophotometer (AAS). Phosphorus was analysed using the Bray-1 method (The Non-Affiliated Soil Analysis Work Committee, 1990). Total carbon determinations were done by dry combustion using the LECO- Truspec Autoanalyser (LECO, 2003). Particle size distribution was determined by the pipette method (Day, 1965).

4.3 Results

4.3.1 Local indigenous soil classification and general potential of the soils for cropping

Six soil types were identified by the farmers, with soil colour, texture and degree of stoniness being the main criteria used in the classification (Table 4.2). The soils were classified as *umhlaba omnyama, dongwe, santi, isidhaka, umhlaba obomvu and urhete*. For these soils, the decreasing order for cropping potential was *umhlaba umnyama* (dark soils), *dongwe* (brown clays), *santi* (sandy soils), *isidaka* (high activity clays), *umhlaba obomvu* (red clays) and *urhete* (stony and shallow soils). *Umhlaba obomvu* was reported to be prone to drought while *urhete* was regarded as unsuitable for cropping, i.e. as non-arable, and was mainly used for grazing.

Laboratory analyses confirmed that *santi* was dominated by high fine sand (32-52%) and relatively high exchangeable sodium percentage (ESP) on those soils with duplex horizons. The *isidhaka* had high clay content (44 – 47%) and high organic carbon (4.45%). The darker soils (*umhlaba omnyama*) were characterized by low values and chroma (10YR 2/1) and high organic carbon (4.02%) and P (6 - 11%). High clay content and low P and C characterized the *umhlaba obomvu* soils (Tables 4.3 and 4.4).

Determinants of soil classification

The most important soil factors used by farmers for their classification were depth, texture, slope position and colour (Table 4.5). However, the importance of each of these factors varied among the three regions. In order of importance, colour and texture were the most important in the Kat River Catchment, depth and texture, in the Tyume River Catchment, and texture and colour, in Middledrift. Slope position came third in the Tyume and Kat River catchments and fourth in Middledrift.

Table 4.2: Indigenous soil classification by traditional smallholder farmers in the Nkonkobe Municipality

Soil type based on indigenous classification	Possible correlation of South African classification system	Possible correlation of World Reference Base	Description of the soils	Land use	Soil potential	*[8]Relative rating	Erosion hazard
Umhlaba omnyama (Black clay soils)	Melanic A horizon	Mollic A horizon	Dark soils on upper and lowerslope positions.	Cropping	High	1	Moderate
Dongwe (Brown clay)	Oakleaf	Cambisols	Brown clays on all slope positions	Cropping	High	2	Low
Santi (Light gray medium textured)	Oakleaf/ Dundee	Cambisols/ Luvisols/ fluvisols	Medium textured soils with high fine sand contents on river terraces	Cropping	High	3	High
Isidaka (Black swelling clay)	Arcadia	Vertisols	Dark clays with vertic properties on lowerslope	Cropping	High	4	Low
Umhlaba obomvu (Red clays)	Shortlands, Hutton	Nitisols	Red clays on mid and upper slope position	Cropping	Low	5	Low
Urhete (Stony)	Glenrosa, Milkwood, Mispah	Leptosols	Stony and shallow soils	Grazing	Low	6	High

[8] *High erosion means distinguishable rills and gullies; moderate means distinguishable sheet erosion; low erosion means no or slightly distinguishable sheet erosion.

Table 4.3: Selected soil indicators of indigenous soil names

Indigenous soil name	Munsell dry color	Depth (mm)	Clay (%)	Fine sand (%)
Umhlaba omnyama	10 YR 2/1	Variable	15 - 33	20 - 22
Dongwe	7.5 YR 3/2	> 800	26 - 31	17 - 35
Santi	10 YR 4/6	Variable	18 - 28	35 - 52
Isidaka	10YR 2/1	>1000	44 - 47	21 - 24
Umhlaba obomvu	2.5 YR 4/6	>800	43 - 57	6
Urhete	Variable	< 300	22 -25	Variable

Table 4.4: Selected soil chemical data of the main soil forms in Nkonkobe Municipality

Local name form	Soil form (SA)	WRB	Soil pH	Organic carbon (%)	Phosphorus	Free Fe (%)	ESP
Santi	Augrabies	Cambisols/ Luvisols/ fluvisols	6.90-7.04	<0.5	12-15	0.182	0.405
Obomvu	Shortlands	Nitisols	5.00-5.22	<0.5	1	1.776	2.02
Urhete	Glenrosa	Leptosols	5.11	< 0.5	1	0.214	0.795
Santi	Sterkspruit/ Estcourt	Natric B	5.29	<0.5	1	0.561	6.23 -
Umhlaba omnyama	Bonheim	Mollic A horizon	6.77-7.41	4.02	1		1.081
Isidhaka	Arcadia	Vertic A horizins	5.46-5.89	4.45	6- 11	0.214	0.721

Table 4.5: Determinants of soil classification of soil

	Tyume River Catchment		Middledrift		Kat River Catchment	
	Score	Ranking	Score	Ranking	Score	Ranking
Texture	3.236	2	3.365	1	2.996	2
Colour	2.779	4	3.247	2	3.064	1
Depth	3.321	1	2.945	3	2.741	4
Slope position	2.948	3	2.664	4	2.800	3

Farmers' determinants of soil productivity ratings

Correlation results showed that soil factors affecting soil productivity ratings were erosion, low soil fertility and moisture content ("the soil does not become wet") (Table 4.6).

In all the 3 catchments, soil erosion was negatively highly correlated with soil productivity with the Kat and Middledrift showing the highest correlation. The soil productivity ratings in Tyume was influenced mainly by erosion (r= -0.326), soil fertility (r=0.279) and soil moisture content (i.e dry consistency and droughtniess) (r=0.182). In the Middledrift, correlation results showed that the soil productivity ratings were strongly influenced soil erosion (-0.435) but weakly correlated with soil moisture (0.294) and soil fertility (0.213). In the Kat River catchment, soil erosion (r=-0440), soil fertility (0.365) and soil compaction (r=0.236) were the major factors influencing soil productivity ratings. Surface stoniness had the least influence on soil productivity in the the 3 catchments.

Table 4.6: Correlations between soil productivity and the farmers' determinants of soil productivity

Deeterminant of crop productivity	Soil productivity		
	Tyume	Middledrift	Kat
Erosion	-0.326**	-0.435**	-0.440**
Soil fertility	0.279*	0.213*	0.365**
Soil moisture content ('the soil does not become wet and droughtiness')	0.182	0.294*	0.154
Soil compaction	0.065	0.193	0.266*
Surface stonniness	0.143	0.0214	0.0721

***. Correlation is significant at the 0.01 level.*

** Correlation is significant at the 0.05 level.*

4.3.2 Mapping of soil potential for maize

Upper Ncera (Tyume River Catchment)

At Upper Ncera, there was one major soil type, *umhlaba obomvu*,which was further classified intothe lighter variant (red) and its darker variant (dark red) covering 55% and 45% of the land, respectively (Fig. 4.4).

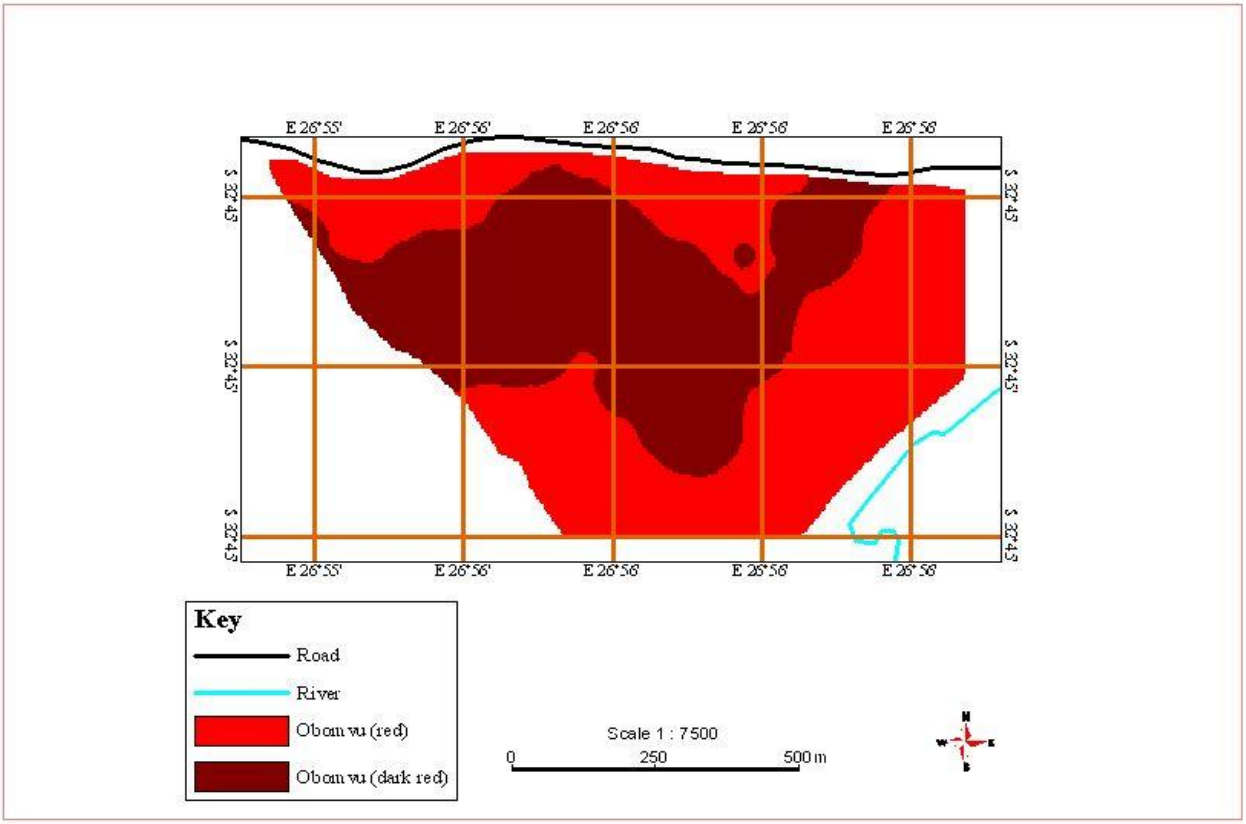

Fig. 4.4: Farmers' soil type map of Upper Ncera

Farmers rated the arable soils as having low (80%), moderate (15%) and high (5%) cropping potential for maize (Fig. 4.5). The soils were medium (17%) and fine (83%) textured (Appendix. 4.1a) and dominated by red (55%) and dark red soils (45%) (Appendix 4.1b). Fifty five percent of the soils were moderately shallow while 17% and 3% were shallow and very shallow respectively. Deep soils (21%) to very deep (4%) soils covered a substantial area of Upper Ncera (Appendix 4.1c). About 20, 64 and 16% of the soils were found on the upperslope, midslope and lowerslope positions, respectively (Appendix 4.1d). The red soils mainly occurred on the crestal, upper slope and lower slope positions and were shallow to moderately shallow. The dark red soils were found mainly on midslope positions and were deep to very deep. The dark red soils on midslope positions were mostly rated as high and moderate.

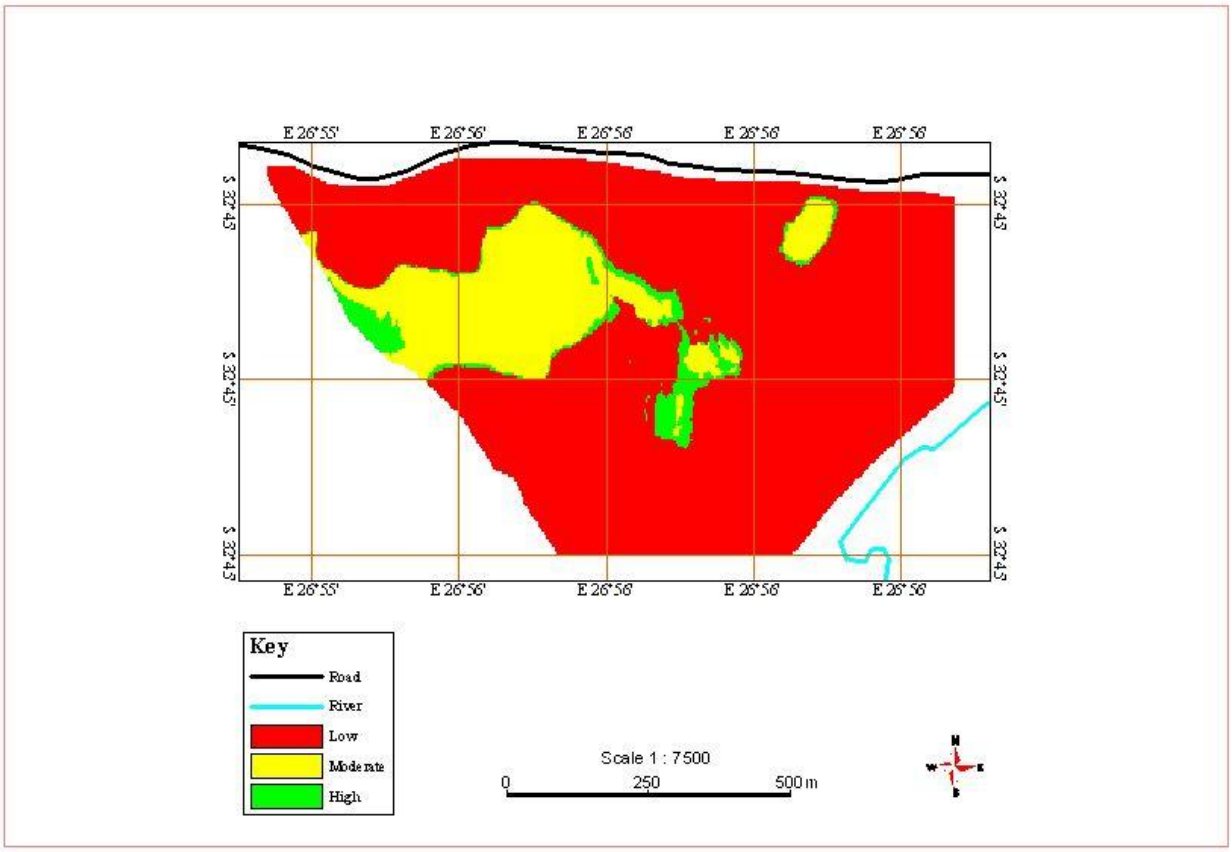

Fig. 4.5: Participatory soil potential map for maize at Upper Ncera

Mbizana (Middledrift)

Four soil types were identified by the farmers at Mbizana, namely (in decreasing order of their potential for maize production), the *dongwe*, *santi, isidhaka and umhlaba obomvu* (Fig. 4.6).

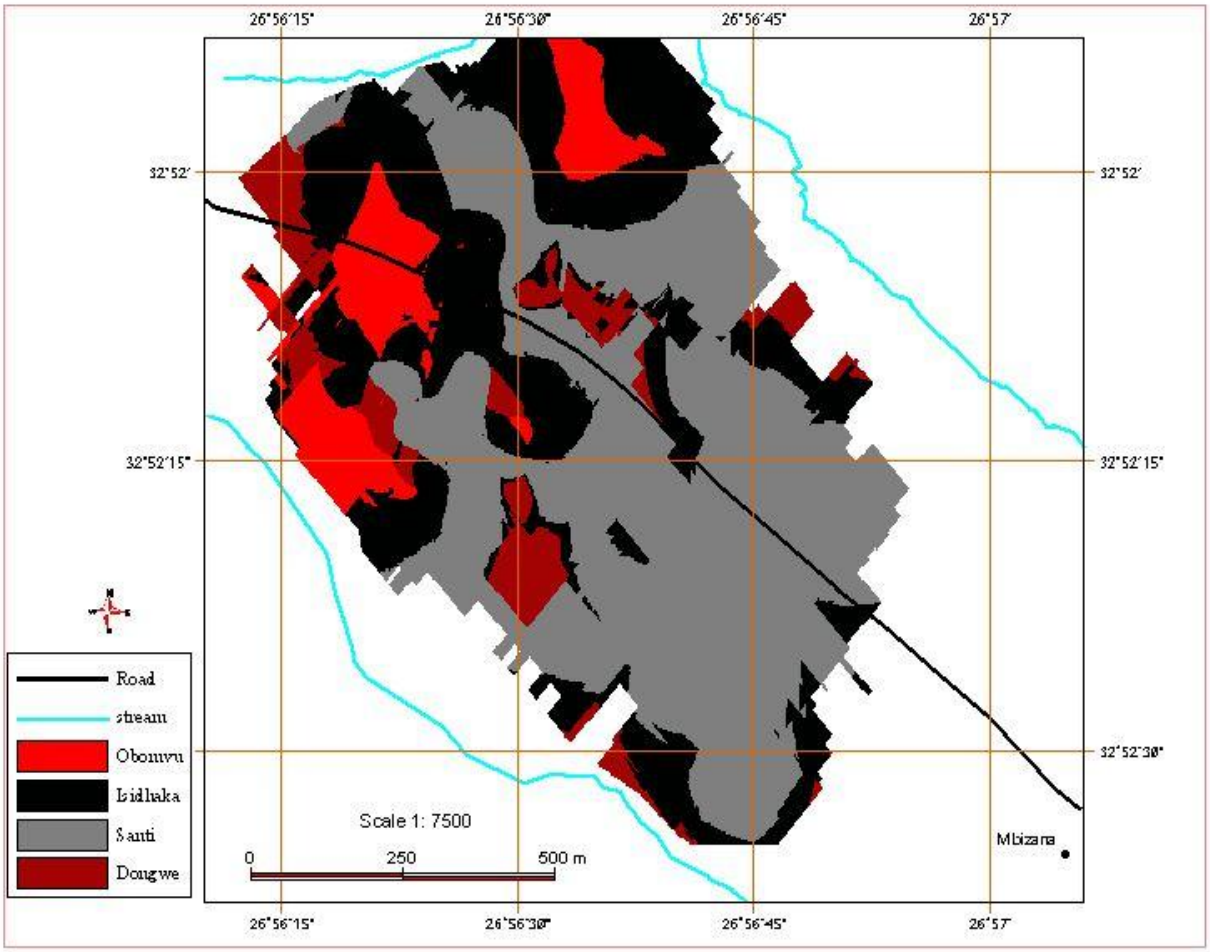

Fig. 4.6: Farmers' soil type map of Mbizana

About 83%, 11% and 6% of the soils were rated as having low, moderate and high maize potential, respectively (Fig.4.7). About 24% of the soils, mainly the *dongwe* and some *santi* were medium textured, while 76% from mainly *the isidhaka, obomvu* and some *santi* soils were fine textured (Appendix 4.2a). The brown (57%) to dark brown (8%) soils, *dongwe* soils were dominant (Appendix 4.2b). However, the majority of the *dongwe* soils were shallow to very shallow, with few areas being moderately shallow to deep (Appendix 4.2c). The *santi* soils (bleached A-horizons) constituted about 30% and were very shallow to shallow, dominated by fine textures (hard dry consistency), with few portions of medium textured soils. The medium textured, moderately shallow to deep soils were responsible for moderate to high potential, while the majority of the fine textured and shallow soils were rated as low (Fig. 4.7). A sharp break in slope occurred between the upper slope which was occupied by 54% of the soils and lower slope

occupying 40% of the soils with the remainder covering the mid slope position (Appendix 4.2d). There was an inconsistent trend between slope position, soil colour and depth.

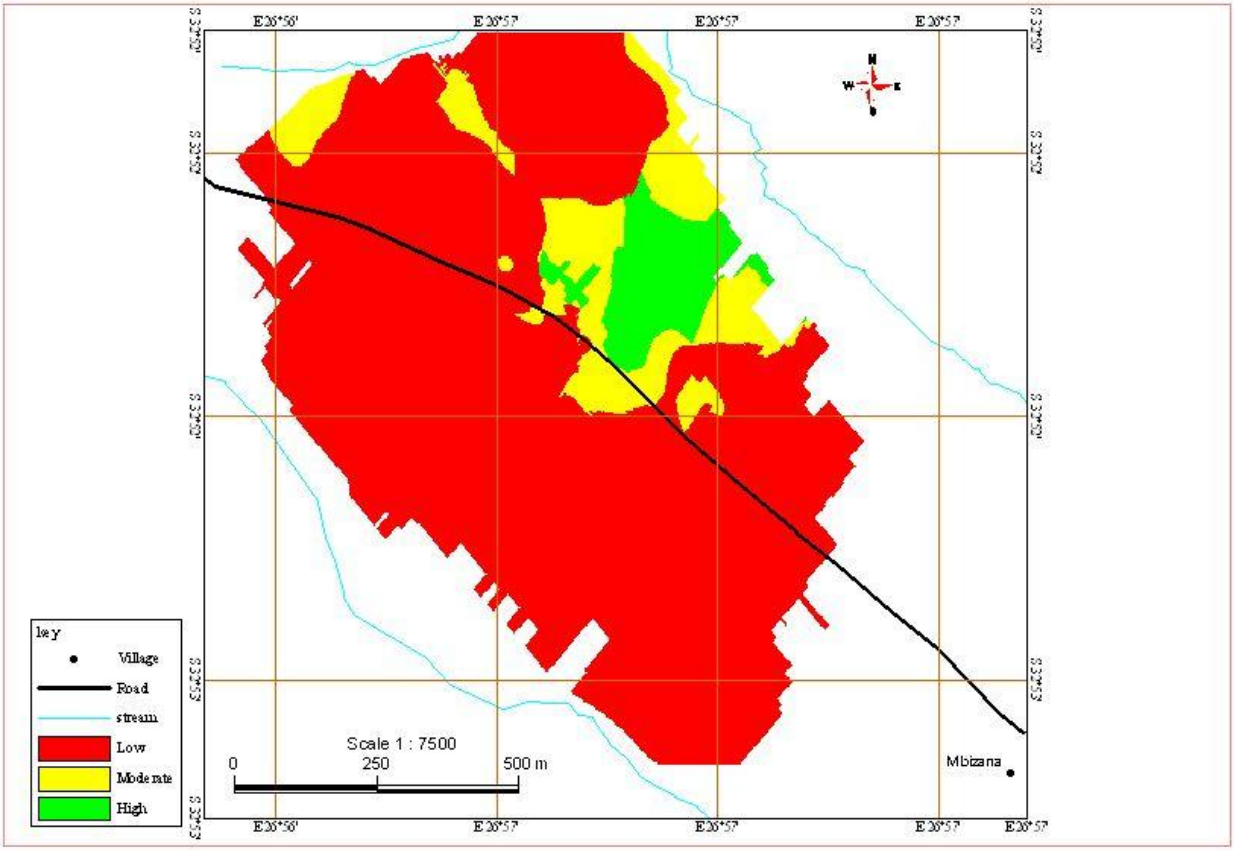

Fig. 4.7: Participatory soil potential map of maize at Mbizana

Blinkwater (Kat River Catchment)

The highest proportions of the soils at Blinkwater were the *dongwe* and the *santi.* The *umhlaba omnyama* and *obomvu* were present in minor proportions (Fig. 4.8).

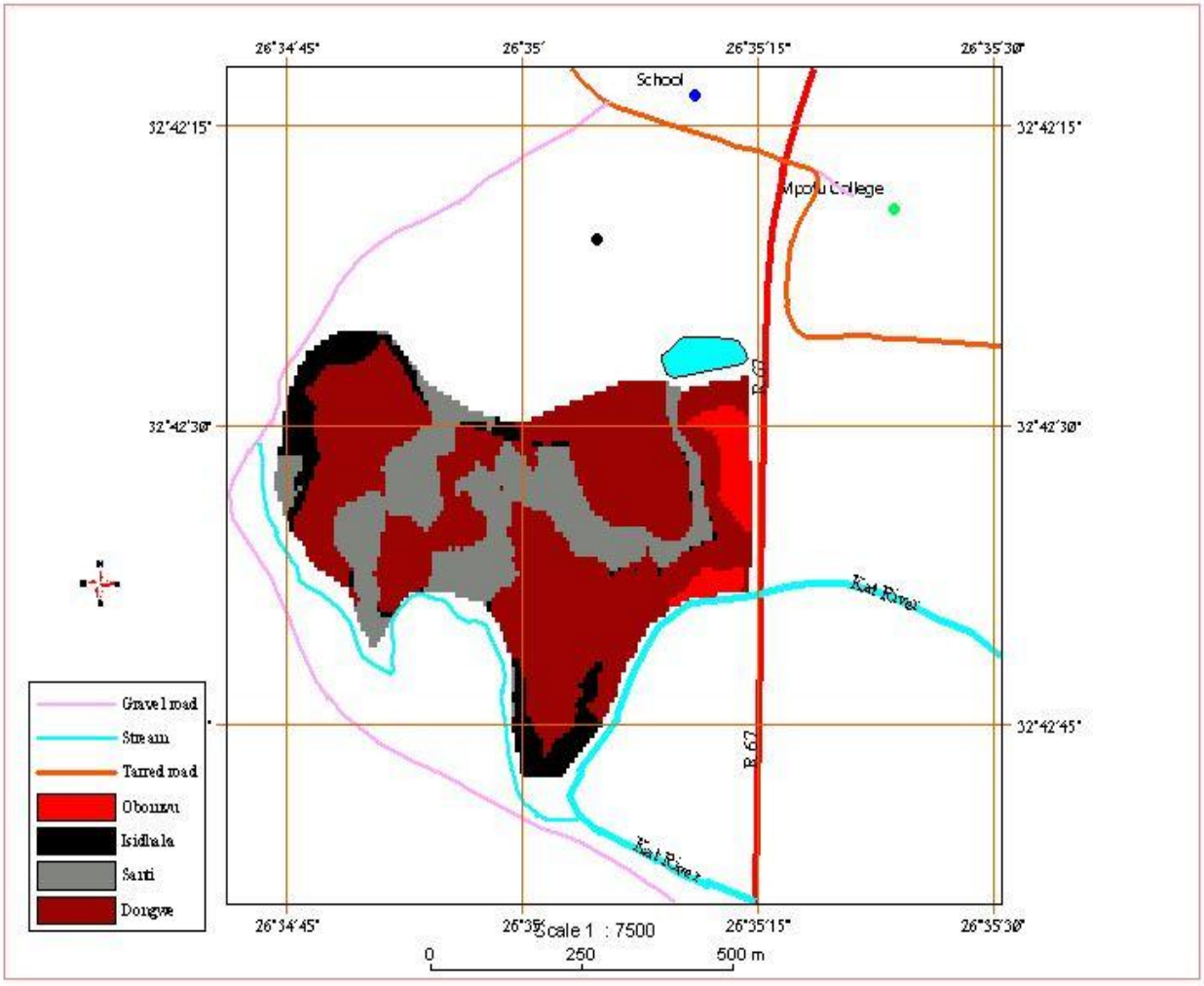

Fig. 4.8: Farmers' soil type map of Blinkwater

Of the three villages, Blinkwater had the highest potential, where 11%, 67% and 22% were rated as having moderately high, high and very high potential for maize production, respectively (Fig. 4.9). Blinkwater was dominated by medium textured soils (75%), with the remainder being fine textured soils (25%) (Appendix 4.3a). *Dongwe* (brown) and *santi* ('whitish') soils represented 44% and 37% of the area, respectively. Black soils (*umhlaba omnyama*) and red soils *(umhlaba obomvu*) represented 15% and 4%, respectively (Appendix 4.3b). All the soils were deep (28%) to very deep (72%) (Appendix 4.3c), with 78% in the lower slope position on the alluvial plain, and the remaining 22% occurring in midslope positions (Appendix 4.3d). Fine textured soils occurred in lower slope positions on the edges of the land near river banks and were mainly brown and black. The *santi* soils were dominated by medium textured soils. The red soils were

found in upper slope positions away from the river. While all the other soils were very deep, the red soils were deep.

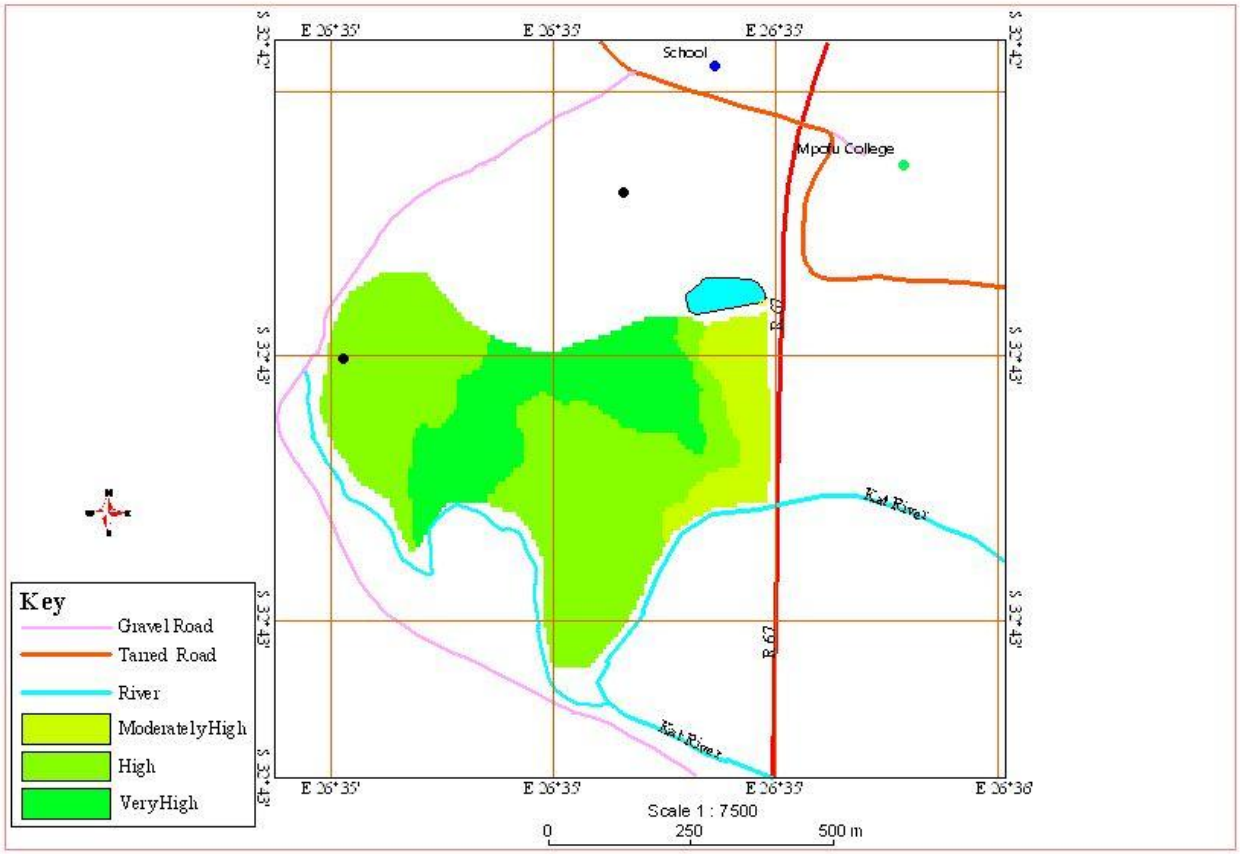

Fig. 4.9: Participatory potential soil map for maize at Blinkwater

Accuracy assessments

The accuracy of the participatory soil potential maps, in comparison with scientific approaches, was very low at Upper Ncera (20%), high at Mbizana (73%) andat Blinkwater (100%).

4.4 Discussion

4.4.1 Local indigenous soil classification, soil mapping and cropping potential

Generally, soil texture was the main determinant of indigenous soil classification and soil potential in the Municipality. The reason for this was the prevalence of fine textured soils which farmers claimed were difficult to cultivate and often droughty. Visual colour determination was the simplest way in which farmers classified their soils and estimated inherent fertility, especially

in the black soils. Soil depth was a relevant determinant of soil classification and soil potential on the *urhete* soil soils and the deep *santi* soils in the Tyume Catchment because the most productive farming takes place in deep alluvial soil of the Tyume River. Deep soils increase the storage volume of water, which is critical for crop growth, particularly in dry environments (Van Averbeke, 1991). Slope position was considered a soil classification and soil potential determinant probably due to a high fertility status and deep soils in the lower slope positions where most cultivation takes place.

While it is difficult to relate indigenous classification with international scientific classification, the importance of colour, texture and soil depth for both classification and soil potential, suggests that some form of correlation is possible. These findings are similar to those in rural Telengana, India, where farmers consider soil colour and texture as the most important determinants of soil potential, with soil depth and slope a distant third and fourth, respectively (Desbiez *et al*., 2003; Sicat *et al*., 2005), while the Mossi in Burkina Faso use colour, stoniness and texture (Dialla, 1992).

Whereas the correlations between indigenous classification and scientific approaches may not be accurate, because the indigenous system is not based on sequences of diagnostic horizons, communication and other extension information can be conveyed. The shallow and stony soil (*urhete)* correlated well with the Leptosols in WRB (FAO, 2006) or Mispah and shallow Glenrosa soils in the South African system (Soil Classification Working Group, 1991). The red structured clays (*umhlaba obomvu*) match the Nitisols in WRB (FAO, 2006) or Shortlands in the South African system (Soil Classification Working Group, 1991). Farmers described *umhlaba obomvu* as prone to drought and hard to cultivate under dryland conditions in semi-arid environments because the low rainfall that is received is held strongly by clay colloids making it difficult to extract and unavailable for plant uptake (Burger, 1983). Participatory mapping at Upper Ncera (section 4.3.2) on mainly *umhalaba obomvvu* revealed that the fine textured soils contributed to low rating for maize production because of the droughty nature and workability challenges while the importance of soil depth was underlined by higher ratings of *umhlaba obomvu* on deep to very deep soils.

The low maize potential of the red soils were guided by their perceived droughty nature and difficulty in cultivation, which could be directly linked to low rainfall and shortages of farm

machinery or draught power, respectively. However, Van Averbeke (1991) obtained exceptionally high maize yields (even at high plant density) at very modest water levels in this area. This may suggest that the major problem is the lack of farming machinery, which could result in late planting and the shortening of the rainy period. Provision of farm machinery could make it easier for farmers to till the soil.

Laker (1980) pointed out that farmers may prefer to cultivate low potential soils instead of the high potential ones because those areas with high potential may only be suitable with irrigation and mechanisation. It would, therefore, be interesting to find out if farmers' low rating of the maize potential of the red Ncera soils would change if irrigation and draught power were provided. Previous studies have revealed that the red soils at Upper Ncera have a higher moisture storage capacity than any other soil in the Tyume Catchment (Van Averbeke, 1991) and, therefore, would be suitable for irrigated agriculture for crops that are adapted to these soils.

The findings at Ncera were in sharp contrast to previous scientific studies done in this area (Hill *et al*., 1977; Burger, 1983; D'Hyuvetter, 1985; Van Averbke, 1991; Land Type Survey Staff, 2001), which gave these red soils a high potential rating. The red soils of this area represent soils of the Hutton form and the well-structured soils of the Shortlands form. The Shortlands soils of the area have been intensively researched and found to be extremely stable against soil erosion – an outstanding characteristic, especially when compared with other soils in Nkonkobe that are highly erodible (D'Huyvetter, 1985; Stern, 1990; Rapp, 1998). The Shortlands (Nitisols) are reckoned to be some of the best soils for smallholder farming elsewhere in Africa where water is not limiting. The contradictions between farmers' soil potential rating and scientific studies at Ncera emphasize the greater need for farmers and scientists to work together to harmonise understanding of these soils and their soil potential. It is also important to realize that some soils with high potential under sophisticated management may be unfavourable for crop production under simple technologies (Laker, 1980) and this seems to be the case here.

The *urhete* soils are also highly erodible and where they have been cultivated erroneously due to incorrect betterment planning, disastrous erosion has occurred (Laker, 1978; D'Huyvetter, 1985). The low overall maize potential of the soils at Mbizana was mainly influenced by the shallow depths. This was consistent with scientific studies, where the agricultural potential of the soils was ranked low because of their shallow depths and high erodibilities (Hill *et al*., 1977; Van

Averbeke and Marais, 1991; Land Type Survey Staff, 2001). The soils in the Middledrift area (except narrow strips along the Keiskamma River) are known to be very shallow (mainly Glenrosa form) and highly erodible (D'Huyvetter, 1985). The overall low potential rating of these soils, thus, makes sense and could be the reason why large areas in the Middledrift area have been abandoned. High correlations between soil productity (section 4.1) and the determinants of soil productivity confirm that soil erosion was the main problem. The *urhete* (stony shallow soils) are unsuitable for crop production and are mainly used for extensive grazing as these soils have inadequate volume for storing water to support crop growth.

The *isidhaka* soils are black vertic (swelling clay) soils, qualifying as Vertisols in the WRB classification or Arcadia in the South African classification system. These soils were lowly ranked in terms of agricultural potential mainly because they are difficult to work on when wet, as well as when dry, with swelling and shrinking properties, which make them very difficult to cultivate. The high clay content makes them extremely hard when dry and sticky when wet (Brady and Weil, 2008). The main limitation of those soils for crop production could be the associated flood hazard and poor drainage close to the Kat River and the heavy textures which render them droughty as observed at Blinkwater. The *isidhaka* were rated higher than the *umhlaba obomvu* because of their better fertility status. Farmers in the Amatola basin in the Tyume catchment also reckoned that they produced a better maize yield on *isidhaka* than on the *umhlaba obomvu* because of its better soil fertily status (Burger, 1983).

The *umhlaba omnyama* soils are non-swelling black clayey soils, qualifying as soils with melanic A horizons in the South African soil classification system and occur mainly in the Tyume catchment, associated with dolerite outcrops. Shallow soils, mainly of the Mayo form (Soil Classification Working Group, 1991), are found on the upper slopes. Deeper examples of these soils, belonging to the Bonheim form, occur on lower slopes at Blinkwater in the Municipality. The melanic A horizons of the South African soil classification system resemble the mollic horizons of international classification systems, such as the WRB, but tend to be thinner and with lower organic matter contents. The high fertility status of the soil caused by the dominance of the alluvial soils, in *umhlaba omnyama* and *isidhaka* discussed above, could have led to the high correlations between soil productivity and soil fertility in section 4.1.

