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**DIRECTORATE OF ENVIRONMENTAL AFFAIRS
MINISTRY OF ENVIRONMENT AND TOURISM**

**NATURAL RESOURCE MAPPING OF THE
KAVANGO REGION**

**SPECIALIST REPORT 2
SOILS OF THE KAVANGO REGION**



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SOILS OF KAVANGO REGION

A Report for the Kavango Environmental Profile Programme



Compiled by E. B. Simmonds
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For:



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1 INTRODUCTION

1.1 PROJECT BACKGROUND

The Directorate of Environmental Affairs, Ministry of Environment and Tourism requested the mapping of natural resources of the Kavango Region as a first step in the compilation of baseline information for an Environmental Profile of the region. The profile aims to document the major environmental processes and resources in the region, as well as the major demands placed on those resources. The final product aims at providing one or more publications which document major environmental issues and processes as well as a set of environmental data which can be used for further analysis and monitoring.

1.2 AIMS AND OBJECTIVES

This study was aimed at the generation of a set of thematic maps comprising polygons showing the distribution of the most prominent and important soil and vegetation units. Polygons were to be linked to tabulations of attribute data in formats that permit interrogation and analysis for both single and multiple themes. Resource values of the different units were to be highlighted.

The detailed aims and objectives of the study are given in the Project Proposal included as Appendix I to this report.

This document reports on the major soil units and land systems of Kavango Region. Attribute data characterising soil condition and land unit features are summarised from representative test pits and field site information. These are submitted in Excel spreadsheet format and linked by unique identification codes. Four projects compiled in ArcView (3.1) GIS format, present mapped information. Map 1 locates the field survey route and sites from which attribute data are drawn, Map 2 describes the land systems of the region and Map 3 delineates the major soil units. Map 4, depicting the vegetation of Kavango, is linked to Maps 1, 2 and 3 and presented in conjunction with the vegetation report.

2 PHYSICAL ENVIRONMENT

2.1 CLIMATE

Located between 17°20' - 19°12' S and 18° - 21° E, the climate of the Kavango Region is semi-arid with an average annual rainfall total of 400 – 600 mm (van der Merwe 1983). The 500mm rainfall isohyet cuts diagonally through the middle of the region in a broad loop from south-west to north-east, with lower mean annual totals recorded for the south. The region receives summer rainfall from December to April, and decades of regional climatic data record no rainfall between May and October.

The mean annual temperature of the regional weather station at Rundu is 22.2°C. Mean summer and winter temperatures differ by more than 5°C with a mean summer temperature (December to February) of 24.8°C and a mean winter temperature (June to August) of 17.1°C (P. Hutchinson, *pers.comm.*, May 1999). Diurnal temperature ranges are highest in winter when frosts can occur. The frequency of high winds increases significantly from August onwards, reaching a maximum in November just prior to the onset of the rainy season. During the same period wind speeds also increase.

Rainfall conditions during the past three seasons were extremely variable with an exceptionally good year in 1997 (Table 1).

Table 1: Total rainfall per season (July–June) measured at Rundu Airport and matched to project activities

Season	Rainfall (mm)	Activity
1996/97	791.5	Satellite image data capture
1997/98	254.5	-
1998/99	485.6	Field reconnaissance survey

2.2 AGROECOLOGICAL ZONES

Table 2: Growing Period Zones and Areas of Influence in Kavango

Dominant Growing Period Zone	Associated Zones	Length of Growing Period	Areas of Influence in Kavango
GP1	GP2		Extreme north along the terraces bordering the Okavango river
GP2	GP3/GP1	Average growing period 91-120 days; dependable growing period 80% of average	North-west, west, north-central and north-east
GP3	GP4/GP2	Average growing period 61-90 days; dependable growing period 60% of average	South-west, central, south-central, east and south-east
		Average growing period 61-90 days; very short dependable growing period	

Explanatory notes supplied by FAO (1991a) define arid climatic zones by an LPG (length of growing period) of less than 75 days, and seasonally dry tropical areas by a dry season lasting between 90 and 285 days. This characterisation places Kavango region in a climatic transition zone, experiencing both arid and semi-arid conditions as reflected by average and dependable lengths of growing period.

Similarly, from the information used to derive the growing periods and their spatial extent (Table 2 and Appendix II), it is evident that a north-east/south-west climatic gradient divides Kavango into two sub-regions in terms of moisture regimes, and therefore of potential moisture availability. Much of the region can expect an average growing period of 61-90 days, although the probability of this ranges from less than 60% in the south-west to over 80% in the north-east. A thin strip of the region to the extreme north experiences an average growing period of more than 120 days in most years. The variability of climatic parameters, rainfall in particular, therefore increases along this gradient in a south-westerly direction.

2.3 GEOLOGY AND GEOMORPHOLOGY

2.3.1 Topography and Regional Drainage Characteristics

The perennial Okavango River flows eastwards along the northern border of Namibia. Situated south of Angola where the river rises, and west of the Botswana where it empties into the Okavango Delta, the administrative boundary of Kavango Region lies entirely within the south-western reaches of the Okavango River basin.

Topographically, Kavango is flat to gently undulating with maximum altitude differences of approximately 200 m across this vast region. The steepest relief gradients are encountered towards the Kavango River and where dry rivers (omiramba) have incised the sand mantle. Regional elevations gradually descend from 1200 m.a.s.l in the extreme south and south-west to 1150 m.a.s.l west of Rundu, and to 1000 m at Andara on the Caprivi West boundary. The south-north regional gradient is thus of the order of 0.8 m/km (0.08%).

Gentle slope factors combined with the deep, highly permeable soils of the sand plains encourage very little surface runoff, and with the exception of rare high intensity rainfall events, soil absorption capacities are rarely exceeded. However, where long slopes, unstable soils and intensive forms of land use are combined, aeolian and sheet-wash erosion surfaces are evident.

Deep horizontal drainage occurs after heavy rains in the catchment areas of well-defined omiramba, although surface flow is ephemeral and generally truncated by sand drift and alluvial deposits. Surface waters collecting at the confluences of deep omiramba with the eastward draining Okavango River are largely the result of lateral flooding by the Okavango River.

In the extreme south and south-west of the region no omiramba are developed. Drainage mainly occurs via shallow depressions into numerous pans where impeded drainage conditions are found in shallow to moderately deep soils overlying and adjacent to calcrete outcrops. Calcrete crusts and hardpans caused by alternating dry and wet cycles have encouraged seasonal ponding in many localities and appear near the surface where sand cover is thin or lacking.

2.3.2 Landforms Summary and Geological Context

Kavango region can be described as a large aggradational land surface characterised by an increasing differentiation of aeolian sands. True Kalahari sands were deposited on the margins of the Kalahari Basin during the Tertiary desert-forming era (1.8 to 66 million years BP), and younger red sands were deposited and later redistributed from the Late Holocene period to the present. During the latter period, wetter conditions prevailed from 49,000 to 34,000 years BP. From 34,000 to 27,000 years BP a period of aridity favoured the precipitation of calcrete deposits, after which a short return to wetter conditions prevailed (27,000 to 25,000 years BP). In the most recent geological time frame, from 25,000 BP to present, a distinct return to aridity has been documented (Heine & Geyh, 1984).

The land surfaces of Kavango are thus characterised by extensive areas of aeolian sand-drift and dune formations deposited on calcrete erosion surfaces, the calcretes having been formed by quasi-pedogenic processes associated with receding water surfaces under increasingly arid conditions.

Sand drift plains cover extensive areas of northern, north-eastern and central Kavango. The depth of sand mantle increases generally to the north and east, as does the extent to which those sands have been worked and reworked by wind. The plains slope gradually to the north-east and east, and are incised by a number of well-defined omiramba. Over large tracts of the northern sand plains surface drainage features are imperceptible or non-existent.

A broad, indistinct sandy plateau in central Kavango marks the water divide between eastern-draining omiramba from the largest north-draining Omatako omuramba. This area is pitted with shallow depressions and defined by average slope gradients of less than 0.07%.

Fault systems, produced by tectonic activity commencing during the early Cretaceous period, exert a strong influence on the directions of omiramba in Kavango. Omiramba were initially incised along fault-weakened zones during a pluvial period post-dating the formation of calcrete layers at the top of the Kalahari Sequence. During subsequent periods of aridity intense aeolian processes have deposited dune sands on the floors of the omiramba valleys. Omiramba valleys are thus a combination of recent fluvial deposits, sandy side slopes of aeolian origin, and steep calcrete faces.

In the case of the omiramba draining eastwards towards Botswana, incision depths into underlying calcretes increase to the east, with the result that their valleys tend to narrow along their length. It is apparent that recent aeolian activity in addition to fluvial processes have influenced the form of these valleys and their environs. Dunes and drifts of wind blown-sand commonly fringe the eastern omiramba, being more pronounced on southern banks.

Basement formations comprising basalt and quartzite underlie some localised areas in the south-east corner of Kavango, but do not surface in the region. These are capped by a discontinuous layer of calcrete deposits and a thin surface cover of aeolian sand. Denudation process have subsequently planed this area down to form a deflation zone.

Western Kavango is characterised by an extensive system of seif dunes, orientated in an east-west direction and deposited on calcrete surfaces during the Late Holocene. Now stabilised by vegetation, the dune system is clearly differentiated by dune amplitude and the depth of sand mantle to underlying calcrete. The widely spaced northern dunes are associated with a deep sand mantle whereas the more narrowly spaced southern dunes are associated with a shallower sand mantle. The latter are characterised by the common occurrence of pans in dune streets, where underlying calcretes are exposed or thinly covered by recent aeolian and colluvial deposits.

The western dune system gradually loses its distinctive morphology towards the east where its fringes are characterised by feathery complexes of flattened dune outliers with in-filled dune streets, and sand-drifts characteristic of the northern sand plains.

The south-west corner of Kavango intersects the northern tip of a broad flat pediplain where calcretes are exposed or lie near the surface of shallow aeolian and predominantly red sands. The pediplain tapers out to the north and east where the calcretes gradually disappear under sand drift and seif dunes.

The perennial eastern-flowing Okavango River is characterised by scroll and point bars, meanders, ox-bow lakes and other erosional and depositional features encompassing a distinct sequence of riverine land units. The floodplain area, two to six kilometres wide, can be divided into two zones. A broad area adjacent to the present course of the river actively receives fresh sediments during regular seasonal periods of inundation. As water levels drop, ponds and lakes remain. Behind this area can be found a drier zone where the floodplain is no longer seasonally inundated. A terrace system differentially covered by alluvial and aeolian deposits is situated approximately six kilometres behind the floodplain.

3 APPROACH AND METHODOLOGY

3.1 SOIL SURVEY METHODOLOGY

3.1.1 Specific Requirements for Soils

The methodology adopted for the soils investigation was designed to fulfill the following end-product requirements:

1. It will identify the most prominent and important soil units in the Region;
2. These units will be delineated and mapped in one or more layers of polygons;
3. Fieldwork will be required to collect sample data for purposes of interpretation and documentation of units;
4. Detailed sets of quantitative descriptive or attribute data will be compiled and linked to the polygon layers in formats which will allow for interrogation and analysis of the data, both as a separate data set and in combination with other sets of data for the region;
5. The attribute data will emphasise the resource values of the units;
6. All data products to be provided by this project will be compatible in ERMAPPER and ArcView data formats;
7. All digital mapped data will conform to a co-ordinate system and projection to be specified by the Environmental Profiles Project;
8. A detailed report on the vegetation and soils of the region will be submitted along with digital information.

With respect to the soils investigation, a number of comments made in the proposal were discussed and the following points were clarified:

- The principal focus of the soils mapping would be to map and provide quantitative descriptions and resource values for identified soil units.
- The identification, mapping and description of landform units were omitted from the ToR although particularly within the Kavango Region, a land systems approach based on identification of landforms would provide diagnostic information essential to the identification of soil units and to the delineation of boundaries.
- Sample data required for the interpretation and documentation of units referred to the collection of soil samples so that detailed sets of quantitative descriptive or attribute data would be compiled.

- With respect to the sampling and analysis of soils, the determination of field sampling methodology and laboratory analytical methods both depend upon the type of classification system required. The ToR did not specify a classification system. The FAO/UNESCO/ISRIC classification system was agreed upon, and the standard requirements of the FAO Revised Legend (1988, 1990) were complied with.
- Laboratory analysis of soil samples were required for the identification and classification of soils at the soil unit level.
- The objectives of a soils investigation designed to emphasize resource values were analogous to those of a soils investigation designed to feed into a land evaluation study. In order to emphasise the resource values of the soil units a land evaluation approach was used so that resource values could later be used for further analysis using FAO procedural guidelines for land evaluation (FAO, 1993).

3.1.2 Modifications to Methodology

Difficulties with satellite data interpretation were encountered at an early stage of the project. To preserve the integrity of the original approach significant modifications to the methodology was warranted.

In terms of the soils investigation, the original procedural design was proposed as follows:

"In view of the lack of appropriate soils information available in FAO format, the mapping of soil resources would be based in the first instance on an unsupervised classification of remotely sensed data to provide soil polygons. A reconnaissance soil survey would then be carried out over the region to transect the polygon boundaries using standard FAO guidelines for description. These samples would be analysed to provide representative profiles for classification and the signatures of these profiles would be employed in a digital image processing exercise for spatial extrapolation purposes. A further short field check should be carried out to verify boundaries".

Preliminary band combination trials were made on the satellite data to cross check compliancy with known landform and soil boundaries mapped for previous studies of the region (FAO, 1984; Schneider, 1987; Simmonds, 1997 & 1998). Band combination 3 5 4 was found to be appropriate as it appeared to highlight gross landform boundaries as well as the presence of pans. An unsupervised classification

was then performed on a combination of 6 bands and produced as a map of 36 land cover classes in digital and hardcopy formats at a scale of 1:125 000.

Field checks commenced in the north-west of Kavango where landform, soils and vegetation variability were expected to produce the clearest distinctions in land resource signatures, and continued south-eastwards to areas where landscape morphology became less distinct. The field checking procedure, however, revealed no relationship at all between the signatures and landforms, soils or vegetation. In some areas one land cover class could account for up to eight land resource combinations, and in others up to three classes would account for no observed differences. Field checking of the 6-band false colour composite data (Landsat TM) also picked up woefully inadequate boundary definitions.