The black soils (*umhlaba omnyama*) were given the highest maize potential rating possibly because they are inherently very fertile especially for small-scale farmers who cannot afford to purchase fertilizers. They can be erodible where soils are shallow, but are much more stable than the other shallow soils in the Nkonkobe district municipality. They are also non-crusting and easier to manage than the swelling and shrinking *isidhaka.*

The *dongwe* and *santi* soils are medium-textured soils that have developed in alluvial sediments on river terraces. The non-calcareous members could be classified as Oakleaf soils in the South African classification system, whereas the calcareous members of the *santi* soils could qualify as soils of the Augrabies form (Soil Classification Working Group, 1991). Both the *dongwe* and *santi* soils could be classified as Cambisols in the WRB system (FAO, 2006).

The *dongwe* soils were described by the farmers as having relatively high clay content but not so high as to cause workability problems. In other words, their clay contents are towards the higher range of medium-textured soils. These soils were rated highly at Mbizana and Blinkwater because of their high fertility status and better workability.

The *santi* soils were ranked below the *dongwe* probably because of their hard setting nature and vulnerability to soil crusting, soil compaction, high erosion risk – and consequently lower yields. This is expected from a scientific view, as the *santi* soils have high fine sand and silt contents and prone to crusting (Laker, 2004b; Nyamapfene, 1991). The *santi* soil was described as the most vulnerable to erosion with the highest probability for the development of gullies. The duplex and pseudo-duplex soils, i.e. especially Estcourt soils, are the most vulnerable to erosion. The farmers' knowledge was spot-on regarding erosion risk assessments when compared with scientific approaches in this regard. The dominance of the highly eroded *santi* soils in Kat, Tyume and Middledrift could be responsible for the strong correlation between soil erosion and soil productivity observed in section 4.2.1.

At Mbizana, a significant portion of santi soils were described as heavy textured. This contradicted an earlier assertion from the broad survey that white (*santi*) soils were medium-textured, with high fine sand contents. The very hard consistency of the *santi* soils, especially when dry, is caused by their possible hard-setting property (Laker, 2001). From farmers' descriptions, dry consistency was explained as 'the tendency of the soil not to become wet'.

Correlations between soil productivity and farmers' determinants of soil productivity (section 4.1) also revealed that in the Middledrift (where Mbizana village falls), dry consistency had a major influence in soil productivity.

The *santi* soils at Blinkwater were described by farmers as medium textured in contrast to the description given by farmers at Mbizana, who described them as heavy textured. The differences were caused by the mode of formation of these soils. One group of soils at Blinkwater was formed from unconsolidated material. Thus, the soils were mainly of the Oakleaf and Dundee soil forms (Luvisols and Fluvisols), and such soils have a high potential with high rainfall efficiency, on flat terrain and high moisture storage capacity (Land Type Survey Staff, 2001; FAO, 2006). The other group of *santi* from Mbizana was formed from consolidated parent material, hard setting, shallow, and prone to erosion. The shallow depths contributed to the low maize potential of the soils.

It is not clear how farmers would rate the soils for the production of other crops. Crops such as sorghum, which are well adapted to clay soils and droughty conditions could have a high potential rating at Ncera and other high clay content soils which were perceived as droughty by the farmers. It is therefore important that soil potential ratings and participatory mapping be done for other important crops in the Municipality.

In the 3 catchments, it is clear from correlation results that farmers viewed soil erosion as a major threat to soil productivity. However, worryingly, the same farmers did not show an understanding of the importance of soil conservation, probably suggesting that conservation was not a priority, even though the farmers were aware of the dangers of erosion. Warren *et al*. (2003) reported similar findings on indigenous views on soil erosion in Niger. Their investigation revealed that farmers did not view soil conservation as a priority but instead perceived soil fertility, labour constraints and unpredictable rainfall as more important. Farmers' understanding of soil erosion could form the basis for introducing erosion control measures, such as the use of stone bunds, planting of trees in eroded areas, maintaining vegetative cover and use cover crops as is done in other former homelands of South Africa (Maswana, 2001; Odhiambo and Nemadodzi, 2007).

4.5 Conclusions

The indigenous soil classification system in Nkonkobe considers soil texture, colour and surface stoniness as main characteristics for classification and cropping potential evaluation. *Isidaka* (vertisols) were considered difficult to work, *umhlaba omnyama* (black melanic soils) as highly fertile, *santi* (medium-textured soils with high fine sand content) as highly erodible, and *umhlaba obomvu* (red soils) as stable to erosion; all consistent with scientific theories.

Accurate correlations between indigenous classification with international scientific classification and soil potential were possible. The low potential shallow and stony soil (*urhete)* correlated well with the Leptosols in World Reference Base (WRB) or Mispah and shallow Glenrosa soils in the South African system. The high potential *dongwe* and *santi* soils developed in alluvial sediments also correlated well with the Dundee, Oakleaf or Augrabies soils in the South African classification system and fluvisols or Cambisols in the WRB system. The non-swelling black clayey soils *(umhlaba omnyama)* were given the highest rating by farmers because of the melanic A horizons. While scientifically this is true for deeper varients, the shallow variant, the Mayo has low potential rating. The major contradiction with scientific theories occurred where high potential red soils were rated as low by the farmers under dryland farming.

Indigenous knowledge could be used for mapping of local soil to the benefit of the farmers. Understanding of indigenous classification especially reasons for underutilization of the red soils and other heavy textured soils could help increase the area under cultivation. The findings on soil erosoin could help in further delineation of high potential land based on soil susceptibility to erosion to ensure sustainable arable crop production. There is need to determine how soil factors including those mentioned by farmers contribute to either soil susceptibility or stability to erosion with a view to long-term cultivation. Scientists should incorporate farmers' indigenous knowledge of their soils when determining and recommending management interventions for their arable lands.

CHAPTER 5

EXAMINATION OF SOIL AND SLOPE FACTORS AS EROSION CONTROLLING VARIABLES UNDER VARYING CLIMATIC CONDITIONS

5.1 Introduction

In South Africa, about 400 million m^3 of soil is lost annually to soil erosion (FAO, 2004) and it is estimated to be more than 20 times the average for the world (Laker, 1990). This problem is more severe in the former 'homelands' (Kakembo and Rowntree, 2002), particularly in the Nkonkobe Municipality, and other parts, of Eastern Cape Province (Maswana, 2001). Extremely serious soil erosion damage is evident in the former homelands of South Africa, including the area now known as Nkonkobe, due to incorrect demarcation of arable land as a result of incorrect assessment of the erodibilities of soils (Laker, 1990, 2004b).

Soil erosion threatens economic and physical survival, and could lead to household and national food insecurity. Crop yields could be reduced by 50 percent within 40 years if soil erosion continued at present rates (FAO, 2004). Controlling soil erosion is, therefore, necessary to ensure the sustainable use of the lands (Mulibana, 2000). This creates a need to predict and combat land degradation.

South Africa has embarked on a land reform programme aimed at equitable redistribution of land among the country's different population groups. Crop based development projects are being envisaged in different regions of the country, including the Nkonkobe Municipality. Sustainable use of local soil resources requires correct identification and delineation of arable land, paying particular attention to the land's vulnerability to erosion.

Soil erosion is a function of many variables, chief among them being rainfall intensity, parent material, soil characteristics, topography, vegetation, landuse and management. The effects of these important soil erosion controlling variables are well documented (Weaver, 1988; Mulibana, 2000; Laker, 2004b). However, most of these studies do not give detailed relationships between soil erosion and important soil variables such as particle size distribution, clay mineralogy, composition of sesquioxides and cations and their imbalances. Kakembo (2000) highlighted the need to examine a range of soil erosion controlling variables giving due attention to soil characteristics.

In Chapter 4 of this study, it was reported that farmers identified soil erosion as one of the main factors affecting crop production and participatory mapping showed that certain types of soils were highly erodible, which led to land abandonment. According to farmers, texture, especially the 'sandy soils' and shallow depth were the main factors leading to high erosion. The effect of such factors on the degree of erosion under varying climatic conditions in the Municipality is not known.

Pioneer work by D'Huyvetter (1985) established maximum permissible slope limits at which different soil forms in parts of the area now known as the Nkonkobe Municipality can be cultivated without causing severe erosion. He deduced the relationships between soil erosion and (i) texture (clay and silt content), (ii) contents and ratios of the three key exchangeable cations (magnesium, sodium and calcium), (iii) soil depth – in the case of shallow soils, (iv) parent material and (v) the slope parameters, gradient and length. However, D'Huyvetter's study assumed a homogenous climate and as such different results could be obtained if information on the variability of climate in the Municipality is used.

There have been contrasting views on how soil variables could affect erosion as climate changes from drier regions to more humid areas of the Municipality (Weaver, 1988; Smith, 1990; Laker, 1990; 2004b). Weaver (1988) found that the degree of erosion decreased as the amount of rainfall increased in a transect from Middledrift to the Amatola mountains in the Nkonkobe district, and concluded that this did not make sense. However, this could have been purely the effect of increased rainfall resulting in higher degrees of pedogenesis and more stable soils, thus, overriding the effect of rainfall erosivity (Laker, 1990; 2004b). Smith (1990) established that highly weathered soils of humid regions are more stable than the less weathered soils of drier regions. This study is aimed at providing empirical evidence to support or dismiss these views.

Neither the study of D'Huyvetter (1985) nor that of Weaver (1988) included the effects of clay mineralogy and iron oxides, which have been reported to be dominant factors controlling erosion in many soils of South Africa, including the Eastern Cape (Stern *et al*., 1991; Buhmann *et al*., 2006). A striking observation in many South African soils is the presence of large quantities of quartz in the clay fraction, which is usually absent in other soils around the world (Buhmann *et al*., 1996; Buhmann *et al*., 2006). It is important to examine the impact of these important soil

properties on erosion intensity in the different climatic conditions prevailing in the Nkonkobe Municipality. This would help in the determination of areas that are either stable or susceptible to erosion; thus, enabling land suitability evaluations for long term sustainability of crop production in the area to be done.

The objective of the study was to determine soil and slope variables controlling soil erosion in different climatic units in the Nkonkobe Municipality for the delineation of land with good potential for cropping.

5.2 Materials and methods

This study was carried out in four aridity zones of the Nkonkobe Municipality which were categorised according to World Meteorological Organisation statutes (WMO, 2001). The study boundaries covered latitudes $32^{o}21'$ and $33^{o}07'$ South and $26^{o}\ 24'$ and $27^{o}\ 13'$ East (Fig. 5.1). The North of the Municipality is dominated by the humid Amatola and Katberg Mountain regions where mean annual precipitation is between 1000 and 1400 mm. The Kat River catchment described in Chapter 3 consists of two main units, namely, the sub-humid upper catchment (700 – 900 mm) found below the Katberg Mountains and the semi-arid Fort Beaufort. Small areas of arid microclimate are also found in the Upper Catchment of the Kat River. Mean precipitation in the semi-arid Seymour is around 560 mm, while that at Fort Beaufort is around 500 mm.

The transect of Tyume River catchment stretches between the escarpment of the Amatola Mountains in the sub-humid areas below the Hogsback Mountains through the semi-arid region at Lovedale and Pleasant View near Alice which receives 580 mm and 611 mm annual precipitation, respectively. The arid zone more dominant further South along the Keiskamma River around Middledrift is made up of a combination of river valleys that are dry with mean annual precipitation at Middledrift about 500 mm, dropping to 390 mm.

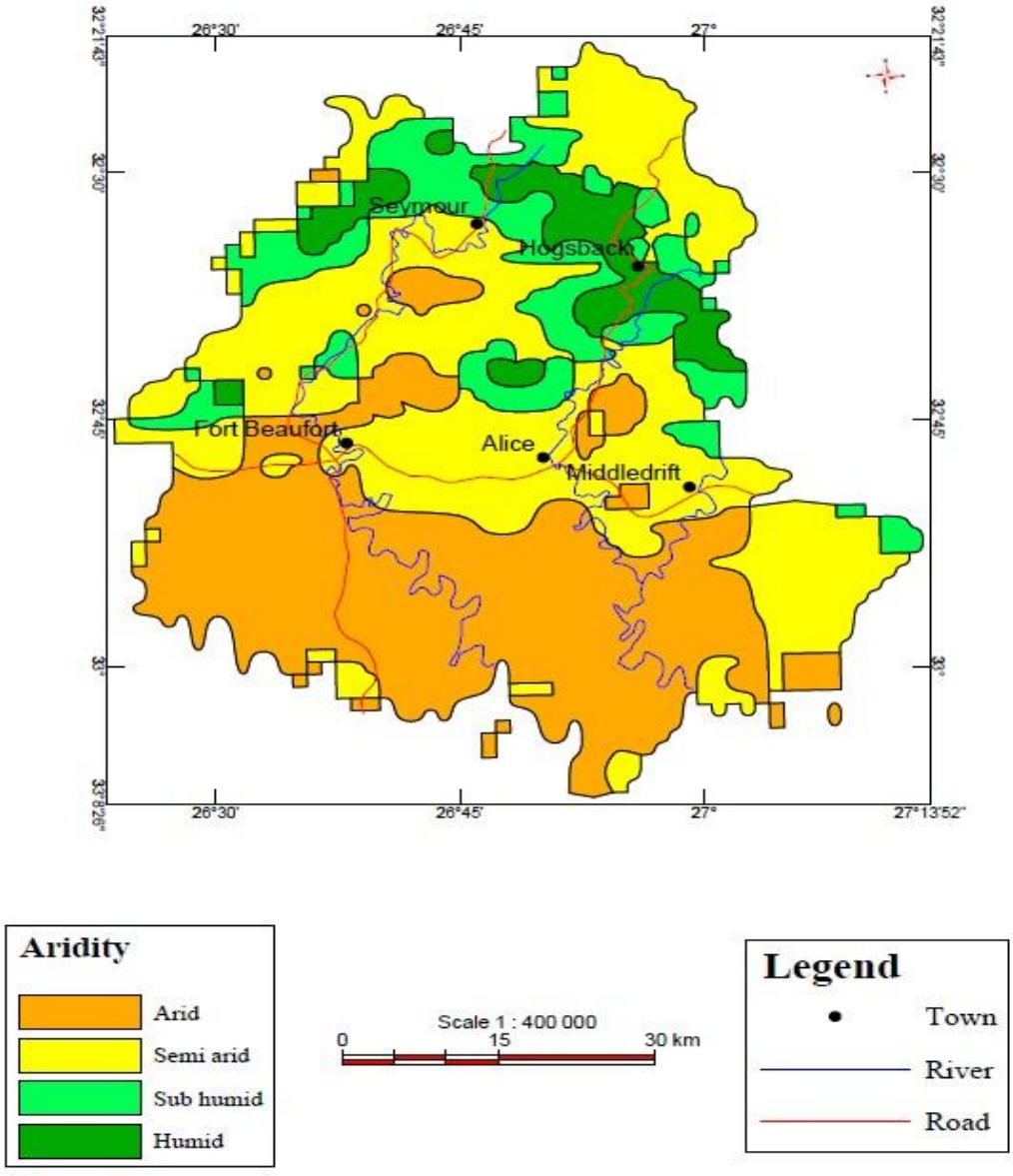

Fig 5.1: Aridity zones of Nkonkobe Municipality

5.2.1 Extent of soil erosion

Field observations, aerial photographs, captured in July 2009, and existing soil erosion maps (Hill *et al*., 1977) were used to determine the degree of soil erosion, using features such as sheet, rill and gully erosion. Erosion degree was coded using the simplified erosion degree scale of

D'Huyvetter (1985) (Table 5.1). D'Huyvetter pointed out that with the traditional 12 class scale it is virtually impossible to get enough data sets per class to enable statistical analysis to be done.

Table 5.1: Simplified erosion degree scale (D'Huyvetter, 1985)

Erosion degree	Erosion Type	Description
0: no erosion	-	No subsurface horizons or layer exposed
1: Slight erosion	Slight Sheet	Upper subsurface horizons or layers have been exposed on less than 30% of the area
2: Moderateerosion	Severe sheet to slight rill	Upper subsurface horizons or layers have been exposed on over 30% of the area
3: Severe erosion	Rill	Lower (deep lying) subsurface horizons or layers have been exposed at the surface
4: Very severe erosion	Gully	Deep removal of soil has occurred over a very large part of the area and gullies are abundant

5.2.2 Soil maps and sampling

Existing soil maps of the area were obtained from the Institute for Soil, Climate and Water of the Agricultural Research Council (ARC-ISCW) of South Africa (Table 5.2). The soil maps were at various scales ranging from reconnaissance (1:250 000), semi-detailed (1: 50 000) to very detailed special survey maps.

The maps were georeferenced and digitized and the soil classifications in them used for preliminary taxonomic soil identification according to the South African soil classification systems (MacVicar *et al*., 1977; Soil Classification Working Group, 1991). The original classifications were done according to the South African binomial classification system (MacVicar *et al*., 1977). The preliminary classification was followed by field verification using the recommended sampling intensity of one auger for every 200 m for semi-detailed surveys (FAO, 2006). The land type map for the area (3226 King William's Town) and its accompanying memoir tables were used in areas not covered by the other, more detailed, maps listed in Table 5.2. The memoir tables give the percentages of different soils on the different terrain morphological units in each land type (Land Type Type Surveys, 2001). Site and soil profile descriptions were done for representative soil profiles for each soil form encountered. Soil samples were collected from each horizon of each soil profile for laboratory analyses. Sub-soils

were used in soil classification and calculations of leaching and luvic status of the soils. Soil classification was done according to the South African taxonomic classification system (Soil Classification Working Group, 1991) and the World Refernce Base system (FAO, 2006). Geographic co-ordinates of the sampling points were captured using Global Positioning System (GPS).

Table 5.2: Collated soil survey maps for Nkonkobe Municipality

Name of soil survey	Scale of survey	Reference
Keiskamma River Basin	1: 50 000	Hill *et al*. (1977)
Kat- Fish River Basin	1: 250 000	Loxton *et al*. (1979)
Soils of the Amatola Basin	1; 5 000	ARDRI (1981)
Kat River Basin (Fort Beaufort to Kat river Dam)	1: 5 000	Hartmann *et al*. (1979)
Fort Cox Agricultural College maps	1: 5000	University of Fort Hare (1979)
Middledrift farm D survey	1: 5 000	Department of Agriculture, Zwelitsha (undated)
Debe Nek, Pawuleni Mission	1: 5 000	Department of Agriculture, Zwelitsha (1975)
Victoria East Upper Tyume (Binfield Park Dam)	1:5 000	Department of Agriculture, Zwelitsha (1975)
Land type map and memoirs 3226 King William's Town	1: 250 000	Land type survey staff (2001).

5.2.3 Soil laboratory analyses

The soil samples were air-dried and sieved (< 2mm) before laboratory analyses.

Soil chemical analyses

Soil pH and electrical conductivity (EC) were determined in 1: 2.5 soil/ water (w/v) ratio using a pH meter (pH meter 330 SET-1, 82362) and EC meter (Cond.330i/ SET 82362), respectively. Exchangeable bases (Ca, Mg, K, and Na) were extracted in 1.0 *M* ammonium acetate (pH 7) and determined using the Atomic Absorption Spectrophotometer (AAS) (The Non-Affiliated Soil Analysis Work Committee, 1990). Free iron oxides were analysed using the citrate- bicarbonate-dithionite (CBD) extraction method (Jackson *et al*, 1986). Total carbon determinations were done by dry combustion using the LECO- Truspec Autoanalyser (LECO, 2013).

Determination of particle size distribution

Particle size distribution was determined after dissolution of calcium carbonate ($CaCO_3$) with 2*M* hydrochloric acid (HCl) and decomposition of organic matter with 30% hydrogen peroxide (H_2O_2), followed by dispersion with calgon, before the separation of the sand fraction by sieving and the determination of the coarse silt (0.05-0.02 mm effective diameter), fine silt (0.02-0.002 mm) and clay (<0.002 mm) fractions by the pipette method (Day, 1965). The sand fractions were then separated by sieving, using the sand grade classes in the South African taxonomic soil classification system, viz. coarse sand (2-0.5 mm effective diameter), medium sand (0.5-0.25 mm), fine sand (0.25-0.1 mm), and very fine sand (0.1-0.05 mm).

Clay mineralogical analyses

Mineralogical analyses were done on both the topsoils and B-horizons for the dominant soil forms found in the Municipality (see Table 5.3). Clay sized fractions (< 2µm) were separated from whole soils by dispersion with calgon and an ultrasound machine, allowing the sand and silt fractions to settle for approximately 7 hr, calculated using Stoke's Law (Day, 1965). The separated clay fractions were divided into two parts. The first portion was flocculated in potassium chloride (1*M* KCl) while the second portion was treated with magnesium chloride (1*M* $MgCl_2$) and left to equilibrate overnight. The flocculated clay was washed to remove excess salt. The salt saturated samples were smeared on ceramic plates with two plates for KCl-saturated clay and three with $MgCl_2$ saturated clay. One plate of the $MgCl_2$-saturated clay was solvated with glycerol vapour at 90^{o}C and another with ethylene glycol at 60^{o}C and while the third was

left to air-dry. One of the KCl-saturated samples was heat treated at 550^{o}C for 4 hours and the second allowed to air-dry (Harris and White, 2007).

X-ray diffraction (XRD) analysis was performed using a Phillips X-ray Diffractometer with graphite monochromated Co-Kα radiation. The samples were run from 3 to 45^{0} 2θ with a step size of 0.05 and a count time of 1 second. Clay mineralogical composition was determined using the position and intensity of the X-ray diffractogram peaks. The presence of vermiculite was shown by peaks at 1.43 and 0.71 nm in Mg-saturated and glycerol-solvated Mg-saturated clay, and the peaks disappeared in K-saturated air-dried and heated (K-550) treatments. Illite peaks occurred at 1.0, 0.5 and 0.33 nm in Mg-saturated diffractograms while kaolinite was detected at 0.71 and 3.56 nm in Mg-saturated treatment which then collapsed in the K550 treatment. A weak shifting peak at 1.43 nm in the Mg-saturated treatment, towards 1.8 nm in Mg saturated-glycerol solvated treatment, indicated the presence of some expandable clay minerals such as smectites (Harris and White, 2007; Raheb *et al*., 2012).

Relative proportions of the clay minerals were determined using peak area estimates on the diffractograms and classified as 1-5 (Wakindiki and Ben-Hur, 2002). The intensity values at positions in the middle between two neighbouring theoretica positions and calculated against the baseline peak position of the diffractogram to estimate the area under the peak curves.

Determination of slope factors

Terrain attributes (slope gradient, aspect, length and curvature) were determined from 30 X 30 m digital elevation models (DEMs) using inbuilt terrain analysis functions in SAGA GIS. The vector points of the observation point i.e. soil profile points were overlaid on the DEM to show the exact point of the soil profile. The slope gradient, aspect, position and curvature, from the position of the vector co-ordinate of the observation point were then determined from the overlaid DEM. The length of the slope was determined by graphically drawing a straight line from the point showing the highest altitude on the DEM, along a reference slope to the observation point. The values for slope aspect were given in a clockwise- direction, starting at zero as the true north. The negative and positive signs on slope curvature depict concavity and convexity, respectively. The straight slopes were depicted by the zero sign on the DEM.

5.2.4 Data analysis

The soil forms were first grouped according to their occurrence within the aridity zones of the Municipality described in sub-section 5.2. Soil forms occurring across aridity zones were grouped and analysed separately.

Numerical values of soil properties (particle size fractions, Ca, Mg, K, Na, ESP, CBD Fe) and slope factors were recorded in MS Excel, correlated and regressed against the erosion severity. Step-wise regressions were done on (i) soils occurring in each of the aridity zones, followed by the same analyses after splitting the data set according to (ii) parent material and, finally (iii) individual soil forms. The degree of erosion (severity) was the dependent variable (Y) while soil factors were the independent variables (X). The erosion severity value of 2 was considered as the critical limit beyond which the land must not be used for cropping (D'Huyvveter, 1985).

Relationships between soil erosion and soil chemical properties

The degree of erosion was also regressed against ESP, Ca: Mg ratio and CBD extractable iron. Total carbon data was only used as supporting information since most soils of Nkonkobe have carbon levels below < 0.5%. However, where the total carbon level was high enough, its role was discussed. It has to be noted that, since the soils had no carbonates in them (except for Augrabies), total carbon was assumed to be equivalent to organic carbon.

Relationships between soil erosion and soil textural fractions

Particle size fractions were categorized into very fine sand (X1), fine sand (X2), medium sand (X3), coarse sand (X4), coarse silt (X5), fine silt (X6), fine sand + very fine sand (X8); fine sand + very fine sand + coarse silt + fine silt (X9); Clay (X10).

Relationships between soil erosion and clay mineralogy

Dominant clay minerals across all soil forms were selected for detailed analysis. The percentage estimates of the clay minerals were grouped into 5 classes ranging from 0 (least percentage) to 5 (over 50% of the clay mineral) (Wakindiki and Ben-Hur, 2002). It is this dominance that was discussed in relation to degree of erosion, climate, parent material, soil forms and other soil factors. Because of the semi-quantitative nature of clay mineralogy data it was not possible to run regression analyses.

Relationships between soil erosion and topographical parameters

The relationships between the slope factors (slope gradient, slope length, aspect and curvature) and degree of erosion for all the samples collected and each individual soil form were analysed using stepwise regression. A Principal Component Analysis (PCA) was used to determine the relationships between soil and slope factors that were significantly related to the degree of erosion and to determine their relative dominance over each other as well as explain the sources of variation. The parameters with loading values > 0.8 were considered to have a significant impact (Nciizah and Wakindiki, 2012).

5.3 Results

5.3.1 Relationships between taxonomic soil classes and erosion degree

Arid and semi-arid zones

Severely eroded soil forms were found in the arid zone of the Municipality. The arid zone consisted of shallow soils of the Glenrosa and Swartland forms derived from mudstones and shales of the Adelaide subgroup of the Beaufort group. The Glenrosa form was represented by the Bisho family, having a bleached A horizon and hard non-calcareous lithocutanic B horizon with no signs of wetness. The Swartland form was represented by the Gemvale family, having a coarse angular blocky B horizon. The soil forms in semi-arid zone consisted of duplex or pseudoduplex soils of the Valsrivier, Klapmuts, Sterkspruit, and Estcourt forms with clayey subsoils and a coarse angular blocky or prismacutanic structure, also derived from Adelaide mudstones and shales. They were represented by the Homepark, Napier and Bethulie families, respectively (Table 5.3).

The Augrabies, Oakleaf and Katspruit soils were moderately eroded. The first two are closely related deep, medium textured soils derived from alluvial deposits on river terraces with low slope gradients. The Katspruit soils were found in low-lying wetlands. Also found in semi-arid zones were the Bonheim (Rockvale family) and Arcadia (Nuweplaas family) derived from dolerite parent material.

Sub-humid and Humid zones

The dystrophic Hutton soils were the most resistant to erosion (Table 5.3). The Hutton soils were derived from dolerite parent material and represented by a highly weathered (dystrophic)

member, viz. Lillieburn family, found in a high rainfall area (Soil Classification Working Group, 1991). The Clovelly soils were also highly resistant to erosion, despite being derived from shale and mustone parent material. The Tukulu soil form of Olivedale family derived from shale and mudstone was dominant in the sub-humid zone below the Hogback Mountains.

Table 5.3: Relationships between taxonomic soil classes and erosion degree

SOIL FORM(S)	**Soil family**	**EROSION**		**REMARKS**
		DEGREE*	**TYPE**	
Hutton (dystrophic)	Lillieburn	0	-	Dolerite derived, high rainfall area
Clovelly	Twyfelaar	1	Slight sheet	Derived from shale/ mudstone. Found in high rainfall areas
Shortlands	Bolweni	1	Slight sheet	Dolerite derived, subhumid areas
Bonheim	Rockvale	1	Slight sheet	Dolerite derived, subhumid areas
Hutton (eutrophic)	Stella Ventersdorp	1	Slight sheet	Dolerite derived, subhumid areas
Oakleaf	Ritchie	2	Sheet	Derived from alluvium and mudstone colluvium
Augrabies	Giyani	2	Sheet	Derived from alluvium, semi-arid areas
Arcadia	Lonehill	2	Sheet	Derived from colluvium, semi-arid areas
Tukulu	Olivedale	2	Sheet	Derived from alluvium, sub-humid
Katspruit	Lammeroor	2	Sheet	Derived from shale and mudstone, poor drainage
Swartland	Gemvale	3	Rill	Derived from shale and mudstone, highly erodible. Mainly found in arid and semi-arid areas. No crop production should be practised on these soils.
Valsrivier	Homepark	3	Rill	
Glenrosa	Bisho	3	Rill	
Klapmuts	Napier	3	Rill	
Sterkspruit	Bethulie	4	Gully	
Estcourt	Nuweplaas	4	Gully	

Soil forms occurring across aridity zones

Soil forms occurring across the arid, semi-arid and sub-humid zones include the moderately eroded Oakleaf derived from from alluviums. The highly resistant Shortlands (Bolweni family) derived from dolerite were found in semi-arid and sub-humid climate while the severely eroded Swartland soil form occurred in the arid and semi-arid zones.

5.3.2 Relationships between soil and slope factors and degree of erosion

Relationships between soil and slope factors and degree of erosion: soil forms occurring across the aridity zones

The Shortlands soil form was one of the least eroded. The degree of erosion was positively correlated with very fine sand (X1) and slope gradient in semi-arid zone and the respective critical limits were of 37.17% and 12.5%. In sub-humid climate the degree of erosion was significantly inversely related to CBD Fe (Table 5.4).

In the Oakleaf soil form occurring in sub-humid zones, degree of soil erosion was inversely correlated with CBD Fe but positively correlated with slope length in semi-arid zone. In arid zone the degree of erosion in Oakleaf soils was positively correlated with very fine sand (X1), and (ii) combinations of very fine sand, fine sand and silt fractions (X9)

In Swartland soils, occurring in semi-arid zone, there was a significant correlation between degree of soil erosion with (i) very fine sand (X1), and (ii) sum of very fine sand, fine sand and silt fractions (X9), and also (iii) a sum of very fine sand and fine sand (X6). Calculated critical upper limit values were 24.33% (X1), 70.60% (X9) and 3.66% (X2) and their mean values 34.55%, 75.85% and 10.23%, respectively. Very fine sand (X1) and the sum of silt, fine sand and very fine sand (X9) showed significant positive relationships with degree of erosion in Swartland occurring in arid zones.

Table 5.4: Relationships between particle size distribution and degree of erosion for individual soil forms

Soil form	Arid	Semi-arid	Sub-humid
Shortlands	-	Y=-3.46 +0.08X1+0.35S1	Y=10.51-1.01CBD Fe
Oakleaf	Y=0.16X1+0.02X9-2.289	Y=-0.01+1.06S2	Y=5.71-2.45CBD Fe
Swartland	Y=1.26+0.09X1+0.05X9	Y=-6.042+0.09X9+0.02X2-0.05X6	-

Relationships between soil and slope factors and degree of erosion in arid climate

The degree of soil erosion on soil derived from shale and mudstone showed significant relationships with very fine sand (X1) and sum of silt, fine sand and very fine sand (X9).

$$Y=1.262+0.090X1+0.048X9$$

Where X1= very fine sand *X9= fine sand + very fine sand + coarse silt + fine silt*

Critical upper limits were 33.32% for X1 and 73.41% for X9, while the mean values were 45.94% and 75.13%, respectively. The degree of erosion was positively correlated with the slope gradient in soils derived from shale and mudstone in arid zone.

$Y= 0.344+0.3S1$ Where S1 = slope gradient

The critical slope gradient limit, above which unacceptable degrees of erosion could occur, was 4.8%.

Relationships between soil and slope factors and degree of erosion in semi-arid climate

Shale and mudstone derived soils

On shale and mudstone parent materials in semi-arid zones, the degree of erosion was positively correlated with fine sand plus very fine sand (X8) and negatively correlated to fine sand (X2) ($P < 0.01$).

The regression equation for this relationship was: $Y= 0.550 + 0.035X8 - 0.014X2$.

In individual soil forms, stepwise regression showed that fine sand (X2) and a sum of coarse silt + finesilt + fine sand + very fine sand (X9) showed significant positive correlations with degree

of erosion in Sterkspruit soils. The critical upper limit for fine sand (X2) in Sterkspruit topsoils was 14.56% while the critical upper limit for silt + fine sand + very fine sand combined (X9) was 69.45%. Silt fractions combined with very fine and fine sand fractions (X9) had the most significant relationship with erosion severity in Klapmuts soils. Their critical upper limit for X9 was 40.53% (Table 5.5).

Table 5.5: Relationships between particle size distribution and degree of erosion soil form derived from shale and mudstone in semi-arid climate.

Soil form	Critical limit	Mean	Regression equation	R^2
Sterkspruit	X2=14.56; X9=69.45	X2=23.80; X9=81.82	Y=0.155X2+0.016X9-2.289	0.970
Klapmuts	40.53	64.41	Y= 0.825 + 0.029X9	0.750

X1= very fine sand; X2= fine sand; X3= medium sand; X4= coarse sand; X5= coarse silt; X6= fine silt; X7= clay; X8= fine sand + very fine sand; X9= fine sand + very fine sand + coarse silt + fine silt; Clay =X10

In the Estcourt and Katspruit soil forms, the degree of erosion was positively related to ESP ($P < 0.01$). The critical ESP limit required to severely erode the Estcourt soil form was 10.14. The average ESP was 11.01 (Table 5.6).

Table 5.6: Relationships between soil chemical factors and degree of erosion for individual soil forms in semi-arid zone

Soil form	Critical limit	Mean	Regression
Katspruit	4.68	3.79	Y=-1+ 0.833*ESP
Estcourt	10.14	11.01	Y= -0.124+0.653*ESP

Slope gradient and length gradient were positively related to degree of erosion but weakly correlated with slope aspect ($p < 0.05$).

The equation for slope factors was:

$$Y= 1.531 + 0.11S1 + 0.327S2 - 0.004S3$$

Where Y= Degree of erosion; S1= slope gradient; S2= slope length; S3 = slope aspect.

Slope length was significantly related to degree of erosion in Estcourt soil form. The critical slope length limit was 0.1 km (Table 5.7).

Table 5.7: Relationships between degree of soil erosion and slope factors for Escourt soil form in semi-arid climate zone

Soil form	Threshold limit	Median	Regression equation	R^2
Slopelength				
Estcourt	0.10 km	0.9 km	Y= 1.7+3.00S2	0.900

Dolerite derived soils

Degree of erosion in soils derived from dolerite was negatively related to extractable CBD Fe. The regression equation for this relationship was: Y= 2.419-0.075*CBD Fe.

However, in individual soil forms in semi-arid climate, the Bonheim soil form showed positive relationships between erosion severity and clay (X10) and the sum of very fine sand and fine sand (X8).

$$Y=30.85+0.590X8+0.331X10$$

The critical upper limit and mean clay values were 45.93% and 47.25 %, respectively while the respective values for sum of very fine sand + fine sand were 29.95% and 27.50%.

Slope length was the main determinant slope factor affecting soil erosion on dolerite derived soils in semi-arid climate.

$$Y= 0.688+ 0.962\ S2$$

In individual soils, slope length was significantly related to degree of erosion in Bonheim and Arcadia soil forms. The respective critical slope length limits were 1.90 km and 1.07 km (Table 5.8).

Table 5.8: Relationships between degree of soil erosion and slope factors for Bonheim and Arcadia soil forms in semi-arid climate zone

Soil form	Threshold limit	Median	Regression equation	R^2
Bonheim	1.90 km	1.30 km	Y=0.721+0.664S2	0.515
Arcadia	1.07 km	0.70 km	Y= 0.654+1.26S2	0.995

When the significant factors (i.e.CBD Fe and slope length) influencing soil erosion on dolerite derived soils in semi-arid zones were regressed against degree of soil erosion, CBD Fe showed a stronger relationship than slope length. The regression equation was: Y = 1.043-0.23CBD Fe + 0.095S2.

[9]Principal Components Analysis

The PCA results for the main soil and slope factors (X1, X2, X8, X9, X1, X10, ESP, CBD Fe, S1 and S2) influencing soil erosion in semi-arid zones are shown in Tables 5.9 and 5.10. Principal Components (PC) 1, 2 and 3 explained 76% of the variation (43.4%, 20.2% and 12.6%, respectively). The dominant factors with the highest loading values in PC 1, which explained most variation, were sum of very fine sand and fine sand (X8) and clay (X10). Clay (X10) loaded negatively while very fine sand (X1), fine sand (X2), fine sand + very fine sand (X8) and slope length loaded positively. Slope factors showed the least loading in the main PC 1. However, slope length recorded the highest and most significant loading value in PC 2.

Table 5.9: Eigenvalues and cumulative percentages of PCA

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.469	43.357	43.357	3.469	43.357	43.357
2	1.620	20.248	63.605	1.620	20.248	63.605
3	1.005	12.564	76.169	1.005	12.564	76.169
4	0.813	10.161	86.330			
5	0.594	7.422	93.752			
6	0.451	5.640	99.392			
7	0.049	0.608	100.000			
8	9.992E-016	1.249E-014	100.000			

[9] A large proportion of soils found in the Municipality were found in semi-arid zones. To determine the dominant soil and slope factors Principal Components Analysis was carried out for all the soils in semi-arid zones.

Table 5.10: Loadings of PCs 1, 2 and 3

Factors	Component		
	1	2	3
Clay % (X10)	-0.962	-0.172	0.039
Fine sand (X2)	0.791	-0.279	-0.204
Very Fine sand (X1)	0.785	0.474	0.151
fine + very fine sand (X8)	0.975	0.146	-0.021
ESP (%)	-0.440	0.357	0.193
Gradient (%)	-0.312	0.681	0.131
Aspect (degrees)	0.234	-0.165	0.928
Length	-0.064	0.805	-0.154

Sub-humid

In the Tukulu soils, there was a significant positive relationship between erosion intensity and fine sand. The critical fine sand limit was 9.14% and the average was 9.03%.

Humid climate

Because the degree of erosion (dependent variable, Y) was constant (Y=0), regression analysis on Hutton and Covelly was not possible. The main soil factor affecting the Clovelly and Hutton soil forms was clay mineralogy. Clay mineralogy results are shown in later sections.

Relationship between clay mineralogy and erosion

From field observations and laboratory analysis results, high erodibilities were found in soils with clay-sised quartz, smectites and micas as dominant clay minerals. Kaolinites, hematite, goethite and gibbsite were the dominant minerals in soils with low erodibilities.