It was discovered, however, that the frequency and spatial extent of fire sequences played a key role in determining the quality of land cover features. With respect to the effects of fire on soils, field evidence strongly indicated that charcoal and ash cover altered surface horizon colours to the point where significantly different colours appeared to be the same. On the basis of surface colour, therefore, boundaries derived from unsupervised classification of satellite data would highlight fire boundaries rather than soil changes.

The soil reconnaissance survey was abandoned after 5 days and the project methodology re-designed to accommodate the difficulties outlined above.

To re-establish the mapping framework, a land regions map was compiled manually at a scale of 1:250 000 from a 1:50 000 topographic information database obtained from the Surveyor General, and digitised. Land regions were split into component land systems, the defining features of which were systematically noted. A high proportion of both defining features and boundaries were based on landform as represented by differences in surface topography. This approach was used in order to identify, and as far as possible to define, land systems in terms of landforms in the interests of having a uniform basis to the mapping.

Information on possible underlying environmental parameters determining vegetation and soil resources was collated and prepared in a GIS-compatible format to enable overlays of different parameters. The reviewed information included:

- False colour satellite images of the Landsat TM images
- Geology (Geological Survey, 1980)
- Land use units (De Sousa Correira & Bredenkamp, 1987)
- FAO land types (FAO, 1984)

- Veld types (Page, 1980)
- Agroecological zones (De Pauw, 1996)
- Soil Associations classified by the South African Taxonomic System (Loxton *et al*, 1971; McVicar *et al*, 1977; Schneider, 1987)
- Topographic maps (Surveyor General)
- Water rest level contours (Namibia Groundwater Consultants, 1991).

A field survey route was established to traverse the boundaries of all land systems and included a soil sampling intensity designed to cover soil reconnaissance survey requirements for classification and land systems analysis.

The main field survey was carried out alongside the soils and vegetation sampling programmes, during the period 24 April – 5 May 1999. The survey route was recorded by GPS. The land regions/systems map was verified by field checks taken at 64 sample sites. FAO guidelines were used in the field to confirm land units. The following individual elements were measured and described: altitude, slope angle and aspect, profile curvatures, land system and facet, micro-topography, surface condition and drainage, and erosion-deposition status. These were incorporated into a preliminary polygon database to identify landform elements, and further combined into land systems and regional patterns. These were used in the first instance to derive base maps for soils and vegetation.

A two-day flight survey was undertaken from 25 - 26 August 1999 to cross-check boundaries and extent of the identified land systems. With the help of an additional 103 geo-referenced waypoints and notes made during the flight, the draft map was reviewed, corrected and finalised accordingly. The final map comprised a combination of 7 land regions, largely determined by drainage patterns, and 19 land systems within these broader land regions. The seven land regions were defined as:

1. Western Stabilised Dunes
2. South-western Karst Pediplain
3. Northern Sandplain
4. Omatako Drainage
5. Ephemeral Catchment Divide
6. Eastern/Southern Panveld
7. Eastern-flowing Paleo Drainage

3.1.3 Soil Survey, Classification and Mapping

The soil survey was designed to acquire field data pertaining to the character and distribution of soil and land unit parameters represented in the project area. The survey was carried out at reconnaissance level in terms of observation density, and adopted a catenary transect approach to identify relationships between landform, slope position and soils. Thirty-eight test pits and 25 auger holes were used to describe profiles and sample the major soil associations within land systems identified on the map. This was supplemented by a further 42 auger holes drilled to verify soil boundaries.

Profile pits were dug at least twice in each significant land unit identified, although accessibility problems precluded the sampling of one land region.

All observations were located GPS. Soil horizons were described in accordance with the FAO Guidelines for Soil Description (1977), and colours were determined on moist samples using the standard Munsell colour chart.

Soil characteristics were determined on representative samples of each significant horizon in all soil pits. Soil property determinations were made by field and laboratory analysis.

Physical, chemical, descriptive and analytical soil survey results were uniquely coded by sample and site identifiers and entered into Excel worksheets. Worksheet information was linked to land system polygon identification codes.

Soils were classified to FAO group, unit and phase levels, and their boundaries drawn on a topographic base map at 1:250 000 scale. Boundaries were delineated by interpretation of recent (1996) aerial photographs at 1: 80 000 scale, by reference to adjoining soils maps prepared for NW Ngamiland, Botswana (Jamagne, 1990), NE Otjozondjupa Region (DRFN, 1999), Cubango Province, Angola (Minader, 1996), and commercial farms bordering south-central Kavango (Wierenga, 1999), and by incorporating the results of previous field-based studies on landform/soil associations in the region (Simmonds; 1997, 1998).

3.2 DATA ANALYSIS

3.2.1 Sample Analysis

All analytical procedures followed standard reference methodologies. Tests used for the determination of soil properties complied with the requirements of the revised FAO system of soil classification (FAO/UNESCO/ISRIC; 1988) and land evaluation (FAO; 1991). Laboratory analyses were carried out by Analytical Laboratory

Services (Windhoek) who performed method validation by direct reference and sample exchange through the Agri Laboratories Association of Southern Africa (ALASA). Details of analytical procedures are given in Appendix III.

3.2.2 Measurement of Soil Conditions

A summary of the measurements made for classification and use in land evaluation is given in Table 3 overleaf. Data and calculations are supplied in spreadsheet format (Excel 97) and presented in Appendix IV.

Although not specifically required for classification purposes, dry bulk density and total porosity measurements were made to estimate the degree of soil compaction observed in test pit profiles in order to determine effective depth for land evaluation.

Table 3: Summary of Measurements for Soil Classification and Land Evaluation

Chemical Properties	Physical Properties	Environmental Setting
Organic Matter (%)	% Clay (<2 μ)	Site coordinates
Organic Carbon (%)	% Silt (2-53 μ)	Land system
pH	% Very fine sand (53-106 μ)	Land facet
Electrical Conductivity ECe (μ S/cm; mS/cm)	% Fine sand (106-250 μ)	Drainage basin
Ca (ppm; me/100g; me/l ⁻¹)	% Medium sand (250-500 μ)	Slope inclination (%) and slope aspect
Mg (ppm; me/100g; me/l ⁻¹)	% Coarse to very coarse sand (500-200 μ)	Surface micro-topography (roughness)
K (ppm; me/100g; me/l ⁻¹)	% Gravel (>2000 μ)	Presence of stones and boulders
Na (ppm; me/100g; me/l ⁻¹)	Textural Class	Soil surface condition; evidence of fire
P (mg/kg)	Moisture Content (%)	Surface drainage status
CaCO ₃ (quant.)	Dry Bulk Density (g/cm ³)	Erosion - deposition status
SO ₄ (S μ g/g)	Porosity (volume %)	Land use intensity
Cu (ppm; me/100g; me/l ⁻¹)	Sample size: 45	Sample size: 64
Zn (ppm; me/100g; me/l ⁻¹)		
Fe (ppm; me/100g; me/l ⁻¹)		
Mn (ppm; me/100g; me/l ⁻¹)		
CEC (me/100g soil)	Soil Profile Characteristics	Derived Indices
CEC (me/100g clay)	Surface crust characteristics	Estimated permeability
Sodium Absorption Ratio (SAR)	Horizon identification	Estimated erodibility (F _b value; SLEMSEA)
Exchangeable Sodium % (ESP)	Horizon colour (Munsell coding) and depth	Erosion hazard potential (rating)
Exchangeable Potassium % (EPP)	Identification of charcoal layers	FAO textural class
Total Exchangeable Bases (me/100g)	Structure + compaction	FAO slope class
Ca:Mg	Carbonates (10% HCl)	FAO depth class
K:Mg	Handling properties and textural changes	FAO permeability class
Clay Content (%)	Pore size distribution	Soil classification to group and unit levels (FAO, 1988)
Moisture Content (%)	Root penetrability; particle consolidation	Soil management phase
Salinity (ECe > 4 mS/cm)	Mottles	
Sodicity (Na > 1 me/100g; ESP > 15)	Moisture content and changes	
Na:CEC (clay)	Internal drainage characteristics	
	Effective depth	

K:CEC (clay)	Estimation of aggregate stability
Sample size:75	Sum test pits: 38 Auger sample size: 25

Clay fraction cation exchange capacities (CEC clay) were determined in addition to total soil CEC to highlight differences in base concentrations of all soils for which a low organic matter content was indicated. Total charcoal contents were estimated independently of other forms of carbon.

Soil properties and the methods used for their estimation are discussed below.

3.3 DISCUSSION OF SOIL PROPERTIES AND METHODS USED FOR THEIR ESTIMATION

3.3.1 Cation Exchange Capacity (CEC)

Cation exchange capacity (CEC) measurements are made as a standard part of the overall assessment of the potential fertility of a soil. For the majority of soils CEC measurements give values that, at a given pH, are related to the sum of cations held by the permanent negative charge on the clay particles and the cations held by the organic matter.

Cation exchange capacity is a property of the colloidal fraction of the soil, derived mainly from the clay and organic matter fractions, although the silt-sized particles contribute significantly. Hence, assessment of CEC values take the clay content, mineralogy and organic matter content of the sample into account.

The FAO (1979) quote CEC values of 8 - 10 me/100g of soil as indicative minimum values in the top 30cm of soil for satisfactory production under irrigation, provided that other factors are favourable. Lower values than these should be highlighted in land suitability classifications and in the assessment of land potential. CEC values < 4 me/100g (measured at the pH of the soil) indicate a degree of infertility normally unsuitable for agriculture.

For soils low in organic matter, Landon (1984; p121) advises that CEC values "can usefully be expressed as a proportion of the clay fraction" where:

$$\text{CEC (me/100g clay)} = [\text{CEC (me/100g soil / \% clay)}] * 100$$

CEC (clay) values derived from the equation above can be used as a rough guide to the clay mineralogy of a sample, although no suggestions on how these values could indicate potential fertility are offered by Landon.

CEC (clay) values, by virtue of the equation used above, will result in higher CEC values. These values have been widely used to support CEC (total) values in the

classification of soil units (FAO, 1991; Siderius, 1992; UNESCO, 1986). Presumably the rationale is that whereas they cannot be used alone to substitute total CEC values as indicators of soil fertility, they can provide an indication of the potential productivity of the clay fraction of soils.

Critical limits have not yet been established for CEC (clay) values as a stand-alone soil property. Landon (*op sit*) and FAO (*op sit*) apply critical limits normally set for CEC (total) values although the FAO also provide guidelines for further interpretation of CEC (clay) values. In comparison, the limits for CEC (total) and CEC (clay) set by Siderius (*op sit*) for land evaluation coincide at the lower end of the rating scale although they differ by up to 40% at the higher end of the scale where the limits set for CEC(clay) are lower.

Despite a certain lack of confidence attached to the setting of appropriate critical levels, the CEC (clay) values derived for the soils of Kavango nevertheless serve to highlight the differences in total cation concentrations found in their clay fractions. These sandy and loamy soils contain extremely low levels of organic matter, little clay, and are otherwise classified as "exhibiting low to very low inherent fertility" when measured against standard CEC (total) critical reference values.

For the purpose of this classification both the standard FAO reference limits for CEC (total) and their recommended limits for CEC (clay) are adhered to. No tests of significant difference are applied to the CEC (clay) results; they are simply presented and used where recommended by FAO guidelines.

For the determination of soil properties requiring CEC as an integral part of their equations, both CEC (total) and CEC (clay) values are used in separate calculations (Appendix IV). However, as no method of validation could be found for the calculations based on CEC (clay) values, no attempt was made to use them either for classification purposes or to support judgement on soil conditions except where specifically recommended.

3.3.1.1 Interpretation of CEC values with respect to potential fertility

With respect to soil fertility, support for the interpretation of total CEC values rested on evidence deduced from other test results. The low values of total CEC determined for the soils of the region in fact suggest a significant and almost universal level of inherent *infertility*. In a broad sense such indications of infertility are supported by, and can be attributed to, genetically low clay and silt fractions combined with the extremely low percentages of organic matter measured in all horizons of all test pit profiles. These soils are the products of reworked aeolian

parent material, intrinsically lacking in colloidal clay. If CEC is a property of the colloidal fraction of a soil, then CEC values can never be high in soils with low colloidal content.

Although not quantitatively expressed, it is clear that the CEC (clay) values reflect differences in *relative soil fertility status* more definitively than do the CEC (total) values. The soils of this region are developing in a semi-arid climatic regime, over a relief loosely described as flat to undulating, and on parent material consisting predominantly of freely draining sands. Despite the genetically low clay and silt fractions, immature horizon development and dearth of soil organic matter, high CEC (clay) values are nevertheless found. Exchangeable salts are actively moving into and out of, and up and down the soil profiles, and whether these salts arrive in solution after storm events or as upwardly mobile evaporative precipitates characteristic of secondary enrichment, differences in their levels of concentration can be measured by CEC (clay) values.

With only 7 exceptions in a group of 75 samples, the CEC (total) values indicated low to very low fertility ratings (<5 me/100g). However, among the same group of samples, significant differences in CEC (clay) values are found, with a range from 1.20 to 518.38 me/100g. These differences can largely be attributed to the following exogenic influences:

- slope position in catenary sequences;
- local depressions on otherwise flat plains
- deposits of alluvial clay and silts along ephemeral river floors;
- depth of underlying calcrete, silcrete and sandstone deposits;
- presence of shallow groundwater levels
- effects of fire
- dry season wind speeds
- rainfall intensity of storm events and rainfall distribution pattern

It is evident that exogenic factors exert a substantial local influence on the soils of Kavango, producing conditions favouring the transport and re-deposition of wind-borne and alluvial clays and silts, the accumulation of exchangeable salts, and the transformation of genetically infertile soil bodies into pockets of high potential productivity. The differences in CEC (clay) values are sufficient to warrant further investigation into the importance of using CEC (clay) as a diagnostic property for the classification and evaluation of soils of the region.

3.3.2 Individual Exchangeable Cations

The levels of exchangeable cations are of more immediate value than the CEC, because they not only indicate existing nutrient status but can also be used to assess balances amongst cations. This is of importance because many effects (e.g. on soil structure and nutrient uptake by plants) are influenced by the relative concentrations of cations as well as by their absolute levels.

Concentrations of exchangeable bases (calcium, magnesium, sodium and potassium) and micronutrients (copper, iron, zinc and manganese) were assessed. Levels of aluminium were not individually assessed because the measured pH (H₂O) values of 93% of the soils were higher than 5.5 - the level above which aluminium is not present in available form.