Dominant clay mineralogy in arid and semi-arid climate

The mineralogy of clay fractions was dominated by clay-sized quartz in soil forms found in arid and semi-arid climatic units of the Municipality (Table 5.11). There were particularly high levels of clay-sized quartz (> 30%) in the Glenrosa, Swartland, Augrabies, Bonheim, Klapmuts, Estcourt, Katspruit and Sterkspruit soils.

Illite (hydrous mica) was found in moderate to small quantities only in the Glenrosa and Swartland soils and the Oakleaf subsoils. The Estcourt, Valsrivier and Arcadia soils had significant amounts of smectites. The smectites were absent in the Klapmuts and Sterkspruit

soils. Duplex and pseudo-duplex soils including the Estcourt, Sterkspruit, Valsrivier and Klapmuts contained small quantities of kaolinite. The Bonheim soil contained some hematite and goethite in small quantities (3-10%). The poorly drained Katspruit soil had between 3-10% goethite. Muscovite was present in moderate quantities (10-30%) in all soils in arid and semi-arid while plagioclase was present in small quantities in all soils, but absent in the highly weathered Hutton and Clovelly soils.

Clay mineralogy in sub-humid and humid climate

The most stable soils, Hutton and Clovelly, had > 30% kaolinite. The levels of clay-sized quartz levels were low in the highly weathered Hutton soil. The other soils found in the sub-humid climate namely Oakleaf and Tukulu soils also had significant quantities of kaolinite. The three most stable soils namely, the Hutton, Shortlands, and Clovelly, also contained high amounts of sesquioxides. The Shortlands soils had high levels of hematite, while the Hutton and Clovelly soils had high levels of hematite, goethite and gibbsite.

Table 5.11: Clay mineralogical properties of the different soil forms in Nkonkobe Municipality

Soil form	Horizon	[10]Clay minerals							
		Muscovite	Quartz	Kaolinite	Plagioclase	Illite	Smectite	Hematite	Goethite
Shortlands	A	[1]	4	3	1			2	
	B	1	3	4	1			3	
Glenrosa	A	2	5		1	2			
Swartland	A	3	5		3	1			
	B	3	5		2	2			
Oakleaf	A	4	3	2	2				
	B	2	4			3			
Augrabies	A	3	5		1				
	B	3	5		1				
Bonheim	A		5	1	1			1	1
	B		5	1	2			1	1
Arcadia	A	3	4		1		2		

[10]

1 = 0-3%; 2=3-10%;3= 10-30%; 4= 30-50%; 5= >50%: Gibbsite was only determine in the Hutton (0-3% for both horizons) and in the Clovelly (at 3-10% in A horizon and 10-30% in the B).

	B	3	4		1	2			
Valsrivier	A	1	4	1	1	2			
	B	4	3	1					
Klapmuts	A	3	5		1				
	B	3	5	1	1				
Estcourt	A	2	5	1	1	1			
	B	2	3		1	3			
Katspruit	A	2	5		1			2	
	B	1	3		1			3	
Tukulu	A		5	2	1				
	B		5	2	1				
Sterkspruit	A	3	5	1					
	B	2	5	1	1				
Clovelly	A	2	3	3			1	1	
	B	2	3	4				1	
Hutton	A	1	1	4			1	2	
	B		1	4			2	2	

1 = 0-3%; 2=3-10%;3= 10-30%; 4= 30-50%; 5= >50%: Gibbsite was only determine in the Hutton (0-3% for both horizons) and in the Clovelly (at 3-10% in A horizon and 10-30% in the B).

5.4 Discussion

5.4.1 Effect of soil and slope factors on erosion

Soils derived from shale and mudstone in arid regions and semi-arid climates

In the arid and semi-arid units, very fine sand and fine sand plus very fine sand and fine sand plus very fine sand plus silt were the most dominant factors influencing soil erosion in shale and mudstone derived soils. This could be explained by the inherent release of fine particles upon the weathering of these parent materials (D'Huyvetter, 1985, Nyamapfene, 1991; Laker, 2004b; He *et al*., 2005). D'Huyvetter (1985) reported that very high fine sand content was the main cause of erosion in several soil forms derived from shale and mudstone in the area.

Shale and mudstone weather to form soils with high "fine sand" contents, including very fine sand and coarse silt (Nyamapfene, 1991; Laker, 2004b). The findings of the present study, thus, give an explanation for the general high erodibility of soils derived from these parent materials. The dominance of very fine sand, a combination of fine sand plus very fine sand, very fine sand plus silt, on individual soil forms derived from shale and mudstone, however, differs, depending mainly on the quantities of these fractions in the soil form. Thus, the fraction with the highest quantity would control the degree of erosion in a soil form.

The soils found in arid and semi-arid regions of the Municipality vis-a.vis; Swartland, Sterkspruit, Klapmuts and Glenrosa forms were highly susceptible to soil erosion because of the high amounts of very fine sand plus fine sand. The mean levels of these fractions were way above the critical limits and as such severe erosion of these soils is expected. The critical upper limit of 22% for fine sand found in this study is within the range stated by Nyamapfene (1991) who reported that fine sand (0.2-0.02 mm) contents higher than 25% were enough to aggravate crusting and erosion. He postulated that fine sand particles clog the pores and prevent further infiltration of water, resulting in increased surface sealing and run-off. The fine sand also consists predominately of inert materials that cannot form bonds and aggregates and are small enough to be easily transported (Buhmann *et al.*, 2006).

Furthermore, in soils derived from shale and mudstone in arid and semi-arid areas, clay mineralogy was dominated by clay-sized quartz and mica. The presence of primary minerals such mica and smectites (2:1 clay minerals) is expected in low rainfall arid and semi-arid climate

because of low degrees of weathering. The mineralogical composition of the soils was mainly affected by the degree of weathering. As expected, smectites, feldspars, micas and quartz were dominant in soils found in semi-arid areas. These phyllosilicate primary minerals resemble their parent material because of low degrees of pedogenesis. For example shale has high amounts of muscovite mica (Buhmann *et al*., 2006; Mandiringana *et al*., 2005) and quartz (Nyamapfene, 1991).

The dominance of clay-sized quartz in Swartland, Sterkspruit, Klapmuts and Glenrosa soil forms could have been a result of the very fine sand and silt particles spilling over into the clay fractions. Soils with significant quartz contents in their clay fraction are highly dispersible and vulnerable to erosion (Laker, 2004b). The high amount of clay-sized quartz is common in most South African soils especially in the Eastern Cape (Buhmann *et al*., 1996; Mandiringana *et al*., 2005; Buhmann *et al*., 2006; Nciizah and Wakindiki, 2012), contrary to most international studies that have reported a general absence of quartz in clay fractions (Buol and Eswaran, 2000). The quartz is inert with charge close to zero and, consequently, does not form strong bonds (Lado & Ben-Hur, 2004).

In Estcourt, Valsrivier and Klapmuts, soil erosion was more pronounced because of the presence of smectites and illites which are highly unstable.When illite particles come together, there is a mismatch of its terraced surfaces, leading to poor contact between the edge and planar surfaces and resulting in high dispersivity (Lado and Ben-Hur, 2004).

On shale and mudstone parent material soils in semi-arid climate, the degree of erosion was positively correlated with ESP. In arid and semi-arid areas, relatively high ESP levels are expected because dry conditions allow exchangeable bases including sodium to remain in the soil i.e leaching is very minimal. The general critical ESP limit for soils derived from shale and mudstone in semi-arid was lower (3.68%) than the FAO critical limit of 15% known to cause serious dispersion. D'Huyvetter (1985) found that erosion reached unacceptable levels at ESP values as low as 2.5% for some soils developed from Beaufort mudstones and shales such as Valsrivier and Glenrosa. Such findings suggest that other factors strongly override the effect of sodium on dispersion and erosion. In other studies, Van der Merwe *et al*. (2001) cited by Laker (2004b) found that the most highly erodible melanic soil had the lowest ESP (only 0.12). In contrast, the soil with by far the highest ESP (7.8) did not have such high erodibility. The high

dispersability of Estcourt soils is normally attributed to high ESP (D' Huyvetter, 1985; Mulibana, 2000), but findings in this study suggest that the presence of high levels of smectites exacerbated the effects of high ESP on the dispersion of these soils.

In addition to the high fine sand content, soil erosion on Glenrosa and Swartland soil forms was exacerbated by limited depth and the strong structure of the pedocutanic-B horizon respectively. Shallow soils have low water storage capacities and the strong structure restricts water movement in the soil which results in increased runoff and erosion. D'Huyvetter (1985) also reported aggravated erosion on shallow Glenrosa soils.

Slope gradient and slope length were the main slope factors influencing soil erosion in soils derived from shale and mudstones in arid and semi-arid zones. As slope gradient and slope length increased, run-off increased, reaching the maximum on the lower footslopes because of its increased velocity and mass (D'Huyvetter, 1985; Laker, 2004b). D'Huyvetter (1985) reported that most erosion in the Eastern Cape, including Nkonkobe, was caused by the cultivation of soils above the acceptable slope limits. Laker (2004b) supported these findings by suggesting that slope gradient is the most importantfactor for correct land suitability evaluation and land use planning for sustainable crop production. The incorrect planning of the betterment schemes, which failed to recognise that different soils have different critical slope gradient limits, has been used to explain the very serious soil erosion seen in the Nkonkobe Municipality. D'Huyvetter (1985) recommended that any presently cultivated land above the critical limits should be withdrawn from cultivation. In this case, the delineation of Glenrosa and Swartland should be withdrawn completely from cultivation, based mainly on the unfavourable soil and slope gradient.

The shorter slope critical length in Estcourt was caused by high smectite levels and high ESP in the case of Estcourt which resulted in increased dispersion and soil erodibility. There are indications that the most serious erosion is found on the flatter lower slopes such as footslopes and valley bottoms (D'Huyvetter, 1985), which is attributed to the high velocity and large volume of water from long slopes above these areas causing a highly erosive water mass at the lower slopes (Laker, 2004b).

Soil loss increases with increasing slope gradient and length because the kinetic energy and mass of runoff water increases exponentially as the slope gradient and length increases, and it is mainly the kinetic energy that is responsible for the transport of soil (Laker 2004b; Rieke-Zapp and Nearing, 2005). Slope gradient had an influence on the erodibilty of Glenrosa and Swartland. The critical slope limits for Glenrosa and Swartland were lower than the reported 6.8% and 10.9% in earlier studies for the respective soil forms (D'Huyvetter, 1985). These differences probably occurred because most observation points on these soil forms were made on less steep slope gradients. However, these results still showed that erosion can be severe even on slopes of around 5%. Soil erosion is also aggravated by the shallow soils with low water storage capacities and sparse vegetation, which results in increased run-off. The Glenrosa and Swartland soils should only be used for natural grazing.

It is essential to note that slope factors only affect soil erodibility when soil factors are beyond acceptable limits. Principal components results showed that soil factors are more influential on soil erosion than slope factors. Thus, the most important factors affecting erosion severity in soils derived from shale and mudstone in arid and semi-arid areason were the fine sand and very find sand contents, clay sized quartz, and ESP particularly in the presence of smectite. These factors could explain the poor stability of the soils as observed by the farmers in these areas (Chapter 4). The farmers' views on erosion were mainly influenced by the amount of fine sand as evidenced by their assertion that the *santi* soils were highly erodible.

Soils derived from dolerite in semi-arid climate

Statistically, there was a negative relationship between degree of erosion and CBD iron in dolerite derived soils found in semi-arid areas of the Municipality. The inverse relationship between extractable CBD Fe and the degree of erosion on dolerite derived soils supports the view that iron oxides stabilise the soil. Dolerite derived soil contains high content of augite (Smith, 1990; He *et al.*, 2005) and the iron oxides formed from weathering of this mineral cement soil particles resulting in good aggregation,and infiltration (Singer & Shainberg, 2004). Iron oxides affect soil structure through the interaction of their positive charges with negatively charged clay particles (Buhmann *et al*., 1996). These soils also have more Ca which acts as a strong cationic bridge supporting aggregation.

The statistical result above contradicts the ground observations where individual dolerite derived soils in semi-arid environment soil forms were less stable. The Bonheim soils had high clay content (> 35%). Because of the excessive amounts of clay, a strongly developed coarse structure develops impeding infiltration resulting in excessive run-off and erosion. In addition, the presence of high amounts of clay-sized quartz in the topsoils resulting from transportation and deposition from the surrounding shale and mudstone derived soils negates the effect of binding effect of iron oxides. This study also discovered moderately eroded Arcadia soils in the Tyume and Kat Catchments. The presence of clay-sized quartz and smectite in Arcadia could have resulted in the dispersion of the soils resulting in increased erosion.

Contrary to other findings that reported slope gradient as the dominant slope factor influencing soil erosion (D'Huyvetter, 1985; Laker, 2004b), slope length had a more significant influence in determining soil erosion in the dolerite derived Bonheim and Arcadia soils. An explanation for this observation is that, where slopes are flat, the slope gradient ceases to be the dominant factor and slope length takes over. The majority of samples from the two soils were found in the Tyume River and Kat River valleys where slopes were relatively 'flat'. Despite slope length having a dominant effect in Bonheim and Arcadia, regression between slope length and CBD showed that CBD Fe remains the most influencial factor in dolerite derived soils in semi-arid areas. This gave a clear indication that iron is the most important factor controlling soil erosion in dolerite derived soils in the semi-arid regions.

Soils derived from shale and mudstone in sub-humid climate

The Tukulu soil forms had high level of quartz, with traces of goethite and plagioclase feldspars in subsurface horizons (Buhmann *et al*., 2006) and were influenced by fine sand. Quartz and fine sand particles contributed to moderate ersoin.

Soils derived from dolerite in humid climate

On dolerite derived soils in humid environments, particle size fractions had no significant relationships with the degree of erosion because these soils were dominated by kaolinite, hematite, goethite and oxides. As the degree of weathering increases, due to high rainfall, the smectites and micas break down forming more stable secondary minerals such as kaolonite and the end-point clay oxides. Stern *et al*. (1991) reported that the presence of kaolinite overrode the effect of high fine sand fractions in the different South African soils they studied. The ability of

the kaolinite to flocculate due to an electrostatic interaction between the edges of the clay platelets and thenegative charges in the soil crystal is responsible for its stabilizing potential (Six *et al*., 2000). Synergic interactions between the kaolinite and iron have also been reported to increase the stability of soils (Six *et al*., 2000; Lado and Ben-Hur, 2004). The increasing degree of weathering in higher rainfall areas releases large amounts of free iron, thereby increasing the stability of the soils (Smith, 1990).

In this study the highly weathered dolerite derived soils (dystrophic Hutton) occurring in the humid Amatola mountainsgave rise to more stable endpoint clay minerals such as kaolinite, gibbsite and hematite.

Soils derived from shale and mudstone in humid areas

The highly weathered Clovelly soil, derived from shale and mudstones appears to have similar relative stability to those of the highly weathered dolerite derived soils, possibly because of the same stabilizing effects of iron and aluminum oxides. It appears highly weathered soils, as reflected by the presence of Fe and Al oxides are affected by the same parameters irrespective of parent material. Highly weathered soils were, generally, the most stable and these should be prioritized as prime cropping land and optimized for crop production. Currently, these areas are either unused or, even worse, are used for non-cropping purposes such as residential areas, which means that they are forever lost.

Soils found across aridity zones

Shortlands soil form in both semi-arid and humid climate were generally stable against soil erosion. D'Huyvetter (1985), like the present study, found the Shortlands soils to be very stable against erosion. The stability of the Shortlands soils from Upper Ncera against erosion was confirmed by Stern (1990) and Rapp (1998) in laboratory scale rainfall simulation studies. In semi-arid climate the Shortlands soils were dominated by high fine sand in the A-horizon and could only erode at critical slope limit of 12.5%. This stability was caused by kaolinite and free iron oxides. Because of the overriding kaolinite and iron oxides, the Shortlands soil form did not erode even with high fine sand content. In sub-humid climate the Shortlands could not erode at any slope gradient. The reasons for better stability were the free iron released as a result of more intense weathering and the absence of clay-sized quartz in addition to the kaolinite present. In

addition to clay mineralogy, the ‘nutty’ granular structure of the Shortlands does not impede infiltration, minimizing runoff.

While soils derived from dolerite provided prime cropping land, most of the soils remained unused by communal farmers in the Municipality due to their droughty nature and high clay content, which made tillage without machinery difficult. As a result, some of these soils remain unused. Provision of irrigation services and farm machinery could alleviate this problem (Chapter 4).

Oakleaf soil was found in 3 aridity zones namely, the arid, semi-arid and sub-humid climates. In the arid zones the sum of very fine sand, fine sand and silt was responsible for its moderate erodibility. The Oakleaf was derived from deposition of shale and mudstone hence the reason for the dominant influence of the particle size fractions. In semi-arid climate the degree of erosion was influenced by slope length. An explanation for this observation is that, where slopes are flat, the slope gradient ceases to be the dominant factor and slope length takes over. The majority of samples from the two soils were found in the Tyume River and Kat River valleys where slopes were relatively ‘flat’. The Oakleaf in sub-humid zone was influenced mainly by CBD Fe and kaolinite. These soil factors were dominant in sub-humid areas and hence they could have been transported from higher rainfall areas and deposited in the flood plains of the Tyume and Kat river Basins downstream. The Oakleaf soil showed a clear increase in the relative stability from arid, through semi-arid to sub-humid zones.

For the Swartland soils, very fine sand, fine sand and silt particles were responsible for soil erosion in both arid and semi-arid zones showing very little climatic influence between arid and semi-arid.

5.5 Conclusions and recommendations

From the above results and discussions it can be concluded as follows:

1. Overall the soil factors affecting erosion were influenced largely by climate, while parent material was also important.
2. The presence of kaolinite and iron oxides, irrespective of parent material, explained the stability of soils from humid and sub-humid regions.
3. Smectite and high clay-sized quartz were important in the erodibility of soils from the dolerite in semi-arid and arid regions (Bonheim and Arcadia) of the Municipality.
4. The 'fine fractions' namely very fine sand, fine sand, silt and the sum of the three, and mica and ESP were responsible for the high degrees of erosion of shale derived soils in arid and semi-arid regions.
5. The influence of slope factors was masked by climate and soil facors. Climate was the most important followed by parent material and slope gradient had the least influence on erosion.
6. Dolerite derived soils were the most stable and should be given the highest priority for cropping development while mudstone and shale derived soils had a lower cropping potential. Thus, soils in the Municipality should be delineated based on climate followed by parent material as the highest categorical order.
7. Cultivation of the areas of Glenrosa, Swartland, Sterkspruit, Klapmuts, Valsirivier, Katspruit and Estcourt in arid and semi-arid regions should be stopped and correct soil reclamation procedures followed. Conservation agriculture practices are highly recommended on high potential soils including Arcadia, Oakleaf and Augrabies occurring in a drier environment as they improve water retention, minimize run-off and improve organic matter which aggregates the fine sand particles that are responsible for high erosion.
8. It is further recommended that the Municipality enact legislation that preserves prime cropping land and that such land be reserved for these purposes only.

CHAPTER 6

DELINEATION OF ARABLE LAND AND EVALUATION OF ITS SUITABILITY FOR SELECTED CROPS UNDER RAINFED CONDITIONS

6.1 Introduction

The decline in crop production in smallholder and former 'white' commercial farms in the former homelands of South Africa is a major threat to food security (Laker, 2004a) and household income. On average 75% of arable land are either underutilized or completely abandoned in Nkonkobe Municipality (Chapter 3). Citrus farms in the Tyume and Kat valleys have collapsed and a number of food crops, such as wheat and sorghum, have also been completely abandoned along the way. Farmers' responses showed that maize, cabbage and potato were the main crops grown, while sorghum and cow-peas were identified as future crops, with a decline in maize production experienced during the last 10 years (Chapter 3). Socio-economic challenges, including shortages of labour, skills and farm machinery are of importance in the Municipality. Deteriorating soil quality, due to erosion, and low and unreliable rainfall were among the biophysical factors responsible for the decline in crop yields and land abanndonment in Nkonkobe Municipality (Chapter 3). A number of agricultural development projects are being envisaged in the Municipality and their success will depend on the suitability of the crops grown (IDP, 2008). Land evaluation for agronomic suitability of the crops could be vital in order to focus production efforts to specific suitable areas.

A large proportion of soils in the region are highly degradable due to their high fine sand content, clay-sized quartz, highly dispersible smectite-type clay minerals and high ESP, together with steep and long slopes, especially in the arid and semi-arid areas (Chapter 5). Soils with good agricultural potential need to be delineated based on their erodibilities, slope limits, soil moisture and water deficits. The Betterment Programme, used a maximum slope limit of 12% for arable cropping, irrespective of the soil type (Laker, 2004b), and this caused severe erosion on some soils (Laker, 1978; D'Huyvetter, 1985), while lowering the upper limit to 6% as suggested by Van Averbeke and Marais (1991) either included a large area of highly erodible soils or excluded some stable soils. Land evaluation needs to prioritise soil erodibility, soil moisture and water deficits and temperature. In view of climate change, which could result in unreliable rainfall, and the need to mitigate against food insecurity in the Municipality, land suitability evaluation needs

to be done for drought-resistant crops such as sorghum and cowpea, which were selected as future crops (Chapter 3). Potato was selected for its potential as a cash crop.

While land evaluation for suitability of maize and sorghum has been done, the studies were generalized, used minimum datasets available (eg texture as a soil factor) and did not consider the soil erodibility as an important factor. On the other hand, land suitability evaluations for cow pea and potato production have not been done (Laker, 1978), and in most cases, general cropping guidelines are used when making cropping decisions.

A number of procedures have widely been used for land suitability evaluation including the FAO Land Evaluation Framework (FAO, 1976), and modifications of this framework such as the FAO Guidelines for Land Evaluation for Rainfed Agriculture (FAO, 1983) and FAO Guidelines for Irrigated Agriculture (FAO, 1985). The FAO (1976) Land Evaluation Framework, from which other guidelines were derived, is based mainly on the interaction between the physical environment including soils, geology, climate, water- and the socio-economic factors, including demographic, cultural, institutional and technological advancement. Its application involves: (i) an assessment and classification of land for growing specific crops guided by the soil and climate requirements; (ii) comparison of the benefits obtained and the inputs needed on different types of land to justify cultivation of earmarked crops on certain soil types; (iii) using a multidisciplinary approach, where contributions from the fields of natural science, the technology of land use, economics and sociology is envisaged; (iv) taking into account the political, cultural and socio-economic context of the area concerned, (v) determining whether a sustained use of the land for the specific use (cropping) is possible. The revised Land Evaluation for Rainfed Agriculture (1983) uses similar principles to the main framework but places greater emphasis on the main local conditions such as (i) soil erosion (ii) water deficits and (iii) soil moisture given the importance of soil moisture reserves in areas with water deficits. The FAO frameworks could be integrated with Geographic Information Systems (GIS) procedures for land suitability evaluation of specified crop under rainfed agriculture.

The integration of FAO frameworks and GIS based models allow for the use of multiple sources of information (Ebrahim, 2007) and the creation of geo-referenced maps showing the spatial and areal extents of land units by using map overlays and query functions (Pereira and Duckstein,

1993; Malczewski, 1999; Belton and Stewart, 2002). The availability of important datasets, for the Nkonkobe Municipality including digital soil maps (soil depth, texture, moisture and drainage), Digital Elevation Models (slope factors), and interpolated rainfall and temperature maps, could make it possible to evaluate land for its suitability for important crops in the Municipality using GIS. The objective of the study was to delineate arable land in Nkonkobe Municipality and evaluate its suitability for maize, potato, cowpea and sorghum under rainfed agriculture.

6.2 Methodology

6.2.1 Natural resources

Land evaluation studies were carried out for the whole Nkonkobe Municipality (Fig 2.1) using the FAO Guidelines for land evaluation for rainfed agriculture (1983) and placing greater emphasis on the main local conditions such as (i) soil erosion (ii) water deficits and (iii) soil moisture. The flow diagram in Fig 5.1 summarises the main parameters involved in the land evaluation process. The biophysical factors assessed were soil factors, topography and climate. The parameters were mostly obtained from findings in chapters 3 and 5 of this study. Soil factors included erodibility, depth, fertility and drainage, while the topographic factors were slope gradient. Climatic variables considered were rainfall amount and distribution, water deficits/ surpluses and mean monthly minimum and maximum temperatures. Evaluation of socio-economic factors was not done in this study. They were assumed to be not limiting.

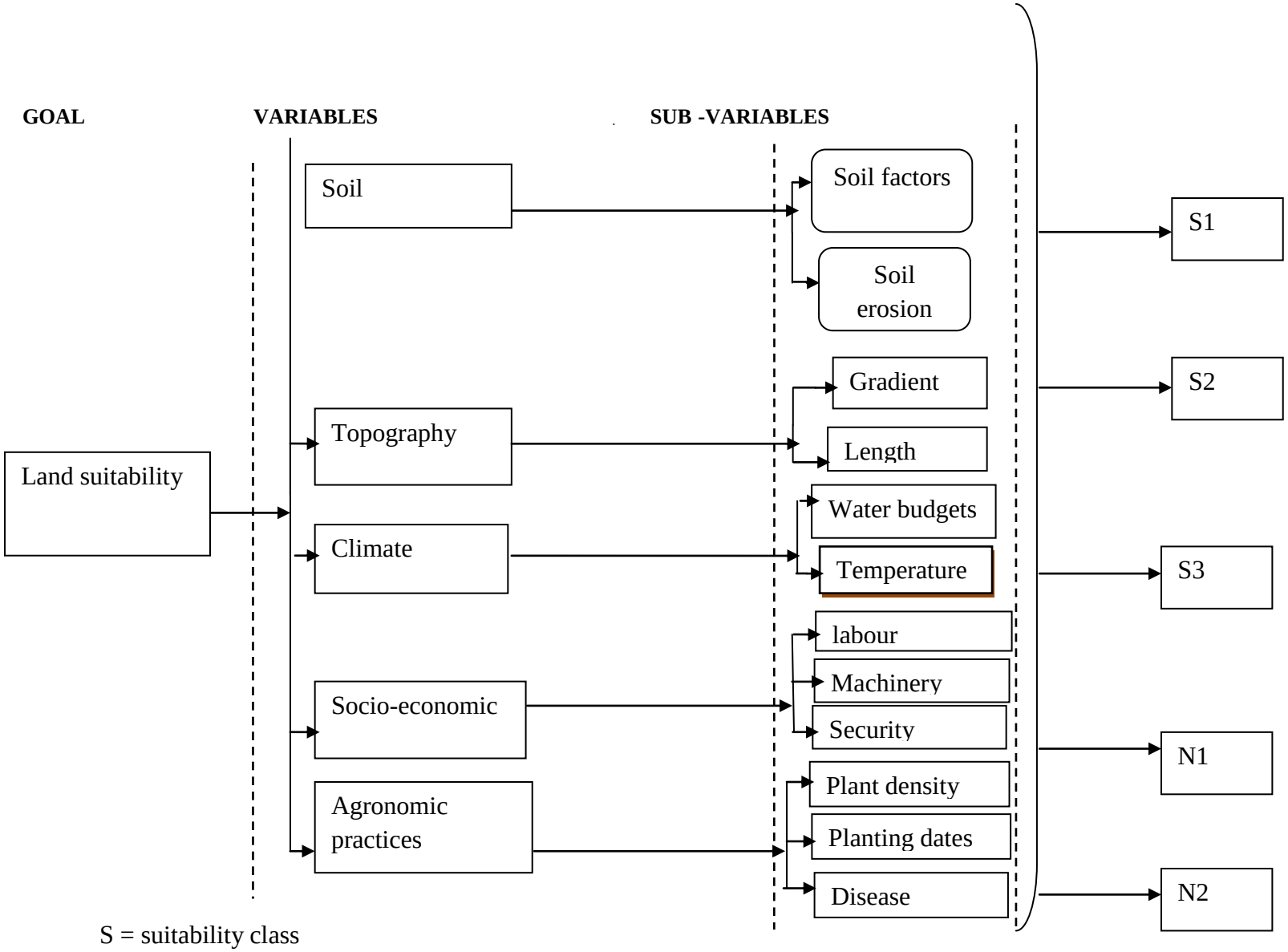

Fig. 6.1: Land suitability evaluation flow diagram

Soils

A 1: 250 000 digital soil map was compiled from the existing Soils of the Kat River Catchment at 1: 250 000 (Loxton *et al.*, 1979) and the Land Type Map 3226 King William's Town at 1:250 000 (Land Type Survey Staff, 2001). The Land Type Map of King William's Town covers areas of the Keiskamma Catchment around Tyume, Middledrift, Sheshegu, Amatola Basin and parts of the western boundary. The Kat River Soil Map covered areas from Seymour to Fort Beaufort town.

The more detailed 1: 50 000 Keiskamma River catchment soil map (Hill *et al*, 1977) was used to show detailed soil mapping units in the Alice and Tyume River Basins (Fig 6.2c). The Keiskamma and Kat River Maps, which were in analogue format, were first scanned, geo-referenced and then digitized. The mapping units in these maps, previously described according to the South African binomial classification system (MacVicar *et al*., 1977), were converted to the South African taxonomic classification system (Soil Classification Working Group, 1991). In cases where conversions of the classifications were not conclusive, the mapping units were verified by field visits.

Slope limits

The critical slope limits (Table 6.1) were derived from Chapter 5 and the pioneer work of D'Huyvetter (1985).

Delineation of arable land

A set of rules were used for the delineation of arable lands based on soils;

1. The Glenrosa, Escourt, Swartland, Klapmuts, Valsrivier and Sterkspruit were deemed non-arable because of their high erodibilities, while the Katspruit was deemed unsuitable for arable crop production because of poor drainage (Chapter5). The 'Replace' command in ArcGIS 10 was used to replace these non-arable soil forms with a zero value. The soils with a zero value were eventually discarded.
2. Slope factors were used to delineate Bonheim, Arcadia, Shortlands, Clovelly, Oakleaf and Augrabies (Table 5.2). This was done by combining the DEM with a raster soil map using binary rasters (either arable or non-arable). Query language in ArcGIS 10 Spatial Analyst was used to identify lands that fell within the different soil and slope factor

limits. For each soil type, soil above the critical limit was discarded and given a value 0 while the soil below the threshold value was deemed arable and given a value 1.

3. Where slope length was used as a determinant for critical slope limit, the relative distance from the apex of the slope to the soil profile was determined by the use of distance buffers in GIS. Laker (2004b) recommended that slope length be determined from the slope apex to the soil form. However, in all the soil forms where slope length was the determinant factor, the critical limits were above the median length and hence the soil forms were retained.
4. On Shortlands the critical slope limit of 12.5% was used as a cut-off point.

Table 6.1: Critical slope limits used for delineation of arable land

Soil form	Slope limit (%)	Reference
Arcadia	12.2	D'Huyvetter (1985)
Tukulu	2.5	Chapter 5
Oakleaf	12.8	D'Huyvetter (1985)
Augrabies	6.1	Chapter 5
Shortlands	12.5	Chapter 5
Bonheim	8.4	Chapter 5
Clovelly	10.0	Chapter 5
Hutton	-	Chapter 5
Glenrosa	4.8	Chapter 5
Estcourt	1.50	Chapter 5
Swartlands	4.4	Chapter 5
Sterkspruit	5.3	Chapter 5
Valsrivier	8	D'Huyvetter (1985)
Klapmuts	1.51	Chapter 5

Table 6.2: Critical factor limits for arable cropping on different soil forms (adopted from Chapter 5)

Soil form	Main determinant limiting factors	*Critical Factor limit	Remarks
Glenrosa	Slopegradient, depth, fine sand particles	4.8% (slope gradient)	Discarded, soil very shallow soils and high fine sand fraction
Estcourt	ESP	10.34 (ESP)	Discarded, extremely erodible because of high ESP
Swartland	Slope gradient, fine sand particles	4.4%	Discarded, particle size fraction above critical limits
Sterkspruit	Fine sand particles	69%	Discarded, particle size fraction above critical limits
Valsrivier	Slope gradient, fine sand particles, coarse structure duplex soils	8% (slope gradient)	Discarded, particle size fractions above critical limits
Klapmuts	Fine sand and very fine sand fractions	40.53% (very fine sand)	Discarded, particle size fractions above critical limits
Katspruit	Drainage	-	Discarded, very poor drainage.
Tukulu	Drainage	-	Marginally suitable due to imperfect drainage
Arcadia	Slope length	1.07 km (slope length)	Arable, but only soils below the critical slope length were retained
Oakleaf	Slope length	2.01 km (slope length)	Arable, soil form retained because slope length is below the critical limit
Augrabies	Slope length	2.14 km (slope gradient)	Arable, soil form closely related to Oakleaf
Shortlands	Slope gradient	12.5% (slope gradient)	Arable, soil form retained, median slope below the critical limit
Bonheim	Slope length	1.90 km (slope length)	Arable, retained slope length below the critical limit
Clovelly	Slope length	1.69 km (slope length)	Arable, slope length below the critical limit
Hutton	-	-	Arable, not limited by slope and soil factors

*The controlling factor is given in brackets. ESP = exchangeable sodium percentage.

Climate

Due to the limited number of weather stations in the Nkonkobe Municipality, interpolated data obtained from ARC – ISWC were used to as spatially geo-referenced climate base maps for the Municipality.

Temperature

Suitability of the test crops was evaluated based on Ehlers agro-ecological zones (ARDRI, 1981). The Ehlers temperature system was developed for South African conditions, and the database contains temperature specifications for more than 400 crops grown in the country, hence it gives farmers a wide range of crops to choose from. The zones are described using four digits e.g 67/25. The first two digits (67) represent the sum of summer months' average temperature in degree Celsius from November to February and the last two (25) represent the sum of the winter month's average temperature from June to August (Zuma-Netshiukhwi and Walker, 2009).

Water Budgets

The water budget maps were interpolated from the point data of the 7 units of the Municipality identified in Chapter 2 (Fig 2.1). Each unit had representative data from at least one weather station. The weather stations used were located at Kat, Lovedale Middledrift, Evelyn Valley, Lenye and Sheshegu (Appendix 6.1)

The water budgets, calculated as differences between precipitation and potential evapotranspiration (PE) plus stored soil moisture, were used to evaluate water surpluses/ deficits in the different units of the Municipality. Potential evapotranspiration was calculated using the Thornthwaite formula:

$$PE = 1.6\,(10T/I)^{a}$$

Where:

PE= monthly potential evapotranspiration (mm).

T= mean monthly temperature (^{o}C).

I= a heat index for a given area which is the sum of 12 monthly index values i. i is derived from mean monthly temperatures using the following formula:

$$i = (T/5)^{1.514}$$

a = an empirically derived exponent which is a function of I,

i.e.; $a = 6.75*10^{-7}I^{3} - 7.71*10^{-5}I^{2} + 1.79*10^{-2}I + 0.49$

Source: Laker (1978)

According to Laker (1978), this model somehow underestimates PE in summer and overestimates PE in winter and as such the PE figures should be regarded as approximations.

Summer deficits which are critical periods for rainfed agriculture were calculated from November to February while winter deficits were calculated from May to October. Using water budgets figures, the land units were qualitatively described as S1 to denote those areas that have sustained periods of water surpluses; S2 for those that appear capable of fair to good yields, (water deficits < -50 mm); S3 for those that give marginal yields (water deficits up to -200 mm) and N for those with severe water deficits (> -200 mm) and not suitable for any rainfed agriculture. A map of water budgets was created by matching the aridity zones of the Municipality to the specific water budget figures and qualitatively assigning the classes given above by using the 'Replace' command in ArcGIS 10.

Contribution of stored soil moisture reserves

Stored soil moisture reserves were determined by adjusting rooting depth, clay content and slope as described by Van Averbeke and Marais (1991). The resultant figures were added to the water budget data (Appendix 6.1).

Determination of the effective rooting depth of the soil

The effective rooting depth of a soil was determined by adjusting the soil depth of all horizons contributing to rooting depth. These adjustments were made to cater for limitations to root development in the different soil forms (Van Averbeke and Marais, 1991). The adjustment factors of the main arable soils in the Municipality are given in Table 6.3.

Table 6.3: Adjustment of soil factors required in the determination of effective rooting depth

Diagnostic B horizon	Soil form	Adjustment factor*
Red apedal	Hutton	1
Yellowish brown	Clovelly	1
Red structured	Shortlands	1
Neocutanic (chroma >3)	Oakleaf; Tukulu	1
Neocarbonate	Augrabies	1
Pedocutanic	Bonheim	0.5

*A factor of 1 implies that root development was not impeded

Determination of the weighted clay content of the profile

The adjustment factor for clay was obtained by determining the weighted percentage of clay for the rooting depth. This value is calculated by multiplying the percentage of clay of each horizon with the depth of the horizon. The sum of these products was then divided by the sum of the depths of all the horizons contributing to the rooting depth. A soil with an A horizon 400 mm deep with clay 15% and B horizon 1000 mm deep with 25% clay would have weighted clay of [(15 x 400) + (25 x 1000)] / 1400 = 22.1%. The weighted clay content was then used to adjust the effective rooting depth by applying a correction factor (Table 6.4)

Table 6.4: Factors for weighted % clay of the rooting depth which must be multiplied by effective rooting depth (Van Averbeke and Marais, 1991)

Weighted clay % of the rooting depth	Factor
<20	1
20-30	0.95
30-40	0.90
>40	0.85

Adjustment of the depth by slope factor

Slope has a major effect on the effectiveness of rainfall and run-off, thus, an increase in slope reduces the crop water supply. The assumption made was that, when the slope is small (< 1%), there is little runoff and maximum infiltration and thus the soil depth should be multiplied by a factor 1 while at slopes of > 10% there was maximum run-off and little infiltration and the soil depth should be multiplied by a factor of 0.5 (Van Averbeke and Marais, 1991). The root zone was adjusted according to the slope percentage (Table 6.5).

Table 6.5: Factors for the percentage of slope which must be applied to obtain effective rooting depth (Van Averbeke and Marais, 1991)

Slope %	Factor
< 1	1
1.1 – 4.0	0.95
4.1-8.0	0.90
8.1- 10.0	0.75
>10.0	0.55

Expected stored soil water in soil (ESWS) was calculated as follows:

ESWS = 42.5 + 0.0164 x ERD - 0.29 WCI - 1.11S

Where, ERD = adjusted effective rooting depth (mm)

WCI = Weighted % clay of the profile

S = % slope

The ESWS of different soils was then added to the water deficits (differences in precipitation and potential evapotranspiration) to determine the final water surpluses/ deficits.

6.2.2 Crop requirements

Information on the soil and climatic requirements of the test crops was obtained from different publications and reports (Van Averbeke and Marais, 1991; Smith, 1997; Deenik *et al*., 2006; FSSA-MVA, 2007; Du Plessis, 2008; NDA, 2010; NDA, 2011).

Crop water requirement figures were based on previous experience by researchers at the University of Fort Hare (Laker, 1978; Burger, 1983; Van Averbeke and Marais, 1991). From their work, figure estimates and suitabilities of the test crops were deduced. Below is an example of the soil, climate and water budget requirements for maize crop.

Maize

Soils

Basic soil requirements for maize crop include good drainage, sand clay loam texture, acid saturation < 20%, deep soils (> 900 mm), organic matter > 1.2%, phosphorus > 15 mg/ kg and potassium > 3.1%. A marginal yield is obtained on shallow sandy soils (Table 6.6).

Table 6.6: Soil requirements for maize production

Rooting Depth	Well drained soils				
(mm)	S1	S2	S3	N1	N2
[1]Texture	SCL	LS	fS	fS	cS
[1]Depth (mm)	> 900	500-900	250-500	-	-
[1]Acid saturation	< 20	-	-	-	-
[1]Organic matter (%)	> 1.2	0.8-1.2	<0.8	-	-
[1]Phosphorus (mg/kg)	15	10-15	-	<5	
[2]Potassium (mg/kg)	> 130	-	-	< 130	

S1 80 – 100% attainable yield;
S2 60 – 80% attainable yield

S3 40 – 60% attainable yield

Source: [1]Smith (1997); [2]FSSA-MVA (2007)

Climate

A high maize yield is obtained for long season varieties with water budget surpluses, within the 77/35 and 67/ 25 Ehler's temperature zones. The yield is lowest for short season varieties with high water deficits at low temperature in 46/14 and 57/25 Ehlers zones (Table 6.7).

Table 6.7: Climatic requirements for maize production

Climate	Climate classes					Reference
characteristics	S1	S2	S3	N1	N2	
Rainfall growing Season (mm)	700-1500	600-700	500-600	-	-	Smith, 1997
Length of growing season (days)	130-170	110–130	90-110	-	<90	Smith 1997
Ehlers temperature zone	77/35; 67/25	-	46/14; 57/25	-	-	Burger, 1983
Water budget (mm)	Surplus	< -50	-50 to -120	> -200	> -200	Laker, 1978

Other Factors

Cultural practices in the production of maize are characterised by low plant densities and late planting (Van Averbeke, 1991; Fanadzo *et al.*, 2007), shortages of seed (Chimonyo, 2012; Chapter 2), poor pest and disease control, low fertilizer input (Hebinck and Lent, 2007; Chapter 2). These are compounded by shortages of labour and farm machinery and lack security (poor fencing and theft) (Hebinck and Lent, 2007; Mnkeni *et al*., 2010; Chapter 3), and limited market outlets (Burger, 1983). The above factors were discussed so that users of the land suitability maps could get hindsight of other important factors besides the biophysical factors evaluated.

The crop requirements for other test crops are given in Appendices 6.2– 6.11.

6.2.3 Crop suitability

Soil suitability

Soil suitability classes were derived by using the attribute data of soil properties of each soil form against soil crop requirements for maize, potato, sorghum and cowpea in line with the FAO Guidelines for Land Evaluation for Rainfed Agriculture (1983). For each crop, the specific soil quality requirements in terms of soil moisture, texture, crusting (especially on the germination of small seeds such as sorghum and cowpea), rooting depth, its nutritional status (chemical properties), salinity status and liability to flooding, among other factors, were critical in the determination of suitability classes and subclasses. Full soils' data, with internal and external soil and land qualities, were obtained from soil surveys, site and profile descriptions (Appendix 5.1) and subsequent soil laboratory analyses for soil fertility status and soil physical characteristics (Appendix 5.4). Soil suitability classification from previous work done in the Municipality was also adopted where there was inadequate soils information, such as for the eutrophic Hutton soils in the Amatola Basin (Burger, 1983; Hill *et al*., 1977). An example is given of the evaluation of soils suitability for maize on Oakleaf soil form, with soil analytical data (Appendix 5.3) and soil crop requirements for maize (Table 6.6). The suitability class determined from soil permanent conditions, such as texture and depth, was given class S2 because of the limitation of the topsoil texture (loamy sand), even though the soil depth (> 1200 mm) was not limiting. The 'law of the minimum' states that, where all land qualities measured are of same importance, a limitation in one land quality limits the overall suitability (FAO, 1983). Hence, the suitability class was

downgraded to S2 because of the light texture. Similarly, looking at both soil analytical data, there were soil fertility limitations because of low P, K and organic matter. Because these qualities could be corrected by using suitable amendments, they were responsible for the determination of suitability subclasses. In addition, Chapter 5 revealed moderate erosion as a limitation. The mapping unit is given an overall suitability subclass S2fe, where f and e denote soil fertility limitation and erosion respectively. This exercise was done for the soil forms delineated as arable, matching the soil requirements for maize and the prevailing soil qualities of that soil form.

After the establishment of the suitability classes and subclasses for each soil form, the different land units were drawn by replacing the soil form with its suitability class, using the 'Replace' function in ArcGIS 10 to produce soil suitability maps for each test crop. Using a similar approach, soil suitabilities for other test crops were deduced.

Temperature suitability

The general Ehlers agro-ecological temperature map, obtained from ARC-ISCW, was used for temperature suitability classification of the test crops. Crop specific temperature maps were created by first establishing the suitability of that crop to the Ehlers temperature zone, using the available Ehlers specifications guides (Laker, 1978; Burger, 1983) and subsequently applying the 'Replace' command in ArcGIS 10 to substitute the temperature zone with its corresponding temperature suitability class for the test crop.

Crop water budgets

The general water budget map produced in section 6.2.1 was used as base map to create the water budget maps for the different test crops. Crop yield estimates in the different aridity zones were qualitatively estimated (Laker, 1978), as those that give high yield (S1); those that give good (moderate) yield (S2), those that give fair (marginal) yield (S3) and those that that are severely restricted (not suitable-NS). These yield estimates were then matched to the aridity zones and water budgets (section 6.2.1) to obtain crop adaptabilities for the test crop (section 6.2.2). The 'Replace' command in ArcGIS 10 was used to assign the suitable crop adaptability class to the appropriate zone for each of the test crops. The major limitation of this approach was the absence of real quantitative data on crop responses to the different water budgets.

Overall crop suitability

The overall land suitability maps for the test crops were produced by using the limiting condition approach or 'law of the minimum', where all land qualities measured are of same importance and a limitation in one land quality limits the overall suitability (FAO, 1983), using the GIS raster overlay approach. In this case the most limiting suitability class is retained as the overall suitability. The vector soil suitability and water budget map were converted to raster maps and resampled so that they could be overlaid with the raster Ehlers maps. The resampled maps were combined, using spatial analyst and the Boolean logic AND to produce the final crop suitability map.

6.3.0 Results and Discussion

Results and discussions were combined in one section to avoid repetitions and to improve the flow in this chapter.

6.3.1 Natural Resources

Soils

Detailed soils information on soil profiles and the accompanying soil information are found in Appendices 5.1 to5.4. The extended legend of the mapping units, showing the soil associations, is also given in Appendix 6.12. Large parts of the Municipality are covered by the Glenrosa, Swartland and Valsrivier soil forms (Table 6.8). These were delineated as non-arable soils and occurred in the drier regions of Middledrift and the Kat river basins near Fort Beaufort and the Southern parts of the Municipality (Fig 6.2a). The Glenrosa and Swartland were shallow with low water storage capacities and highly erodible.

Table 6.8: Areal extent of different soil forms in Nkonkobe Municipality

Soil form	Area (ha)	Soil form	Area (ha)
Hutton	12 415.22	Estcourt	247.01
Clovelly	4 396.00	Swartland	60 213.00
Oakleaf	21 513.09	Glenrosa	231 242.83
Augrabies	2938.06	Klapmuts	3 517.00
Shortlands	8 351.24	Katspruit	930.19
Bonheim	45. 19	Sterkspruit	278.64
Tukulu	11 461.70	Valsrivier	1013.05
Arcadia	83.62		

Sources: Department of Agriculture (1975); Hill *et al*. (1977); ARDRI (1981); Burger (1983); Land Type Survey (2001)

The Valsrivier form, developed in mixed mudstone and dolerite colluviums (ARDRI, 1981), the pseudoduplex Sterkspruit and Escourt soils were also delineated as unsuitable for crop production because of high erodibilities, as a result of high fine sand and sodium contents. The Valsrivier soils were badly eroded but the soils constitute a significant portion of the land that is currently under cultivation in the Middledrift and Tyume Valley. Therefore, cultivation on these soils should be discontinued and the soils used for other appropriate land use practices such as controlled grazing.

Only 20% of the soils in Nkonkobe were arable for crop production (Fig 6.2b). The figure confirms estimates from other from studies done in the Municipality which reported that 70-85% of the soils were not suitable for crop production, because of severe erosion, crusting, shallow depths and poor infiltration (Van Averbeke and Marais, 1991; Verdoodt*et al*., 2003). Farmers estimated that 75% of available arable land currently lying idle or underutilized is due to unfavourable biophysical conditions, and shortages of farm machinery, as well as labour shortages (Chapter 3). In view of the limited land suitable for arable cropping in the Municipality, optimisation of the available land by growing the most suitable crops is necessary.

Areas delineated for cultivation were found on alluviums along the Tyume, Keiskamma and Kat rivers. A detailed soil map showing some of the soils with high potential that can be used for further agricultural development is shown in Fig 6.2c. Detailed information of the soil soil forms

are found in Appendices 5.1 – 5.4. The dominant arable soils were the high potential Oakleaf soils of the Jozini and Limpopo series (now Oakleaf and Augrabies) that occupy 43.2% of the Kat River alluviums. The Oakleaf and Augrabies also occupy a large proportion of the arable soils in the Tyume valley, the Amatola basin and Middledrift (Department of Agriculture, 1975; Hill *et al*., 1977; ARDRI, 1981; Burger, 1983). Most of Oakleaf and Augrabies soil forms in the Kat river catchment were under citrus plantations.

(a) (b)

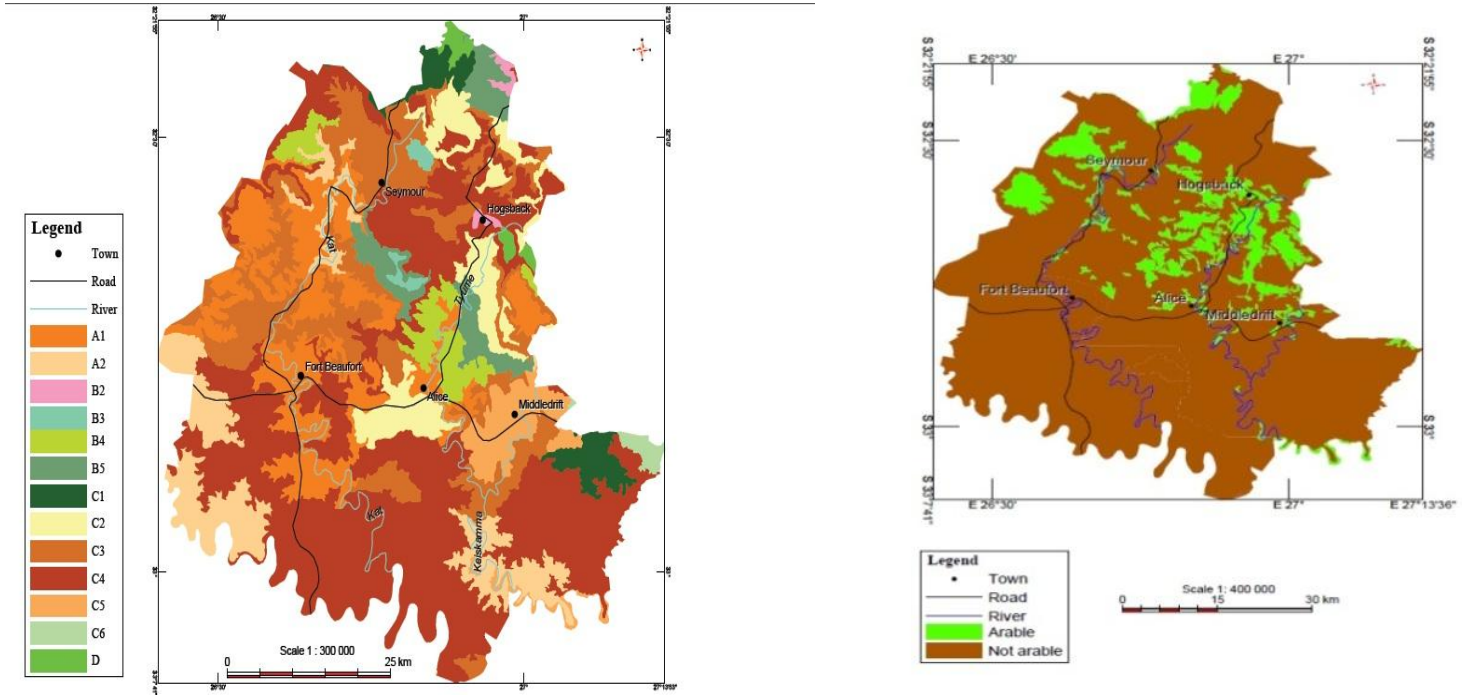

Fig 6.2: (a) Dominant soil units, (b) arable soils of Nkonkobe Municipality

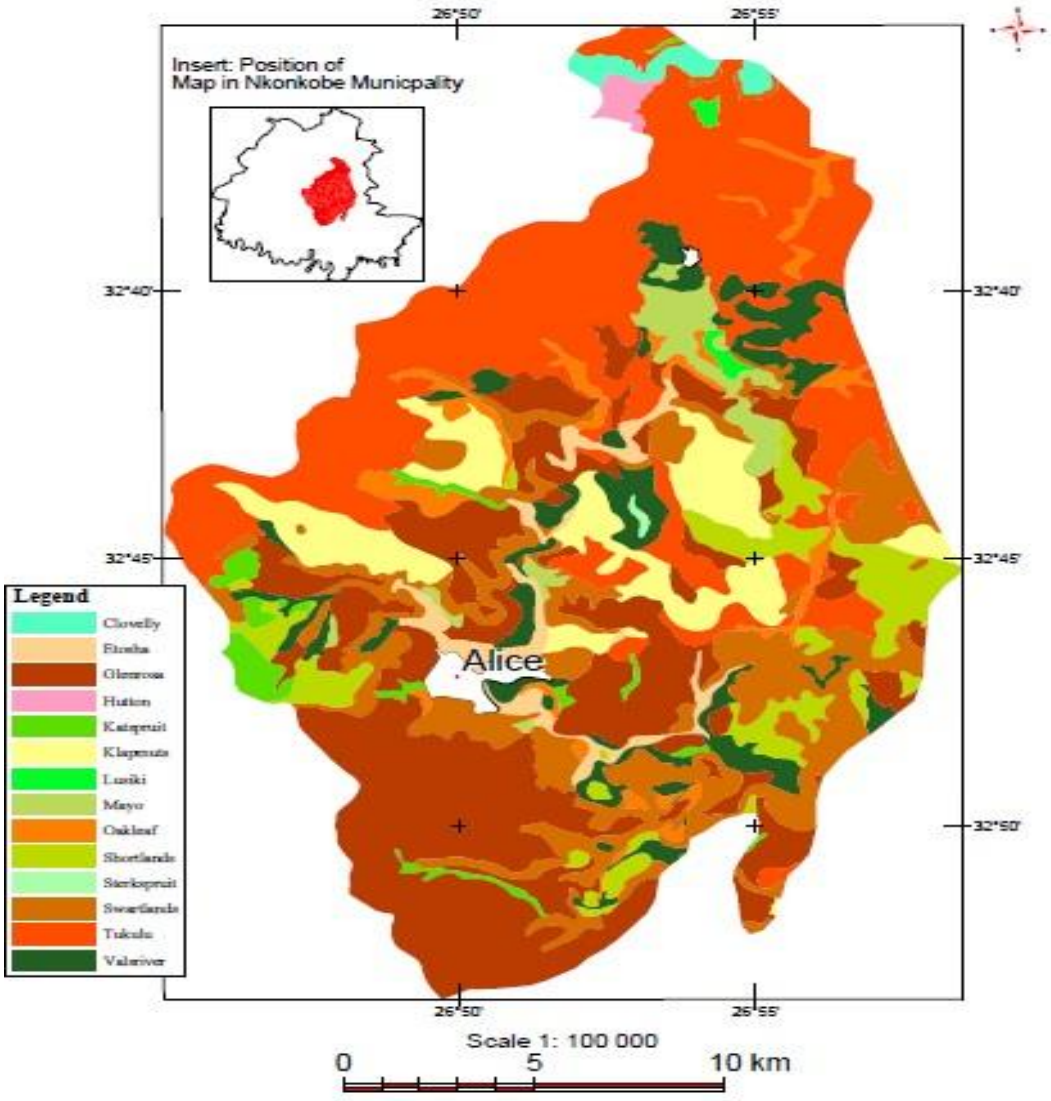

Fig 6.2c: Detailed 1:50 000 soil map of Tyume Catchment

Some of the citrus plantations on these high potential soils have collapsed and a significant portion of the land lies abandoned as discussed in Chapter 3. Farmers' perspectives attributed this decline in the planted area to poor management and unfavourable biophysical characteristics such as degraded soils and a harsh climate. These need to be revitalised for full agricultural development.

The red soils derived from dolerite around Upper Ncera (Shortlands) and in the sub-humid climate below the Amatola mountains (ARDRI, 1981) were also delineated as highly stable and were eutrophic (base saturation > 50%) (Appendix 5.4). In the Amatola Basin of the Municipality, the soils with high cropping potential include the clayey eutrophic Hutton soils of the Stella or Ventersdorp families, some mesotrophic (Hayfield/ Suurbekom families) and dystrophic Hutton of the Lillieburn family in the high rainfall areas. The Clovelly of the Twyfelaar and Hutton of the Lillieburn soil families on the Amatola Mountain (Hill *et al*., 1977) were resistant to erosion but their major limitation was poor soil fertility as indicated by high acid saturation > 40% and strong possibilities for P-fixation. Appropriate liming and fertilisation regimes could improve the cropping potential of the soil. The strong structure of the Shortlands of the Zebediela family, found in the Amatola Basin, lowers their potential relative to the Shortlands of the Bolweni family in the Tyume valley's Upper Ncera and the Hutton in the Amatola Basin. Strong structure impedes water infiltration, increasing run-off and erosion in the process (Soil Classification Working Group, 1991; Laker, 2004b).

Most of the high potential soils identified in this study are currently under-utilized and could make a significant contribution to food security if production is optimized through careful crop selection. The next sections focus on the suitability of the delineated arable land for cultivation of the crops grown by the farmers in the Nkonkobe Municipality.

Climate resources

The Municipality falls within the Ehlers zone 67/25, which comprises the largest fraction, including the semi-arid region, 46/14, 46/15 and 57/25, comprising mainly the cooler Amatola Mountains and their surrounding areas and zone 77/35 falling mainly within the arid climate (Burger, 1983). Burger (1983) reported that the influence of temperature in the Ehlers zones 46/14, 46/15 and 57/25 was very similar and because of this the Ehlers temperature zones were grouped to form one land unit during test crop temperature suitability classification, effectively limiting temperature classification in the Municipality to 3 Ehlers zones. The 46/14, 46/15 and 57/25 Ehlers zone covered a great proportion of Hogsback and the Katberg mountains and the surrounding cooler areas. Moving Southwards, in the Tyume Valley, Kat basin and the Amatola Basin, the 67/25 dominated the Ehlers climatic zone. The far southern part of the municipality

which covers Middledrift, Alice and Sheshegu were dominated by the 77/35 Ehlers temperature zone (Fig. 6.3a).

The humid Amatola and Katberg mountain region received the highest mean annual precipitation between 1000 - 1400 mm. The Kat River catchment consists of two main units, namely, the sub-humid upper catchment around Blinkwater and the semi-arid Fort Beaufort. Small areas of arid microclimate are also found in the Upper Catchment of the Kat River. Mean precipitation at Seymour is around 560 mm, while that at Fort Beaufort is around 500 mm.

The Tyume River catchment which stretches between the escarpment of the Amatola Mountains and Alice, receives annual rainfall ofabove 700 mm, in the sub-humid areas below the Hogsback Mountains, while the semi-arid region receives between 580 mm at Lovedale and 611 mm at Pleasant View near Alice (Laker, 1978). The arid zone is more dominant further South along the Keiskamma River around Middledrift, Sheshegu, and Breakfastvlei near Debe Nek is made up of a combination of river valleys that are dry with meanannual precipitation at Middledrift about 500 mm, dropping to 390 mm(Fig. 6.3b).

The humid Amatola and Katberg Mountains have the highest total water surplus (1054 mm) and summer water surplus (516 mm) (Appendix 6.1). This region is generally suitable for crops with high water requirements and adapted to cool temperatures, and for the purposes of this study, it was qualitatively described as highly suitable (S1). Small total water and summer deficits (-75 mm and -42 mm, respectively) were recorded at Lenye in the upper parts of the Amatola Basin, qualitatively described as moderately suitable. This station is located in the sub-humid region of the Municipality. This region is suitable for rainfed agriculture and good crop yields have been reported (Burger, 1983).

Generally, potential evapotranspiration was more than the precipitation for the weather stations situated in semi-arid and arid regions of the Municipality. The summer water deficits in semi-arid regions of the Kat River Basin at Seymour, Mt Pleasant View and the lower parts of the Amatola Basin were between 114 and 159 mm but were more severe at Lovedale (-185 mm). Rainfed cropping is marginal (S3) and productivity is largely dependent on the stored moisture reserves of the soils. In Middledrift, total deficits were more severe (> 330 mm) with the summer

water deficit > 190 mm recorded. Rainfed cropping is, therefore, severely restricted in the area. The arid regions of Sheshegu and Dank Den Goewerneur were not suitable (NS) for rainfed agriculture as they had total water deficits > 400 mm and summer deficits > 250 mm (Fig. 6.3c).

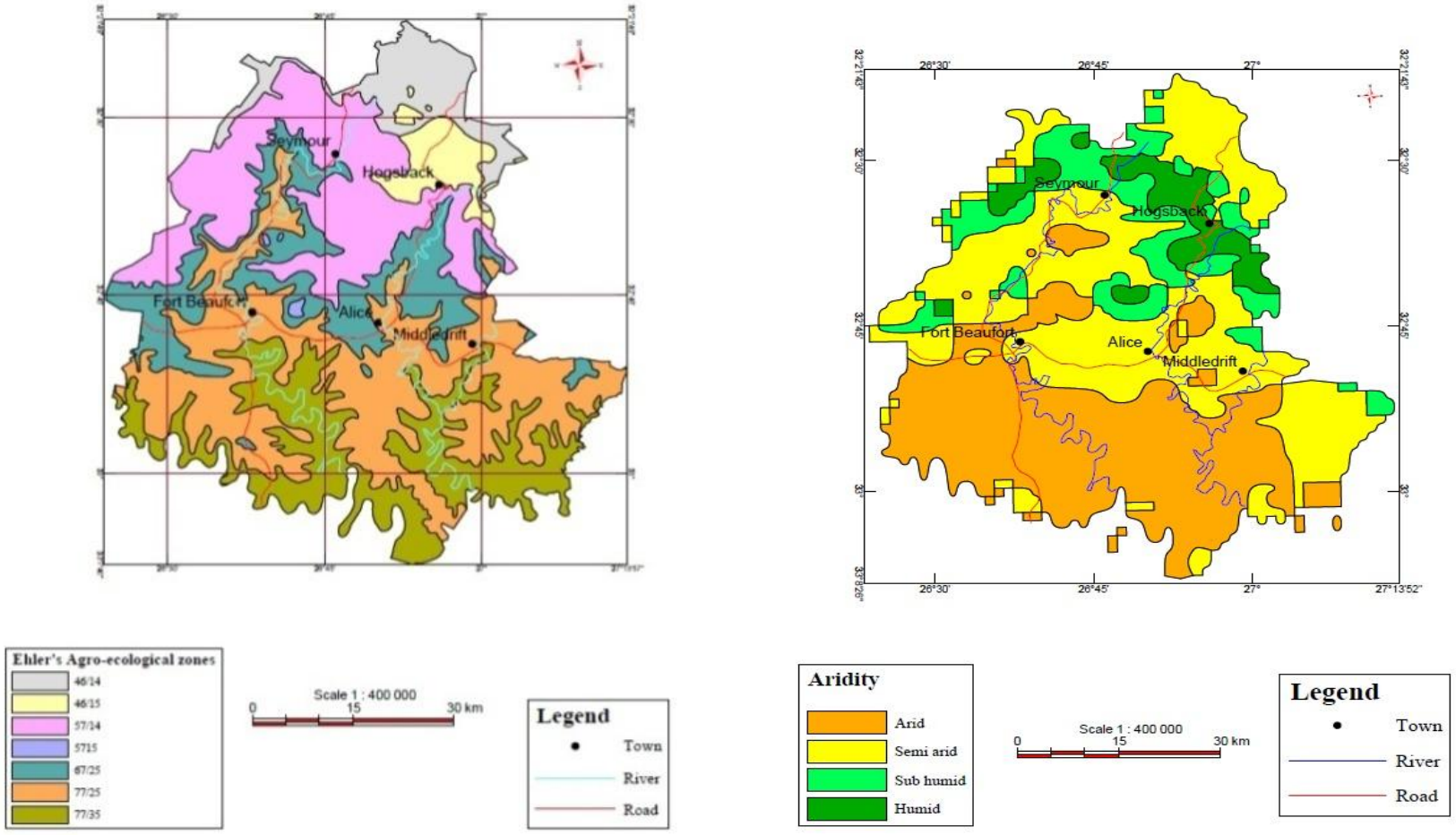

Fig. 6.3: (a) Ehlers and (b) aridity map of Nkonkobe Municipality

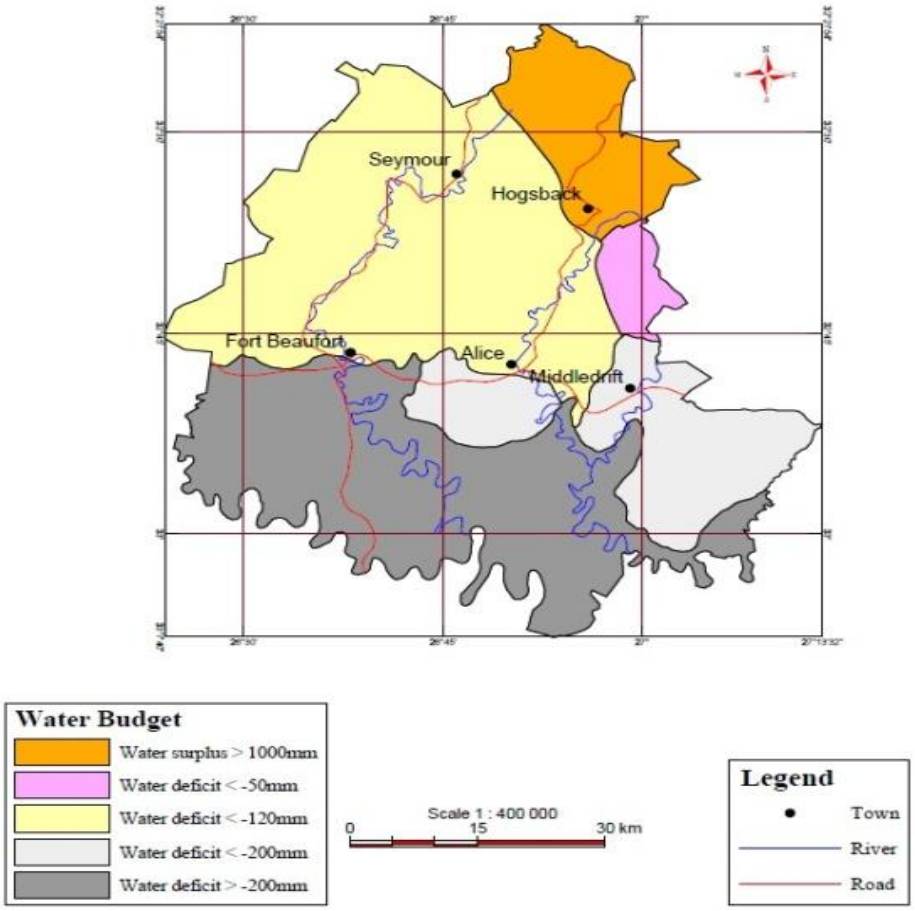

Fig.6.3 (c): Water budget maps of Nkonkobe Municipality

Effective soil moisture stored by the soils

The expected contributions by water reserves stored in soils were highest in the Oakleaf, Tukulu and Augrabies while the Bonheim, Arcadia and Shortlands made moderate contributions, with the Hutton and the Clovelly making the least contribution (Table 6.9).

Table 6.9: Effective soil moisture stored by the arable soils (ESWS)

Soil type	Effective rooting depth (mm)	Weighted % clay	ESWS (mm)
Oakleaf	1140	22.11	54.78
Augrabies	1080	33.73	48.21
Bonheim	513	22.01	42.31
Arcadia	969	46.70	40.41
Clovelly	561	41.80	25.40
Tukulu	1083	20.13	53.31
Shortlands	918	52.41	35.70
Hutton	561	59.53	23.30

Based on the soil moisture reserve figures from planting to maturity (Table 6.9) and the water budget figures (Appendix 6.1) the following important deductions could be made:

1. The Hutton and the Clovelly had the least contribution of the stored soil moisture reserves but were found in high rainfall areas that were characterized by huge water budget surpluses.
2. In the Amatola Basin the stored soil moisture reserves for all soils except the Clovelly and the Hutton were able to offset water deficits represented by the weather station at Lenye.
3. The stored moisture reserves calculated for all arable soils were not able to offset the water deficit in the Kat and Tyume Basins and the phenomenon was worse in the Middledrift and Sheshegu regions.

Generalized crop production potential

The major cropping areas for rainfed agriculture were found in the sub-humid Tyume Catchment and Upper regions of the Amatola basin (Fig 6.4). The majority of the Kat and Tyume Catchments and the Middledrift have limited suitability for rainfed agriculture. The mountainous Amatola and Katberg regions are suitable for forestry while some hilly and steep areas surrounding them are suitable for grazing. The arid regions south of the Municipality including Sheshegu and Breakfast Vlei are suitable for grazing only.

However, this is only a generalised map and does not show the suitability of individual crops, which could depict a very different picture to the one given by the generalised crop potential map. This necessitated a detailed crop suitability analysis of the test crops as indicated in the sections that follow.

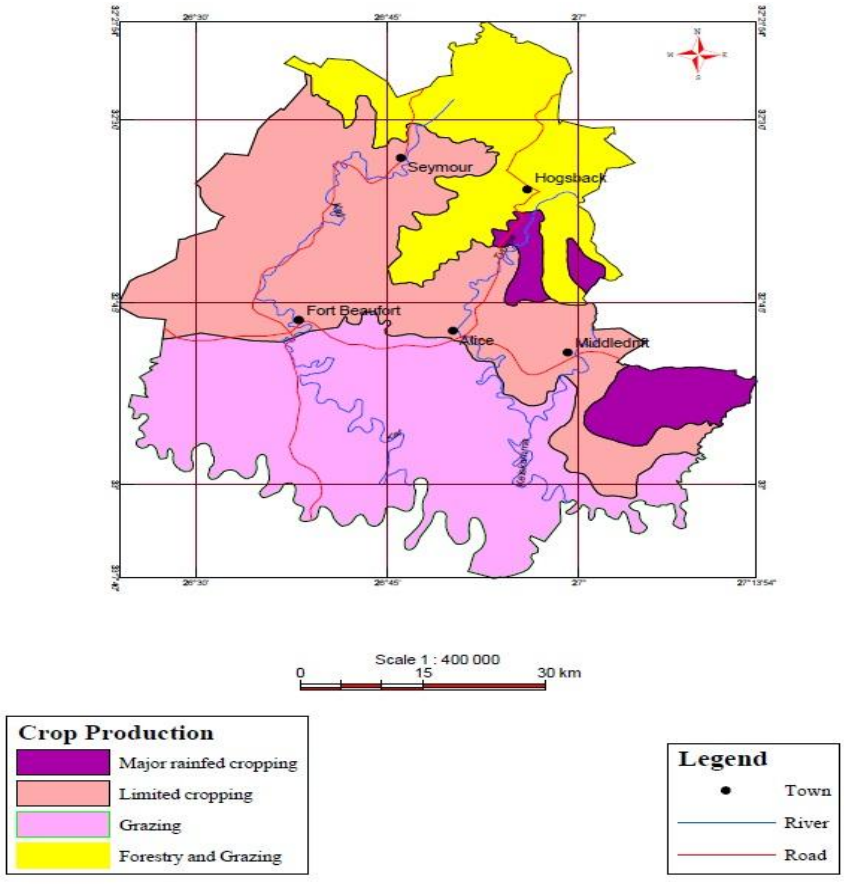

Fig. 6.4: Generalised crop production potential map of Nkonkobe Municipality

6.3.2 Crop Suitability

Maize

About 52 730 ha and 11 461 ha of the soils in the Municipality were moderately and marginally suitable for maize production respectively (Table 6.10). The Oakleaf and Augrabies, found along the Tyume and Kat river valleys, were moderately suitable (Fig 6.5a; Table 6.11). This is because their effective rooting depth had the best water storage capacities. In addition, they had low weighted clay content and were found on small slopes, factors contributing to better moisture storage. Such soils could be utilized in the marginal rainfall areas of the Kat and Tyume Catchments. Because of their alluvial origins, their soil fertility status is better than that of other soils. These soils were also given a good rating by farmers at Blinkwater because of their slope position, better fertility status and better workability (Chapter 4).

Table 6.10: Proportions of suitable soils in Nkonkobe Municipality (ha)

	Soil suitability class			
Crop	High suitable (S1)	Moderately suitable (S2)	Marginally suitable (S3)	Not suitable
Maize	0	52730	11461	307438
Potato	0	33881	30226	307438
Cow-pea	0	39301	24893	307438
Sorghum	0	52815	11376	307438

Table 6.11: The suitability classes of different soil forms found in Nkonkobe Municipality for selected crops under dryland conditions

	Maize	Potatoes	Sorghum	Cow-pea
Oakleaf	S2e	S2f	S2e	S2e
Augrabies	S2ne	S3ne	S2e	S2ne
Bonheim	S2e	S3se	S2e	S3se
Hutton (eutrophic)	S2f	S2sf	S2	S2s
Hutton (dystrophic)	S2f	S3sf	S2f	S2f
Clovelly	S2f	S3f	S2f	S2f
Shortlands	S2sf	S3s	S2f	S3s
Arcadia	S3se	N	S2e	S3se
Tukulu	S3w	S3w	S3w	S3w

S1= high suitability; S2= moderate suitability; S3= marginal suitability; N= not suitable
Limitations: e= erosion; f=fertility (organic matter, P, Zn); n= calcium carbonates; s= soil physical characteristics (clayey and fine sand textures); w= wetness (drainage)

The Shortlands and Bonheim were downgraded to moderately suitable because of their high clay content (Table 6.11). In lower rainfall areas of the Kat and Tyume catchments, soils with high clay content are less likely to be maintained at an optimum available moisture status (Smith, 1997). Verdoodt *et al*. (2003), in their studies at Ncera reported that the rainfall during the crop cycle was insufficient to replenish available water reserves in soils with large total available water capacities (i.e deep soils with high clay content). High clay content and the droughty nature of these soils were the main reasons for farmers' low suitability rating of the Shortlands in Upper Ncera and Arcadia in Blinkwater. This assertion was also supported by ethnopedological findings in Chapter 4 where farmers at Ncera cited that these soils were droughty and therefore difficult to cultivate and hence, the lower potential rating. The local people, however, considered

the red soils (Shortlands/ Nitisols) to have lower potential than the black (Arcadia/ Vertisols) soils although both soils are very clayey because the Arcadia forms have a self mulching surface, thus making them easier to cultivate than the Shortlands and better for soil fertility management (Chapter 3).

In the sub-humid regions of the Upper Ncera, where rainfall was higher (700-900 mm), Van Averbeke and Marais (1991) reported the best maize yields (7000 kg/ ha) than any other red soils including the Hutton in the humid Amatola mountain regions. This is because the soils were able to remain at field capacity thereby providing a constant supply of water to the maize plant.

The dystrophic Clovelly and Hutton soils in the humid Amatola Mountain region were moderately suitable but had serious soil fertility limitations as indicated by soil fertility analyses (Appendix 5.3). Yields have been found to be lower than in the sub-humid regions mainly because of high acid saturation and low phosphorus. High acid saturation restricts root development due to aluminium toxicity (FSSA-MVA, 2007). The other major limitation in the Amatola Mountains was the terrain (steep slopes) which resulted in reduced water infiltration, effectively limiting stored soil moisture levels (Van Averbeke and Marais, 1991). In addition, the use of farm machinery is restricted; hence, the steep slopes were normally reserved for forestry (Laker, 1978).

The Middledrift and other areas south of the Municipality were dominated by unsuitable shallow soils, except along river channels where portions of moderately suitable soils were found. High erodibility and restricted root development due to shallow depth were the main limitions on Glenrosa and Swartland soil forms. These soils had shallow effective depth to support plant growth as well as low water storage capacities.

Climate

About 250735 ha and 121815 ha of the land experienced high and marginal temperature suitability respectively (Table 6.12). Maize is highly suitable in the 67/25 and 77/35 Ehlers temperature zones, spatially located in the Tyume and Kat River Catchment, Middledrift, Alice and Sheshegu areas but moderately suitable in the 46/15, 46/14 and 57/25 temperature zone found in the cooler Amatola Mountains (Fig. 6.5b; Table 6.13).