For the assessment of complex soil properties such as 'nutrient status' or 'fertility', the utility of exchangeable base measurements lies more in the proportional representation of each base in relation to other bases and to total CEC, than in the stand-alone interpretation of individual base values.

Indices of plant-available calcium are of little value, since the availability varies enormously from soil to soil and is highly dependent on a number of factors. Normally Ca deficiency as a plant nutrient occurs only in soils of low CEC at pH values of 5.5 or less, although high K values may inhibit plant uptake of Ca in soils having a more neutral reaction. Ca may also be deficient at high pH levels when there is excessive Na content. This can occur when the measured available Ca levels are well in excess of those considered adequate for less extreme soils. (Landon, 1984).

A deficiency threshold of 0.2 me/100g is often given for magnesium levels in tropical soils, although as with Ca, cation relationships affect plant availability. Increasing Ca:Mg ratios above 5:1 reduces the Mg availability to plants, although when Mg is present in much larger amounts than Ca, the latter becomes less available and the soil structure weaker. Similarly, where K:Mg ratios are greater than 2:1 plant uptake of the latter becomes inhibited. In neither event is it possible to give precise ratios within which fertility is assured and beyond which deficiency symptoms will occur.

Critical values of available potassium are most useful when given as a percent of the total CEC, known as the exchangeable potassium percentage (EPP). The minimum relative level quoted by Jones and Wild (1975; in Landon, 1984) is at least 2% of the sum of all exchangeable bases.

Sodium is not an essential plant nutrient and its absence, or presence in very small quantities, is therefore not usually detrimental to plant nutrition. However, high concentrations of exchangeable sodium salts, particularly in proportion to the other cations present (as in alkali or sodic soils) produces soil structural breakdown which reduces permeability, aeration, infiltration rates and soil workability.

Saline and alkali (sodic) soils are classified mainly on the basis of their soluble salt concentration (electrical conductivity) and exchangeable sodium content.

As with exchangeable potassium, the exchangeable sodium in a soil is assessed as a percent of the total CEC, known as the exchangeable sodium percentage (ESP), where:

$$\text{ESP} = [\text{Exchangeable Na} / \text{CEC}] * 100$$

An ESP of 15 is regarded as the critical limit between sodic and non-sodic soils, with sodicity being indicated at values greater than 15. This is an arbitrary figure since the properties of soils often exhibit no sharp change as the content of exchangeable Na increases. In some soils an exchangeable Na concentration of 2 to 3 me/100g is used as a more suitable criterion for distinguishing sodic samples, although the particular circumstances under which this limit is best applied have not been defined (Landon, 1984). In general, soils with exchangeable Na greater than 1 me/100g should be regarded as potentially sodic.

For the classification of Kavango soils, both ESP values greater than 15 and values of exchangeable Na greater than 1me/100g were used to determine potential sodicity. This precautionary measure was taken to cross-check the values of CEC-dependent results against Na concentrations, which are independent of CEC.

In all cases where ESP was greater than 15, exchangeable Na values were also greater than 1me/100g. In soils where ESP values were less than 15 but higher than 14, exchangeable Na values were always less than 1me/100g. These soils were considered to be marginally sodic, and classified accordingly.

3.3.3 Micronutrients

Four trace elements considered essential for plant growth - copper, iron, manganese and zinc were measured directly. For reference purposes, a small set of boron levels was obtained from the results of recent commercial surveys on representative soils

of the region. These were later discounted as the values were found to be affected by the presence of soil additives (*pers. comm.* Wierenga, 1999).

With the exception of boron, little information is available on trace element levels which may cause toxicity problems; much more attention has been paid to the critical levels below which deficiency symptoms may appear. Similarly, whilst it is accepted that the availability of trace elements to plants is affected by many soil and environmental factors, little information is available on the effect of environmental conditions whereas a wealth of investigations provide data on specific soil element interactions.

Standard methods for measuring trace elements are not widely agreed, with the most common methods designed to quantify water-soluble, cation-exchangeable, readily reducible or complexed forms. Values of critical deficiency are dependent upon the extracting agent although an acceptable summary of calibrations has been produced to standardize results (Cox and Kamprath in Landon, 1984).

Micronutrients from Kavango soils were extracted by 1 M ammonium acetate (Appendix III). Deficiency levels in soils using this method are given as:

Table 4: Standard Critical Deficiency Levels of Soil Micronutrients

Micronutrient (available form)	Critical Deficiency Level (ppm)
Cu	0.2
Fe	2
Mn	20
Zn	0.3 - 2.3

The soils of Kavango were found to be deficient in iron, zinc and manganese. In the case of manganese the majority of values were significantly lower than the critical deficiency levels set for the extractant used. Precise values for copper could not be obtained because, with only one exception, the measurements of concentration fell below 0.5 ppm - the lowest accurate level of detection. At 0.2 ppm, the critical deficiency level for copper is reasonably close to this level, and therefore it was assumed that the concentration levels of this micronutrient, if not proven to be deficient, were marginally deficient at best.

3.3.3.1 Interpretation of Low Micronutrient Concentrations

The low micronutrient status of Kavango soils can be attributed to observed environmental and genetic conditions. Although many factors affect the concentrations of single micronutrients, not the least being the levels of other soil

elements, the conditions summarised in Table 5 below consistently appear to control and limit their overall availability as a nutrient resource. Factors interacting with copper, iron, manganese and zinc have been included to indicate the areas of co-dependency with other soil elements, although the nature and direction of these interactions have not been investigated further.

Table 5: Environmental and Genetic Conditions Limiting Micronutrient Availability

Available Micronutrient	Interacting Factors	Kavango Soils: Conditions Limiting Micronutrient Availability
Cu	N, Fe, Mg, Mo, P, Zn	<ul style="list-style-type: none"> • Sandy texture of aeolian origin
Fe	pH, K, Mn, Ca, Mg, P, Cu, Mo, Zn	<ul style="list-style-type: none"> • Free CaCO³ • Extreme soil moisture conditions • Soil temperature extremes • Low organic matter • Parent material deficiency (genetic)
Mn	pH, OM, K, Mo, P, Fe, Cu, Zn	<ul style="list-style-type: none"> • Soil alkalinity • Dry climate conditions
Zn	pH, Cu, N, P, Ca	<ul style="list-style-type: none"> • Calcareous soils • Low organic matter • Restricted root zones (compaction)

3.3.4 Anions

Of all the major plant nutrients, phosphorous is the most versatile and complex in both its organic and inorganic forms. Inorganic phosphorous can occur as various compounds of Ca, Fe and Al, in solution, in surface films, in the solid state, or as exchangeable anions held by the positive charges on the edge of clay particles.

Exchange reactions involving adsorbed phosphate ions are slow compared with the reactions of individual cations, and therefore the rate of its release is also slow. Interactions of P with exchangeable cations tend to be dependent on soil pH. For example, at low pH values (<5.5) phosphate ions combine with Al and Fe to form compounds not readily available to plants. At high pH values (>8.0) in the presence of calcium, phosphate tends to be converted to calcium phosphate and the availability of P to plants is reduced. Above pH 8.5 the presence of sodium may increase phosphate availability by formation of soluble sodium phosphate.

For the soils of Kavango, available P was estimated by the Olsen method. By this method a critical deficiency level of <5 ppm and a high availability value of 15 ppm are quoted in Landon (1984) for all soils, especially where pH is > 7.

3.3.5 Organic Matter

The quantity of organic matter in a soil is pivotal to the FAO system of classification, for which these values are used in the determination of diagnostic properties and horizons and in the categorisation of soil groups and units (FAO, 1988).

Estimation of organic matter content is normally carried out by the standard Walkley-Black dichromate method of organic carbon determination. Particularly for the soils of Kavango, however, difficulties were expected to arise in the determination and interpretation of such results because of the very low *observed* levels of organic matter combined with an almost ubiquitous presence of carbon in the form of charcoal. Furthermore, charcoal was found to occur not only in the form of mottles and fragments dispersed throughout profiles as would be expected after periodic sequences of burning by fire, but also embedded in thin, compact and sometimes consolidated layers bonded by cementing agents.

In view of the fact that low organic matter and the presence of charcoal were expected to influence analytical results, an amendment to the standard methodology was made in an attempt to isolate the influences of each.

The colourimetric Walkley-Black method was used in place of the standard method as this procedure yields more accurate results on soils with low organic matter content (see Appendix III). Results were expressed as organic carbon weight percentages.

Total organic matter content was estimated by loss-on-ignition (L.O.I.) on sub-samples of the same sample set used for the Walkley-Black method. Results were expressed as organic matter weight percentages, and compared to those determined for organic carbon content.

No direct method could be found to quantify the interference of organic carbon results by charcoal, although a crude estimation of total charcoal content was made. Undisturbed samples previously used for bulk density estimation and samples used in loss-on-ignition procedures were completely oxidized by ashing at 500°C, and re-weighed. Weight losses after oxidization at 500°C provided values of total

charcoal content for the loss-on-ignition sample set. For the bulk density sample set, values of total carbon content were produced and used for reference purposes only.

3.3.6 Free Carbonates

Carbonates in soil profiles may be derived from carbonate-rich rocks (especially from calcite CaCO_3 and dolomite CaCO_3 and MgCO_3) but are more commonly encountered as a secondary deposition from groundwater.

Kalahari aquifers under Kavango are believed to be recharged from dolomite mountains to the west. Shallow calcrete deposits underly most of the aeolian sands blown into Kavango and significant areas were found exposed on dune streets and omiramba floors. From these sources the soils of Kavango would be expected to receive sufficient quantities of free carbonates to warrant classification based on enrichment horizons.

Free carbonates were measured for soils with minimum pH (H₂O) values of 7.0 as below this pH Ca and Mg carbonates are seldom present. The presence of free carbonate normally indicates that the clay complex is dominated by exchangeable Ca, which usually implies favourable soil physical conditions. Excess Ca, however, can lead to deficiencies of minor elements as well as antagonising the action of others. High levels of carbonate (>15%) affect the physical, as well as the chemical, properties of a soil.

There are no precise ratings for levels of free carbonates, but values of over 40% can be considered as extremely calcareous. A CaCO_3 equivalent of >15% is used in the FAO definition of a calcic horizon and >40% for the calcareous material underlying shallow soils.

3.3.7 Gypsum

Where cemented and indurated layers were observed in soils for which the field testing of carbonates yielded negative results, the presence of gypsic horizons was questioned. In all cases however, analytical testing for gypsum was rejected for classification purposes on the grounds that the zones of suspected enrichment were always less than 15cm thick. This disqualified the horizons in question from being used as diagnostic of soil type.

3.3.8 Sulphates

Sulphur is a necessary plant nutrient but rarely determined because of interpretative problems, which are due to the complex nature of S compounds in soils. Available sulphur ($\text{SO}_4 - \text{S}$) values were measured for the sole purpose of cross-checking with individual exchangeable base concentrations and free carbonate measurements, to support other parameters in the identification of diagnostic horizons and classification of soils.

3.3.9 Erodibility and Erosion Hazard Ratings

Erodibility factors are not required for the classification of soils, but for land evaluation their values can provide a good indication of resource value in terms of soil potential based on a combination of the soil and land qualities specific to any one area.

The SLEMSA Soil Loss Estimator model was developed to take into account the variety of soils and soil environments experienced in Southern African conditions, and SLEMSA Erodibility Factor values (F_b values) have been established for South African soil types classified under the RSA taxonomic system (Republic of South Africa, 1976). Maps of soil associations produced in the early 1970s (Loxton *et al*, 1971) for northern Namibia used the RSA taxonomic system, although soil erodibility factors under Kavango conditions were not attached. For many reasons, soils classified under the RSA system are difficult to correlate to the FAO Revised Legend (Simmonds, 1998) and have not been achieved for Namibian soils.

A qualitative and site-specific estimation of erodibility and erosion hazard was made for a number of Kavango soils during the course of this field survey. Site observations were made on soil properties influencing runoff properties and resistance to detachment (crusting, strength, internal drainage, aggregate stability, texture) and environmental factors (ground condition, ground cover, surface drainage, slope length, slope %, evidence of erosion and deposition). Individual site co-ordinates were then overlaid onto a soil map classified under the RSA taxonomic system and soil types were determined. Erodibility factors already derived for these soil types in South Africa were amended according to the conditions experienced at each site in Kavango, and assigned an erosion hazard potential on a qualitative rating scale (very low to very high).

These values are presented in Appendix IV, although they should be treated with caution as the method itself has not been validated. Sources of error have undoubtedly crept in (e.g. the RSA system of assigning one erodibility factor to

each soil type), and many more sites would be needed to justify extrapolation into a regional soil erodibility map.

3.3.10 Sodium Adsorption Ratio (SAR)

Although of little importance to the classification of Kavango soils, sodium adsorption ratios were calculated to demonstrate an independent empirical relationship with ESP which can be used to monitor change in the quality of soils under irrigated agriculture. As a measure of changing resource values, this relationship would be particularly appropriate to establish on the soils of the Okavango river terraces and old floodplain in areas already placed under irrigated cultivation. Using the equation:

$$\text{SAR} = [\text{Na}^+] / \sqrt{(0.5 [\text{Ca}^{++} + \text{Mg}^{++}])} \quad (\text{all units in me/l}^{-1})$$

- the ESP and SAR of soils under irrigation can be related empirically by the following equation:

$$\text{ESP} = 100 (-0.0126 + 0.01475 \text{ SAR}) / 1 + (-0.0126 + 0.01475 \text{ SAR})$$

The estimated ESP is then used as the ESP value to be expected in association with measured SAR values of soils which have reached equilibrium under irrigation.

Sodium adsorption ratios were calculated for the soils of Kavango although their values have no current application. Exchangeable sodium percentages estimated from these SAR values demonstrated no clear relationship with ESP calculations derived from field samples simply because the soils measured do not regularly or consistently receive water. The results are nevertheless presented in Appendix IV as they can be used in the screening of soils for potential suitability under irrigation, and to provide a baseline for monitoring change in SAR values under future irrigation.

4 SOIL CLASSIFICATION

Soils were classified to the FAO/UNESCO/ISRIC Revised Legend (1988) using general principles and nomenclature recommended by FAO (1990).

At the first level of generalization, 6 major soil groups were identified. These were subdivided at the second level into 11 soil units, of which 3 were further subdivided into an additional 4 sub-units. Through this process, one first-level and two second-level inter-grades were identified. A total, therefore, of 15 distinct soil types were identified.