Table 6.12: Proportions of temperature and water budget suitability (ha)

	Ehlers Zones			Water budgets		
Crop	High suitable (S1)	Moderately suitable (S2)	Marginally suitable (S3)	High suitable (S1)	Moderately suitable (S2)	Marginally suitable (S3)
Maize	250734.71	121815.04	-	32581.62	10110.40	149042.05
Potato	121815.04	60035.02	-	32581.62	10110.40	149042.04
Cow-pea	-	372550.75	-	191734.16	57051.93	122518.86
Sorghum	-	250 734.71	-	191734.16	15795.98	122518.86

Table 6.13: Crop adaptation to the Ehlers agro-ecological zones 46/14, 46/15, 57/25, 67/25 and 77/35

46/14	57/25	67/25	77/35
Maize[3]	Maize[3]	Maize[1]	Maize[1]
Potatoes[1]	Potatoes[1]	Potatoes[2]	Potatoes[N]
Sorghum[N]	Sorghum[N]	Sorghum[2]	Sorghum[2]
Cowpea[1]	Cowpea[1]	Cowpea[1]	Cowpea[1]

Source: Burger (1983) 1=High; 2= Moderate; 3=sub-optimal; 4=marginal; N= not suitable

The cooler Amatola Mountains (32582 ha), received summer water surpluses but the temperatures, though moderately suitable, did not provide the best conditions for maize cultivation. Parts of the Amatola Basin covering about 10 110 ha had moderate (S2) temperature suitability.

Water deficits in the sub-humid Amatola Basin and areas below the Hogsback Mountains were low. The recorded smaller summer water deficits were compensated for by the utilization of water reserves stored in the soils. About 149 042 ha of the land in the Upper Tyume, Mt Pleasant View and Seymour, with a higher water deficit (>100 mm) were marginally suitable for rainfed maize. About 179571 ha of the area South of the Municipality, around Dank Den

Goewerneur and Sheshegu had severe summer water deficits (> 200 mm) with the highest monthly deficits in the critical month of January(Fig. 6.5c; Table 6.14).

Table 6.14: Crop adaptability to water budgets

	Crop suitability based on water budgets			
Unit	Maize	Potato	Cow-pea	Sorghum
Kat (Seymour)	3	3	1	1
Amatola(Evelyn Valley)	1	1	1	1
Tyume (Mt Pleasant View)	3	3	1	1
Amatola Basin (Lenye)	2	2	1	1
Alice (Garfield)	4	4	2	2
Middledrift	4	4	2	2
Dank Den Goewerneur	4	4	3	3

1= high; 2= Moderate; 3= Marginal; 4= not suitable

Maize requires a minimum rainfall amount of 500 mm (Smith, 1997) and arid climatic zones in the Middledrift, Lower Sheshegu and South of Alice, with high evapotranspiration experience huge water deficits, making such areas unsuitable for maize production. In addition, the arable soils were not able to store enough water to supply the crop in times of water stress. Ultimately the high evapotranspiration and low rainfall in arid zones made these areas unsuitable for rainfed agriculture including rainfed maize production.

The temperature plays two contrasting roles: the positive being the enhancement of metabolic processes such as photosynthesis leading to increased biomass, while the negative is increased evapotranspiration, causing huge water deficits.

Despite a more favourable rainfall regime (>500 mm) in the Kat and Tyume Catchments, the high evapotranspiration made such areas marginally suitable for rainfed maize production. The soil moisture reserves were not enough to offset the water deficits and to supply the plant with adequate water. The long dry spells in mid-January also exacerbated the problem.

The overall land suitability evaluation for maize crop in the Municipality showed that about 2 331 ha and 50 055 hawere moderately and marginally suitable respectively (Table 6.15). Although maize was the main crop (Chapter 3), it was the least suitable (in terms of area) of all the tested summer crops. Overall, Van Averbeke and Marais (1991) reported a very marginal maize yield (< 1053 kg/ ha) in semi-arid regions because of shallow effective rooting depth, low plant populations, low rainfall and stored moisture reserves. However, in Oakleaf soils, the average yield was 3093 kg/ha because the soils were able to store more water and therefore capable of supporting higher plant populations. However, in Shortlands, in semi-arid region, slightly unexpected findings were observed, where higher yields were obtained despite of the droughty nature of the soil. This was attributed to the fresh rock and perched water table which were able to provide water to the roots (Van Averbeke, 1991). To optimise maize production on arable areas in the arid and semi-arid regions, irrigation should be introduced. Soil fertility should also be monitored especially phosphorus, nitrogen and zinc, the common deficient nutrients (Mandiringana*et al*., 2005). If irrigation services were provided, large tracts of marginal land with suitable soils could be brought back to cultivation. Examples are the irrigation schemes at Fort Hare Agri-Park and along the Kat River, where people's lives have been transformed as a result of irrigated agriculture. The areas around Middledrift and Sheshegu were unsuitable both on the basis of climate and soils (Fig.6.6).

Table 6.15: Proportions of overall crop suitability of the test crops

	Overall suitability			
Crop	High suitable (S1)	Moderately suitable (S2)	Marginally suitable (S3)	Suitability ranking
Maize	0	2331	53 055	6
Potato	0	7 887	32 75	5
Cow-pea	0	37 641	25080	2
Sorghum	0	15 581	6 603	3

(a) (b) (c)

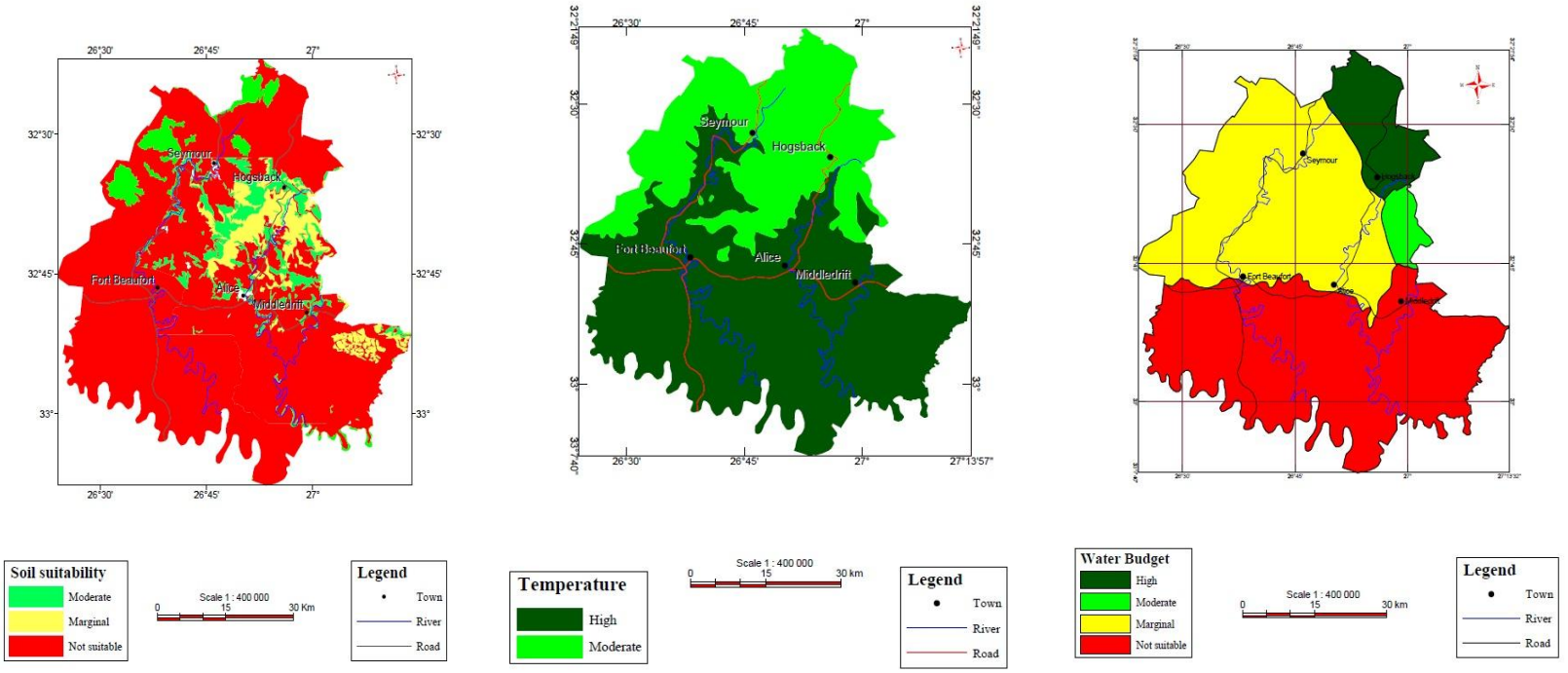

Fig.6.5: (a) Soil suitability (b) temperature suitability and (c) water budget maps of maize crop for Nkonkobe Municipality

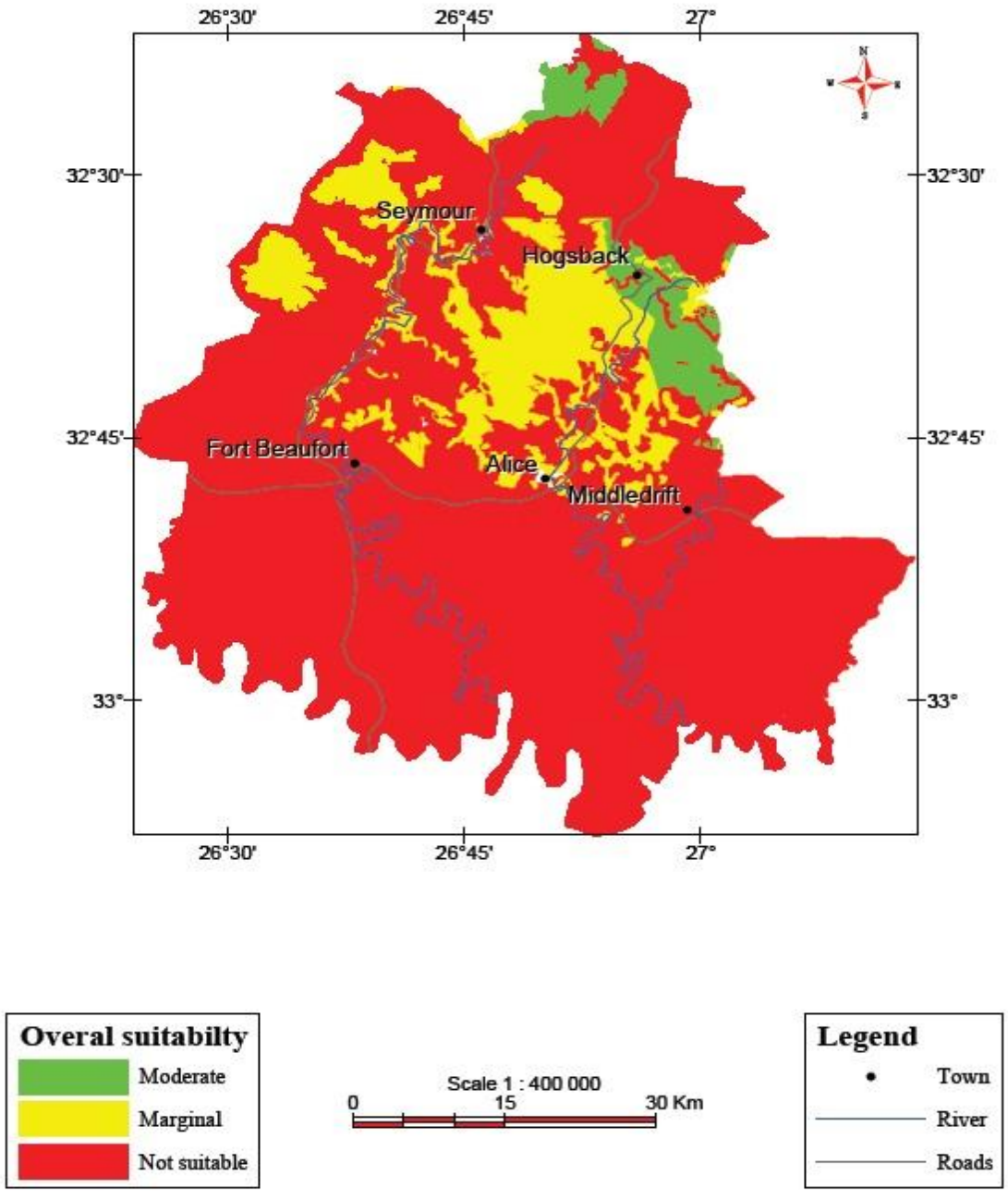

Fig.6.6: Land suitability map for maize

Cow-pea

Soil suitability for cow-pea production in the Municipality was moderate on 39 301 ha and marginal on 24 893 ha (Table 6.10). The moderately suitable soil forms (Oakleaf and Augrabies were limited by poor fertility (low P and Zn, organic matter and nitrogen) and the risk of soil erosion (Table 6.11). They were mainly found on alluvial soils in the Tyume and Kat river valley (Fig. 6.7a). The Bonheim, Arcadia, Shortlands, Hutton and Clovelly were severely restricted by high clay content which restricts root development. Severe acidity was a huge limitation in the dystrophic Hutton and Clovelly soil forms in the humid Amatola Mountains. Many cow-pea varieties are sensitive to the high acidity, high soluble aluminium and low base status, which characterise the high rainfall areas (FSSA-MVSA, 2007).

The highly crusted soils of the Municipality could create serious germination problems. In their study on sunflower, huge yield reductions were reported due to the 'neck-break effect', a condition where a delicate small plant breaks at germination as the plumule forces its way through the crust. Similarly, this could be a problem during germination of the cow-pea.

According to the Ehlers temperature zones, the cow-pea is highly suitable in all zones (Table 6.13; Fig. 6.7b), while the crop is also able to withstand the severe water deficits in the dry and semi-arid regions of the Municipality (Fig.6.7c). Cow-pea is a heat-loving and drought tolerant crop (Van Rensburg *et al*., 2007) but is also adaptable to cooler and high rainfall areas (NDA, 2011). It is this excellent adaptability to a wide range of climatic conditions and the presence of many varieties that makes this crop highly suitablefor the climate of the NkonkobeMunicipality.

Overall, the cow-pea was the most suitable crop with about 37 641 ha and 25 080 ha of area having a moderate and marginal suitability rating respectively (Table 6.15). The areas with moderate cropping suitability were found in the Kat and Tyume river valleys and the Amatola Basin (Fig. 6.8). The areas around Middledrift and Sheshegu were not suitable because of shallow soils. Cow pea is suitable in the arid regions of Middledrift and semi-arid regions of the Kat and Tyume River valleys, as well as the sub-humid and humid climate of the Amatola Mountains and their surroundings. Varietal selection is important in the production of cowpeas. Drought resistant varieties could be grown in the semi-arid and arid regions of the Municipality

while those adaptable to cooler climates could be grown around the Amatola Mountain Regions provided the soils are limed to increase soil pH.

While the cow-pea was never the main crop in the Nkonkobe Municipality (Chapter 3), it has been grown successfully in other former homelands in Limpopo and Mpumalanga (Van Rensberg *et al.*, 2007). Since farmers in this Municipality have shown an interest in growing this crop, it could be tested. Already researchers in this region have started cropping programs that include the determination of its nutritional value and use as an intercrop (Adeyemi *et al*., 2012; Musunda, 2010). These findings could stimulate interest among farmers and researchers who have been sceptical about this crop.

(a) (b) (c)

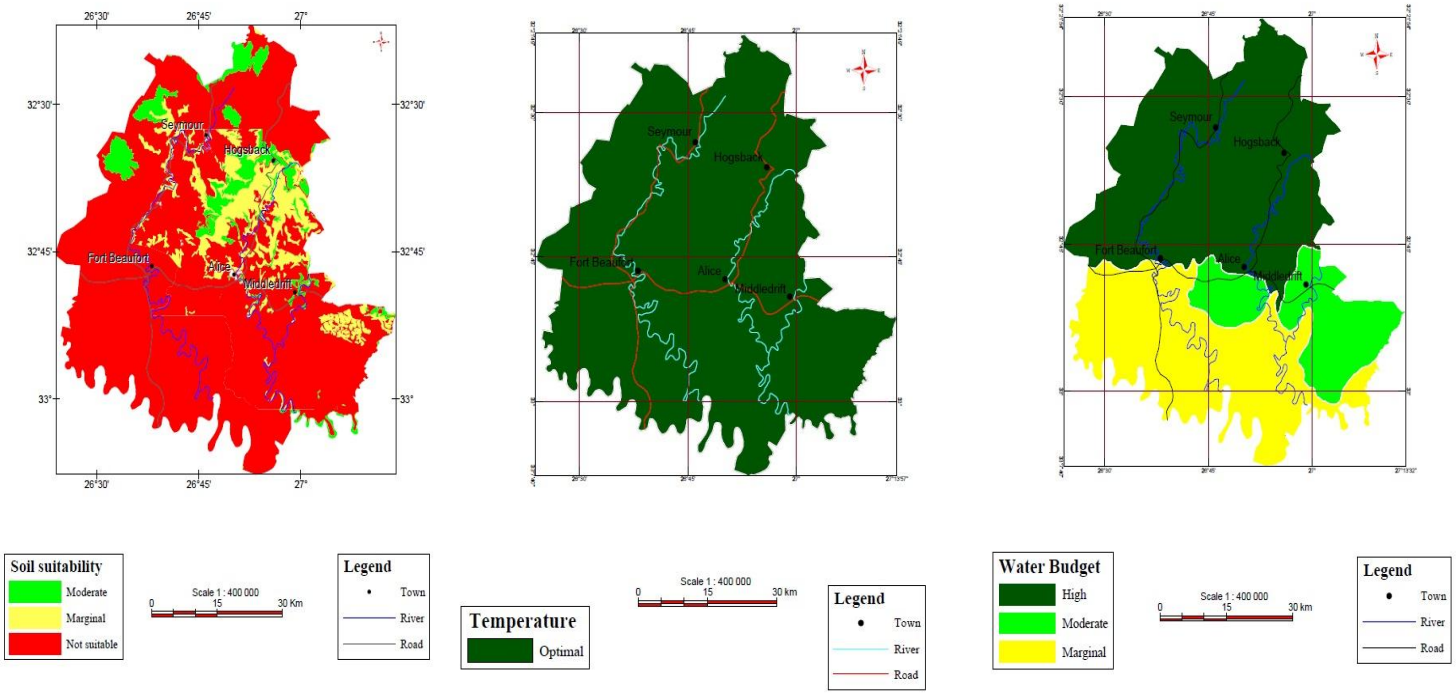

Fig. 6.7: (a) Soil suitability (b) temperature suitability and (c) water budget maps for cowpea in Nkonkobe Municipality

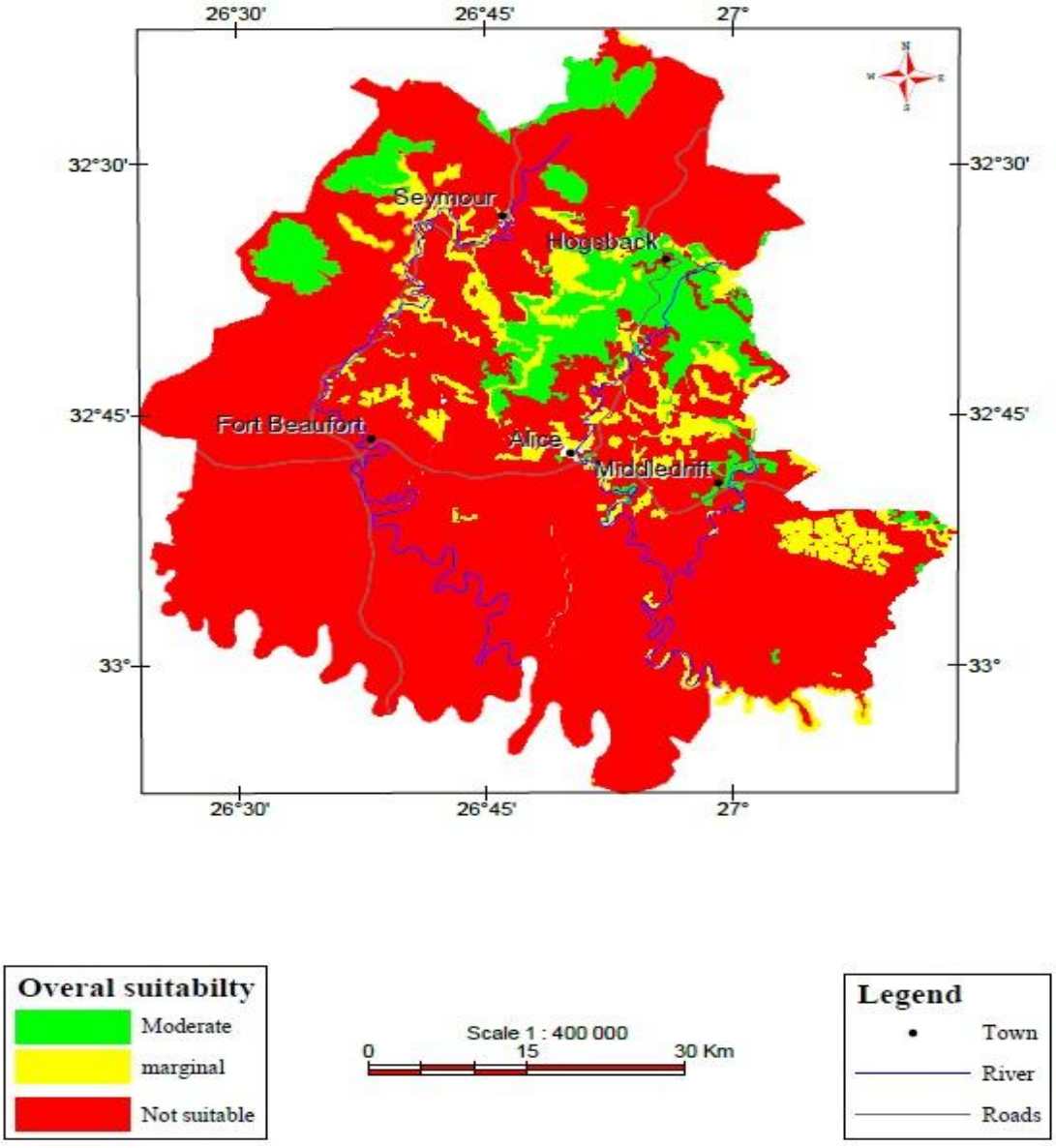

Fig.6.8: Land suitability map for cow-pea

Sorghum

Sorghum had the largest proportion of suitable soils in the Municipality because the crop can adapt to a wide range of soils. A soil suitability evaluation showed that about 52 815 ha and 11 376 ha of the soils were moderately and marginally suitable respectively (Table 6.10; Fig. 6.9a). Soil fertility and high acidity, in the case of Hutton, Clovelly and Shortlands and susceptibility to erosion in Oakleaf, Augrabies, Bonheim and Arcadia were the main limitations (Table 6.11). Morphologically, sorghum is adapted to drought conditions because of (i) its small leaf area per plant which limits transpiration and (ii) a finely developed root system efficient in extraction of water from soils. This improves sorghum's adaptability to soils with high clay content such as Arcadia, Shortlands, Hutton, Clovelly and Bonheim. In addition, the crop also has (iii) leaves which fold up efficiently in warm temperatures; (iv) the stomata closes up easily and there is a waxy layer protecting the plant against desiccation (Du Plessis, 2008) and (v) the crop can enter into a state of dormancy during dry spells and re-generate after rains (Van Averbeke and Marais, 1991). Sorghum is also tolerant to salinity; hence, it could be grown on Augrabies soil with high levels of carbonates.

The major soil constrains were the low reserves of organic matter, P and nitrogen (Van Averbeke and Marais, 1991). The marginal suitability of sorghum caused by high acid saturation and poor soil fertility was evidenced by the drop in reported yield at Hogsback (Van Averbeke and Marais, 1991). Sorghum was highly suitable (122 518 ha) in the 77/35 Ehlers temperature zone, moderately suitable (13443 ha) in the 67/25 but not suitable in 46/14, 46/15 and 57/35 zones (Fig. 6.9b; Table 6.12). Water deficits were not limiting but there was marginal water adaptability in Sheshegu, Middledrift and Alice units (Fig.6.9c).

The crop was the second most suitable of the tested crops in the Municipality. Overall suitability was moderate (15 581 ha) in sub-humid and semi-arid regions around the Tyume and Kat rivers marginal (6 603 ha) in arid regions at Middledrift and Upper Ncera but not suitable in Hosgback and other cooler areas (Table 6.15; Fig.6.10) because of low temperatures. Van Averbeke (1991) reported that sorghum yields in alluvial soil in sub-humid areas were the highest (3 530 kg ha^{-1}) and marginally higher than the red soils of Upper Ncera (3 280 kg ha^{-1}) and the Oakleaf soil forms in the semi-arid Tyume valley (2 322 kg ha^{-1}). On Hutton and Clovelly soils found in

humid areas, yields dropped to 2 000 kg ha^{-1}. The sub-humid climate and eutrophic soils of the Amatola Jozini ecotope contributed to the highest yield while yield reduction in Tyume Valley ecotope was due to reduced rainfall. In the humid Amatola Mountains, soil acidity and cold temperatures were responsible for yield reduction

In arid regions of the Middledrift, sorghum is not suitable because of shallow soils (Department of Agriculture, 1975) that cause restricted root growth. Perhaps the major drawback for sorghum production is bird damage risk. Verdoodt *et al*. (2003), in their studies in Upper Ncera, reported that the entire sorghum crop was destroyed by birds. Early planting would ensure that sorghum is fully mature before migratory birds reach this region. Van Averbeke and Marais (1991) reported a 28% reduction in sorghum yield as a result of deferred planting. In the Municipality it is recommended that sorghum be planted in September or during early rains in October (Burger, 1983).

Historically, sorghum was grown successfully and was once the second most important cereal crop in the region (Taylor, *undated*) but it has since been abandoned because of labour shortages, bird damage and lack of interest (Chapter 3). Because of the favourable biophysical characteristics, this crop could match production levels in the Free State and Mpumalanga, two important sorghum producing areas in South Africa (Du Plessis, 2008). Beverage companies through contract farming could take a lead in revitalising production and marketing, as this has proved successful in other African countries where sorghum is cultivated (Taylor, *undated*). Sorghum has the potential to drive the Nkonkobe economy if appropriate decisions and promotions are made.

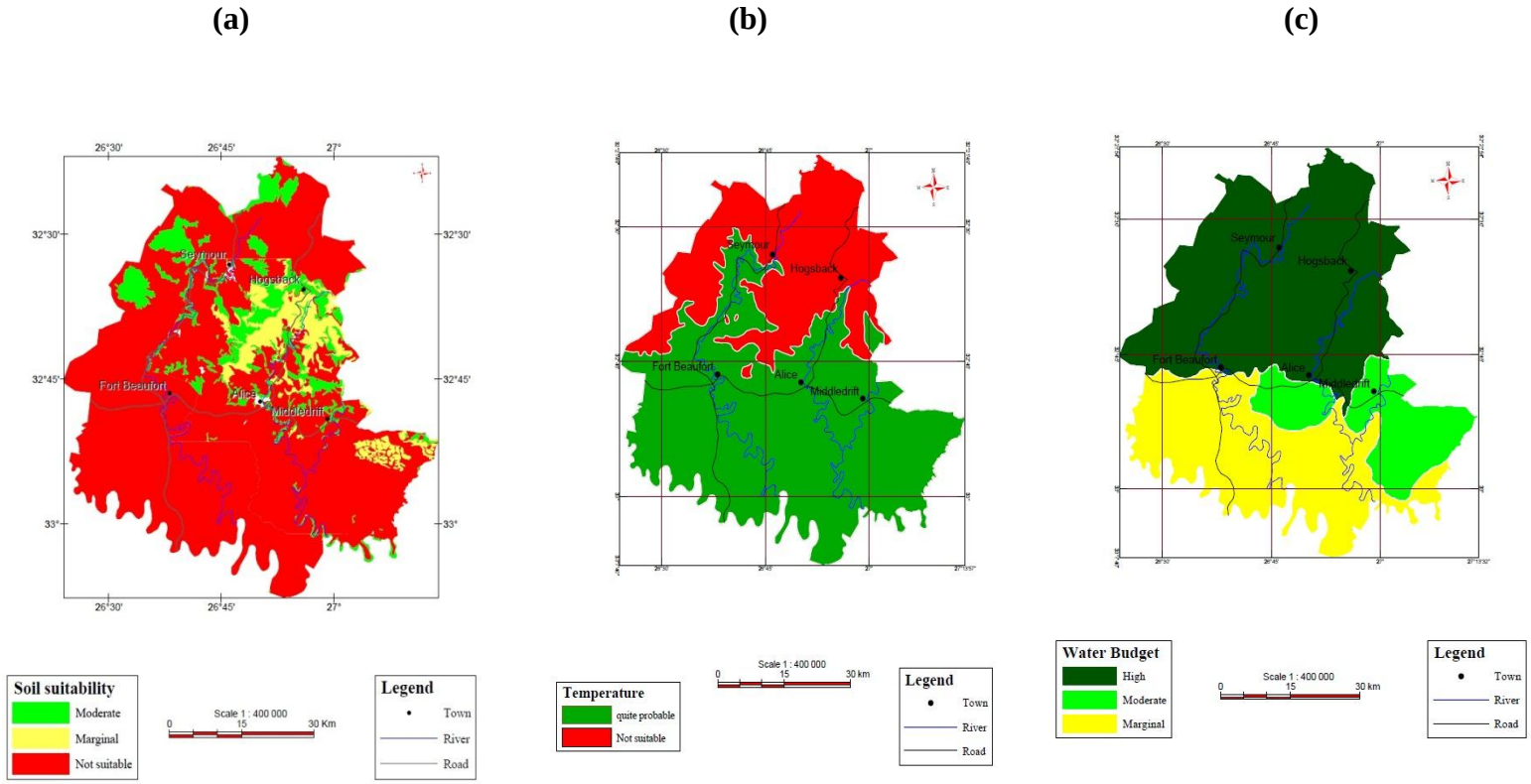

Fig. 6.9: (a) Soil suitability (b) temperature suitability and (c) water budget maps for sorghum in Nkonkobe Municipality

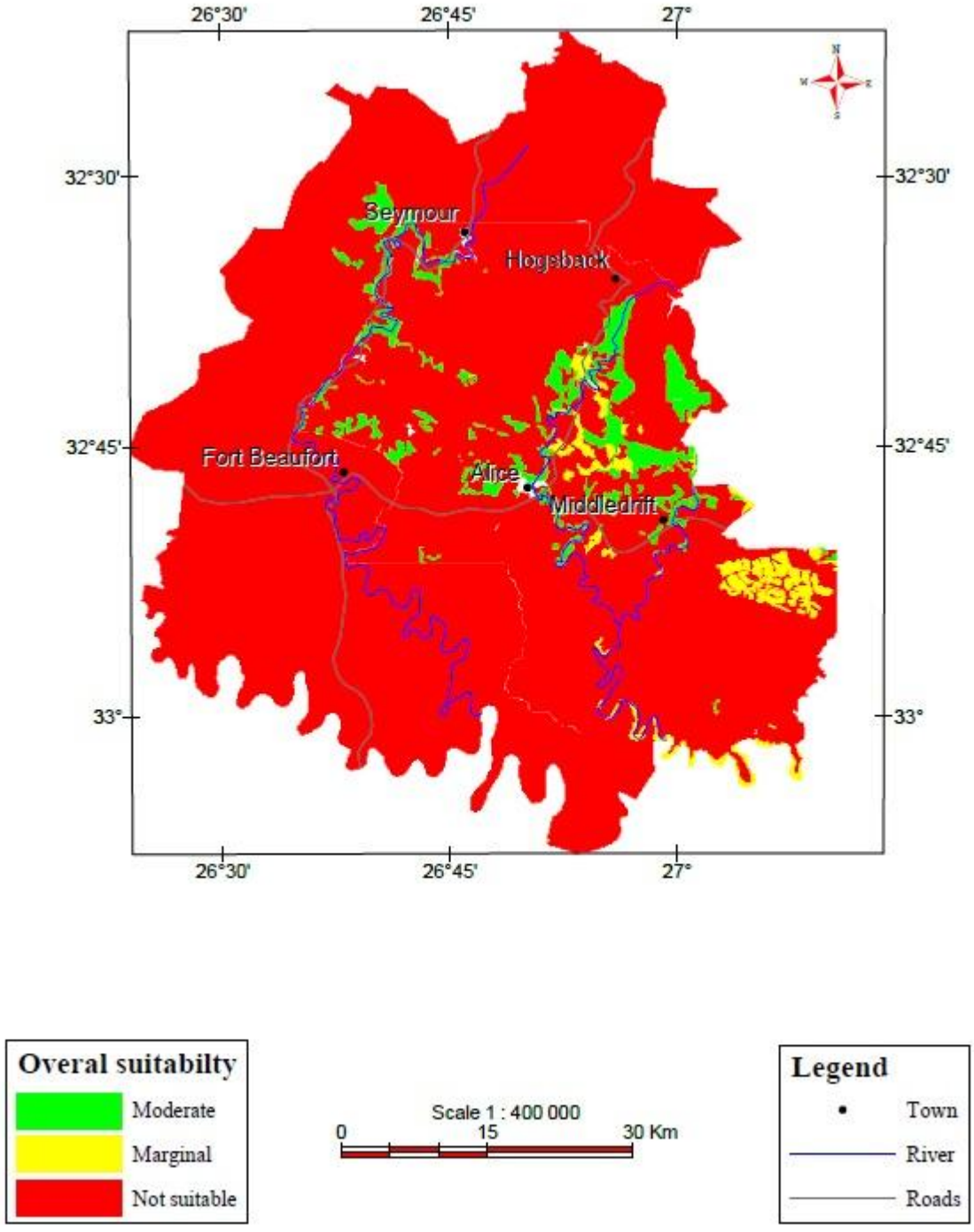

Fig. 6.10: Overall land suitability map for sorghum

Potato

In the Nkonkobe Municipality, 11 403 ha and 44 218 ha of the soils showed moderate and marginal suitability respectively (Table 6.10). The alluvial Oakleaf and Augrabies soils in the Tyume, Kat and Keiskamma river valleys were moderately suitable for potato production (Fig.6.11a). While low clay content made Oakleaf soils favourable for potato production, susceptibility to erosion in Oakleaf and high carbonate levels in Augrabies, which reduces yield due to bicarbonate toxicities, were the main limitations (FSSA-MVSA, 2007).

Clayey soils such as Arcadia, Shortlands, Hutton and Clovelly create problems when uplifting the potatoes while large clods interfere with sorting of tubers (Smith, 1997). Van Averbeke and Marais (1991) stated that mudstone and shale derived soils tended to become extremely hard and compact when dry making uplifting of potatoes difficult. The pruning effect in Arcadia soils reduces the grading value for commercially produced potato. The areas around Middledrift and Sheshegu were not suitable because of shallow soils, low P and organic matter.

Potato was highly adapted in the 46/ 14, 57/25 and 67/35 Ehlers temperature zones found in the Amatola Mountains and semi-arid areas around Tyume and Kat River Catchment respectively, but not suitable in the 77/35 temperature zone found in Middledrift and Alice and Sheshegu areas (Table 6.13; Fig. 6.11b). Production of potato is restricted to summer because of severe frost in winter.

A good potato crop response/ adaptability to water budgets was confined to the Amatola basin and the humid Amatola Mountains (Table 6.14; Fig. 6.11c). The crop was highly suitable in the humid Amatola Mountains, which received summer water surpluses and moderately suitable in lower parts of the Amatola Basin where water deficits were < 50 mm but marginally suitable in the high water deficits (approximately 100 mm) around Upper Tyume, Mt Pleasant View and Seymour. Stored water utilization could however make rainfed agriculture attainable. The areas around Middledrift, Alice and Sheshegu had severe summer water deficits rendering potato rainfed production unsuitable. Smith (1997) reported that an acceptable yield could be obtained where rainfall is between 500 and 700 mm, which is the typical rainfall range for the semi-arid Tyume and Kat River Catchments. However, the 67/25 and 77/35 Ehlers' temperature regimes and huge water deficits prevailing in this area are major constraints to the physiological

development of the crop. Therefore, the semi-arid and arid regions are not suitable for rainfed potato production. Optimum yield is obtained at rainfall > 800 mm accompanied by low evapotranspiration; hence the cool sub-humid and humid areas of the Amatola Mountains are highly suitable. However, these areas are prone to frost and planting dates should be selected in such a way that the crop reaches maturity before the winter frost. Results from potato trials conducted in the Amatola Basin showed that the highest yields were obtained for early spring planted potato. These are harvested in April before the frost prone winter (Burger, 1983).

Compared to other test crops in this study, potato was ranked third in terms of suitability. The overall crop suitability showed that 7887 ha were moderately suitable and 3276 ha were marginally suitable (Table 6.15). The areas with moderate crop suitability were found in the Amatola Basin and the Amatola Mountains (Fig. 6.12). Rainfed potato production was severely restricted in the Kat and Tyume river valleys and practically impossible in areas around Middledrift and Sheshegu.

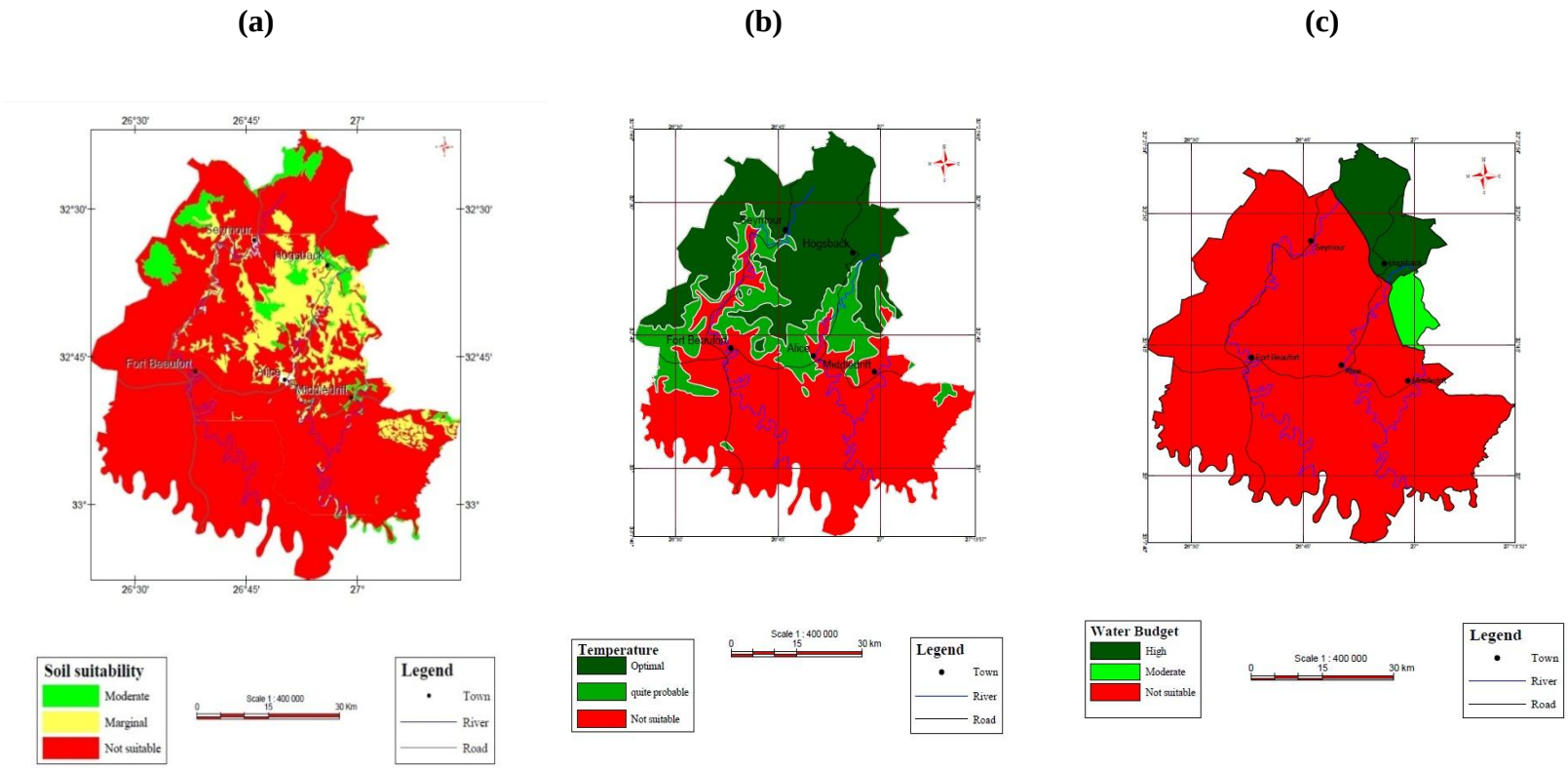

Fig. 6.11: (a) Soil suitability (b) temperature suitability and (c) water budget maps for potato in Nkonkobe Municipality

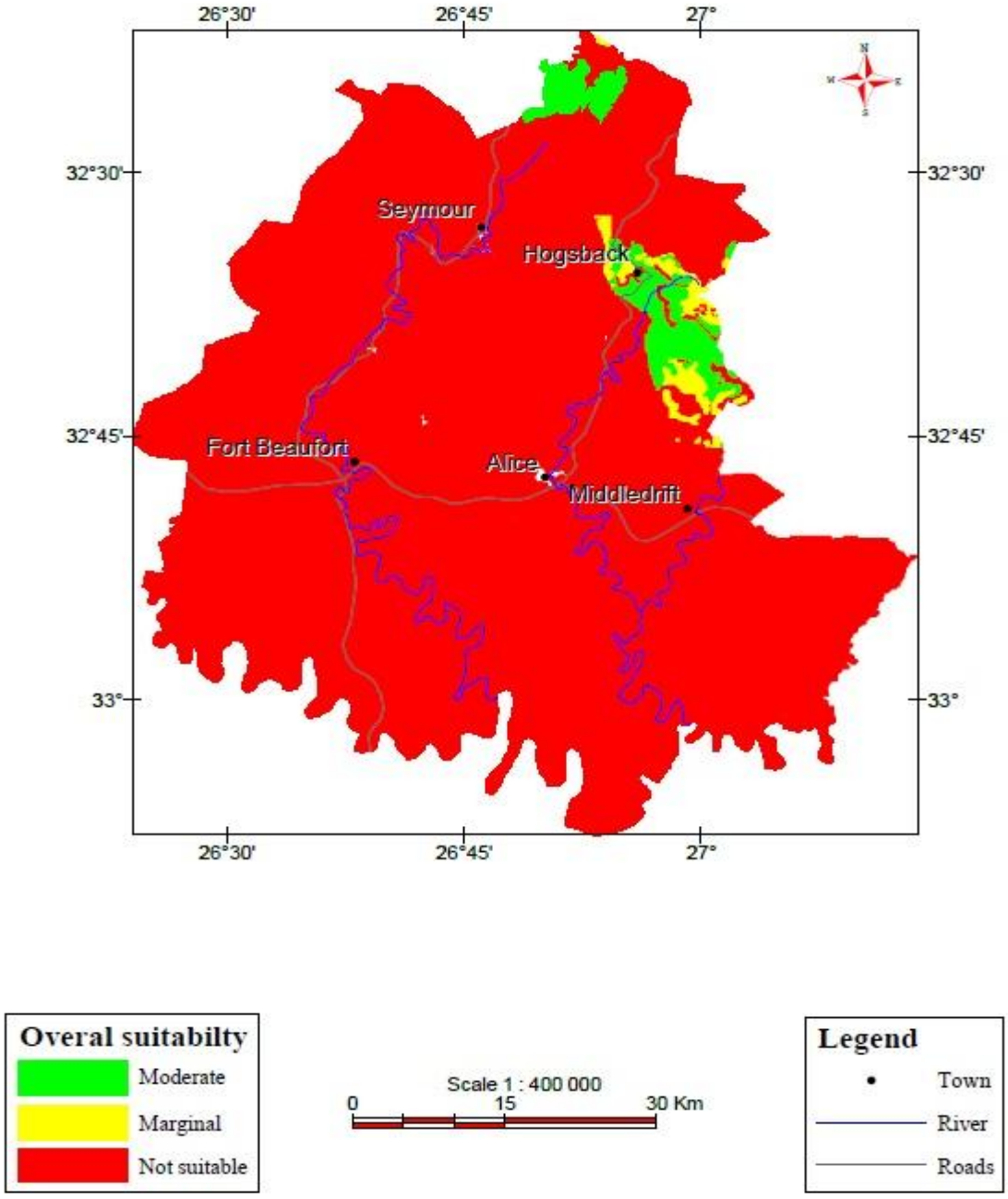

Fig.6.12: Land suitability map for potato

General remarks

Current crop choices were driven by farmers' preferences and not their suitability to the biophysical characteristics in the Municipality. Those crops that were the most suitable were the least cultivated while the least suitable were the most cultivated.

Maize and potato were the major crops grown in the Municipality (Chapter 3) yet the area suitable for the rainfed production of these crops is low. For maize, the high farmers' preference is not surprising as it is the country's staple food and farmers would strive to grow this crop for food security even when biophysical conditions are limiting, while potato fetches good prices and is grown mainly as a source of income for the farmers.

It is important to note that these evaluations are based on general rainfall requirements of the crops per growing period, which is normally taken as October to March. The relative variability of monthly rainfall is far greater than the annual rainfall. This calls for good agronomic practices such as early planting, awareness of the peak moisture demand stage and an understanding of strategies to mitigate rainfall unreliability. Burger (1983) suggested that all production techniques should be aimed at conservation of moisture to guarantee successful production. Conservation agriculture has been prioritized bythe University of Fort Hare, Agricultural Research Council (ARC) and other institutions are currently doing research on conservation agriculture practices, which can make a contribution to crop production for the Nkonkobe Municipality.

A limitation of the study was the absence of quantitative data on crop responses to the different water budgets. In this regard, further studies to quantify test crop responses to different water budgets in the Municipality need to be carried out. It must be emphasised that the resource maps and evaluations are on a very broad scale (lack detail) and indicate promising areas where these crops can be grown. If development in any such areas is considered, detailed resource surveys (large scale) and land suitability must be done at those high potential sites.

6.4 Conclusions and recommendations

- About 61 200 ha which is only 20% of the whole Municipality was suitable for cropping. Areas delineated for cultivation were found on alluviums along the Tyume, Keiskamma and Kat rivers and the Middledrift occupying about 24 450 ha. Other areas of good potential include those that are under Shorlands, Clovelly and Hutton covering a combined total of 25 160 ha on dolerite sills of Upper Ncera and the Katberg and Hogback mountains.

- In view of such scarcity of arable land, there is need to maximize crop production in those areas with high potential.

- Cowpeas and sorghum were the most suitable crops in the region. Cow-pea can be grown in less clayey soils along river valleys of the Tyume, Kat and Keiskamma River Valleys but moderately suitable in humid areas of the Amatola Region. Sorghum was suitable in semi-arid and arid areas of the Municipality including the Keiskamma, Kat and Tyume River catchments and not suitable in the cooler Amatola Mountains.
- Maize and potato production was suitable in selected areas of the Municipality. Maize was moderately suitable in sub-humid to humid areas of the Hogsback and Katberg highlands but marginally suitable in the Tyume and Kat River catchments. Potato is suitable in humid areas of the Amatola Region. The two crops were the least hectarge of land suitable for rainfed agriculture.
- The prime land should be used judiciously while unsuitable land should be protected from erosion. Cultivation should be discontinued on some unsuitable land that is currently being cultivated.

- A more detailed analysis of the economic suitability is therefore recommended for future studies.
- Furthermore, since rainfall was one of the major limiting factors, the suitability of the test crops under irrigated conditions needs to be established.

CHAPTER 7

GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

Crop production in Nkonkobe District Municipality, in the former Ciskei homeland, is low due to abandonment and/ or underutilization of large pieces of potentially productive land. The Municipality set a growth target in agricultural production of 10% by 2011 (IDP, 2008). Achieving this target requires an understanding of the causes of the currently low levels of production and land utilization. The causes of low production could be understood better by using participatory and scientific approaches to subsequently identify, delineate and evaluate the land, through the assessment of biophysical, cultural and socio-economic factors affecting crop production. The main objective of this study was to use an integrated approach to determine reasons for low crop productivity and land abandonment in order to identify and delineate land with potential for cropping in Nkonkobe Municipality. The approach was divided into four phases, namely: (i) the use of farmers' perspectives to evaluate potential problems related to arable cropping; (ii) ethnopedological and participatory mapping of soils in the area; (iii) using scientific approach to determine effects of climate and parent material on critical soil factors causing land degradation and abandonment and (iv) the development of guidelines that could be used to delineate arable land for crop production and subsequent land evaluation for the suitability of maize, potato, sorghum and cowpea.

Arable land for crop production constituted 61 200 ha and a large proportion of it was found on alluviums along the Tyume, Keiskamma and Kat rivers. The alluvial soils constituted the high potential Oakleaf and Augrabies that cover about 24 450 ha in the Tyume, Kat River and the Middledrift. Other areas of good potential included those that are under Shorlands, Clovelly and Hutton covering a total of 25 160 ha on dolerite sills of Upper Ncera and the Katberg and Hogback mountains. This study revealed that more than half of the arable land was not utilized for crop production and that more than 75% of such land was completely abandoned. Based on the farmers' responses, 75% of this land was completely abandoned (Chapter 3), and this translated to almost 45 900 ha of potentially arable land in the Municipality being abandoned. As such huge tracts of land, that could be used to meet the Municipality's set target if full production in those lands was attained, could be lying idle.

While the general reasons given by farmers for abandonment of land in the Municipality were mainly shortages of farm machinery, land degradation and unfavourable climate, the impact of these could vary between localities due to differences in climatic conditions and soil types within the Municipality. The main reasons for abandonment in the Tyume, Kat river valleys were financial mismanagement and absentee farmers (Chapter 3). Figures released suggest that the Tyume River and the Kat River areas, lost about 205 000 citrus trees, an equivalent to some 730 ha (Page, 1982). If production was brought to full potential in collapsed farms the economy of the Municipality could improve, considering that 75% of the produce is exported and given the devaluation of the rand against other currencies, which results in firming of export prices. These figures alone could go a long way towards achieving the 10% growth target.

Understanding the reasons for land abandonment and low productivity of the land required the integration of indigenous knowledge systems and scientific approaches, which highlighted the complementary benefits that could be derived from using the two systems. Farmers identified the conventional role of rainfall and temperature, which agreed with the strong correlations between land abandonment and low rainfall. They understood the role of climate in terms of the physiological crop water and temperature requirements. However, the role played by climate and parent material in pedogenesis and erodibility of soil, did not form part of the indigenous knowledge, possibly due to lack of knowledge of soil forming factors. The roles of climate and parent material on erodibility of soils were later revealed in scientific studies.

The inclusion of the role of climate on erosion has managed to solve some unanswered questions which were previously raised by other researchers in the same Municipality. One important biophysical factor responsible for land abandonment was found to be erosion. Weaver (1989) could not explain why the degree of erosion decreased as the amount of rainfall increased while D'Huyvetter (1985) concluded that slope gradient and fine sand fractions were entirely responsible for erosion in the whole Municipality. The findings by D'Huyvetter (1985) could not explain the stability of the soils in the wetter areas as observed by Weaver (1989). In the current study the increased stability of soil was mainly influenced by secondary clay minerals and iron oxide which increases with increased rainfall (Chapter 5; Smith, 1990). Parent material influenced the fine sand fractions, and these fractions and slope gradient were responsible for

erosion only in arid and semi-arid regions of the Municipality. In humid areas, the secondary clay minerals overrode all the other factors, which explain the observations of Weaver (1989). Soils from mudstone and shale and dolerite in humid areas were not erodable at any slope gradient, due to stabilization by secondary minerals. These soils were among the soils with potential for crop production in the Municipality, with suitability of the crops being limited by temperature requirements.

Indigenous knowledge of the farmers in the Municipality revealed a good understanding of the soil degradation, particularly erosion problems which correlated well with scientific findings. The farmers were able to clearly distinguish between highly erodible and stable soils, as well as fertile soils but were unable to give explanations. Farmers identified the *santi* soil type, an indigenous equivalent for 'sands', as the main soils that were highly erodible. A clear distinction was made by the farmers in terms of the use and erodibility of the *santi* soils. On one hand, the farmers recognized that the *santi* derived from consolidated parent material were highly erodible and low in potential while those derived from unconsolidated parent material on river valleys had higher potential. The corresponding soil forms in scientific terms for the *santi* formed from consolidated parent materials were Swartland, Glenrosa, Klapmuts, Sterkspruit, Estcourt and Valsrivier formed from shale and mudstone, which were found to be highly erodible, particularly in the arid and semi-arid areas. While indigenous knowledge systems could not give proper scientific explanations for the high erodibilities of these soils, follow up scientific work established that the erodibilities were influenced by the 'fine sand fractions', which mainly included very fine sand, fine sand and fine sand plus very fine sand, high contents of clay size quartz and high ESP. These findings were in agreement with D'Huyvetter (1985), who attributed erodibility of soils to fine sand and silt, Na and slope of the same semi-arid to arid areas. Due to the dry environment in arid and semi-arid regions, leaching was minimal, and in the soil derived from shale and mudstone Na remained in the soil system, causing soil dispersion and accelerated soil erosion (D'Huyvetter, 1985; Laker, 2000; He *et al*., 2005). Such dispersion could have been worsened by large quantities of clay sized quartz in the clay fraction, which was not part of the D'Huyvetter model and only a few studies have reported the presence of such size quartz in the clay fraction.

The bulk of these soils were found in in Middledrift, Alice, Sheshegu and Fort Beaufort. Scientifically, in agreement with farmer evaluations, this group was delineated as unsuitable for crop production. The *santi* soils were the reasons for strong correlations reported between erosion (causing subsequent land degradation) and land abandonment. These soils were the most degraded and abandoned although some of the soils in this group are still under cultivation. Some of these soils were erroneously demarcated for cultivation during the betterment scheme, where a general slope limit of up to 12% was recommended irrespective of the soil type (Laker, 2004b). This could explain the erosion observed in the Municipality. While these soils were found unsuitable for cropping based on soil factors and erodibility, they were further limited by the low rainfall and limited soil moisture reserves for the production of the evaluated crops, maize, cowpea, sorghum and potato. A combination of these factors provides a scientific explanation for the abandonment of large tract of land in the Municipality. Having been trying and failing to produce crops on these soils farmers could have found it unreasonable to continue. The findings of this study could be useful in rectifying such anomalies, by encouraging the withdrawal of these lands from cultivation and the reclamation of those lands that have been degraded.

A large proportion of the land (about 297 450 ha of the study area), of the arid and semi-arid areas, is covered by these soils, which were found to be unsuitable for cropping, based on farmer perspectives and scientific land evaluation exercises. This constitutes a large proportion of land that could be used for other land uses, including grazing in mixed farming systems. However, careful planning on stocking densities would be essential considering the impact of high stocking densities on soil erosion potential (Laker, 2004b), worse-still for such highly erodible soils. On the other hand, the highly degraded land needs protection and reclamation. Reclamation could include the use of community based conservation strategies which were successful in Malindi village in the Central Eastern Cape of South Africa because the approach built self-satisfaction and trust between farmers and scientists. Common practices used involved planting of *Agave americana* along contour strips, the exclusion of livestock from badly eroded areas by fencing, the use of trees species such as the honey locust (*Robinia pseudoacacia*) and training programmes for farmers (Maswana, 2001). In Limpopo, the use of stone bunds proved successful

(Odhiambo and Nemadhodzi, 2007) though farmers in the Eastern Cape believed this was labour intensive (Maswana, 2001).

The *santi* soil types derived from unconsolidated alluvial deposits corresponded with the Oakleaf and Augrabies found in the Tyume and Kat river valleys, which were deep, and had high fertility and low erodility. Erodibility of these soils could not be explained by fine sand, very fine sand and silt, Na and slope as found for other *santi* soils derived from consolidated shale and mudstone and were not in agreement with D'Huyvetter (1985), although the bulk of them lie in the semi-arid areas. This group was rated highly by the farmers and the soils are currently under cultivation by small-scale farmers and co-operatives in both the Kat and Tyume river valleys. The significant depth of these soils provides sufficient storage volume for water, which is critical for crop growth especially in the dry environments (Van Averbeke, 1991). Scientifically, the water reserves stored in soils were also the highest in the respective soil forms (Chapter 6). These soils are therefore among the best soils in the Municipality both using indigenous knowledge and scientific approaches. The crops that could be grown on these soils may need to include cow-pea and sorghum, which were found to be more adaptable, during the land evaluation exercise. Cow pea has been found to be suitable in the arid regions of Middledrift and semi-arid regions of the Kat and Tyume River valleys as well as for the sub-humid and humid climate of the Amatola Mountains and their surroundings. Drought resistant varieties of cow pea should be grown in the semi-arid and arid regions of the Municipality. Whereas sorghum is adaptable to most environments and soils in the Municipality, about 80 – 90 kg P/ ha should be applied on soil forms in arid and semi-arid environments for optimum sorghum production in smallholder farms.

From both farmers' perspectives and scientific research maize production is hindered by soil factors and water deficits in these soils. Van Averbeke (1991) established that water deficits were responsible for low maize production in ecotopes in the semi-arid regions. Verdoodt *et al*. (2003) reported that high water deficits were the main factors affecting maize yield. Supplementary irrigation would be required, as is already the case with some irrigation schemes in the Tyume and Kat river Valleys. Where there is no irrigation, home gardens have proved successful in the production of maize (Van Averbeke and Hebinck, 2007). Most of the areas

except the Amatola Basin and Mountains had huge water deficits that restricted the production of potatoes.

Other soils found in semi-arid zones include the Arcadia (*isidhaka*) and Bonheim (*umhlaba omnyama*). Whereas less weathered soils derived from the shale/ mudstone, in arid and semi-arid areas, were generally prone to erosion and least desirable for arable cropping, dolerite derived soils were more stable to erosion and thus most desirable for cropping. The excessive amounts of clay (> 35%) in these younger dolerite derived soils led to a strongly developed coarse structure which impedes infiltration resulting in excessive run-off and erosion. In addition, the presence of high amounts of clay-sized quartz and smetites negates the effect of binding effect of any iron oxides that may be present.

The *isidhaka* soil were difficult to work on and was given a low rating by the farmers based on its clay content and swelling and shrinking properties. In addition to the problem identified by the farmers, the high smectite levels increased the vulnerability of the Arcadia soil to soil erosion (Chapter 5; Singer and Shainberg, 2004). The *umhlaba omnyama* (equivalent to the Bonheim) had a high farmers' rating because of their perceived high fertility. The 'high' organic matter was responsible for high fertility. The perceived high rating using indigenous knowledge was inconsistant with scientific rating of the Bonheim. Scientifically, the Bonheim have a low rating because of the clayey pedocutanic-B horizon which causes poor infiltration (Soil Classification Working Group, 1991) and high fine sand content, which gave the soils a high erosion risk rating (Chapter 5). Similarly, the shallow Mayo soils were also rated high and yet they are scientifically unsuitable for cropping (Verdoodt *et al*., 2003). These soils are found in Sheshegu, Middledrift, Fort Beaurfort and Alice.

Indigenous knowledge also provided answers on why farmers behaved in a particular way, on certain soils. For example, indigenous knowledge explained why large tracts of high potential Shortlands soil (*umhlaba obomvu*) covering about 8350 ha were abandoned, in the semi-arid areas of the Municipality. While the soils were not eroded, due to the stabilizing effects of kaolinite and Fe and Al oxides, the abandonment was caused by the high clay content, high water requirements and the droughty nature of the soils (Verdoodt *et al*., 2003), which made it difficult for farmers to till. Concuring with farmers' observations, on the droughty nature of the soils, the

Hutton and Shortlands reported the least moisture reserves during the land evaluation exercise (Chapter 6). The clay soils, as a result, were difficult to till using small implements, due to shortage of farm machinery (Chapter 4). The higher water requirements of the clayey soils led to the abandonment of these soils in semi-arid regions because of low rainfall, in the drier parts of the Municipality. The low amount of rainfall in semi-arid zones was insufficient to replenish available water reserves in soils with large total available water and high clay content (Verdoodt *et al*., 2003). This subsequently led farmers to cite lack of farm machinery, as a major limiting factor to crop production. Participatory mapping of the red soils showed that the amount of clay in these soils was the overriding factor in farmer's rating. Scientifically, these are high potential soils and they could be brought to full production if farm machinery and / or irrigation services were provided.

Soils with high clay content, such as the Shortlands at Upper Ncera, Bonheim and Arcadia were high to moderately suitable for production of sorghum because of the sorghum's ability to extract water from these soils (Du Plessis, 2008). The major limitations were the low reserves of organic matter, P and N (Van Averbeke and Marais, 1991). About 120 – 140 kg P/ ha is required to optimise potato production on Arcadia, Bonheim and Aurgrabies. These soils had limited potential for maize and potato.

Highly weathered soils in subhumid and humid areas were found to be stable and less susceptible to erosion as a result of sesquioxide content and kaolinite type clays. Similarly the soils had moderate potential for cropping (Chapter 6). This was inconsistent with the model of D'Huyvetter (1985) which depended on fine sand and silt and Na, together with slope. Soils of the subhumid and humid areas, whether formed from shale, mudstone or dolerite, were stabilized by the iron oxide content. Higher rainfall increases the degree of weathering, resulting in smectites and micas breaking down, forming more stable secondary minerals such as the kaolonite and the end-point clay oxides in sub-humid and humid zones (Six *et al*., 2000). The stability of these soils resulted in them being the major component of the soils that are suitable for cultivation, based on the land evaluation. The soils are mainly found at Upper Ncera in the Tyume and humid and subhumid zones of the Municipality. It is strongly recommended that the Municipality enact laws/ regulations that declare illegal the use such areas for anything other

than agriculture. The findings further helped in the development of guidelines for the delineating of arable soils for long term cultivation. The red soils should be regarded as high priority areas for crop development. While cow pea and sorghum were found to be the most adaptable crops, high clay content and soluble aluminum and low base status, which characterise the high rainfall Amatola Mountain regions, could pose a major set-back to their production in these areas. Cow pea varieties that are adaptable to cooler climates and acid soils could be grown around the Amatola Mountain Regions, where lime could be used to increase soil pH (Madamba *et al*., 2003). Lime would be required to neutralize acidity of the soils in the Amatola Mountain Region (Appendix 7.1), and 60 kg P/ ha and at least 125 kg K/ ha are needed for optimum cow-pea production, the highest requirement being on Clovelly, Shortlands and Hutton soil forms. In areas with adequate water supply, like the Amatola Basin and Mountains, soil acidity and poor fertility could restrict potato production, and 140 - 160 kg P/ ha and 250 – 420 kg K/ ha, are required to optimize potato production on Clovelly, Hutton and Shortlands soil forms. High clay could create problems when uplifting the potatoes while large clods interfere with the sorting of tubers, thus, reducing the commercial value of the crop (Smith, 1997). About 60 kg P/ ha, 125 kg K/ ha and about 8 t/ ha of dolomitic limestone are required on Hutton, Clovelly, Shortlands on smallholder farms are required for the minimum maize target yield of 4 tonnes/ ha under rainfed conditions.

Farmers did not recognize slope as one of the causes of erosion despite the obvious undulating and steep slopes in the Municipality. While this seemed like an oversight at first glance, the observation was later backed by the greater dominance of soil factors on erosion compared to slope factors, which was in agreement with farmer perspectives. This study reported a wide variation of critical slope limits which were dependent on soil form. Some soils, such as the Klapmuts were heavily eroded on slope gradient as low as 1.51% while on the other hand some soils such as the Clovelly and Hutton did not erode even at slope gradient > 12%. As such, unlike in other parts of South Africa and the world (Chapter 5), the use of standard slope limits for delineation of land and land evaluation could be meaningless in Nkonkobe Municipalitity due to the dominance of soil particle-size distribution and mineralogy as affected by climate and parent material.

Delineation of arable soils was necessary to separate high potential soils from those that were unsustainable for long-term cropping. Extent of weathering, as affected by rainfall amount and parent material was found to be the most important for delineation of arable lands. Humid and subhumid areas have highly weathered soils that are stabilized by kaolin type clays and sesquioxides, while lower rainfall resulted in less stable soils. In addition dolerite derived soils were more stable than the shale derived soils (Chapter 5; Smith, 1990). The stability of these soils has a huge influence of the suitability for the different crops.

Although the land evaluation exercise showed that cow pea and sorghum were the most adaptable and suitable crop, with about 37 640 ha of land being moderately suitable to cow pea in the Municipality, current production is very low, possibly due to the preference of staple crops such maize. Development in cow pea and sorghum production could greatly reduce the area of abandoned land, while improving food security. Contract farming by beverage companies could make a contribution in this regard (Du Plessis, 2008). On the other hand maize production in the Municipality is influenced by food security issues and tradition rather than its suitability. The limited land that is only moderately suitable for maize production under rainfed agriculture, could explain the decrease in farmers growing maize, the most preferred crop, considering that only about 2 000 ha were suitable. While the farmers indicated that potato was the second most important crop, overall suitability was low because of its high water and low temperature requirements. Only 7 887 ha of land were suitable for production of potato. Based on the findings of the land evaluation exercise, a change from maize and potato to the more suitable cow-pea and sorghum could reduce land abandonment and improve crop production and food security.

The following conclusions could be drawn:

- Using both scientific research and farmers' perspectives, it was established that soil and climate were the main biophysical constaints to crop production and that maize was the main crop grown by the farmers alongside potato, spinach and cabbage.
- There was a good match between farmers' assessment of the cropping potential using indigenous soil classification system and scientific approaches but in some cases, such as the red soils, scientifically high potential soils were rated as low by the farmers due to

difficulties in management caused by shortages of farm machinery, especially under dryland farming.

- Climate and parent material influenced the effects of soil factors on soil erodibility and the important factors are fine sand content, clay mineralogy, iron oxides and ESP and slope gradient and length at the lower level.
- In high rainfall areas, the soils were generally stable, with a high potential because of the presence of kaolinite and sesquioxides, while in semi-arid regions, soil depth and fine sand content and clay-sized quartz and ESP could be used as indicators of the erodibility of the soils
- The most suitable crops cited by farmers, for rainfed agriculture, in the Municipality were in-order of areal coverage of **s**uitable land; cow-peas, sorghum, potato and maize.
- The production of maize and potato under rainfed agriculture was inspired by the need to grow these crops rather than land suitability.
- Farmers' perspectives and ethnopedological knowledge could be integrated with scientific approaches for land evaluation and delineation of good potential the land and subsequent crops that are suitable in the Municipality.

Recommendations

1. The local Municipality should enact laws that preserve prime land for crop production and rehabilitate degraded lands.
2. Soil and water conservation strategies should be prioritised to optimise the use of the available soil and water resources.
3. Optimisation of the recommended crops should be prioritised, with emphasis given to irrigation, agronomic practices and conservation agriculture.
4. Further studies could include the assessment of the test crops for irrigation and their economic suitability

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APPENDICES

Appendix 3.1: Draft questionnaire survey on farmers' perspectives to crop production in Nkonkobe Municipality

General information

Village name_____

Name of farmer_____

Age of farmer_____

Education level of farmer_____

Full-time or Part-time farmer_____

Farming Experience_____

Location of field: Latitude_____ Longitude_____

List the five most important factors limiting crop production on your farm/plot

Factor	**Degree of limitation***

* Use the following ratings: 1= Severe 2= Moderate 3= slightly limiting

List the five most important crops that you normally grow – in decreasing order of importance from top to bottom

Crop	**Productivity rating***	**Reason for growing this crop**

*Use the following: 1 = High 2 = Moderate 3 = Low

List crops that you have grown in the past, but no longer grow (maximum five)

Crop	**Reason for no longer growing it**

List crops that you would like to grow in future (maximum five)

Crop	**Reason why you would like to grow it**	**Reason why you are not growing it at present**

What proportion of the total land area of your village is according to you suitable for crop production? (Tick off one.)

Proportion of area suitable for crop production	Tick of relevant block (√)
Less than one quarter	
Between one quarter and half	
Between half and three quarters	
More than three quarters	

What proportion of the total land area of your village which is according to you suitable for crop production is actually used for crop production? (Tick off one.)

Proportion of area suitable for crop production actually used for crop production	Tick of relevant block (√)
Less than one quarter	
Between one quarter and half	
Between half and three quarters	
More than three quarters	

What are the main reasons why all the land that is available for crop production in your village is not used for crop production? Give in order of decreasing importance. (Maximum five).

What proportion of the land that had previously been used for crop production is no longer used for crop production, i.e. has been abandoned? (Tick off one.)

Proportion of previously cultivated areas that are no longer used for crop production	Tick of relevant block (√)
Less than one quarter	
Between one quarter and half	
Between half and three quarters	
More than three quarters	

What are the main reasons why some areas that had been cultivated before are no longer used for crop production? Give in order of decreasing importance. Maximum five.

Classification, description and use of the soils of your village

Local name for soil	Description of soil (texture, colour, slope position etc)	Main use of soil*

* Indicate as 1 = Cropping or 2 = Grazing

Give your rating of each soil for the growing of each of the crops that you are growing mainly at present (Refer to 3)

Local soil name	**Soil suitability rating for each crop****				
	*	*	*	*	*

*Use the following: 1 = High 2 = Moderate 3 = Low

13. What are the general soil problems?

Category	**tick**	**Extent of problem***
Erosion		
Soil fertility		
Soil physical (compaction, crusting)		
Soil depth		
Other (state)		

*Use: 1= mostproblematic, 2= moderate 3= slightly problematic 4= least problematic

14. To what extent is soil type affected by soil erosion?

Soil type	**Degree of erodibility[1]**	**Erosion Type 1= sheet , 2= rill, 3= gully, 4= No erosion**	**Whichconservation technique is used?***	**Which is the most effective conservation technique?***

***Indicate using: 1=** Terracing 2= Mulching 3= Intercropping 4=Not sure

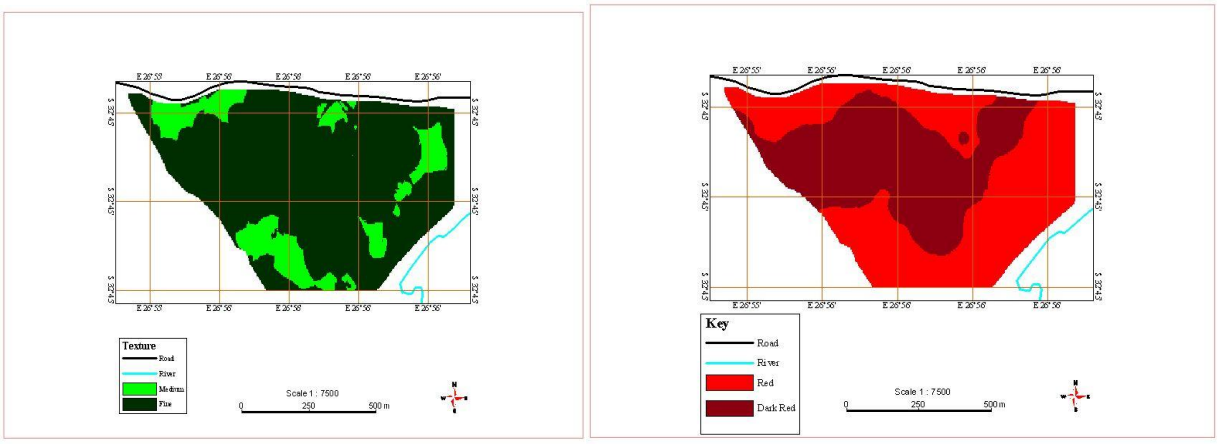
[1]**Use** 1= High, 2= Moderate, 3= Low, 4= Very low

15. Which of the factors do you consider as important in agricultural soil potential determination?

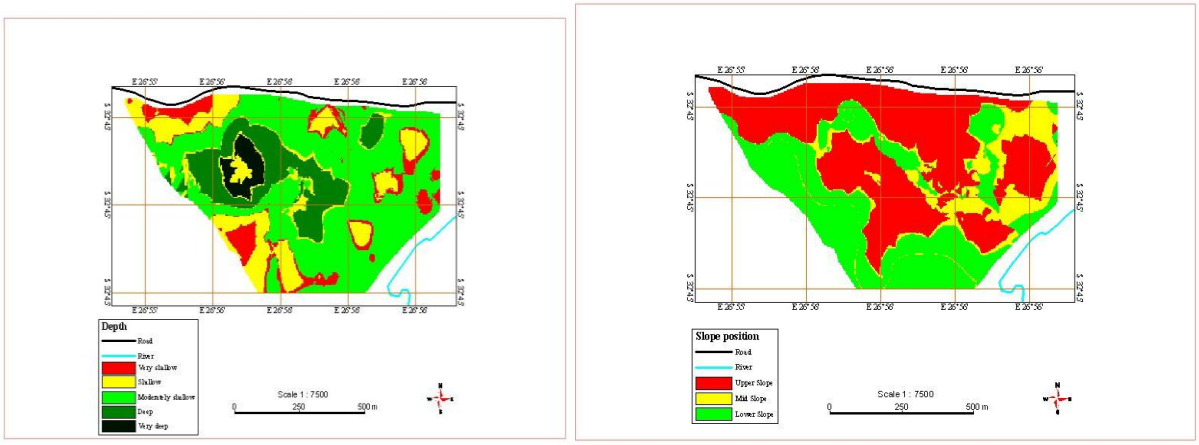
Factor	**Degree of importance ***
Colour	
Texture	
Depth	
Slope position	

***Use 1= highly important 2= Important 3= Least important 4= Not important at all

(a) (b)

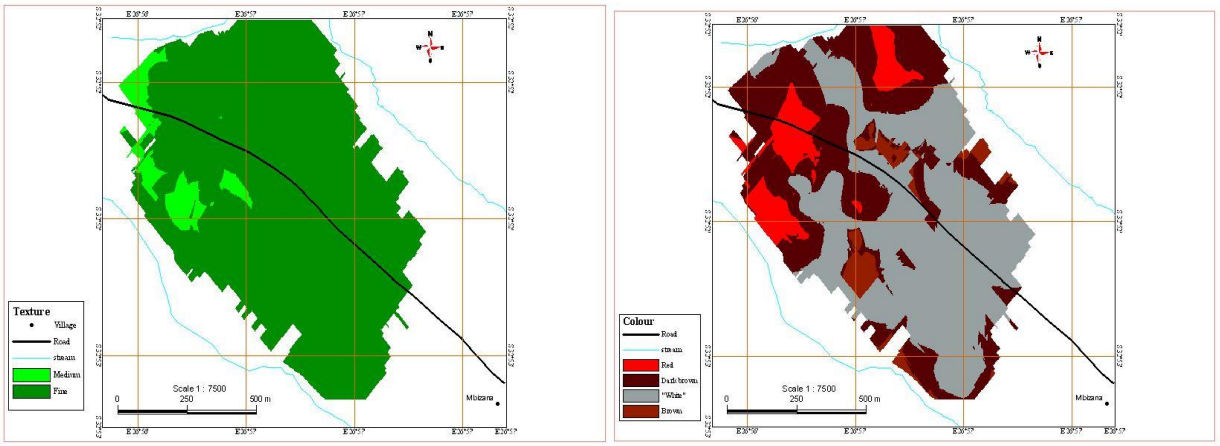


(c) (d)



Appendix 4.1: Soil texture (a), colour (b), depth (c) and slope position (d) at Ncera

(a) (b)