Six phases were assigned to soils in specific areas of Kavango where surface and/or subsurface features of the land (e.g. arid conditions, cementation of parent material) formed constraints to their management and use. Phases cut across boundaries of different soil units and therefore are not shown on the soil map (Map 2). A description of the phases is given in Section 4.3; where evidence of such conditions was found by the field survey, a phase level has been appended to the soil unit name (Appendices IV and V).

The formative elements used to name soil groups and units in Kavango are tabulated below.

Table 6: Formative elements used for naming major soil groups

Name	Formative element
Arenosol	From L. <i>arena</i> , sand; connotative of weakly developed coarse textured soils
Calcisol	From L. <i>calx</i> , lime; connotative of accumulation of calcium carbonate
Fluvisol	From L. <i>fluvius</i> , river; connotative of alluvial deposits
Solonetz	From Russian <i>sol</i> , salt, and <i>etz</i> , strongly expressed
Anthrosol	From Gr. <i>anthropos</i> , man; connotative of human activities
Alisol	From L. <i>alumen</i> ; connotative of high aluminium content

Table 7: Formative elements used for naming soil units and sub-units

Name	Formative element
Albic	From L. <i>albus</i> , white; connotative of strong bleaching
Calcaric	Form L. <i>calcarius</i> , calcareous; connotative of the presence of calcareous material
Calcic	From L. <i>calx</i> , lime; connotative of accumulation of calcium carbonate
Cambic	From late L. <i>cambiare</i> , to change; connotative of changes in colour, structure and consistence
Dystric	From Gr. <i>dys</i> , ill, dystrophic, infertile; connotative of low base saturation
Ferralic	From L. <i>ferrum and alumen</i> ; connotative of a high content of sesquioxides
Haplic	From Gr. <i>haplous</i> , simple; connotative of soils with a simple, normal horizon sequence
Luvic	From L. <i>luere</i> , to wash, 'lessiver'; connotative of accumulation of clay
Petric	From L. <i>petra</i> , stone; connotative of the presence of an indurated layer at shallow depth
Sodic	From L. <i>sodium</i> , connotative of high content of exchangeable sodium
Xanthic	From gr. <i>xanthos</i> , yellow; connotative of yellow coloured soils

4.1 DIAGNOSTIC HORIZONS

Sets of quantitatively defined properties produced by soil forming processes made it possible to base the classification on general principles of soil genesis. Objectivity was secured in that the processes themselves were not used as criteria but rather in their effects expressed in terms of morphological properties that had identification value.

4.1.1 Horizon Definitions

The following **MASTER HORIZONS** are present in Kavango:

A = Mineral horizon formed at or adjacent to the surface, lacking the properties of B or E horizons, but having morphology distinct from parent material.

E = Mineral horizon showing concentration of sand and silt fractions high in resistant minerals, resulting from a loss of silicate clay, iron or aluminium. Eluvial, generally underlying an H, O or A horizon and overlying a B horizon

B = Mineral horizon with either illuvial clays, residual sesquioxides or alteration of material from original condition.

C = Mineral horizon (or layer) of unconsolidated material from which the solum is presumed to have formed and which does not show properties diagnostic of any other master horizons.

4.1.1.1 Transitional Horizons

Soil horizons in which the properties of two master horizons merge are indicated by the combination of two capital letters (e.g. AE, BC, AB, AC) The first letter marks the master horizon to which the transitional horizon is most similar.

Mixed horizons that consist of intermingled parts, each of which are identifiable with different master horizons, are designated by two capital letters separated by a diagonal stroke (e.g. E/B, B/C). The first letter marks the master horizon that dominates.

4.1.1.2 Letter Suffixes

A small letter was added to the capital letter to qualify the master horizon designation. Suffix letters were combined to indicate properties which occurred concurrently in the same master horizon (e.g. Ahz, Btg, Cck). No more than two suffixes were used in combination and in transitional horizons no use was made of suffixes which qualified only one of the capital letters. A suffix was used, however, when it applied to the transitional horizon as a whole (e.g. BCk, ABg).

Suffix letters qualifying the master horizons of Kavango soils:

- b. Buried or bisequal soil horizon (e.g. Btb).
- c. Accumulation in concretionary form; this suffix is commonly used in combination with another which indicates the nature of the concretionary material (e.g. Bck).
- g. Mottling reflecting variations in oxidation and reduction (e.g. Bg, Btg, Cg).
- k. Accumulation of calcium carbonate (e.g. Ak)
- m. Strongly cemented, consolidated, indurated; this suffix is commonly used in combination with another indicating the cementing material (e.g. Cmk marking a petrocalcic horizon within a C horizon).
- n. Accumulation of sodium (e.g. Btn).
- p. Disturbed by ploughing or other tillage practices (e.g. Ap). **

- r. Strong reduction as a result of groundwater influence (e.g. Cr).
- t. Illuvial accumulation of clay (e.g. Bt).
- u. Unspecified; this suffix is used in connection with A and B horizons which are not qualified by another suffix but have to be subdivided vertically by figure suffixes (e.g. Au1, Au2, Bu1, Bu2).
- w. Alteration in situ as reflected by clay content, colour, structure (e.g. Bw).
- x. Occurrence of a fragipan (e.g. Btx).
- ** For horizons which showing accumulations of charcoal, the suffix 'p' has been applied.

4.1.1.3 Qualification by Charcoal Accumulation

Charcoal accumulations posed a problem with the assignation of an appropriate suffix to indicate its presence. Suffix 'p' denotes disturbance by ploughing or other tillage practices, although fires are not specified. The suffix 'h' denotes the accumulation of organic matter in mineral horizons (e.g. Ah, Bh). For the A horizon, the 'h' suffix is applied only where there has been no disturbance or mixing from ploughing, pasturing or other activities of man. The 'h' and 'p' suffixes are thus mutually exclusive.

Burning is not a tillage practice *per se* in Kavango although large areas have been repeatedly burned for field preparation and to create greater visibility (flushing out of game; pre-Independence military operations). Fires of various magnitudes and heat regimes have also been induced by natural events (lightning) and are widespread throughout the region (Trigg, 1997).

The suffix 'h' was not assigned to horizons showing accumulations of charcoal because even though its presence in different part of the profile suggests fire sequences, the disturbance caused by fires could not definitely be attributed to either natural events or the activities of man.

4.1.1.4 Figure Suffixes

Horizons designated by a single combination of letter symbols were vertically subdivided by numbering each subdivision consecutively, starting at the top of the horizon (e.g. Bt1 - Bt2 - Bt3).

The suffix number always followed all of the letter symbols and the number sequence applied to one symbol only so that the sequence was resumed in case of

change of the symbol (e.g. Bt1 - Bt2 - Btx1 - Btx2). Numbered subdivisions were also be applied to transitional horizons (e.g. AB1 - AB2), in which case the suffix applied to the entire horizon and not only to the last capital letter.

4.1.1.5 Figure Prefixes

When it was necessary to distinguish lithological discontinuities, Arabic numerals were prefixed to the horizon designations concerned (e.g. when the C horizon was different from the material in which the soil was presumed to have formed the following soil sequence was given: A, B, 2C. Strongly contrasting layers within the C material were shown as an A, B, C, 2C...sequence.

The following diagnostic horizons were found in the soils of Kavango:

4.1.1.5.1 Ochric A horizon

An ochric A horizon is one that is too light in colour, has too high a chroma, too little organic matter, or is too thin to be mollic or umbric, or is both hard and massive when dry. In separating Yermosols from Xerosols a distinction used to be made between very weak and weak ochric A horizons.

4.1.1.5.2 Argillic B horizon

An argillic B horizon is one that contains illuvial layer-lattice clays. This horizon forms below an eluvial horizon, but it may be at the surface if the soil has been partially truncated.

4.1.1.5.3 Natric B horizon

This is an argillic horizon with additional diagnostic properties connotative of sodium salt accumulation. It has a columnar or prismatic structure in some part of the B horizon or a blocky structure with tongues of an eluvial horizon, AND a saturation with exchangeable sodium of more than 15% within the upper 40cm of the horizon or more exchangeable Mg + Na than Ca plus exchange acidity at pH 8.2 within the upper 40cm of the horizon.

4.1.1.5.4 Cambic B horizon

An altered B horizon lacking properties that meet requirements of argillic, natric or spodic horizon; lacking the dark colours, organic matter content and structure of a histic H horizon, or the mollic and umbric A horizons; showing no cementation, induration, or brittle consistence when moist, AND having the following properties:

- Very fine sand, loamy very fine sand, or finer

- Structure in at least 50% of horizon
- CEC > 16me/100g clay
- Higher clay content than underlying horizon, or
- Stronger chroma or redder hue than underlying horizon, or
- Evidence of removal of carbonates - lower carbonates than underlying horizon of calcium carbonate accumulation, or
- Evidence of reduction processes - chroma of 2 or less if mottling; if no mottling and value is < 4, the chroma is < 1; if the value is 4+ then chroma is 1 or less; hue is no bluer than 10Y .
- Enough thickness that its base is at least 25cm below soil surface.

4.1.1.5.5 Calcic horizon

The calcic horizon is a horizon of accumulation of calcium carbonate. The accumulation may be in the C horizon, but it may also occur in a B or in an A horizon.

The calcic horizon consists of secondary carbonate enrichment over a thickness of 15cm or more, has a calcium carbonate equivalent content of 15% or more and at least 5% greater than that of the C horizon. The latter requirement is expressed by volume if the secondary carbonates in the calcic horizon occur as pendants on pebbles, or as concretions or soft powdery forms; if such a calcic horizon rests on very calcareous materials (40%+ calcium carbonate equivalent) the % of carbonates need not decrease with depth.

4.1.1.5.6 Albic E horizon

The albic E horizon is one from which clay and free iron oxides have been removed, or in which the oxides have been segregated to the extent that the colour of the horizon is determined by the colour of the primary sand and silt particles rather than by coatings on these particles.

An albic E horizon has a moist colour value of 4+. If the moist value is 6+ then the chroma should be 3 or less. If the parent materials have a hue of 5YR or redder, a moist chroma of 3 is permitted in the albic E horizon where the chroma is due to the colour of uncoated silt or sand grains. An albic E horizon may overlie a spodic B, an argillic or natric B, a fragipan, or an impervious layer that produces a perched watertable.

4.2 DIAGNOSTIC PROPERTIES

A number of soil characteristics used to separate the soil units could not be considered as horizons. They were rather diagnostic features of horizons or of soils which, when used for classification purposes, needed to be quantitatively defined.

Diagnostic properties present in the soils of Kavango Region:

4.2.1 Abrupt Textural Change

This is a considerable increase in clay content within a very short distance in the zone of contact between an A or E horizon and the underlying horizon. When the A or E horizon has less than 20% clay content (as with all soil profiles sampled), the clay content of the underlying horizon is at least double that of the A or E within a vertical distance of 8cm or less.

4.2.2 Albic Material

Albic material are exclusive of E horizons, and have a moist colour value of 4+. If the value is 6+, the moist chroma is less than 3. If parent materials have a hue of 5YR or redder, a moist chroma of 3 is permitted if the chroma is due to the colour of uncoated silt or sand grains.

4.2.3 Calcareous

The term calcareous applies to soil material which shows a strong effervescence with 10% HCL in most of the fine earth, or which contains more than 2% calcium carbonate equivalent.

4.2.4 Calcaric

The term calcaric refers to soils which are calcareous throughout the depth between 20 and 50cm.

4.2.5 Ferralic Properties

Ferralic properties are used in connection with Arenosols which have a CEC of less than 24me/100g (clay) in, respectively, at least some of the cambic B horizon or immediately underlying the A horizon.

4.2.6 Fluvic Properties

1. An organic carbon content that decreases irregularly with depth or that remains above 0.2% to a depth of 125cm. Thin strata of sand may have less organic carbon if the finer sediments below, exclusive of buried A horizons, meet the requirement.
2. Stratification in at least 25% of the soil volume within 125cm of the surface

Fluvic properties indicated by the second requirement dominate the soils of the Okavango floodplain, and are strongly evident on the inner curves of meanders and at the confluence of the Omatako omuramba. Soils of the NW omiramba floors show a similar stratification, meeting the requirements of 2 above.

4.2.7 Hydromorphic properties

Gleysols - soils strongly influenced by groundwater, do not exist in Kavango. However, soils of which only the lower horizons are influenced by groundwater (gleyic) do occur where the water table is shallow (1-5m below surface) in parts of NE Kavango, and on the Okavango floodplain.

A gleyic condition describes a reducing moisture regime virtually free of dissolved oxygen due to saturation by groundwater or its capillary fringe.

Hydromorphic properties in the soils of Kavango refer to the existence of the following property only:

"Saturation with water at some period of the year, or artificially drained, with evidence of reduction processes or of reduction and segregation of iron. This can be reflected in a number of ways, not all relevant to the soils observed".
Of relevance are:

In horizons with textures finer than loamy sand:

- If hues are as red as or redder than 10YR and there is mottling, chromas of 2 or less; if there is no mottling and values are <4, chromas of <1; or if values are 4+, chromas of 1 or less.
- If hues are between 10YR and 10Y are there is distinct or prominent mottling, chromas of 3 or less; of there is no mottling, chromas of 1 or less.

4.2.8 Interfingering

Interfingering consists of penetrations of an albic E horizon into an underlying argillic or natric B horizon along ped faces, primarily vertical faces. The penetrations are not wide enough to constitute tonguing but form continuous skeletans (ped coatings of clean silt or sand over 1mm thick on the vertical ped faces). A total thickness of more than 2mm thick is required if each ped has a coating of more than 1mm. Because quartz is such a common constituent of soils, the skeletans are usually white when dry, and light grey when moist, but their colour is determined by the colour of the sand or silt fraction.

The skeletans constitute more than 15% of the volume of any subhorizon in which interfingering is recognised. They are also thick enough to be obvious by their colour, even when moist. Thinner skeletans that must be dry to be seen as a whitish powdering on a ped are not included in the meaning of interfingering.

4.2.9 Slickensides

Slickensides are polished and grooved surfaces that are produced by one mass sliding past another. Some of them occur at the base of a slip surface where a mass of soil moves downward on a relatively steep slope.

Although slip surface conditions occur in Kavango on the base slopes of the Okavango river terraces and steeper dunes de-stabilised by vegetation removal, slickensides are very rare due to the lack of swelling clays.

4.2.10 Soft Powdery Lime

Soft powdery lime refers to translocated authigenic lime, soft enough to be cut readily with a finger nail, precipitated in place from the soil solution rather than inherited from a soil parent material. It should be present in significant accumulation.

To be identifiable, soft powdery lime must have some relation to the soil structure or fabric. It may disrupt the fabric to form spheroidal aggregates (white eyes) that are soft and powdery when dry, or the lime may be present as soft coatings in pores or on structural faces. If present as coatings, it covers a significant part of the surface; commonly it coats the whole surface to a thickness of 1-5mm+. Only part of a surface may be coated if little lime is present in the soil. The coatings should be thick enough to be visible when moist and should cover a continuous area large enough to be more than filaments. Pseudomycelia which come and go with

changing moisture conditions are not considered as soft powdery lime in this definition.

Soft powdery limes are present in Kavango on some omiramba floors and dune streets, in the SE Sikeretti area (in association with paleo-pans) and on the SW pediplain.

4.2.11 Takyric Features

These soils have a heavy texture, crack into polygonal elements when dry and form a platy or massive surface crust.

Takyric features are almost unknown in Kavango. The only observed areas with **borderline** takyric features were on eastern-draining omiramba floors in the vicinity of small longitudinal pans. In these areas thick layers of alluvial silts cover the surface.

4.2.12 Tonguing

Tonguing is connotative of the penetration of an albic E horizon into an argillic B horizon along ped surfaces, if peds are present. Tongues must have greater depth than width, have horizontal dimensions of 5mm+ in fine textured argillic horizons (clay, silty clay and sandy clay), 10mm+ in moderately fine textured argillic horizons, and 15mm+ in medium or coarser textured argillic horizons (silt loams, loams, very fine sandy loams or coarser), AND must occupy more than 15% of the mass of the upper part of the argillic horizon.

Tonguing is only present in Kavango where Cambic Arenosols occur.

4.2.13 Aridic Moisture Regime

Where factors such as local climate, parent material and catenary position combine with soil morphology to produce a "soil climate" showing a propensity for low moisture availability at critical periods of the growing season, such soils exhibit an aridic moisture regime.

Under the FAO (1974) legend this property was used to characterise Yermosols and Xerosols and to separate them from soils outside arid areas which have a comparable morphology. It has now been deleted from the revised legend, along

with Yermosols and Xerosols, to conform to the general principle *not* to use climatic criteria to define soil units (FAO, 1990).

This deletion has repercussions on the classification of Kavango soils where, in the absence of this diagnostic condition and with no other condition to separate them, large areas of deep, light sandy soils are classified as modal Haplic Arenosols. A useful sub-division of these soil units could nevertheless be made on the basis of differences in soil moisture availability to rank them for management purposes and environmental resource value (for supporting properties refer to the Yermic phase in section 4.3 below). The conditions defining soils with an aridic moisture regime would then follow the FAO legend as it was originally presented in FAO (1974), as follows:

- In most years these soils have no available water in any part of the moisture control section for more than half the time (cumulative) that the soil temperature at 50cm is above 5°C. (The moisture control section lies approximately between 10-30cm for medium to fine textures, between 20- 60cm for medium to coarse textures, and between 30-90cm for coarse textures).
- There is no period as long as 90 consecutive days when there is moisture in some or all parts of the moisture control section while the soil temperature at 50cm is continuously above 8°C.
- In most years the moisture control section is never moist in all parts for as long as 60 consecutive days during the 3 months following the winter solstice, where mean summer and mean winter temperatures differ by 5°C or more and mean annual temperature is less than 22°C.

In this regard, even though Kavango is not an arid region, large areas are covered by deep, friable and freely draining sands. Depending on the depth of consolidated parent material and on relative slope position, some of these soils are very unlikely to have available water in the moisture control section for over 90 consecutive days while the soil temp. is above 8°C, and they are equally unlikely to have available water in any part of the moisture control section for more than 50% of the time that the soil temp is over 5°C.

In terms of the climatic conditions necessary to satisfy the soil conditions described above, a preliminary cross-check of regional data revealed that the mean annual temperature of the regional weather station (Rundu) is just 0.2°C above the critical maximum of 20°C. However, the mean summer and winter temperatures differ by more than 5°C, where:

June = 16.1°C; July = 16.1°C; August = 19.0°C (mean = 17.1°C);
Dec = 25.4°C; Jan = 24.9°C; Feb = 24.2°C (mean = 24.8°C).

Several decades of rainfall data strongly indicate that no rain falls between May and October in an average year.

4.3 SOIL PHASES

Soil phases are subdivisions of soil units based on characteristics which are significant to the use or management of the land, but are not diagnostic for the separation of the soil units themselves.

In terms of resource value, phases add an extra dimension to the diagnostic signature of any soil unit by indicating those factors which currently constrain its potential, or may do so if managed inappropriately.

Descriptions of phases assigned to the soils of Kavango are given below.

4.3.1 Phreatic Phase

The phreatic phase refers to the occurrence of a groundwater table within 5m from the surface, the presence of which is not reflected in the morphology of the soil. Therefore the phreatic phase is not shown with Fluvisols. Its presence is important for the water regime of the soil, and because of this, especially in areas under irrigation, attention should be paid to effective water use and drainage in order to avoid salinization as a result of rising groundwater.

Phreatic phase sub-units occur in the north east and east of Kavango, particularly in a wide band stretching 50km to the north and 40km to the south of Kaudam camp in the streets of the incipient dunes and floors of paleo-drainage channels.

4.3.2 Yermic Phase

The yermic phase applies to soils which have less than 0.6% organic carbon in the surface 18cm when mixed, or less than 0.2% organic carbon if the texture is coarser than sandy loam, and which show one or more of the following features connotative of arid conditions:

1. presence in the surface horizon of gravels or stones shaped by the wind or showing desert varnish (manganese coatings at the upper surface) or both. When the soil is not ploughed these gravels or stones usually form a surface pavement; they may show calcium carbonate or gypsum accumulating immediately under the coarse material.
2. Presence in the surface horizon of pitted and rounded quartz grains showing a matte surface which constitute 10% or more of the sand fraction having a diameter of 0.25mm or more.
3. Presence of 2% or more palygorskite in the clay fraction in at least some subhorizon within 50cm of the surface.
4. Surface cracks filled with in-blown sand or silt; when the soil is ploughed this characteristic may be obliterated, although cracks may extend below the plough layer.
5. A platy surface horizon which frequently shows vesicular pores and which may be indurated but not cemented.
6. Accumulation of blown sand on a stable surface.

Over 70% of Kavango soils meet the first-level low organic matter requirements of the Yermic phase, and 40% of the soil units contain one or more features connotative of arid conditions. Arid conditions are described almost entirely by features 4 and 6 above, and to a lesser extent by feature 2. Features 1, 3 and 5 do not occur in the region.

4.3.3 Fragipan Phase

The fragipan phase marks soils which have the upper level of the fragipan occurring within 100cm of the surface. A fragipan is a loamy (uncommonly a sandy) subsurface horizon which has a high bulk density relative to the horizons above it, is hard or very hard and seemingly cemented when dry, is weakly to moderately brittle when moist; when pressure is applied peds or clods tend to rupture suddenly rather than undergo slow deformation. Dry fragments slake or fracture when placed in water.

A fragipan is low in organic matter, slowly or very slowly permeable and often shows bleached fracture planes that are faces of coarse or very coarse polyhedrons

or prisms. Clayskins may occur as patches or discontinuous streaks both on the faces and interiors of the prisms. A fragipan commonly, but not necessarily, underlies a B horizon. It may be from 15-200cm thick with commonly an abrupt or clear upper boundary, while the lower boundary is mostly gradual or diffuse.

Cambic Arenosols occurring in the eastern paleo-drainage system of Kavango show the only evidence of fragipan layering, where fragipans underlie incipient argillic B (illuviated) horizons.

4.3.4 Duripan Phase

The duripan phase marks soils in which the upper level of a duripan occurs within 100cm of the surface. A duripan is a subsurface horizon cemented by silica so that dry fragments do not slake during prolonged soaking in water or in hydrochloric acid.

Duripans vary in the degree of cementation by silica and in addition they commonly contain accessory cements, mainly iron oxides and calcium carbonate. As a result, duripans vary in appearance but all of them have a very firm or extremely firm moist consistency, and they are always brittle even after prolonged wetting.

Duripan sub-units occur in Kavango in association with Calcisols and Solonetz soils and where Cambic Arenosols occur in association with Solonetz. The most evident duripans are located in the south-central area where they lie to the east of the Omatako omuramba on the western edge of the watershed with the eastern paleo-drainage system.

4.3.5 Rudic Phase

The rudic phase marks areas where the presence of gravel, stones, boulders or rock outcrops in the surface layers or at the surface makes the use of mechanized agricultural equipment impracticable. Hand tools can be used and also simple mechanical equipment if other conditions are particularly favourable. Fragments with a diameter up to 7.5cm are considered as gravel; larger fragments are called stones or boulders.

Gravel, stones and boulders are not present in Kavango, although outcrops do occur. Basement outcrops occur in the SE corner of the region near Sikeretti on level to gently undulating slope classes. Occasional calcrete outcrops occur below the crests of both east- and west-facing slopes of the main Omatako omuramba

channel, and where these occur slope angles are of the order of 5-8%. Significant areas of calcrete lie within the plough layer of soils in the longer north-flowing omiramba and in the eastern-draining Khaudom omuramba.

4.3.6 Petrocalcic Phase

The petrocalcic phase marks soils in which the upper part of a petrocalcic horizon occurs within 100cm of the surface.

A petrocalcic horizon is a continuous cemented or indurated calcic horizon, cemented by calcium carbonates and in places by calcium and some magnesium carbonate. Accessory silica may be present. The petrocalcic horizon is continuously cemented to the extent that dry fragments do not slake in water and roots cannot enter. It is massive or platy, extremely hard when dry so that it cannot be penetrated by auger or spade, and very firm to extremely firm when moist. Non-capillary pores are filled; hydraulic conductivity is moderately slow to very slow. It is usually thicker than 10cm.

Petrocalcic phase soils are present in Kavango over where a petrocalcic layer underlies a calcic B horizon (i.e. as a petrocalcic C horizon) within 100cm of the surface. Areas include the SW pediplain, omuramba floors and narrow dune streets, and in southern Kavango on level to gently undulating slopes forming the watershed between the paleo-drainage system to the east, and the Omatako omuramba to the west. In the latter case, large areas of calcrete deposits were observed to underlie soil profiles at shallow depths. In these areas, where a soil unit has been classified on the basis of a petrocalcic horizon, the name assumes the phase.

4.4 CLASSIFICATION SUMMARY

The FAO/UNESCO/ISRIC Revised Legend was used as far as possible as it is presented in World Soil Resources Report 60. Where discrepancies existed between field evidence and guidelines for classification efforts were made to enhance the base of the legend without diminishing the integrity of its general principles. In particular the presence, causes and possible effects of charcoal accumulations could not be ignored and were therefore documented to qualify master horizons. In the case of 'soil climate' where soil properties warranted a more appropriate subdivision of Arenosols, no attempt was made to invent new criteria for classification although suggestions were made for the further use of such properties to the management and future evaluation of these soils.

Bearing these caveats in mind, the soils of Kavango are summarized below.

4.5 EXPLANATORY LEGEND TO THE RECONNAISSANCE SOIL MAP OF KAVANGO REGION

Of the eight columns offered by the Revised Legend to reflect evolutionary and geographical background, four are represented in the region. The first column includes soils which are not bound by specific zonal climatic conditions: the Fluvisols. The second column comprises soils in which soil formation is conditioned by parent material: the Arenosols. Soils of the fourth column show accumulations of salts connotative of aridic conditions or physiological drought: the Calcisols and Solonetz. In the eighth and last column soils are distinctive in having characteristics and processes profoundly altered by human influences: the Anthrosols. The seventh column, where soils are conditioned by intense weathering (the Alisols), is only marginally represented.

4.5.1 Soils Conditioned by Parent Material

Arenosols: soils developed in sands

AR	ARENOSOLS
ARh	Haplic Arenosols
ARb	Cambic Arenosols
ARo	Ferralic Arenosols
ARc	Calcaric Arenosols
Arhk	Calci-Haplic Arenosols

The most abundant parent materials of Kavango Region include the extensive wind-blown sands on which extensive areas of Arenosols have developed.

Arenosols are defined as soils which are coarser than sandy loam to a depth of at least 100cm of the surface, with less than 35% of rock fragments or other coarse fragments in all subhorizons within 100cm of the surface (exclusive of materials which show fluvic or andic properties). No diagnostic horizons other than an ochric A horizon or an albic E horizon are required.

Fine sands are the dominant size fraction of Arenosols in Kavango, indicating without any doubt the aeolian nature of the parent material. The total fine sand is generally more than 50% and often greater than 70%. Clay and silt are less than 10% and often around 6%.

These soils are marked by the absence of any significant soil profile development and profiles are generally uniform throughout the depth. They are highly permeable and storage of available water is low within normal rooting depths. This is supported by high porosity values of about 42% with a preponderance of large and free-draining pores. Consequently these soils are poor in moisture retention and experience prolonged periods of moisture stress. The low moisture availability can be attributed to their predominantly sandy textures. Surface horizons have slightly higher moisture contents of about 8% compared to that of subsurface horizons which is in the range of 3-6%.

In common with the Arenosols of neighbouring northwest Ngamiland (Botswana) and northeast Otjosondjupa Region, these sands behave remarkably like structurally stable soils under rainfall conditions. Although they do not have any aggregation, they also do not develop crusts because on the loose sand surfaces. Infiltration rates are high with initial rates being much higher (DRFN, 1999), in keeping with the coarse granular textures and lack of surface crust development. Runoff therefore can be expected to be minimal even on slopes with up to 5% inclination. Thus, in terms of erodibility, they can be considered to provide a certain amount of resistance to erosion somewhat like structurally stable soils.

4.5.2 Soils Conditioned by Limited Leaching

Solonetz: sodic soils

SN	SOLONETZ
SNh	Haplic Solonetz
SNhx	Haplic-xanthic Solonetz
SNk	Calcic Solonetz

Solonetz soils are formed in Kavango where sodium is present in the soil matrix in excess over calcium. These soils are found in conditions of impeded drainage controlled by shallow layers of indurated or consolidated parent materials on the high plains of the ephemeral watershed. In low catenary positions they are found in association with pans and shallow underlying calcrete on the gently undulating sand plains and omiramba floors of the eastern drainage region.