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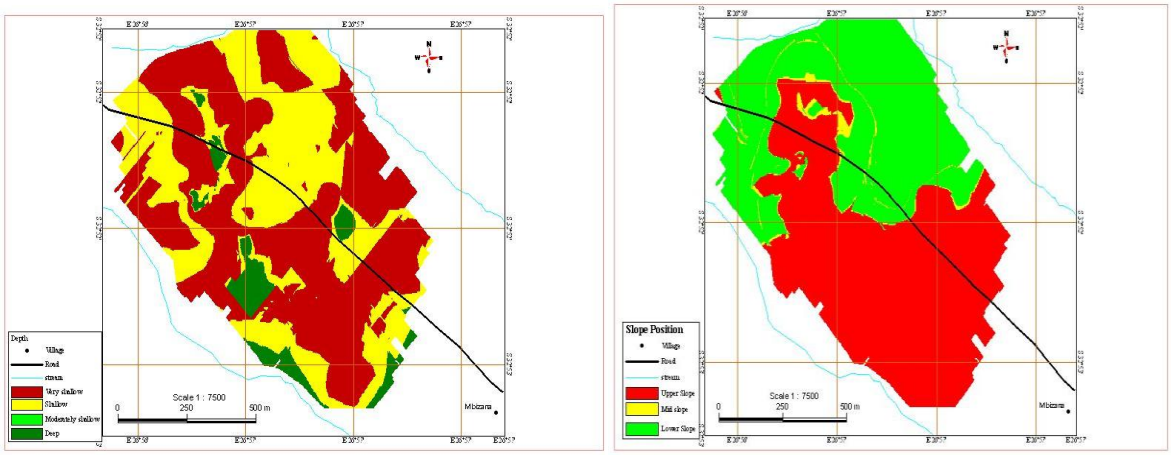
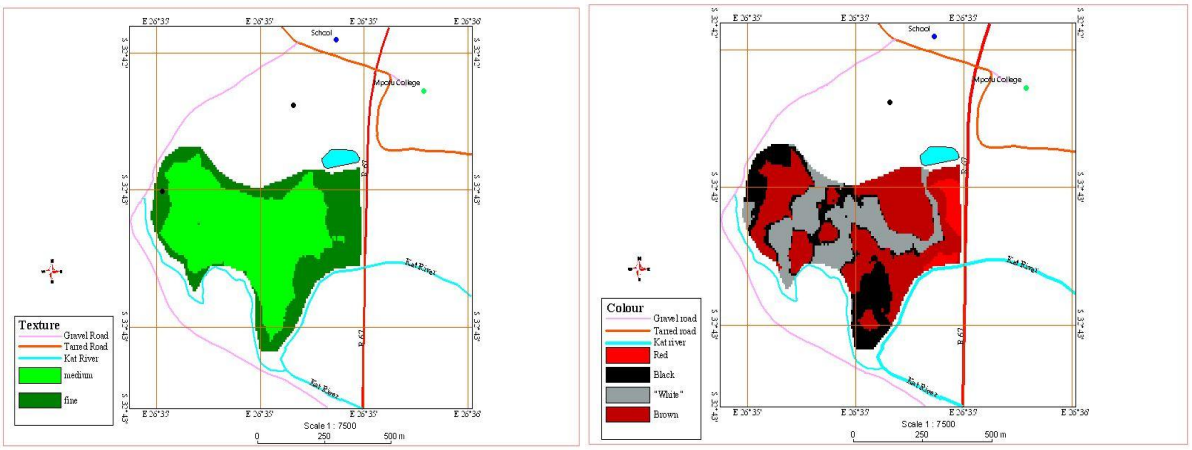
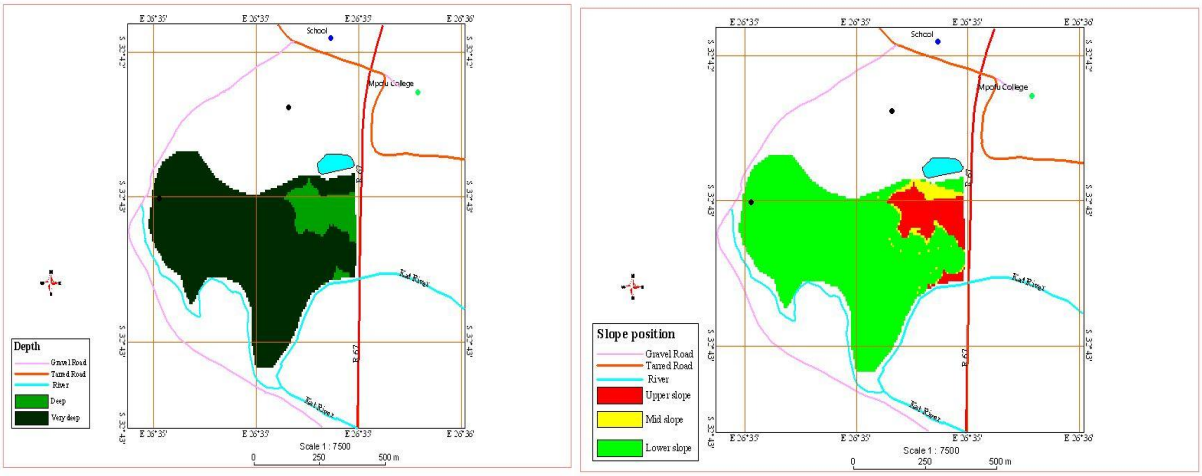


Appendix 4.2: Soil texture (a), colour (b), depth (c) and slope position (d) at Mbizana village

(a) (b)



(c) (d)



Appendix 4.3: Soil texture (a), colour (b), depth (c) and slope position (d) at Blinkwater village

Appendix 5.1: Site and profile decriptions of the main soil forms in Nkonkobe Municipality

Profile number	**A01**	
Location	Somugandla farm	
Elevation	497 m	
Co-ordinates	S32^{o}46.905’	E026^{o} 50.661’
Landform and topography		
Landscape (form)	Floodplain	
Landscape (shape)	Almost flat	
Slope (position)	Lowerslope	
Slope (%)	< 2%	
Slope (aspect)	0 degrees	
Surface characteristics		
Erosion (severity)	Nil/slight	
Erosion (type)	Sheet	
Landuse and vegetation		
Land use	Cabbage cultivation	
Parent material		
Parent material	Tyume alluvium	
Effective depth	>120 cm	
Soil classification		
South Africa	Oakleaf	
WRB	Haplic Luvisols	

Description:

0 - 23 cms	Dark brown (10YR 4/3 m); fine grained sandy loam; moist friable, plastic, sticky consistence; weak fine subangular blocky structure; good permeability; well drained; many fine roots; clear smooth transition to :
23 - 80 cms	Dark grayish brown (10YR 4/2 m); fine grained sandy loam; moist friable; plastic, sticky consistence; moderate medium subangular blocky structure, clay cutans; good permeability; well drained; few fine roots; clear smooth transition to:
80 - 120 cms +	Dark grayish brown (10YR 4/2 m); Clay; moist very friable; slightly plastic, slightly sticky consistence; moderate medium subangular blocky; good permeability; well drained; few fine/ coarse roots.

Profile number	**A 02**
Location	Lower Qgumashe
Elevation	528 m
Co-ordinates	S32^{o} 45.325’ E026^{o}51.090’
Landform and topography	
Landscape (form)	Floodflain
Landscape (shape)	Almost flat
Slope (position)	Midslope
Slope (%)	2 %
Slope (aspect)	135 degrees
Surface characteristics	
Erosion (severity)	Slight
Erosion (type)	Sheet
Capping	moderate
Land use	Maize,
Effective depth	> 120 cm
Parent material	lluvium
Soil classification	
South Africa	Oakleaf
WRB	Haplic Luvisols

Description:

0 - 27 cms	Dark yellowish brown (10YR 4/6 m) fine grained sandy loam; moist friable, plastic, sticky consistence; medium moderate subangular blocky structure; good permeability; well drained; many fine roots; gradual smooth transition to :
27 - 80 cms	Dark yellowish brown (10YR 4/4m) fine grained sand clay loam; moist friable, plastic, sticky consistence; medium moderate subangular blocky structure; good permeability; well drained; many fine roots; compacted; clay cutans; gradual smooth transition to :
80 - 150 cms	Dark yellowish brown (10YR 4/6 m) fine grained sand clay; moist friable, plastic, sticky consistence; medium moderate subangular blocky structure; good permeability; well drained; few fine roots; clay cutans

Profile number	**A03**	
Location	Hogsback	
Elevation	1464 m	
Co-ordinates	S 32^{o}33.673’	E26^{o} 54.607’
Landform and topography		
Landscape (form)	Pediplain	
Landscape (shape)	Undulating	
Slope (position)	Midslope	
Slope (%)	3- 4 %	
Slope (aspect)	0 degrees	
Surface characteristics		
Erosion (severity)	Nil/slight	
Erosion (type)	Sheet	
Landuse and vegetation		
Land use	Plantation	
Vegetation	Pine	
Parent material		
Parent material	Dolerite	
Effective depth	150 cm	
Soil classification		
South Africa	Hutton	
WRB	Humic Ferrasols	

Description:

0 - 30 cms	Dark brown (7.5YR3/2 m) clay; moist very friable, plastic,sticky consistence; granular structure; good permeability; well drained; few fine roots; clear smooth transition to :
30 - 80 cms	Reddish brown (2.5YR 4/4 m); clay; moist very friable, slightly plastic, slightly sticky consistence; weak fine subangular blocky structure; good permeability; well drained; few fine roots; clear smooth transition to :
80 - 150 cms	Red (2.5YR 4/6m); clay; moist very friable, plastic, sticky consistence; weak subangular blocky structure; rapid permeability; well drained; occassional fine roots

Profile number	**A 04**
Location	
Elevation	1424
Co-ordinates	32° 34.377’ 26° 53.825’
Landform and topography	
Landscape (form)	Pediplain
Landscape (shape)	Gently undulating
Slope (position)	Midslope
Slope (%)	4-6 %
Slope (aspect)	0 degrees
Surface characteristics	
Erosion (severity)	slight
Erosion (type)	sheet
Landuse and vegetation	
Land use	Pasture
Parent material	
Parent material	Mudsone
Effective depth	>120
Soil classification	
South Africa	Clovelly
WRB	Haplic Acrisols

Description:

0 - 25 cms	Very dark grayish brown (10YR 3/2 m); fine grained sandy clay loam; moist friable, plastic, sticky consistence; moderate medium subangular blocky structure; good permeability; well drained; many fine roots; clear smooth transition to :
25 - 56 cms	Dark grayish brown (10YR 4/2 m); clay; moist friable; plastic, sticky consistence; weak fine subangular blocky structure, good permeability; well drained; clay skins; few fine roots; clear smooth transition to:
56 - 120 cms +	Dark yellowish brown (10YR 4/6 m); Clay; moist very friable; plastic, sticky consistence; weak fine subangular blocky, good permeability; well drained; No roots;

Profile number	**A 05**
Location	Ncera
Elevation	749 m
Co-ordinates	S 32° 45.129’ E 26°54.951’
Landform and topography	
Landscape (form)	Pediment
Landscape (shape)	Undulating
Slope (position)	Midslope
Slope (%)	5 - 8%
Slope (aspect)	0 degrees
Surface characteristics	
Erosion (severity)	nil/slight
Erosion (type)	sheet
Landuse and vegetation	
Land use	Maize cultivation
Parent material	
Parent material	Dolerite
Effective depth	>120
Soil classification	
South Africa	Shortlands
WRB	Rhodic Nitisol

Description:

0 - 29 cms	Dark reddish brown (2.5YR 3/3 m); fine grained sandy clay loam; moist friable, plastic, sticky consistence; moderate medium subangular blocky structure; good permeability; well drained; many fine roots; gradual smooth transition to :
29 - 69 cms	Red (2.5YR 4/6 m); clay; moist friable; plastic, sticky consistence; moderate medium subangular blocky structure, good permeability; well drained; clay skins few fine roots; diffusel smooth transition to:
69 - 120 cms +	Red (2.5YR 4/6 m); Clay; moist very friable; plastic, sticky consistence; Strong coarse subangular blocky, good permeability; moderately well drained; few fine; clay skins and cutans

Profile number	**A 06**
Location	Mbizana Village
Elevation	562 m
Co-ordinates	S 32 52.063 E 26 56.348
Landform and topography	
Landscape (form)	Pediplain
Landscape (shape)	Gently undulating
Slope (position)	Crest
Slope (%)	4-6 %
Slope (aspect)	0 degrees
Ssurface characteristics	
Erosion (severity)	Moderate
Erosion (type)	sheet
Landuse and vegetation	
Land use	Maize
Parent material	
Parent material	Mudstone
Effective depth	32 cm
Soil classification	
South Africa	Glenrosa
WRB	Leptosols

Description :

0 - 32 cms	Very dark brown(10YR 2/2 m); fine grained sandy clay loam; moist friable, plastic, sticky consistence; moderate medium subangular blocky structure; good permeability; well drained; many fine roots; clear smooth transition to :
32 cms	Soft weathering

Profile number	**A 07**	
Location	Mbizana villages	
Elevation	555 m	
Co-ordinates	S 32 52.013	E 26 56.360
Landform and topography		
Landscape (form)	Pediplain	
Landscape (shape)	Undulating	
Slope (position)	Midslope	
Slope (%)	5 - 8%	
Slope (aspect)	0 degrees	
Surface characteristics		
Erosion (severity)	Moderate	
Erosion (type)	Sheet	
Landuse and vegetation		
Land use	Maize cultivation	
Parent material		
Parent material	Shale	
Effective depth	85 cm	
Soil classification		
South Africa	Swartlands	
WRB	Leptic Luvisols	

Description:

0 - 30 cms	Dark brown (10YR 3/3 m); fine grained sandy loam; moist friable, plastic, sticky consistence; moderate medium subangular blocky structure; good permeability; well drained; many fine roots; clear smooth transition to :
30 - 50 cms	Very dark brown(10YR 2/2 m); fine grained sandy clay loam; moist friable, plastic, sticky consistence; moderate medium subangular blocky structure; good permeability; well drained; few coarse fine roots; diffuse smooth transition to :
50 - 85 cms	Very dark brown(10YR 2/2 m); fine grained sandy clay; moist friable, plastic, sticky consistence; massive structure; good permeability; moderately well drained; few coarse roots; clear smooth transition to :
85cms	Soft weathering

Profile number	**A 08**
Location	Sub-humid
Elevation	828 m
Co-ordinates	S32 36.880 E026 54.415
Landform and topography	
Landscape (form)	Pediment
Landscape (shape)	Undulating
Slope (position)	Midslope
Slope (%)	5 - 8%
Slope (aspect)	0 degrees
Surface characteristics	
Erosion (severity)	Nil/slight
Erosion (type)	Sheet
Landuse and vegetation	
Land use	Uncultivated
Parent material	
Parent material	Dolerite
Effective depth	>120
Soil classification	
South Africa	Lusiki
WRB	Rhodic Nitisol

Description :

0 - 24 cms	Dark brown (7.5YR 3/2 m); fine grained sandy clay loam; moist friable, plastic, sticky consistence; strong crumb structure; good permeability; well drained; many fine roots; clear smooth transition to
24 - 45 cms	Dusky red (2.5YR 3/2 m); clay; moist friable; plastic, sticky consistence; strong coarse subangular blocky structure, good permeability; well drained; clay skins few fine roots; clear smooth transition to:
45 - 70 cms +	Dark reddish brown (2.5YR 3/4 m); Clay; moist very friable; plastic, sticky consistence; weak fine subangular blocky, good permeability; moderately well drained; few fine; clay skins and cutans
70- 150 cms +	Red (2.5YR 4/6 m); Clay; moist very friable; plastic, sticky consistence; Strong coarse subangular blocky, good permeability; moderately well drained; few fine; clay skins and cutans

Profile number	**A 09**
Location	Phandulwazi Agricultural College
Elevation	758 m
Co-ordinates	S32 39.185 E026 54.983
Landform and topography	
Landscape (form)	Pediplain
Landscape (shape)	Almost flat
Slope (position)	Midslope
Slope (%)	< 2 %
Slope (aspect)	180 degrees
Surface characteristics	
Erosion (severity)	Moderate
Erosion (type)	Sheet
Capping	Moderate
Land use	Uncultivated,
Effective depth	60 cm
Parent material	Shale
Soil classification	
South Africa	Oakleaf
WRB	Haplic Luvisols

Description:

0 - 30 cms	Very dark greyish brown (10YR 3/2 m) fine grained sandy loam; moist friable, plastic, sticky consistence; weak fine subangular blocky structure; good permeability; well drained; many fine roots; gradual smooth transition to :
30 - 60 cms	Dark yellowish brown (10YR 3/2m) fine grained sand clay ; moist friable, plastic, sticky consistence; medium moderate subangular blocky structure; good permeability; well drained; many fine roots; compacted; clay cutans; gradual smooth transition to :
60 cms	Soft weathering material

Profile number	**A10**	
Location	Binfield Dam	
Elevation	725 m	
Co-ordinates	S32 39.524	E026 54.389
Landform and topography		
Landscape (form)	Pediment	
Landscape (shape)	Undulating	
Slope (position)	Upperslope	
Slope (%)	5-8 %	
Slope (aspect)	180 degrees	
Surface characteristics		
Erosion (severity)	Severe	
Erosion (type)	Sheet/ rill	
Capping	Moderate	
Land use	Uncultivated,	
Effective depth	80 cm	
Parent material	Shale	
Soil classification		
South Africa	Sterkpruit	
WRB	Haplic Cambisols	

Description:

0 - 45 cms	Dark yellowish brown (10YR 4/4 m) fine grained sand; moist friable, plastic, sticky consistence; weak fine subangular blocky structure; good permeability; well drained; many fine roots; abrupt smooth transition to :
45 - 80 cms	Dark yellowish brown (10YR 4/6m) fine grained sand clay; moist very friable, plastic, sticky consistence; Strong coarse prismatic structure; good permeability; moderately well drained; few coarse roots; compacted; clay cutans; abrupt smooth transition to :
80 cms	Soft weathering material

Profile number	**A 11**	
Location	Woburn Farm	
Elevation	615 m	
Co-ordinates	S32 42.244	E026 53.235
Landform and topography		
Landscape (form)	Pediplain	
Landscape (shape)	Almost flat	
Slope (position)	Midslope	
Slope (%)	< 2 %	
Slope (aspect)	180 degrees	
Surface characteristics		
Erosion (severity)	Moderate	
Erosion (type)	Sheet	
Capping	Moderate	
Land use	Abandoned orange farm	
Effective depth	60 cm	
Parent material	Shale	
Soil classification		
South Africa	Oakleaf	
WRB	Haplic luvisols	

Description:

0 - 35 cms	Very dark greyish brown (10YR 3/2 m) fine grained sandy loam; moist friable, plastic, sticky consistence; weak fine subangular blocky structure; good permeability; well drained; many fine roots; gradual smooth transition to :
35 - 60 cms	Dark yellowish brown (10YR 3/2m) ,clay; moist friable, plastic, sticky consistence; medium moderate subangular blocky structure; good permeability; well drained; many fine roots; compacted; clay cutans; gradual smooth transition to :
60 cms	Soft weathering material

Profile number	**A 12**
Location	Stofile Village
Elevation	544 m
Co-ordinates	S 32 48.621 E 26 54.070
Landform and topography	
Landscape (form)	Pediment
Landscape (shape)	Gently undulating
Slope (position)	Midslope
Slope (%)	3%
Slope (aspect)	0 degrees
Surface characteristics	
Erosion (severity)	Nil/slight
Erosion (type)	Sheet
Landuse and vegetation	
Land use	Maize cultivation
Parent material	
Parent material	Dolerite
Effective depth	>80
Soil classification	
South Africa	Shortlands
WRB	Rhodic nitisol

Description :

0 - 22 cms	Dark reddish brown (2.5YR 3/3 m); fine grained sandy clay loam; moist friable, plastic, sticky consistence; moderate medium subangular blocky structure; good permeability; well drained; many fine roots; gradual smooth transition to :
22 - 60 cms	Red (2.5YR 4/6 m); clay; moist friable; plastic, sticky consistence; moderate medium subangular blocky structure, good permeability; well drained; clay skins few fine roots; diffusel smooth transition to:
60 - 80 cms +	Red (2.5YR 4/6 m); Clay; moist very friable; plastic, sticky consistence; Strong coarse subangular blocky, good permeability; moderately well drained; few fine; clay skins and cutans; Fe/ Mn conceretions

Profile number	**A13**
Location	Upper Qgumashe
Elevation	684 m
Co-ordinates	S32 45.860 E026 53.612
Landform and topography	
Landscape (form)	Pediplain
Landscape (shape)	Rolling
Slope (position)	Upperslope
Slope (%)	8 %
Slope (aspect)	180 degrees
Surface characteristics	
Erosion (severity)	Severe
Erosion (type)	Sheet
Capping	Moderate
Land use	Abandoned orange farm
Effective depth	60 cm
Parent material	Shale
Soil classification	
South Africa	Klapmuts
WRB	Haplic cambisols

Description:

0 - 25 cms	Dark yellowish brown (10YR 3/4 m) fine grained sandy loam; moist friable, plastic, sticky consistence; weak fine subangular blocky structure; good permeability; well drained; many fine roots; gradual smooth transition to :
20 - 25 cms	Yellowish brown (10YR 5/6m) Coarse grained sand ; loose; non- sticky non-plastic; apedal; rapid permeability; excessively well drained; few fine roots; clear smooth transition to :
25 - 50 cms	Dark yellowish brown (10YR 3/2m) ,clay; moist friable, plastic, sticky consistence; medium moderate subangular blocky structure; good permeability; well drained; many fine roots; clay cutans; gradual smooth transition to :
50+ cms	Soft weathering material

Profile number	**A 14**	
Location	Upper Ncera	
Elevation	684 m	
Co-ordinates	S32 44.754	E026 55.641
Landform and topography		
Landscape (form)	Pediplain	
Landscape (shape)	Almost flat	
Slope (position)	Lower slope	
Slope (%)	< 2 %	
Slope (aspect)	180 degrees	
Surface characteristics		
Erosion (severity)	Slight	
Erosion (type)	Sheet	
Capping	Nil	
Land use	Maize	
Effective depth	120 cm	
Parent material	Dolerite	
Soil classification		
South Africa	Boheim	
WRB	Phaozems	

Description:

0 - 20 cms	Very dark grey (10YR 3/1 m) medium grained sandy loam; moist friable, plastic, sticky consistence; weak fine subangular blocky structure; good permeability; well drained; many fine roots; gradual smooth transition to
20 - 40 cms	Dark yellowish brown (10YR 3/2m) , clay; moist friable, plastic, sticky consistence; medium moderate subangular blocky structure; good permeability; well drained; many fine roots; clay cutans; gradual smooth transition to :
40 - 60 cms	Dark greyish brown (10YR 4/2m),clay; moist friable, plastic, sticky consistence; medium moderate subangular blocky structure; good permeability; well drained; few fine roots; clay cutans; gradual smooth transition to :
60 – 120+ cms	Dark grayish brown (10YR 4/2m) clay; moist friable, plastic, sticky consistence; medium moderate subangular blocky structure; good permeability; moderately well drained; few fine roots; clay cutans;

Profile number	**A 15**
Location	Binfield Village
Elevation	687 m
Co-ordinates	S32 40.573 E026 53.823
Landform and topography	
Landscape (form)	Plain
Landscape (shape)	Gently undulating
Slope (position)	lowerslope
Slope (%)	4%
Slope (aspect)	180 degrees
Surface characteristics	
Erosion (severity)	Moderate
Erosion (type)	sheet
Landuse and vegetation	
Land use	Maize cultivation
Parent material	
Parent material	Shale
Effective depth	60 cm
Remarks	ubsurface wetness
Soil classification	
South Africa	Tukulu
WRB	Ferric luvisols

Description :

0 - 30 cms	Dark greyish brown (10YR 4/2 m); fine grained sandy loam; moist friable, plastic, sticky consistence; weak fine subangular blocky structure; good permeability; well drained; many fine roots; clear smooth transition to :
30 - 60 cms	Dark grayish brown (10YR 4/2 m); fine grained sandy loam; moist friable; plastic, sticky consistence; moderate medium subangular blocky structure, clay cutans; good permeability; well drained; few fine roots; clear smooth transition to:
60 - 120 cms +	Very dark grey (10YR 3/1 m); Clay; moist very friable; plastic, sticky consistence; moderate medium subangular blocky; poor permeability; moderately well drained; red mottles.

Profile number	**A 16**	
Location	Blinkwater	
Elevation	468 m	
Co-ordinates	S32 42.552	E026 35.083
Landform and topography		
Landscape (form)	Floodflain	
Landscape (shape)	Almost flat	
Slope (position)	Midslope	
Slope (%)	< 2 %	
Slope (aspect)	135 degrees	
Surface characteristics		
Erosion (severity)	Slight	
Erosion (type)	Sheet	
Capping	Moderate	
Land use	Cabbage	
Effective depth	> 120 cm	
Parent material	Alluvium	
Soil classification		
South Africa	Etosha/ Addo	
WRB	Calcic kastanozems	

Description:

0 - 30 cms	Dark grey (10YR 4/1 m) fine grained sandy loam; moist friable, plastic, sticky consistence; medium moderate subangular blocky structure; good permeability; well drained; many fine roots; gradual smooth transition to:
30 - 60 cms	Dark yellowish brown (10YR 4/4m) fine grained sand clay loam; moist friable, plastic, sticky consistence; medium moderate subangular blocky structure; good permeability; well drained; many fine roots; clay cutans; soft carbonates; gradual smooth transition to :
60 - 150 cms	Dark yellowish brown (10YR 4/6 m) fine grained sand clay; moist friable, plastic, sticky consistence; medium moderate subangular blocky structure; good permeability; well drained; few fine roots; clay cutans ; soft carbonates

Profile number	**A 17**	
Location	Kat river bridge	
Elevation	560 m	
Co-ordinates	S32 36.371	E026 39.916
Landform and topography		
Landscape (form)	Floodflain	
Landscape (shape)	Almost flat	
Slope (position)	Upperslope	
Slope (%)	< 2 %	
Slope (aspect)	0 degrees	
Surface characteristics		
Erosion (severity)	Slight	
Erosion (type)	Sheet	
Capping	Moderate	
Land use	Citrus, granadilla	
Effective depth	> 120 cm	
Parent material	Alluvium	
Soil classification		
South Africa	Etosha	
WRB	Calcic kastanozems	

Description:

0 - 35 cms	Very dark grayish brown (10YR 3/2 m) fine grained sandy loam; moist friable, plastic, sticky consistence; medium moderate subangular blocky structure; good permeability; well drained; many fine roots; gradual smooth transition to :
35 - 70 cms	Dark yellowish brown (10YR 4/3m) fine grained sand clay loam; moist friable, plastic, sticky consistence; medium moderate subangular blocky structure; good permeability; well drained; many fine roots; clay cutans; soft carbonates; gradual smooth transition to :
70 - 150 cms	Dark yellowish brown (10YR 3/6 m) fine grained sand clay; moist friable, plastic, sticky consistence; medium moderate subangular blocky structure; good permeability; well drained; few fine roots; clay cutans ; soft carbonates

Profile number	**A 18**	
Location	Solly's farm	
Elevation	514 m	
Co-ordinates	S32 38.589	E026 39.973
Landform and topography		
Landscape (form)	Floodflain	
Landscape (shape)	Almost flat	
Slope (position)	Midslope	
Slope (%)	< 2 %	
Slope (aspect)	135 degrees	
Surface characteristics		
Erosion (severity)	Slight	
Erosion (type)	Sheet	
Capping	Moderate	
Land use	Citrus, oranges	
Effective depth	> 120 cm	
Parent material	Alluvium	
Soil classification		
South Africa	Boheim	
WRB	Phaozems	

Description:

0 - 40 cms	Very dark gray (10YR 3/1 m), clayt friable, plastic, sticky consistence; strong coarse subangular blocky structure; good permeability; well drained; many fine roots; gradual smooth transition to :
40 - 75 cms	Very dark greyish brown (10YR 3/2m) clay; moist friable, plastic, sticky consistence; strong coarse subangular blocky structure; good permeability; well drained; many fine roots; clay cutans; gradual smooth transition to :
75 - 150 cms	Very dark greyish brown (10YR 3/2 m) clay; moist friable, plastic, sticky consistence; strong coarse subangular blocky structure; good permeability; well drained; few fine roots; clay cutans ;

Profile number	**A 19**	
Location	Mandla farm	
Elevation	514 m	
Co-ordinates	S32 38.058	E026 41.342
Landform and topography		
Landscape (form)	Plain	
Landscape (shape)	Gently undulating	
Slope (position)	Midslope	
Slope (%)	4 %	
Slope (aspect)	0 degrees	
Surface characteristics		
Erosion (severity)	Slight	
Erosion (type)	Sheet	
Capping	Moderate	
Land use	Citrus, oranges	
Effective depth	80cm	
Parent material	Dolerite	
Soil classification		
South Africa	Swartlands	
WRB	Leptic cambisols	

Description:

0 - 30 cms	Very dark grayish brown (10YR 3/2 m) fine grained sandy loam; moist friable, plastic, sticky consistence; strong coarse subangular blocky structure; good permeability; well drained; many fine roots; gradual smooth transition to :
30 - 50 cms	Very dark greyish brown (10YR 3/2m) fine grained sand clay loam; moist friable, plastic, sticky consistence; strong coarse subangular blocky structure; good permeability; well drained; many fine roots; clay cutans; gradual smooth transition to :
50 - 80 cms	Red (2.5YR 4/6 m) fine grained sand clay loam; moist friable, plastic, sticky consistence; strong coarse subangular blocky structure; good permeability; well drained; few fine roots; clay cutans ;

Profile number	**A 20**	
Location	Mavuso location	
Elevation	550 m	
Co-ordinates	S32 46.205	E026 49.142
Landform and topography		
Landscape (form)	Valley	
Landscape (shape)	Almost flat	
Slope (position)	Lowerslope	
Slope (%)	< 2 %	
Slope (aspect)	0 degrees	
Surface characteristics		
Erosion (severity)	Slight	
Erosion (type)	Sheet	
Capping	Moderate	
Land use	Fallow	
Effective depth	100cm	
Parent material	Dolerite/ alluvial	
Soil classification		
South Africa	Arcadia	
WRB	Vertisols	

Description:

0 - 20 cms	Black (10YR 2/1 m) ,clay, moist firm, plastic, sticky consistence; strong coarse subangular blocky structure; good permeability; moderately well drained; many fine roots; gradual smooth transition to :
20 - 40 cms	Black (10YR 2/1 m), clay, moist friable, plastic, sticky consistence; strong coarse subangular blocky structure; good permeability; moderately well drained; many fine roots; clay cutans and vertic properties; gradual smooth transition to :
40 - 80 cms +	Black (10YR 2/1 m) clay; moist friable, plastic, sticky consistence; strong coarse subangular blocky structure; good permeability; moderately well drained; few fine roots; clay cutans vertic properties;

Profile number	**A 21**	
Location	Lower Qgumashe Farm	
Elevation	538 m	
Co-ordinates	S32 45.349	E026 51.226
Landform and topography		
Landscape (form)	Pediment	
Landscape (shape)	Undulating	
Slope (position)	Midslope	
Slope (%)	4 %	
Slope (aspect)	135 degrees	
Surface characteristics		
Erosion (severity)	Slight	
Erosion (type)	Sheet	
Capping	Moderate	
Land use	Maize cultivation	
Effective depth	60 cm	
Parent material	Dolerite	
Soil classification		
South Africa	Valsrivier	
WRB	Chromic Luvisols	

Description:

0 - 29 cms	Very dark grayish brown (10YR 3/2 m) fine grained sandy loam; moist firm, plastic, sticky consistence; strong coarse subangular blocky structure; good permeability; moderately well drained; many fine roots; gradual smooth transition to :
29 - 60 cms	Black (10YR 2/1 m) fine grained sand clay loam; moist friable, plastic, sticky consistence; strong coarse subangular blocky structure; good permeability; moderately well drained; many fine roots; clay cutans and vertic properties; gradual smooth transition to :
60 - 100 cms +	Yellowish brown (10YR 5/6 m) fine grained sand clay loam; moist friable, plastic, sticky consistence; apedal structure; good permeability; moderately well drained; few fine roots

Profile number	**A22**
Location	Somgadla mountain
Elevation	524 m
Co-ordinates	S 32 46.259 E 26 51.573
Landform and topography	
Landscape (form)	Pediment
Landscape (shape)	Gently undulating
Slope (position)	lowerslope
Slope (%)	4-6 %
Slope (aspect)	0 degrees
Surface characteristics	
Erosion (severity)	Moderate
Erosion (type)	Sheet
Landuse and vegetation	
Land use	Maize
Parent material	
Parent material	Colluvial
Effective depth	30 cm
Soil classification	
South Africa	Glenrosa
WRB	Leptosols

Description:

0 - 32 cms	Very dark brown(10YR 2/2 m); fine grained sandy clay loam; moist friable, plastic, sticky consistence; moderate medium subangular blocky structure; good permeability; well drained; many fine roots; clear smooth transition to :
32 cms	Soft weathering

Profile number	**A 23**
Location	Somugandla farm
Elevation	507 m
Co-ordinates	S32 46.794 E026 50.491
Landform and topography	
Landscape (form)	Floodflain
Landscape (shape)	Almost flat
Slope (position)	Midslope
Slope (%)	< 2 %
Slope (aspect)	0 degrees
Surface characteristics	
Erosion (severity)	Slight
Erosion (type)	Sheet
Capping	Moderate
Land use	Grazing
Effective depth	> 120 cm
Parent material	Alluvium
Soil classification	
South Africa	Oakleaf
WRB	Haplic Luvisols

Description:

0 - 30 cms	Very dark gray (10YR 3/2 m) fine grained sandy loam; moist friable, plastic, sticky consistence; moderate medium subangular blocky structure; good permeability; well drained; many fine roots; gradual smooth transition to :
30 - 65 cms	Very dark greyish brown (10YR 4/2m) fine grained sand clay loam; moist friable, plastic, sticky consistence; strong coarse subangular blocky structure; good permeability; well drained; many fine roots; clay cutans; gradual smooth transition to :
65 - 150 cms	Very dark greyish brown (10YR 4/2 m) fine grained sand clay loam; moist friable, plastic, sticky consistence; moderate medium subangular blocky structure; good permeability; well drained; few fine roots; clay cutans ;

Profile number	**A24**	
Location	Fort hare farm	
Elevation	510 m	
Co-ordinates	S 32 47.526	E 26 51.543
Landform and topography		
Landscape (form)	Plain	
Landscape (shape)	almost flat	
Slope (position)	lowerslope	
Slope (%)	<2 %	
Slope (aspect)	0 degrees	
Surface characteristics		
Erosion (severity)	Moderate	
Erosion (type)	Sheet	
Landuse and vegetation		
Land use	Maize	
Parent material		
Parent material	Mudstone	
Effective depth	30 cm	
Soil classification		
South Africa	Katspruit	
WRB	Gleysols	

Description:

0 - 30 cms	Very dark grayish brown (2.5Y 3/2 m); fine grained sandy clay loam; moist friable, plastic, sticky consistence; moderate medium subangular blocky structure; imperfect permeability; poorly drained; few fine roots; clear smooth transition to :
30 cms	Gleyic horizon and waterlogged

Profile number	**A 26**	
Location	Gaga	
Elevation	649 m	
Co-ordinates	S32 45.169	E026 47.133
Landform and topography		
Landscape (form)	Plain	
Landscape (shape)	Undulating	
Slope (position)	Midslope	
Slope (%)	5-8 %	
Slope (aspect)	0 degrees	
Surface characteristics		
Erosion (severity)	Severe	
Erosion (type)	Gully	
Capping	Moderate	
Land use	Uncultivated,	
Effective depth	37 cm	
Parent material	Shale	
Soil classification		
South Africa	Escourt	
WRB	Solonetz	

Description:

0 - 30 cms	Dark yellowish brown (10YR 4/4 m) fine grained sandy loam; moist friable, plastic, sticky consistence; weak fine subangular blocky structure; good permeability; well drained; many fine roots; abrupt smooth transition to :
30 – 37 cms	Dark grayish brown (10YR 3/2m); coarse sand; loose; apedal, single grain ; many roots
37 - 120 cms	Yellowish brown (10YR 5/6m); clay; moist very friable, plastic, sticky consistence; Strong coarse prismatic structure; imperfect permeability; moderately well drained; no roots ; compacted; clay cutans;

Appendix 5.2: Correlation of South Soil Systems (Soil Forms) to WRB Soil Units

South African system	WRB	Indigenous Classification
Oakleaf	Luvisols/ Cambisols	Santi
Valsrivier	Chromic luvisols	dongwe
Augrabies	Calcic luvisols	Santi
Bonheim	Phaozems	Umhlaba omnyama
Shortlands	Chromic nitisols	Umhlaba obomvu
Clovelly	Lixisols	-
Hutton	Ochric Ferralsols	Umhlaba obomvu
Katspruit	Gleysols	-
Tukulu	Gleyic luvisols	-
Escourt	Solonertz	santi
Swartland	Leptic cambisols	santi
Sterkspruit	Haplic cambisols	santi
Arcadia	Vertisols	Isidhaka
Glenrosa	Leptosols	urhete
Klapmuts	Haplic cambisols	Santi
Dundee	Fluvisols	Santi
Inanda	Humic ferrsalsol	
Rensburg	Vertic gleysols	Isidhaka
Westleigh	Plinthic luvisols	dongwe
Mayo	Luvic leptosols	urhete

Appendix 5.3: Soil chemical data of the main soil forms in Nkonkobe Municipality

Soil form	Depth (cm)	Acid saturation	pH	%OC	P (%)	Mg	Ca	Na	K	Free Fe (%)	ESP	Leaching status
Oakleaf	150	1	6.8	0-0.5	0.0-6	267	1358	8.5927	65 - 105	0.169	2.83	43.5-65.0
Augrabies	150	1	6.90-7.04	0-0.5	12-15				113-274	0.182	6.23	39.1-51.4
Hutton	150	40-50	3.94-4.03	2.5	2	79	221	5.885764	125-221	1.950	8.195	2.8-3.8
Clovelly	150	52-78	3.92-4.12	0.6-2	2	87	193	20.28947	71-139	0.945	3.668	2.7-5.0
Shortlands	150	1	5.00-5.22	0.5	1	374	904	19.31894	193-198	1.776	2.02	20.4-24.3
Lusiki	150	1	5.21-5.33	1.6	1	607	1909	78.34343	37-91	2.723	7.386	27.7-35.0
Glenrosa	32	1	5.11	0.5	1	170	1006	13.36492	198	0.214	0.795	34.3-78.2
Swartlands	85	1	5.26-6.50	0.5	12 - 36	192	1296	9.661175	437-1287	0.284	2.32	33.2-35.4
Sterkspruit	80	1	5.29	0.5	1				34-43	0.561	-	41.6-78.0
Klapmuts	60	1	5.22-5.77	0.5	1	213	826	19.44031	99-115	0.239	0.372	40.5-45.3
Bonheim	150	1	6.77-7.41	0.5-1.5	1				38-80	0.405	1.081	55.9-88.1
Tukulu	60	1	5.05-6.33	0.5	1				44-84	0.121	5	55.5-61.3
Arcadia	150	1	5.46-5.89	0.5	6- 11				127-198	0.214	0.721	89.0-100
Valsrivier	80	0	5.46-5.90	0.5	1-4				134-205	0.456	1.219	40.1-46.4
Katspruit	30	0	6.98	0.5	8				523	0.148	3.957	52.6-54.5
Escourt	37	0	6.21-7.35	0.5	3-5				130-169	0.116	4.588	