All Solonetz soils in Kavango are recognised by a thin loose litter cover resting on black humified surface material about 2-3cm thick. This overlies a brown granular A

horizon which abruptly changes into a natric B horizon with coarse prismatic or columnar structure elements and grading with depth into a massive subsoil.

Sodium carbonate (Na_2CO_3) may be formed in these soils by the evaporation of water containing sodium bicarbonate or by the biological reduction of sodium sulphate. Under either of these conditions clay is dispersed and worked into the subsoil, forming a dense accumulation horizon with columnar or prismatic subsoil structures. Clays held in surface horizons are decomposed in the high pH conditions resulting from the presence of Na_2CO_3 , and in conditions of periodically low salt content combined with high exchangeable sodium.

The essential characteristic of Solonetz soils is therefore a natric B horizon which has an exchangeable sodium percentage (ESP) of 15 or more. Such a high value will also affect the concentration and balance of other ions, particularly the divalent ions that are preferentially adsorbed at the exchange complex. The high ESP of Solonetz is both directly and indirectly harmful to plants whereby a high proportion of sodium ions in the soil induces toxicity directly in salt sensitive plants and obstructs the uptake of other essential plant nutrients.

In terms of textural characteristics the Solonetz soils occurring in Kavango are variable, depending on the depth and consolidation of parent material and on catenary position. Fine to very fine sands dominate the sand fraction with a content of 50-75%, although sand content as a whole varies from 21-90%. Similarly in the finer particle fraction silt contents vary from 5 to 72%, although clay content remains low at 3-9%. Soils on lower topographic sites in eastern Kavango are generally heavier textured, whereas soils in areas of impeded drainage on local high ground (where duripans underlie soils of the ephemeral catchment divide) are light textured. Solonetz soils with local concentrations of clay are waterlogged in the wet season.

Moisture retention properties of the Solonetz soils are not dependent on pore size distribution alone as part of the soil moisture is always retained due to osmotic potential. Due to these conditions, moisture content is never constant and this property does not reflect moisture availability to plants.

Calcisols: Soils with a Calcium Carbonate Accumulation

CL	CALCISOLS
CLh	Haplic Calcisols
CL1	Luvic Calcisols
CL1p	Hyper-Luvic Calcisols
CLp	Petric Calcisols

Calcisols occur in Kavango in all land systems with the exception of the Okavango floodplain. These soils always occupy low catenary positions in local landscape sequences and are always found in association with shallow calcrete deposits. Whereas the pans scattered across Kavango are not always associated with calcrete, those pans which are formed on petrocalcic layers are found in association with Calcisols.

The most prominent feature of Calcisols is the translocation of calcium carbonate from the surface horizons to an accumulation layer at depth. This layer may be soft and powdery or consist of hard concretions or calcite pendants, and can eventually become indurated and cemented.

In terms of profile characteristics the Calcisols of Kavango are distinctly recognizable by a thin brown A horizon over a darker brown Bck horizon and/or a yellowish brown Cck or Cmk horizon that is speckled with white calcite mottles. The organic matter content of the surface soil is low on account of sparse vegetation and rapid decomposition of vegetal debris. The surface soil is crumb or granular, but platy structures also occur where this horizon is enhanced by a high percentage of adsorbed magnesium. Subsurface horizons are weakly platy in structure or structureless. The highest calcite concentration is found in the deeper B horizons.

The Calcisols do not appear to follow any noticeable trend in particle size distributions although medium textures prevail with fine to very fine sands dominating the sand fraction at 40-70%. Silt fractions vary between 7 and 37% and clays between 5-14%.

Total porosities are remarkably high at 41-64% with an overall increase in pore size due to the presence of calcium carbonate in the profiles. Consequently there is an increase in the proportion of freely draining macro-pores and a decrease in the proportion of slow and non-conducting micropores which would otherwise retain adsorbed moisture. Moisture retention properties are therefore lower than the clay

contents indicate, although available moisture levels are significantly higher. Infiltration rates are moderate with average values being more closely related to the higher porosities in the calcic horizon than to the proportion of micropores.

The Calcisols are therefore inherently well-drained. Where the surface soils are silty in the south-east corner of Kavango, slaking and crust formation no doubt hinders infiltration, causing runoff, sheet-wash erosion, and in places the exposure of a petrocalcic horizon. Where they lie on shallow petroclastic horizons on the southwest pediplain, however, they tend to become waterlogged.

They are also potentially fertile soils as they are rich in mineral nutrients, although the high calcium may also result in iron and zinc deficiencies.

4.5.3 Soils Conditioned by Relief

Fluvisols: soils of alluvial lowlands

FL	FLUVISOLS
FLd	Dystric Fluvisols

Fluvisols have developed in recent fluvial deposits on the floodplain of the Okavango River. On the banks and active floodplain of the Okavango river these soils are periodically wet in all or part of the profile due to the presence of seasonal flood water.

The floodplain area, two to six kilometres wide, can be divided into two zones in terms of soil development and modification. A broad area adjacent to the present course of the river actively receives fresh sediments during regular seasonal periods of inundation and hence the soils are regularly rejuvenated. The soils of this zone, although used for wet season cropping and dry season grazing, are not profoundly modified by agricultural activities and can therefore be classified by their fluvic properties.

Soil profiles and auger holes show stratified layers of coarse and fine materials with a predominance of fine to very fine sands and silts in shallower horizons and an increase in clay content with depth. Significantly, the deposition of clay layers is uncommon and clay contents even at depth are consequently lower than would be expected in these alluvial soils. This attribute can be linked to the scarcity of clays in the provenance areas (Minader, 1996). Surface clay contents are lower than subsurface horizons with an average of 6%, increasing irregularly to 14% in lower

horizons. Low clay contents combined with low and irregular levels of organic matter are also linked to relatively low nutrient concentrations and CEC (total) levels. Whereas these soils are not infertile, they are also not highly productive.

4.5.4 Soils Conditioned by Human Influence

Anthrosols

AT	ANTHROSOLS
ATd	Dystric Anthrosols

Away from the main Okavango River channel in a broad zone of variable width, the floodplain is no longer seasonally inundated. In this area soils resembling buried Fluvisols at depth and Arenosols nearer to the surface have developed on colluvial sands lying over older dry fluvial deposits.

Intensively used for both dryland and irrigated cultivation, these soils have been significantly modified. Evidence from borehole records and sample analyses (Weirenga, 1999) indicate that the original morphology of these soils would have included buried accumulation horizons of stratified coarse and fine materials under moderately deep fine sands of colluvial and aeolian origin. Analytical and profile records from Mashere Agricultural College indicate that the surface horizons have been physically mixed by ploughing, chemically altered by the addition of organic materials, leached by irrigation water and generally deficient in potassium.

These soils therefore have been classified as Anthrosols to indicate the degree to which modification by agricultural use has altered a number of their diagnostic properties. Judging by the inherently low CEC status of the Arenosol group, by the relatively low nutrient concentrations of the underlying Fluvisols, and by the fact that organic additives are needed to increase the concentration of base cations, these soils have been categorized as Dystric Anthrosols.

4.6 SOIL UNIT SUBDIVISIONS

Soil units defined in the Legend to the Reconnaissance Soil Map of Kavango are tabulated and summarized below.

Table 8: Soil Units of Kavango

Group 1		Group 4		Group 7	
FL	FLUVISOLS	CL	CALCISOLS	AL	ALISOLS
FLd	Dystric Fluvisols	CLh	Haplic Calcisols	ALh	Haplic Alisols
		CL1	Luvic Calcisols		
		CL1p	Hyper-Luvic Calcisols		
Group 2				Group 8	
AR	ARENOSOLS	CLp	Petric Calcisols	AT	ANTHROSOLS
ARh	Haplic Arenosols			ATd	Dystric Anthrosols
ARb	Cambic Arenosols	SN	SOLONETZ		
ARo	Ferralic Arenosols	SNh	Haplic Solonetz		
ARc	Calcaric Arenosols	SNhx	Haplic-xanthic Solonetz		
ARhk	Calci-Haplic Arenosols	SNk	Calcic Solonetz		

4.6.1 Fluvisols (FL)

Soils showing fluvic properties and having no diagnostic horizons other than an ochric, a mollic or an umbric A horizon, or sulphidic material within 125cm of the surface

Dystric Fluvisols (FLd)

Fluvisols having a base saturation (by NH₄Oac) of less than 50% at least between 20 and 50cm of the surface; lacking a sulphidic horizon and sulphidic material within 125cm of the surface.

4.6.2 Arenosols (AR)

Soils which are coarser than sandy loam to a depth of at least 100cm of the surface, having less than 35% of rock fragments or other coarse fragments in all subhorizons within 100cm of the surface, exclusive of materials which show fluvic or andic properties; having no diagnostic horizons other than an ochric A horizon or an albic E horizon.

Haplic Arenosols (ARh)

Arenosols having no diagnostic horizon other than an ochric A horizon; lacking ferralic properties; lacking gleyic properties within 100cm of the surface. Deep to

very deep moderately well to somewhat excessively drained, dark grey to white sands to sandy loams.

Cambic Arenosols (ARb)

Arenosols showing colouring or alteration characteristic of a cambic B horizon immediately below the A horizon; lacking lamellae of clay accumulation; lacking ferralic properties; lacking an albic E horizon with a minimum thickness of 50cm; lacking gleyic properties within 100cm of the surface; non-calcaric. Deep to very deep, well to somewhat excessively drained, strong brown to red, loamy sands to loamy fine-medium sands.

Ferralic Arenosols (ARo)

Arenosols showing ferralic properties, and colouring of the B horizon expressed by chromas of 5 or more or hues redder than 10YR; lacking a clay increase or lamellae of clay accumulation within 125cm of the surface; lacking an albic E horizon with a minimum thickness of 50cm; lacking gleyic properties within 100cm of the surface; non-calcaric. Deep to very deep, well to excessively drained, yellowish brown to dark red, coarse sands to loamy fine sands.

Calcaric Arenosols (ARc)

Arenosols which are calcaric; lacking gleyic properties within 100cm of the surface. Deep to very deep, moderately well to well drained, dark grey to pale brown fine sands to loamy sands.

Calci-Haplic Arenosols (ARhk)

Haplic Arenosols having calcic properties within 125cm of the surface; lacking the properties diagnostic of Calcisols and Calcaric Arenosols. Deep to very deep, well drained, dark reddish brown, loamy medium-fine sands.

4.6.3 Calcisols (CL)

Soils having one or more of the following; a calcic horizon, a petrocalcic horizon or concentrations of soft powdery lime within 125cm of the surface; having no diagnostic horizons other than an ochric A horizon, a cambic B horizon or an argic B horizon which is calcareous; lacking the characteristics which are diagnostic for Vertisols or Planosols; lacking salic properties; lacking gleyic properties within 100cm of the surface.

Haplic Calcisols (CLh)

Calcisols lacking an argic B horizon and a petrocalcic horizon. Moderately deep to deep, imperfect to moderately well drained, dark brown and greyish brown to yellowish brown, sands to sandy loams.

Luvic Calcisols (CL1)

Calcisols having an argic B horizon; lacking a petrocalcic horizon. Moderately deep to deep, imperfectly to moderately well drained, brownish black, fine loamy sands.

Hyper-Luvic Calcisols (CL1p)

Luvic Calcisols resting on very calcareous material which has more than 40% CaCO₃ equivalent. Moderately deep, imperfect drainage, brownish black to greyish yellow brown, fine sandy loams.

Petric Calcisols (CLp)

Calcisols having a petrocalcic horizon. Shallow to moderately deep, imperfect drainage, dark reddish grey to brownish grey, sandy loams.

4.6.4 Solonetz (SN)

Soils having a natric horizon.

Haplic Solonetz (SNh) / Haplic-xanthic Solonetz (SNhx)

Solonetz having an ochric A horizon; lacking stagnic properties and lacking gleyic properties within 100cm of the surface. Moderately deep to deep, poor to imperfect drainage, greyish brown to dull yellow orange/brown, silty fine sands to sandy loams

Calcic Solonetz (SNk)

Solonetz having a calcic horizon or concentrations of soft powdery lime within 125cm of the surface; lacking a gypsic horizon; lacking stagnic properties and lacking gleyic properties within 100cm of the surface. Shallow to moderately deep, poor to imperfect drainage, dull yellowish orange to dark reddish grey, fine sandy loams to silty loams.

Calci-haplic Solonetz (SNhk)

Haplic Solonetz having calcic properties; lacking the properties diagnostic of Calcic Solonetz. Shallow to moderately deep, poorly drained, dull yellowish brown sands.

4.6.5 Anthrosols (AT)

Soils in which human activities have resulted in profound modification or burial of the original soil horizons through removal or disturbance of surface horizons, cuts and fills, secular additions of organic materials, long-continued irrigation, etc.

Dystric Anthrosol (ATd)

Anthrosols which have a base saturation (by Na_4OAc) of less than 50% at least from 20 to 50cm from the surface. Moderately deep to deep, moderately well to well drained, dark brown fine sands to sandy loams. This unit of classification does not appear in the FAO revised legend. Based on field experience, however, it best describes the soil characteristics modified by man on the old and now drying Okavango floodplain (no longer periodically inundated). It is suggested as a refinement to the legend.

5 LAND SYSTEMS

5.1 MAPPING UNITS

The integrated land systems approach enabled complete coverage of the physical environment. Final mapping units employed were based on a combination of landforms, surface drainage, depth of sand mantle, shallow groundwater rest water levels, growing period zones, regional climate, soils and vegetation.

Three principal levels of mapping unit were employed - the land region, land system and land unit (used synonymously with land facet) - using a nested hierarchical system of aggregation.

Land units within each system were often causally linked by surface geology, the occurrence of shallow groundwater and locally active geomorphological processes. These units were not illustrated on the final land systems map, although as they are fully represented by soil unit changes, soil phase and catenary position, the soils map (Map 3) can be overlaid to locate specific land units.

Land regions were delineated as aggregations of land systems contained within discrete regional surface drainage areas. Within each drainage region land systems were represented as areas with a recurring pattern of topography, landform, depth of sand mantle, soil and vegetation associations within relatively uniform growing period zones

Seven land regions, 19 land systems and 62 land units were identified in Kavango Region.

Each land system was unique and numbered. The land units within each system were given connotative titles, e.g. floodplain: seasonally inundated.

5.2 EXPLANATORY LEGEND TO THE RECONNAISSANCE LAND SYSTEMS MAP OF KAVANGO REGION

A legend to the Land Systems Map describing its main features is given below.

5.2.1 Land Region 1: Western Stabilised Dunes

Land System	Land Unit	Soil Unit
Wide Dunes	Dune crests and slopes	Cambic Arenosols
	Inter-dune valleys: no pans	Haplic Arenosols
Narrow Dunes	Dune crests and slopes	Cambic Arenosols
	Inter-dune valleys: thin sand mantle, no pans	Ferralic Arenosols
	Inter-dune valleys: pan zones	Petric Calcisols
Dune Fringes	Dune crests and slopes	Cambic Arenosols
	Inter-dune valleys: thin sand mantle, no pans	Ferralic Arenosols
	Sand-drift plain	Haplic Arenosols
	Pan zones	Petric Calcisols
Dune Outliers - wide dunes, NE Kavango	Crests and mid-slopes	Cambic Arenosols
	Interdune valleys	Haplic Arenosols
Dune Outliers - narrow dunes, SE Kavango	Crests and mid-slopes	Cambic Arenosols
	Interdune valleys: thin sand mantle	Ferralic Arenosols
	Interdune valleys: pan zones	Petric Calcisols

Western Kavango is characterised by an extensive system of seif dunes, orientated in an east-west direction and deposited on calcrete surfaces during the Late Holocene. Now stabilised by vegetation, the dune system is clearly differentiated by dune amplitude and the depth of sand mantle to underlying calcrete. The widely spaced northern dunes are associated with a deep sand mantle whereas the more narrowly spaced southern dunes are associated with a shallower sand mantle. The latter are characterised by the common occurrence of pans in dune streets, where underlying calcretes are exposed or thinly covered by recent aeolian and colluvial deposits.

The western dune system gradually loses its distinctive morphology towards the east where its fringes are characterised by feathery complexes of flattened dune outliers with in-filled dune streets, and sand-drifts characteristic of the northern sand plains.

5.2.2 Land Region 2: SW Pediplain

Land System	Land Unit	Soil Unit
Karst pediplain	Gentle rises and flat areas: thin sand mantle	Calcaric Arenosols
	Depressions on hard plain ,	Petric Calcisols

The south-west corner of Kavango intersects the northern tip of a broad flat pediplain where calcretes are exposed or lie near the surface of shallow aeolian and predominantly red sands. The pediplain peters out to the north and east where the calcretes gradually disappear under sand drift and seif dunes. Thought to be the fringe of a calcrete apron skirting the Karst Otavi mountain complex, the pediplain is characterised by numerous pans and dune remnants.

5.2.3 Land Region 3: Northern Sandplain

Land System	Land Unit	Soil Unit
Okavango river and terraces	Floodplain: seasonally inundated	Dystric Fluvisols
	Floodplain: dry back floor & base of terraces	Dystric Anthrosols
	Terraces: mid slopes	Haplic Arenosols
	Terraces: crests	Ferralic Arenosols
Sand plain incised by short omiramba	High sites & flat areas: central & northern sand plain	Haplic Arenosols
	Flat areas with shallow water table: NE Kavango	Ferralic Arenosols
	Local depressions with shallow water table	Haplic Calcisols
	Flat areas: NW Kavango	Haplic Arenosols
Northern omiramba	Omiramba crests and slopes	Cambic Arenosols
	Omiramba floors: thin sand mantle	Ferralic Arenosols
	Omiramba floors: deep sand mantle and/or colluvial deposits	Cambic Arenosols
	Omiramba floors: pan zones	Haplic Calcisols

Sand drift plains cover extensive areas of northern, north-eastern and central Kavango. The depth of sand mantle increases generally to the north and east, as does the extent to which those sands have been worked and reworked by wind.

The plains slope gradually to the north-east and east, are incised by a number of well-defined north and east draining omiramba, and are bordered by the perennial Kavango River system in the north. Over large tracts of the northern sand plains surface drainage features are imperceptible or non-existent.

Fault systems, produced by tectonic activity commencing during the early Cretaceous period, exert a strong influence on the directions of omiramba. Omiramba were initially incised along fault-weakened zones during a pluvial period post-dating the formation of calcrete layers at the top of the Kalahari Sequence. During subsequent periods of aridity intense aeolian processes have deposited dune sands on the floors of the omiramba valleys. Omiramba valleys are thus a combination of recent fluvial deposits, sandy side slopes of aeolian origin, and steep calcrete faces.

The perennial eastern-flowing Okavango River is characterised by point bars, meanders, ox-bow lakes and other erosional and depositional features encompassing a distinct sequence of riverine land units. The floodplain area, two to six kilometres wide, can be divided into two zones. A broad area adjacent to the present course of the river actively receives fresh sediments during regular seasonal periods of inundation. As water levels drop, ponds and lakes remain. Behind this active floodplain area can be found a drier zone where the floodplain is no longer seasonally inundated. A terrace system differentially covered by alluvial and aeolian deposits is situated approximately six kilometres behind the floodplain.

5.2.4 Land Region 4: Omatako Drainage

Land System	Land Unit	Soil Unit
Main channel	Channel floor: pan zones	Haplic Calcisols
	Channel floor & confluences: thin sand mantle	Ferralic Arenosols
	Mid slopes: shallow calcrete	Calcaric Arenosols
	Mid slopes: deep sand mantle	Cambic Arenosols
	Crests	Ferralic Arenosols
Tributaries	Tributary floors: pan zones	Haplic Calcisols
	Tributary floors and side slopes: shallow calcrete	Calcaric Arenosols
	Tributary floors & side slopes: deep sand mantle and/or colluvial deposits	Cambic Arenosols
Upper slopes	Western tributaries top slope transition to dunes: thin sand mantle	Ferralic Arenosols
	Western tributaries top slope transition to dunes: shallow calcrete, pan zones	Petric Calcisols
	Eastern tributaries: upper slopes, thin sand mantle	Ferralic Arenosols
	Eastern tributaries: upper slopes, shallow calcrete, south-west of watershed	Petric Calcisols
	Eastern tributaries: upper slopes, shallow calcrete, north-west of watershed	Haplic Calcisols

Because of its extent and influence far beyond the Kavango Region, the Omatako Omuramba has been assigned an individual land region map unit. The systems within this region, comprising the broad main channel floor, the tributary areas and the upper slopes, may be viewed as areas with recurring patterns of genetically linked land units.

In terms of catenary sequencing the region is divided into systems individually displaying distinctly different erosion-deposition relationships between their component land units. Within the region as a whole the land systems also link up to form a cascading 'meta-system' functioning as a series of simple erosion catenas. This is compounded in places (particularly between the main Omatako channel and steep valley side slopes) by more complex local erosion-deposition sequences, whereby surface wash is greatest on the lower steeper parts of slopes leading to the preferential removal of fine soil particles and leaving a coarse-grained soil at slopes bases.

5.2.5 Land Region 5: Ephemeral Catchment Divide

Land System	Land Unit	Soil Unit
Watershed	Local depressions and flat areas with thin sand mantle	Cambic Arenosols
	Local crests: shallow calcrete	Calci-Haplic Solonetz

A broad, indistinct sandy plateau in central Kavango marks the water divide between eastern-draining omiramba from the largest north-draining Omatako omuramba. This area is pitted with shallow depressions and defined by average slope gradients of less than 0.07%.

One of the most complex map units, the ephemeral catchment divide provides a mosaic of localised differential substrate conditions ranging from deep sand to calcrete outcrops. Extensive areas of indurated and consolidated parent material lie in shallow subsurface layers impeding drainage throughout the region.

5.2.6 Land Region 6: Southern/Eastern Panveld

Land System	Land Unit	Soil Unit
High plain	Flat areas: thick sand mantle	Haplic Arenosols
	Depressions: shallow calcrete	Petric Calcisols

The northern tip of the Tsumke Panveld intersects the southern Kavango boundary to the west of the transitional hardpan system of Land Region 7. The boundaries of this region were mapped from aerial photographs and confirmed by aerial reconnaissance. From this bird's eye viewpoint the high plain of the southern panveld appears not to form part of the eastern catchment of the Omatako omuramba. By the direction of its slope gradient it should form a link to the hardpan areas of the eastern drainage system, although it stands isolated in the landscape of southern Kavango, resembling most closely the ephemeral catchment divide located further north. It may in fact be a relic ephemeral watershed now physically separated from the main catchment divide by sand drift. From secondary information sources (DRFN, 1999; De Pauw, 1996; FAO, 1984) the soils of this area are inferred to be Arenosols formed in simple catenary sequence with Calcisols overlying shallow calcrete deposits.

5.2.7 Land Region 7: Eastern-flowing Paleo Drainage

Land System	Land Unit	Soil Unit
Sand plain with common small pans	Low dune crests, mid slopes & flat areas: thick sand mantle	Haplic Arenosols
	Low dune crests, mid slopes & flat areas: shallow calcrete	Calci-Haplic Arenosols
	Slope bases & depressions: shallow calcrete	Calcic Solonetz
Sand plain with large pans	Low dune crests, mid slopes & flat areas: shallow calcrete	Haplic Calcisols
	Higher sites & crests of long gentle slopes: thin sand mantle	Ferralic Arenosols
	Pan zones	Haplic-xanthic Solonetz
Hard pan	Sand-drift plain: shallow calcrete	Calcaric Arenosols
	Convex crests: shallow calcrete	Hyper-Luvic Calcisols
	Pan zones	Petric Calcisols
Transitional system between hard pan & sand plain with large pans	Crests of long rises & eastern draining tributary base slopes	Luvic Calcisols / Haplic Alisols
	Pan zones	Petric Calcisols
Eastern omiramba	Omiramba crests	Haplic Arenosols
	Omiramba: mid & base slopes	Cambic Arenosols
	Omiramba floors: shallow calcrete	Petric Calcisols
	Omiramba floors: pan zones	Calcic Solonetz
	Omiramba floors: thin sand mantle	Ferralic Arenosols
	Omiramba tributary floors: thick sand mantle	Cambic Arenosols

Calcrete deposits underlie the extensive sand plains of this region, and where they surface or lie at shallow depths in depressions, they are associated with numerous small and large pans. Depth of calcrete, relief gradients and local water transfer mechanisms play important roles in the formation of Calcisols and Solonetz soils in this region. Where gradients are lowest Calcisols tend to form in large faintly bowl-shaped areas underlain by shallow calcrete, in association with large pans. Where relief is controlled by incipient dune formations and minor omiramba incisions through calcrete deposits, Solonetz soils tend to form in the more defined longitudinal depressions containing numerous small pans.

In the case of the omiramba draining eastwards towards Botswana, incision depths into underlying calcretes increase to the east, with the result that their valleys tend to narrow along their length. It is apparent that recent aeolian activity in addition to fluvial processes have influenced the form of these valleys and their environs. Dunes and drifts of wind blown-sand commonly fringe the eastern omiramba, being more pronounced on southern banks.

Basement formations comprising basalt and quartzite underlie areas in the south-east of this region but do not surface. The formations are capped by surface deposits of calcrete and consolidated aeolian sands forming a complex 'hardpan' surface.

From a geomorphological point of view the hardpan land system represents a deflation zone in which the entire surface has been differentially denuded and eroded by aeolian processes. It is a residual landscape of inverted features where former dunes have been eroded down to lower positions, and now act as wind corridors between higher areas more resistant to denudation. On top of the higher areas lie the remains of former pans and their associated, now dessicating, soils. These soils are now perched on gently convex crests with ample opportunity for surface runoff as opposed to their original locations on flat, interdune floors with conditions more conducive to the collection of surface water.

The hardpan system loses its morphology towards the west in a broad transitional zone which merges with extensive sand plains and large pans east of the ephemeral catchment divide.

6 FACTORS CONTROLLING SOIL DEVELOPMENT

6.1 CLIMATE, PARENT MATERIAL AND GEOMORPHOLOGICAL PROCESSES

True desert soils (arid) are not found in Kavango, nor are the true semi-arid soils representative of dry woodlands, grasslands and savannas. On the one hand, the soils of the region indicate a greater aridity than would be expected from the present-day semi-arid climatic record. On the other hand, no other evidence could be found to support the existence of truly arid environmental conditions. Rocky outcrops occur, although weathering has not produced coarse regolith. The sorting action of moving water and wind has not differentiated the parent material into rocky, gravelly, and sandy areas that are consistent with present-day aridity, although the genetic history of the parent material includes hyper-arid paleo-climatic conditions.

The parent material is simply an almost complete surface coverage, a virtual blanket, of pre-weathered, non-cohesive sand, whether deposited by alluvial or aeolian processes. Such parent material would certainly arrest soil formation and favour arid soil moisture regimes; conditions which are repeatedly documented in the great majority of the soils analysed by the immaturity of profile development and lack of horizon differentiation.

6.1.1 A residual landscape

Basement formations comprising basalt and quartzite underlie areas in the south-east of Kavango but do not surface. The formations are capped by surface deposits of calcrete and consolidated aeolian sands forming a complex 'hardpan' surface.

From a geomorphological point of view the hardpan land system represents a deflation zone in which the entire surface has been differentially denuded and eroded by aeolian processes. It is a residual landscape of inverted features where former dunes have been eroded down to lower positions, and now act as wind corridors between higher areas more resistant to denudation. On top of the higher areas lie the remains of former pans and their associated, now desiccating, soils. These soils are now perched on gently convex crests with ample opportunity for surface runoff as opposed to their original locations on flat, interdune floors with conditions more conducive to the collection of surface water.

6.2 SOIL COLOUR, GENETIC INHERITANCE AND CATENARY SEQUENCES

The majority of soils in Kavango, in common with the neighbouring soils of northwest Botswana and south-central Angola, form on either sandy or loamy parent materials.

6.2.1 Soil colours and genetic inheritance

The older Tertiary parent materials are completely recycled, having been thoroughly weathered and eroded before their present deposition. As a result, the soils developed on these substrates have not inherited the end-products of *in situ* weathering and individual soil particles of the present soils are therefore not commonly coated by oxidized iron. The only soils in which oxidized iron coatings would give the soils a red colour are the younger red aeolian sands blown in and deposited on top of the older Tertiary aeolian deposits, and the soils developed on top of the alluvial deposits of the Okavango river terraces.