Appendix 5.4: Particle size distribution (%) of the main soil forms in Nkonkobe

Soil form	Clay %	Course silt	Fine silt	Course sand	Meduim sand	Fine sand	Very Fine sand
Oakleaf	16.02	7.62	8.66	0.45	1.45	23.62	41.19
Etosha	37.73979	9.704858	16.6261	0.667541	0.754906	8.823122	25.88274
Hutton	59.23	7.80	17.73	0.54	0.57	2.55	16.82
Clovelly	41.74	8.46	24.96	1.00	0.73	4.75	18.49
Shortlands	43.54973	7.492899	11.85923	0.866583	0.577882	6.289978	29.29742
Lusiki	53.63424	3.769475	30.80199	0.576464	1.048117	3.249163	8.961402
Glenrosa	22.0786	3.50083	8.06621	2.263572	2.759511	26.37257	33.00515
Swartlands	20.58927	6.420573	7.880816	0.446299	1.642749	28.55185	33.00024
Sterkspruit	12.84618	4.454739	10.87781	2.268399	2.898508	14	42.69728
Klapmuts	33.72855	4.826611	10.52716	0.764152	0.586836	11.08757	37.96602
Bonheim	47.25016	4.540292	13.69246	2.089223	1.881636	5.557142	21.91778
Tukulu	17.71203	8.947599	12.02392	1.105232	2.125826	9.025923	48.79702
Arcadia	46.43259	8.935114	20.42006	3.544949	1.720343	2.971501	15.11816
Valsrivier	24.63382	4.62001	6.193738	0.367412	2.133895	30.67054	28.97388
Katspruit	41.12204	4.992199	11.15037	1.452834	1.248751	5.205105	32.14213
Escourt	54.48	3.45	9.26	2.57	1.99	4.92	22.16

Appendix 6.1: Water budget data for the different units

Nkonkobe MunicipalityUnits		Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Total
Kat	PE (mm)	114	97	85	58	40	27	25	37	49	70	87	109	798
	Rainfall (mm)	59	67	84	44	35	23	23	24	38	47	61	61	566
	Water deficit	-55	-30	-1	-14	-5	-4	-2	-13	-11	-23	-26	-48	-232
	Summer deficit													-159
	Winter deficits													-161
Lovedale	PE (mm)	125	109	98	66	45	30	30	39	54	75	95	114	880
	Rainfall (mm)	64	67	76	45	36	21	23	23	41	53	65	62	576
	Water deficit	-61	-42	-22	-21	-9	-9	-7	-16	-13	-22	-30	-52	-304
	Summer deficit													-185
	Winter deficits													-76
Woburn	PE (mm)	110	97	89	63	41	28	28	40	51	70	87	106	810
	Rainfall (mm)	50	49	80	40	24	11	19	13	38	47	57	49	477
	Water deficit													-333
	Summer deficit													-196
	Winter deficits													-105
Mt Pleasant view	PE (mm)	108	95	88	64	41	29	29	39	51	69	85	104	802
	Rainfall (mm)	75	62	80	46	35	16	24	19	44	68	72	70	611
	Water deficit	-33	-33	-8	-18	-6	-13	-5	-20	-7	-1	-13	-34	-191
	Summer deficit													-114
	Winter deficit													-51
Dank Den Goewerneur	PE (mm)	117	102	96	67	51	35	29	44	56	71	83	102	853
	Rainfall (mm)	38	65	59	21	18	8	18	9	24	44	46	40	390
	Water deficit	-79	-37	-37	-46	-33	-27	-11	-35	-32	-27	-37	-62	-463
	Summer deficit													-215
	Winter deficit													-157
Middledrift	PE (mm)	114	98	94	65	45	30	29	42	51	68	85	108	829

	Rainfall (mm)	52	59	70	38	33	12	18	18	33	53	62	51	588
	Water deficit	-62	-39	-24	-27	-12	-18	-11	-24	-18	-15	-23	-57	-330
	Summer deficit													-189
	Winter deficit													-101
Sheshegu (Garfield)	PE (mm)	122	106	96	69	50	37	33	45	58	77	94	117	904
	Rainfall (mm)	40	48	68	34	26	14	19	15	33	37	44	39	417
	Water deficit	-82	-58	-28	-35	-24	-23	-14	-30	-25	-40	-50	-78	-487
	Summer deficit													-268
	Winter deficit													-157
Keiskammahoek	PE (mm)	111	99	92	67	48	34	33	45	55	71	86	103	844
	Rainfall (mm)	71	76	83	49	34	21	23	25	45	61	70	70	628
	Water deficit	-40	-23	-9	-18	-14	-13	-10	-20	-10	-10	-16	-33	-216
	Summer deficit													-112
	Winter deficit													-77
Evelyn valley	PE (mm)	85	78	75	56	44	33	32	43	45	56	66	79	692
	Rainfall (mm)	217	199	210	200	85	57	53	65	133	119	207	201	1746
	Water deficit	132	121	135	144	41	24	21	22	88	63	141	122	1054
	Summer surplus													516
	Winter surplus													538
Lenye	PE (mm)	105	94	91	61	47	34	31	43	52	65	79	98	800
	Rainfall (mm)	82	83	101	54	39	21	28	24	53	71	82	87	725
	Water deficit	-23	-11	10	-7	-8	-13	-3	-19	1	6	3	-11	-75
	Summer deficit													-42
	Winter deficit													-32

Appendix 6.2: Soil requirements for cowpea

Rooting Depth (mm)	S1	S2	S3	N1	N2
Texture[1]	15-35% clay	<15% clay	Clay >35% clay	-	-
Depth[1]	>1000	750-1000	500-750	>500	>500
[3]**Crusting**	No/little	Moderate	Severe	-	-
[4]**Soil pH**	>4.5	-	-	-	-
[2] **Phosphorus(mg/kg)**	>15	-	-	-	
[2]**Potassium (mg/kg)**	>160	-	-	<20	

Sources:[3]Van Averbeke and Marais (1991); [4]NDA (2011*)*

Appendix 6.3: Climate requirements for cow-pea

Climate characteristics	**Climate classes**					**Reference**
	S1	S2	S3	N1	N2	
Annual rainfall (mm)	>700	400- 750	-	-	Any	Smith, 1997
Length of growing season (days)	90-200	-	-	-	Any	Smith, 1997
Ehlers zone	-	-	-	-	-	Burger, 1983
Water budget (mm)	< -120	-120 to -200	>200	-	-	Laker, 1978

Appendix 6.4: Soil requirements for sorghum

Rooting Depth (mm)	S1	S2	S3	N1	N2
[1]**Texture**	10- 35% clay	>35% clay	-	-	-
[1]**Depth**	>750	500-750	<500	-	-
[3]**Crusting**	No/little	Moderate	Severe	-	-
[5]**Soil pH**	5.5 – 8.5	-	-	-	-
[2]**Phosphorus (mg/ kg)**	>15	-	-	-	
[2] **Potassium(mg/ kg)**	>160	-	-	<20	

[5] Du Plessis (2008)

Appendix 6.5: Climatic requirements for sorghum production

Climate characteristics	**Climate classes**					**Reference**
	S1	S2	S3	N1	N2	
Annual rainfall (mm)	600-1200	400-400	350-1500	-	Any	Smith, 1997
Length of growing season (days)	120-240	90-200	75-300	-	Any	Smith, 1997
Ehlers zone	77/35	67/25	57/25	46/14	46/14	Burger, 1983
Water budget (mm)	< -120	-120 to -200	>200	-	-	Laker, 1978

Appendix 6.6: Soil requirements for Potato

Rooting Depth (mm)	S1	S2	S3	N1	N2
Texture[1]	Sand <15% clay	Loam 15-35% clay	Clay >35% clay	-	-
Depth[1]	>1000	750-1000	500-750	<500	<500
[2]**Soil pH**	> 4.5	-5- 7.0	-<4.5; >7.0	-	-
[2]**Salinity (mS m$^{-1)}$**		>250			
[2]**Organic matter (%)**	> 1.2	0.8-1.2	<0.8	-	-
[2]**Phosphorus (mg/ kg)**	> 15	-	-	-	
[2]**Potassium (mg/ kg)**	160	-	-	<20	

Appendix 6.7: Climatic requirements for potato

Climate characteristics	**Climate classes**					**Reference**
	S1	S2	S3	N1	N2	
Monthly rainfall (mm)						Smith. 1997
1st month	> 45	>30	>20	-	Any	Smith, 1997
2nd month	> 80	>65	>50	-	Any	
3rd month	> 80	>65	>50	-	Any	
4th month	> 20	Any	-	-	-	
Ehlers' Zone	46/14; 57/25	67/25	-	77/35	77/35	Burger, 1983
Water budget (mm)	Surplus	< -50	-	> -50	-	Laker, 1978

Appendix 6.8: Soil requirements for cabbages production

Rooting Depth (mm)	S1	S2	S3	N1	N2
[1]**Texture**	15-35% clay	<15% clay; >35% clay	-	-	-
[1]**Depth (mm)**	>750	600- 750	>600	-	-
[2]**Soil pH (KCl)**	>4.5	-	-	-	-
[3]**Phosphorus (mg/ kg)**	>35	-	-	-	
[2]**Potassium (mg/ kg)**	>160	-	-	<20	

Sources: [1]Smith (1997); [2]FSSA-MVA; [3]Deenik*et al*. (2006)

Appendix 6.9: Climatic requirements for cabbages

Climate characteristics	**Climate classes**					**Reference**
	S1	S2	S3	N1	N2	
Annual rainfall (mm)	300-450	-	-	-	-	Smith, 1997
Length of growing season (days)	90-120	-	-	-	-	Smith, 1997
Ehlers zone	-	-	-	-	-	Burger, 1983
Water budget (mm)	< -50	-50 to -120	-120 to -200	> -200	> -200	Laker, 1978

Appendix 6.10: Soil requirements for Navel oranges

Rooting Depth (mm)	S1	S2	S3	N1	N2
6Texture	15-35% clay	Sand <15% clay	Clay >35% clay	-	-
[1]Depth	>1000	750-1000	500-750	>500	>500
6Soil pH	>5.5-6.5	-	-	-	-

Source:[6]NDA (2010))

Appendix 6.11: Climatic requirements for Navel oranges

Climate characteristics	**Climate classes**					**Reference**
	S1	S2	S3	N1	N2	
Annual rainfall (mm)	750	-	-	-	-	NDA, 2010
Ehlers zone	77/35	77/35	67/35	57/25; 46/14	57/25; 46/14	Burger, 1983
Water Budget (mm)	Surplus	< -120	< -200	> -200	> -200	Laker, 1978

Appendix 6.12: Extended legend of the Nkonkobe Municipality soil associations

Mapping unit	Dominant soil form	Sub-dominant	Rare	General description of the soil
A1	Oakleaf	Dundee	Augrabies	A dark grayish brown , apedal, moderately deep to deep (> 1000 mm), rapidly to moderately permeable fine sandy loam to sandy clay loam topsoil overlies, at depth of 250 – 350 mm, a deep, dark grayish brown, apedal to weak medium blocky, with moderately dark cutans. Minor soils occupy lower terraces with rare faint reddish yellow mottles and soft carbonate concretions.
A2	Augrabies	Etosha	Valsrivier	A very dark grey to grayish brown, deep (> 1000 mm) apedal, moderately permeable fine sandy loam, strongly cutanic, with upper subsoil which contains free lime. Below 400 – 550 mm is a dark grey to grayish brown structured highly calcareous clay.
A3	Tukulu	Westleigh	Katspruit	A brown to dark brown and brown to dark grayish brown, weak, moderately to rapidly permeable fine sandy loam at depths, 200 – 300 mm, overlying a very dark grayish moderately angular blocky clays. At depth 400 – 600 mm, very dark grey moderately developed blocky. Many grayish and red mottles with imperfect permeability.
B1	Arcadia	Bonheim	Rensburg	A black, moderately deep to deep, strongly structured, slowly permeable self mulching clay with vertic topsoil horizon overlying a black poorly drained clay with strongly developed cutans with slickensides at depths, 300 – 400 mm. Slightly saline.
B2	Hutton	Inanda	Mayo	Dark brown, deep (> 1000 mm), fine grained sand yloam weak to moderate granular topsoils overlying reddish brown, fine grained sandy clay loam to sandy clay, rapidly permeable, apedal to weak fine subangular blocky structure. Sometimes topsoils are dark and enriched with organic matter. Rock outcrops are fairly common

B3	Clovelly	Mayo	-	A thick, very dark grayish brown to dark brown, apedal, rapidly permeable loam to clay loam or sandy clay topsoil overlying a deep, dark brown to brown or yellowish brown pale apedal dystrophic loam, at depths 400 – 900 mm , clay loam or clay. Dark reddish brown lithosols occur on steep slope topsoils.
B4	Shortlands	Mayo	-	A dark reddish brown or dark brown, deep (> 100 mm) well drained sandy loam and sandy clay loam moderately developed blocky structure overlying a reddish brown subsoil with nitic features at depth 300 – 500 mm. Rare shallow soils occur on crest of steep slopes or weathered dolerite at 500 mm.
B5	Bonheim	Arcadia	-	A very dark grey to black, deep (> 900 mm) moderate to strongly structured slowly permeable clay or clay loam topsoil overlying a deep grayish brown to black moderately structured expanding clay subsoil soil at depths 200- 400 mm.
C1	Valsrivier	Augrabies	-	A very dark grey to grayish brown, apedal, moderately permeable loam topsoil overlies at depths, 200 – 300 mm, a dark grayish brown to very dark grayish brown, moderately structured, cutanic sany clay loam, At 600 – 800 mm a pale brown or brown weakly to moderately structured, highly calcareous clay occur. Abrupt topsoil- subsoil transitions are common.
C2	Klapmuts	Valsrivier	Sterkspruit	A brown to very dark grayish brown, sandy clay loam overlying a thin albic horizon at 250 -350 mm and yellowish brown, moderately permeable strongly developed blocky sandy clay to clay with cutans. Weathering material occurs between 600 – 800 mm.
C3	Swartland	Glenrosa	-	A brown to dark brown and brown to reddish brown, apedal, moderately to rapidly permeable fine sand loam and loamy topsoils, 200 – 300 mm, overlying a brown or reddish brown, apedal to moderately angular blocky with moderately developed clay cutans weathering rock occurs at depth 400 – 600 mm. Sometimes the subsoil consists of shale and mudstone saprolytic material with tongues of cutans at depth 400 – 850 mm.
C4	Glenrosa	Mispah		A brown to dark grayish brown, apedal, moderately permeable, gravelly sandy clay loam, overlying

				weathered material and ferruginised gravelly at depths , 100 – 400 mm. Sometimes a shallow, dark grayish brown cutanic clay occurs between topsoil and the weathering material. In some cases the hard rock limits depth at 200- 400 mm.
C5	Estcourt	Sterkspruit	-	A dark grey to brown, weakl, moderately developed blocky, permeable fine sandy loam topsoil abruptly overlies, at depths of 250 – 350 mm, a thin albic horizon occurs and a yellowish brown, strongly structured (prismatic), cutanic, sodic impermeable clays .
C6	Sterkspruit	Estcourt	Klapmuts	A dark grey to brown, apedal, moderately permeable fine sandy loam topsoil abruptly overlies, at depths of 200 – 250 mm, a dark brown to dark reddish brown, moderately to strongly structured (prismatic), cutanic often calcareous clay loam to clay subsoil. Occasionally, soils with abrupt topsoil-subsoil textural transitions a thin albic horizon occurs. At 500 – 900 mm the soils maybe sline or sodic.
D	Katspruit	-	-	A brown to dark brown and brown to dark grayish brown, weak, moderately to rapidly permeable fine sandy loam at depths, at 300 mm, overlying a very dark grayish, waterlogged gleyic horizon.

Appendix 7.1: Soil test and fertilizer recommendations of the test crops

SORGHUM												
	NITROGEN		PHOSPHORUS			POTASSIUM			LIME			
Sample ID	Yield target t/ha	Req. N kg /ha	Sample soil test mg/L	Target soil test mg/L	Req. P kg/ha	Sample soil test mg/L	Target soil test mg/L	Req. K kg/ha	Sample acid sat. %	PAS %	Req. Lime t/ha	Lime type
A1-H1	6	50	6	19	55	105	100	0	1	10	0	-
	9	75	6	24	80	105	100	0	1	10	0	-
	12	120	6	24	80	105	100	0	1	10	0	-
A2-H1	6	50	1	22	75	68	100	80	1	10	0	-
	9	75	1	26	90	68	100	80	1	10	0	-
	12	120	1	26	90	68	100	80	1	10	0	-
A3-H1	6	50	5	11	55	29	100	175	40	10	4	
	9	75	5	14	85	29	100	175	40	10	4	
	12	120	5	14	85	29	100	175	40	10	4	
A4-H1	6	50	2	11	90	139	100	0	52	10	8	dol
	9	75	2	13	110	139	100	0	52	10	8	-
	12	120	2	13	110	139	100	0	52	10	8	-
A5-H1	6	50	1	15	95	72	100	70	1	10	0	-
	9	75	1	18	115	72	100	70	1	10	0	-
	12	120	1	18	115	72	100	70	1	10	0	-
	6	50	1	19	85	198	100	0	1	10	0	-
A6-H1	6	50	36	19	20	547	100	0	1	10	0	-
	9	75	36	23	20	547	100	0	1	10	0	-
	12	120	36	23	20	547	100	0	1	10	0	-
A7-H1	6	50	28	20	20	437	100	0	1	10	0	-
	9	75	28	24	20	437	100	0	1	10	0	-
	12	120	28	24	20	437	100	0	1	10	0	-
A8-H1	6	50	1	10	95	51	100	125	0	10	0	
	9	75	1	12	120	51	100	125	0	10	0	
	6	50	1	18	85	82	100	45	2	10	0	-
A9-H1	9	75	1	22	105	82	100	45	2	10	0	-

	12	120	1	22	105	82	100	45	2	10	0	-
A10-H1	6	50	8	19	50	96	100	25	1	10	0	-
	9	75	8	23	70	96	100	25	1	10	0	-
	12	120	8	23	70	96	100	25	1	10	0	-
	6	50	1	18	80	98	100	25	1	10	0	-
A11-H1	9	75	1	22	100	98	100	25	1	10	0	-
	12	120	1	22	100	98	100	25	1	10	0	-
A12-H1	6	50	1	15	90	234	100	0	0	10	0	-
	9	75	1	18	110	234	100	0	0	10	0	-
	12	120	1	18	110	234	100	0	0	10	0	-
A13-H1	6	50	1	18	85	38	100	155	1	10	0	-
	9	75	1	22	105	38	100	155	1	10	0	-
	12	120	1	22	105	38	100	155	1	10	0	-
A14-H1	6	50	1	20	75	43	100	145	1	10	0	-
A15-H1	6	50	1	18	85	84	100	40	1	10	0	-
	9	75	1	22	105	84	100	40	1	10	0	-
	12	120	1	22	105	84	100	40	1	10	0	-
A16-H1	6	50	12	14	20	139	100	0	0	10	0	-
	9	75	12	17	35	139	100	0	0	10	0	-
	12	120	12	17	35	139	100	0	0	10	0	-
A17-H1	6	50	4	15	70	258	100	0	0	10	0	-
	9	75	4	18	90	258	100	0	0	10	0	-
	12	120	4	18	90	258	100	0	0	10	0	-
A18-H1	6	50	20	18	20	532	100	0	1	10	0	-
	9	75	20	22	20	532	100	0	1	10	0	-
	12	120	20	22	20	532	100	0	1	10	0	-
	6	50	8	17	50	361	100	0	1	10	0	-
A19-H2	9	75	8	21	70	361	100	0	1	10	0	-
	12	120	8	21	70	361	100	0	1	10	0	-
	6	50	1	18	85	444	100	0	1	10	0	-
	9	75	1	22	105	444	100	0	1	10	0	-
A19-H3	12	120	1	22	105	444	100	0	1	10	0	-
	6	50	6	15	60	198	100	0	0	10	0	-
	9	75	6	18	80	198	100	0	0	10	0	-
	12	120	6	18	80	198	100	0	0	10	0	-

A20-H1	6	50	11	15	25	127	100	0	0	10	0	-
	9	75	11	18	45	127	100	0	0	10	0	-
	12	120	11	18	45	127	100	0	0	10	0	-
	6	50	4	15	75	142	100	0	0	10	0	-
A20-H2	9	75	4	18	95	142	100	0	0	10	0	-
	12	120	4	18	95	142	100	0	0	10	0	-
	6	50	4	17	70	205	100	0	0	10	0	-
	9	75	4	21	90	205	100	0	0	10	0	-
A20-H3	12	120	4	21	90	205	100	0	0	10	0	-
	6	50	1	17	90	156	100	0	0	10	0	-
	9	75	1	20	105	156	100	0	0	10	0	-
	12	120	1	20	105	156	100	0	0	10	0	-
A21-H1	6	50	8	15	45	134	100	0	0	10	0	-
	9	75	8	18	65	134	100	0	0	10	0	-
	12	120	8	18	65	134	100	0	0	10	0	-
	6	50	3	18	75	188	100	0	0	10	0	-
A21-H2	9	75	3	22	95	188	100	0	0	10	0	-
	12	120	3	22	95	188	100	0	0	10	0	-
	6	50	9	19	45	102	100	0	0	10	0	-
	9	75	9	23	65	102	100	0	0	10	0	-
A21-H3	12	120	9	23	65	102	100	0	0	10	0	-
	6	50	8	18	50	88	100	30	0	10	0	-
	9	75	8	22	70	88	100	30	0	10	0	-
	12	120	8	22	70	88	100	30	0	10	0	-
A23-H1	6	50	8	18	50	523	100	0	0	10	0	-
	9	75	8	22	70	523	100	0	0	10	0	-
	12	120	8	22	70	523	100	0	0	10	0	-
	6	50	3	19	70	130	100	0	0	10	0	-
A23-H2	9	75	3	24	90	130	100	0	0	10	0	-
	12	120	3	24	90	130	100	0	0	10	0	-
	6	50	5	15	70	169	100	0	0	10	0	-
A26-H2	6	50	4	18	70	70	100	75	0	10	0	-
	9	75	4	22	90	70	100	75	0	10	0	-
	12	120	4	22	90	70	100	75	0	10	0	-
	6	50	6	18	60	74	100	65	0	10	0	-

A26-H3	9	75	6	22	80	74	100	65	0	10	0	-
	12	120	6	22	80	74	100	65	0	10	0	-
	6	50	6	17	55	178	100	0	0	10	0	-
	9	75	6	21	80	178	100	0	0	10	0	-
A23-H1	12	120	6	21	80	178	100	0	0	10	0	-

COWPEA

	NITROGEN		PHOSPHORUS			POTASSIUM				LIME		
Sample ID	Yield target t/ha	Req. N kg /ha	Sample soil test mg/L	Target soil test mg/L	Req. P kg/ha	Sample soil test mg/L	Target soil test mg/L	Req. K kg/ha	Sample acid sat. %	PAS %	Req. Lime t/ha	Lime type
A1-H1	1	40	6	19	55	105	100	0	1	5	0	-
	2	80	6	19	55	105	100	0	1	5	0	-
	3	120	6	19	55	105	100	0	1	5	0	-
A2-H1	1	40	1	22	75	68	100	80	1	5	0	-
	2	80	1	22	75	68	100	80	1	5	0	-
	3	120	1	22	75	68	100	80	1	5	0	-
A3-H1	1	40	5	11	55	29	100	175	40	5	4.5	
	2	80	5	11	55	29	100	175	40	5	4.5	
	3	120	5	11	55	29	100	175	40	5	4.5	
A4-H1	1	40	2	11	60	139	100	0	52	5	9.5	Dol/ cal
	2	80	2	11	60	139	100	0	52	5	9.5	Dol/ cal
	3	120	2	11	60	139	100	0	52	5	9.5	-
A5-H1	1	40	1	15	60	72	100	70	1	5	0	-
	2	80	1	15	60	72	100	70	1	5	0	-
	3	120	1	15	60	72	100	70	1	5	0	-
A6-H1	1	40	36	19	20	547	100	0	1	5	0	-
	2	80	36	19	20	547	100	0	1	5	0	-
	3	120	36	19	20	547	100	0	1	5	0	-
A7-H1	1	40	28	20	20	437	100	0	1	5	0	-
	2	80	28	20	20	437	100	0	1	5	0	-
	3	120	28	20	20	437	100	0	1	5	0	-
A8-H1	1	40	1	10	60	51	100	125	0	5	0	

	2	80	1	10	60	51	100	125	0	5	0	
	1	40	1	18	60	82	100	45	2	5	0	-
A9-H1	2	80	1	18	60	82	100	45	2	5	0	-
	3	120	1	18	60	82	100	45	2	5	0	-
A10-H1	1	40	8	19	50	96	100	10	1	5	0	-
	2	80	8	19	50	96	100	10	1	5	0	-
	3	120	8	19	50	96	100	10	1	5	0	-
	1	40	1	18	60	98	100	5	1	5	0	-
A11-H1	2	80	1	18	60	98	100	5	1	5	0	-
	3	120	1	18	60	98	100	5	1	5	0	-
A12-H1	1	40	1	15	60	234	100	0	0	5	0	-
	2	80	1	15	60	234	100	0	0	5	0	-
	3	120	1	15	60	234	100	0	0	5	0	-
A13-H1	1	40	1	18	60	38	100	155	1	5	0	-
	2	80	1	18	60	38	100	155	1	5	0	-
	3	120	1	18	60	38	100	155	1	5	0	-
A15-H1	1	40	1	18	60	84	100	40	1	5	0	-
	2	80	1	18	60	84	100	40	1	5	0	-
	3	120	1	18	60	84	100	40	1	5	0	-
A16-H1	1	40	12	14	20	139	100	0	0	5	0	-
	2	80	12	14	20	139	100	0	0	5	0	-
	3	120	12	14	20	139	100	0	0	5	0	-
A17-H1	1	40	4	15	60	258	100	0	0	5	0	-
	2	80	4	15	60	258	100	0	0	5	0	-
	3	120	4	15	60	258	100	0	0	5	0	-
A18-H1	1	40	20	18	20	532	100	0	1	5	0	-
	2	80	20	18	20	532	100	0	1	5	0	-
	1	40	8	17	50	361	100	0	1	5	0	-
A19-H2	2	80	8	17	50	361	100	0	1	5	0	-
	3	120	8	17	50	361	100	0	1	5	0	-
A20-H1	1	40	11	15	25	127	100	0	0	5	0	-
	2	80	11	15	25	127	100	0	0	5	0	-
	3	120	11	15	25	127	100	0	0	5	0	-
A21-H1	1	40	8	15	45	134	100	0	0	5	0	-
	2	80	8	15	45	134	100	0	0	5	0	-

	3	120	8	15	45	134	100	0	0	5	0	-
A23-H1	1	40	8	18	50	523	100	0	0	5	0	-
	2	80	8	18	50	523	100	0	0	5	0	-
	3	120	8	18	50	523	100	0	0	5	0	-
A26-H2	1	40	4	18	60	70	100	75	0	5	0	-
	2	80	4	18	60	70	100	75	0	5	0	-
	3	120	4	18	60	70	100	75	0	5	0	-
	1	40	6	18	60	74	100	65	0	5	0	-
A26-H3	2	80	6	18	60	74	100	65	0	5	0	-
	3	120	6	18	60	74	100	65	0	5	0	-
	1	40	6	17	55	178	100	0	0	5	0	-
	2	80	6	17	55	178	100	0	0	5	0	-
A23-H1	3	120	6	17	55	178	100	0	0	5	0	-

POTATO

	NITROGEN		PHOSPHORUS			POTASSIUM			LIME			
Sample ID	Yield target t/ha	Req. N kg /ha	Sample soil test mg/L	Target soil test mg/L	Req. P kg/ha	Sample soil test mg/L	Target soil test mg/L	Req. K kg/ha	Sample acid sat. %	PAS %	Req. Lime t/ha	Lime type
A1-H1	20	90	12	23	80	139	160	110	0	30	0	-
	40	160	12	23	80	139	200	150	0	30	0	-
	60	200	12	23	80	139	240	250	0	30	0	-
A2-H1	20	90	4	25	140	258	160	50	0	30	0	-
	40	160	4	25	140	258	200	70	0	30	0	-
	60	200	4	25	140	258	240	90	0	30	0	-
A3-H1	20	90	1	16	160	51	160	275	0	30	0	
	40	160	1	16	160	51	200	375	0	30	0	
	20	90	1	29	140	82	160	195	2	30	0	-
A4-H1	20	90	2	18	160	139	160	110	52	30	4	Dol
	40	160	2	18	160	139	200	155	52	30	4	-
	60	200	2	18	160	139	240	255	52	30	4	-
	20	90	1	19	160	66	160	235	68	30	5	-

A5-H1	20	90	1	24	155	72	160	220	1	30	0	-
	40	160	1	24	155	72	200	320	1	30	0	-
	60	200	1	24	155	72	240	420	1	30	0	-
A6-H1	20	90	36	32	40	547	160	0	1	30	0	-
	40	160	36	32	80	547	200	0	1	30	0	-
	60	200	36	32	80	547	240	0	1	30	0	-
A7-H1	20	90	28	33	40	437	160	0	1	30	0	-
	40	160	28	33	80	437	200	0	1	30	0	-
	60	200	28	33	80	437	240	0	1	30	0	-
A8-H1	20	90	1	16	160	51	160	275	0	30	0	
	40	160	1	16	160	51	200	375	0	30	0	
	20	90	1	29	140	82	160	195	2	30	0	-
A9-H1	40	160	1	29	140	82	200	295	2	30	0	-
	60	200	1	29	140	82	240	395	2	30	0	-
A10-H1	20	90	8	31	105	96	160	160	1	30	0	-
	40	160	8	31	105	96	200	260	1	30	0	-
	60	200	8	31	105	96	240	360	1	30	0	-
	20	90	1	31	140	98	160	155	1	30	0	-
A11-H1	40	160	1	31	140	98	200	255	1	30	0	-
	60	200	1	31	140	98	240	355	1	30	0	-
A12-H1	20	90	1	25	155	234	160	65	0	30	0	-
	40	160	1	25	155	234	200	85	0	30	0	-
	60	200	1	25	155	234	240	105	0	30	0	-
A13-H1	20	90	1	29	140	38	160	305	1	30	0	-
	40	160	1	29	140	38	200	405	1	30	0	-
	60	200	1	29	140	38	240	505	1	30	0	-
A15-H1	20	90	1	30	140	84	160	190	1	30	0	-
	40	160	1	30	140	84	200	290	1	30	0	-
	60	200	1	30	140	84	240	390	1	30	0	-
A16-H1	20	90	12	23	80	139	160	110	0	30	0	-
	40	160	12	23	80	139	200	150	0	30	0	-
	60	200	12	23	80	139	240	250	0	30	0	-
A17-H1	20	90	4	25	140	258	160	50	0	30	0	-
	40	160	4	25	140	258	200	70	0	30	0	-
	60	200	4	25	140	258	240	90	0	30	0	-

A18-H1	20	90	20	31	50	532	160	0	1	30	0	-
	40	160	20	31	80	532	200	0	1	30	0	-
	60	200	20	31	80	532	240	0	1	30	0	-
	20	90	8	28	110	361	160	0	1	30	0	-
A19-H2	40	160	8	28	110	361	200	20	1	30	0	-
	60	200	8	28	110	361	240	40	1	30	0	-
A20-H1	20	90	11	24	90	127	160	115	0	30	0	-
	40	160	11	24	90	127	200	180	0	30	0	-
	60	200	11	24	90	127	240	280	0	30	0	-
A21-H1	20	90	8	25	110	134	160	115	0	30	0	-
	40	160	8	25	110	134	200	165	0	30	0	-
	60	200	8	25	110	134	240	265	0	30	0	-
A23-H1	20	90	8	30	110	523	160	0	0	30	0	-
	40	160	8	30	110	523	200	0	0	30	0	-
	60	200	8	30	110	523	240	0	0	30	0	-
	20	90	3	32	125	130	160	115	0	30	0	-
A24-H1	40	160	3	32	125	130	200	175	0	30	0	-
	60	200	3	32	125	130	240	275	0	30	0	-
A25-H1	20	90	4	30	125	70	160	225	0	30	0	-
	40	160	4	30	125	70	200	325	0	30	0	-
	60	200	4	30	125	70	240	425	0	30	0	-
A26-H1	20	90	6	29	120	178	160	90	0	30	0	-
	40	160	6	29	120	178	200	110	0	30	0	-
	60	200	6	29	120	178	240	155	0	30	0	-

MAIZE

	NITROGEN		PHOSPHORUS			POTASSIUM				LIME		
Sample ID	Yield target t/ha	Req. N kg /ha	Sample soil test mg/L	Target soil test mg/L	Req. P kg/ha	Sample soil test mg/L	Target soil test mg/L	Req. K kg/ha	Sample acid sat. %	PAS %	Req. Lime t/ha	Lime type
A16-H1	4	50	12	17	35	139	100	0	0	10	0	-
	5	75	12	17	35	139	100	0	0	10	0	-
	6	120	12	17	35	139	100	0	0	10	0	-
A17-H1	4	50	4	18	60	258	100	0	0	10	0	-
	5	75	4	18	60	258	100	0	0	10	0	-
	6	120	4	18	60	258	100	0	0	10	0	-
A3-H1	4	50	1	12	60	51	100	125	0	10	0	
	5	75	1	12	60	51	100	125	0	10	0	
	6	120	1	12	60	51	100	125	0	10	0	-
A4-H1	4	50	2	13	60	139	100	0	52	10	8	Dol/ cal
	5	75	2	13	60	139	100	0	52	10	8	Dol/ cal
	6	120	2	13	60	139	100	0	52	10	8	-
A5-H1	4	50	1	18	60	72	100	70	1	10	0	-
	5	75	1	18	60	72	100	70	1	10	0	-
	6	120	1	18	60	72	100	70	1	10	0	-
A7-H1	4	50	28	24	20	437	100	0	1	10	0	-
	5	75	28	24	20	437	100	0	1	10	0	-
	6	120	28	24	20	437	100	0	1	10	0	-
A8-H1	4	50	1	12	60	51	100	125	0	10	0	
	5	75	1	12	60	51	100	125	0	10	0	
	6	120	1	12	60	51	100	125	0	10	0	-
A9-H1	4	50	1	22	60	82	100	45	2	10	0	-
	5	75	1	22	60	82	100	45	2	10	0	-
	6	120	1	22	60	82	100	45	2	10	0	-
A10-H1	4	50	8	23	60	96	100	10	1	10	0	-
	5	75	8	23	60	96	100	10	1	10	0	-
	6	120	8	23	60	96	100	10	1	10	0	-
	4	50	1	22	60	98	100	5	1	10	0	-

A11-H1	5	75	1	22	60	98	100	5	1	10	0	-
	6	120	1	22	60	98	100	5	1	10	0	-
	4	50	1	22	60	136	100	0	1	10	0	-
	5	75	1	22	60	136	100	0	1	10	0	-
A12-H1	4	50	1	18	60	234	100	0	0	10	0	-
	5	75	1	18	60	234	100	0	0	10	0	-
	6	120	1	18	60	234	100	0	0	10	0	-
A13-H1	4	50	1	22	60	38	100	155	1	10	0	-
	5	75	1	22	60	38	100	155	1	10	0	-
	6	120	1	22	60	38	100	155	1	10	0	-
A15-H1	4	50	1	22	60	84	100	40	1	10	0	-
	5	75	1	22	60	84	100	40	1	10	0	-
	6	120	1	22	60	84	100	40	1	10	0	-
A16-H1	4	50	12	17	35	139	100	0	0	10	0	-
	5	75	12	17	35	139	100	0	0	10	0	-
	6	120	12	17	35	139	100	0	0	10	0	-
A17-H1	4	50	4	18	60	258	100	0	0	10	0	-
	5	75	4	18	60	258	100	0	0	10	0	-
	6	120	4	18	60	258	100	0	0	10	0	-
A18-H1	4	50	20	22	20	532	100	0	1	10	0	-
	5	75	20	22	20	532	100	0	1	10	0	-
	6	120	20	22	20	532	100	0	1	10	0	-
	4	50	8	21	60	361	100	0	1	10	0	-
A19-H2	5	75	8	21	60	361	100	0	1	10	0	-
	6	120	8	21	60	361	100	0	1	10	0	-
A20-H1	4	50	11	18	45	127	100	0	0	10	0	-
	5	75	11	18	45	127	100	0	0	10	0	-
	6	120	11	18	45	127	100	0	0	10	0	-
A21-H1	4	50	8	18	60	134	100	0	0	10	0	-
	5	75	8	18	60	134	100	0	0	10	0	-
	6	120	8	18	60	134	100	0	0	10	0	-
A23-H1	4	50	8	22	60	523	100	0	0	10	0	-
	5	75	8	22	60	523	100	0	0	10	0	-
	6	120	8	22	60	523	100	0	0	10	0	-
A24-H1	4	50	4	22	60	70	100	75	0	10	0	-

	5	75	4	22	60	70	100	75	0	10	0	-
	6	120	4	22	60	70	100	75	0	10	0	-
	4	50	6	22	60	74	100	65	0	10	0	-
A25-H1	5	75	6	22	60	74	100	65	0	10	0	-
	6	120	6	22	60	74	100	65	0	10	0	-
	4	50	6	21	60	178	100	0	0	10	0	-
	5	75	6	21	60	178	100	0	0	10	0	-
A26-H1	6	120	6	21	60	178	100	0	0	10	0	-