Between these two soils the genetic chemical conditions favouring iron coatings are very different. In the case of the younger red aeolian sands, it is possible that previous weathering conditions did not completely remove the iron pigment which consequently remains coated on quartz grains giving a pale pink to red colouration. In the case of soils on alluvial terraces, the immature sediments forming the parent material would have originated in humid paleo-environmental conditions of central Angola and provide the source of iron.

The upward vertical movement of oxides in solution and subsequent precipitation as fine grained pigment throughout soil profiles are characteristic processes operating in the current climatic conditions of Kavango. These processes do give a distinct red colouration to soils, with the hues, values and chromas of soil colour indicating the concentration of the source material and the intensity of its redistribution processes. The iron oxides precipitated as pigment are, however, never quantitatively abundant enough to affect the total iron content of the soils.

6.2.2 Soil colour change, subsurface drainage and catenary sequences

Genetic inheritance together with the mobility of oxides in solution have produced a series of changes in soil properties from the upper to the lower members of catenas in all land systems. The variation in soil colour is one of the more obvious sequences, and this can be related to the subsurface drainage dynamics of the predominantly sandy upper slopes.

Upland, well-drained soils are usually reddish-brown, the colour showing the presence of non-hydrated iron oxides in the soil. The iron is well dispersed and usually partly attached to the clay fraction.

On the middle and lower parts of slopes, drainage is slower. These soils remain moist longer and dry out less frequently and less completely leading to an increasing degree of hydration of iron. The red colour then changes to a brown or yellow one; depending on the character of the hydrated iron oxides (limonite and goethite ?). The colour changes are not sudden; there is a gradual change from the original reddish-brown of the upper soils to orange-brown, and then to yellow-brown on the lower slopes.

On the lowest slopes, where drainage can be very poor and where part or all of the soil profile may be waterlogged for part of the year, reduction of iron and other soil compounds takes place. Under these conditions, bacteria obtain their oxygen from the oxygen-containing compounds and these are then reduced to other compounds. These soils are usually neutral grey in colour. In parts of the soil profile where the water-table fluctuates mottling is likely to be produced.

Genetic inheritance, differences in drainage potential and differential mobility of oxides in solution are responsible for the gradual colour changes that are frequently seen in the catenas of Kavango. The drainage differences can be due to a variety of factors including textural change and the presence of compacted or indurated sub soils but in each case the gradation within catenas can be related to oxidation-reduction balances.

6.3 THE VERTICAL MOVEMENTS OF SALTS

Unlike the case of humid regions where precipitation is greater than evapotranspiration the movement of soluble constituents in the soils of Kavango is either negligible or predominantly upwards. This is due partly to the low intensity of weathering generally and to the movement of soil solution towards the soil surface during evaporation and evapotranspiration.

Many single processes - e.g. salinization, solonization, solodization, - operate with generally low degrees of intensity in the region but they may all be combined and described under the process of **calcification**. This term is used generally to describe the process which forms calcic horizons (usually within the B horizon).

Soils which undergo transformation by calcification are also described as soils dominated by accumulation of silicate clays and/or bases. Whereas accumulations of silicate clays are not common in Kavango due to the predominance of pre-

weathered aeolian parent material, the accumulation of bases is a common soil characteristic in both the Calcisols and Solonetz soils of the region.

The term 'base' is used for both the cations of the alkali metals (e.g. sodium and potassium) and alkaline earth (e.g. calcium and magnesium). The basic cations are very mobile and so tend to form soluble compounds (e.g. sodium chloride) more readily in the soil. The common denominator of Calcisols and Solonetz soils in Kavango is the accumulation of bases somewhere within the profile. The accumulation may occur in all horizons or in particular horizons, depending on the controlling processes.

The accumulation of bases in the soil profile takes two main forms. They may be found as free salts (sodium chloride, calcium carbonate) in combination with soil anions, or as cations adsorbed onto the soil colloids, e.g. silicate clays.

Bases in the form of adsorbed cations are only present in soils formed on alluvial deposits where clay particles are present in sufficient quantities to warrant a loamy texture. These soils are found on the Okavango river terraces and on interdune and omiramba floors. In the remaining areas of Kavango bases as adsorbed cations are not common due to the low proportion of colloidal particles in re-worked aeolian deposits. In these areas bases are found as free salts.

The formation of free salts presupposes that the soil colloids, where present, are base-dominated. That is, the presence of free salts of a certain base element indicates a concentration in the soil of that element in excess of what is required to exchange cations on the soil colloids.

6.3.1 Origin of bases in soils of Kavango region

The bases that accumulate in the soils of arid and semi-arid areas generally originate from parent material, invasion by saline water, and rainwater. In Kavango, the bases are primarily derived from the following sources:

1. **Parent material** (divided into non-coherent and coherent deposits)
 - 1a. The mixture of materials comprising the alluvial deposits of the Okavango river terraces derive their bases from weathered origins in humid paleo-environmental conditions of central Angola. Non-coherent.
 - 1b. A greater part of the regional land surface is covered by deposits of pre-weathered and unconsolidated aeolian sand - a porous, non-equilibrium

assemblage of detrital materials, defined as loose, non-cohesive and granular, with grain sizes ranging from 0.0625 to 2.00mm diameter.

- 1c. In numerous localities sand is cemented by calcium carbonate to produce a nodular to highly indurated near-surface layer of calcrete.
- 1d. In places, calcium carbonate cementation is replaced by silica cement giving rise to silcrete at shallow depths.
- 1e. Consolidated sands.
- 1g. Shallow buried sandstone. Possibly diagenetic with low porosity through compaction and cementation, loss of many unstable detritals, and gains of stable authigenic precipitates.

2. Fire Effects

- 2a. Burnt organic mottles and fragments. The greater part of Kavango has been subjected to repeated, and over the last 15 years or so, increasingly frequent burning of vegetation. These are started naturally by lightning strikes on dry, easily combustible organic material, or artificially by man. Collections of burnt organic fragments on the soil surface, and burnt organic mottles dispersed down root channels are common.
- 2b. Ash. Thin surface deposits of nutrient-rich light coloured ash cover large areas of Kavango as a consequence of vegetation burning. Carbon detritus in the form of charcoal fragments, together with water-soluble bases released from volatilised organic compounds, are differentially deposited onto soil surfaces and subsequently incorporated into the solum. Both the rate and exact location of incorporation of these bases will depend on the timing and intensity of the first rainfall event subsequent to a burn. Prior to this event, wind may play an important role in their removal and re-deposition. Climatic records for Kavango region indicate that the frequency of high winds increases significantly from August onwards, reaching a maximum in November just prior to the onset of the rainy season. During the same period wind speeds also increase.

3. Water

- 3a. Saline groundwater
- 3b. Base-rich irrigation water. Base influx through application of fertilizer salts in solution
- 3c. Okavango river. Over-bank flow and seasonal inundation of nutrient-rich river water onto floodplain. Intrusion of salts in solution from river to shallow aquifers.
- 3d. Rainwater. Intrinsic salts.

6.3.2 The end-products of calcification

The most extreme form of the calcification process - salinization - is not evident in the soils of Kavango and therefore saline soils are not found. In terms of climatic zonation increasing humidity encourages leaching to 'set in' and the amount of available vegetation increases. Before the effect of vegetation becomes apparent however, a series of 'desert soils' occur in the following sequence of increasing wetness: solonetz - solodized-solonetz - solodic. Solonetz soils occur in eastern part of the region although neither solodized-solonetz nor solodic soils, more characteristic of humid conditions, have developed.

Climatic conditions experienced in Kavango rarely encourage the formation of humus, thus limiting the type of soils formed, whether sodic, calcic or not. Whereas climatic conditions do encourage the rapid growth of grasses and herbs, summer temperatures are hot rather than warm and only moderately humid. From early in the dry season onwards wind also encourages the rapid desiccation of dead organic matter, providing a ready supply of combustible material rather than an accumulation of nutritive organic matter for humus formation. Therefore, although the late summer droughts and winter frost conditions would normally arrest the decomposition of organic matter and keep it available for humus formation, most potential sources of organic matter are lost through dessication and fire well before the next rainy season, when humification processes would become effective.

6.4 SUB-SURFACE DRAINAGE AND SOIL DEVELOPMENT

The properties of Arenosols produce a high water transfer potential. Combining this with the spatial variability of these soils it is evident that the Arenosols act as an important agent in the rapid sub-surface transfer of water between top slopes and channels (catenary influence), local rises and depressions.

The Arenosols of the eastern drainage region in particular appear to be taking the role of main distributary from local rises to depressions where solonetz and calcisols develop, acting as the supplier of salts. As the medium through which leakage occurs, these soils are therefore able to act as catalysts of soil development in Solonetz soils and altering balance of sodium and calcium cations in Calcisols.

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APPENDICES

APPENDIX A.5.

WOOD UTILISATION

Table A.5.1.

Imports and Exports of Wood and Wood
Consuming Articles (x000 UA)

	1981	1982	1983	1984
Wood and wood articles* (Art 44)				
Imports	9,358	9,795	8,464	11,099
Exports**	157	207	612	1,901
Net Imports	9,201	9,588	7,852	9,197
Paper, articles of paper pulp (Art 48) (net imports)	8,708	12,144	13,688	15,787
Printed books, newspapers, etc. (Art 49)	3,527	7,108	6,074	6,380
net imports-total	21,432	28,840	27,614	31,364
As % of total imports	3.1	3.9	3.4	3.1

* Mainly construction wood, planks and manufacturing wood.

** Note the rapid increase in export of wood (mostly railway sleepers)

Source: External Trade Statistics, 1983/84.

Table A.5.2.

Preferred Fuelwood species included in Biomass Resources Assessment

<u>Setswana Name</u>	<u>Scientific Name</u>
Mhudioo	<u>Combretum apiculatum</u>
Moduba/Modubana	<u>Combretum zeyheri/C.erytrophullum</u>
Mogotho/Mogotlha	<u>Acacia erioloba</u>
Mohahu	<u>Acacia fleckii/A. erubescens</u>
Mohudiri	<u>combretum apiculatum</u>
Mokabe/Mokabi	<u>Combretum herereoense</u>
Mokala/Mokale	<u>Accia erioloba</u>
Mokgalo	<u>Ziziphus mucronata</u>
Mokgwelekgwele	<u>Acacia leuderitzii</u>
Mokoba	<u>Acacia nigrescens</u>
Molota/Moloto	<u>Acacia erubescens</u>
Mongana	<u>Acacia mellifera</u>
Mophane	<u>Colophospermum mopane</u>
Moselesele	<u>Dichrostachys cinerea</u>
Mosetha/Mosetlha	<u>Peltophorum africanum</u>
Motswiri/Motswere	<u>Combretum imberbe</u>

Source: ERL, 1985

Note: Surprisingly, some species are not mentioned (e.g. Acacia tortilis, Mosu)

Table A.5.3.

Location and Area of Woodlots and Plantations in Botswana

Location	Hectares	Comments
Forestry Unit		
Diphawana	3.7	
Francistown	25.0	Part taken over by Town Council
Gaborone	80.0	Mainly over-mature
Good Hope (1)	5.0	" " "
Good Hope (2)	41.8	" " "
Kasane	6.0	
Lobatse	20.1	
Palapye	2.5	
Phareng	4.4	
Rauthebane	34.8	
Tonota	5.0	
Tsabong	5.0	Sand dune stabilisation
	<u>233.4</u>	
Kweneng, Rural Development Association		
Kopong	44.0	
Lethakeng	18.6	
Molepolole (Airport)	148.0	
Ntsono	9.9	
	<u>220.5</u>	
Brigades etc.		
Serowe	40.0	Very poor survival
Mahalapye	1.0	
S.P. Lions/Mmadinare Cooperative		
Selibe Phikwe	5.0	Agro-forestry project
Kgatlang Development Board		
Morwa	25.0	Poor survival in parts Currently being harvested
Kgalagadi Settlements Projects		
Takatokwane	6.0	
Community Schemes		
Hukuntsi	30.0	
Shoshong	25.0	
Commercial Sector		
Jwaneng	50.0	
Total area =		635.9 hectares

Table A.5.4.

Estimated Fuelwood Consumption⁽¹⁾

Country	Fuelwood m ³	Consumption Source tonnes
PER CAPITA		
Botswana (Rural)	0.57	0.51 ERL 1985
Botswana (Rural)	0.70	0.63 USAID (1981)
Botswana (Rural)	1.25	1.13 White (1979)
Botswana (Rural)	0.42	0.38 Van Vegten (1981)
Botswana (Gaborone)	0.25	0.23 BRET (1985)
Botswana (Lobatse)	0.49	0.44 BRET (1985)
Bangladesh (Ohanishwar Village)	0.6	0.54 Mont.Eng. (1976)
Sudan (Basra)	4.4	Digernes (1980)
Gambia	1.2	1.08 Floor (1977)
Thailand	1.5	1.35 Openshaw (1976)
Liberia (Monrovia)	1.3	1.17 Roitt (1970)
Kenya	1.1	0.99 Marquand (1978)
Kenya	1.0	0.9 Muchiri
Kenya	1-2	0.9-1.8 Western (1978)
Tanzania	2-1	Openshaw (1978)
Upper Volta	0.8-1.1	0.7-0.99 Earnst (1977)
Upper Volta	0.7	0.63 Floor (1977)
India (Pura Village)	0.8	0.70 Reddy (1918)

* Conversion Factor used is 1.11m³ per ton
Sources: ERL (1985)
 Moss, R.P. and Morgan, W.B. (1980)

Table A.5.5.

Socio-Economic Level and Wood Consumption per day
 Kg. of Wood Burning (1 kg) per household per day

Income State	Gaborone	S/Phikwe	Lobatse	Serowe	M/polole	Palapye	Mean
Very low	3.6	6.2	3.1	5.8	3.5	6.1	4.6
Low	2.3	8.9	3.8	7.0	4.5	6.5	5.5
Middle	1.3	4.2	3.5	3.8	3.6	6.5	3.7
High	0.7	1.6	0.7	6.4	4.2	3.8	2.4
Very high	0	0.8	0.7	8.3	7.7	-	2.8
Mean	1.5	5.6	2.6	5.7	4.0	5.8	4.0

Source: Gay and Zietlow (1985)

Table A.5.6.

Woodfuel Prices in Botswana in 1984

Good Hope	2-wheel donkey- cart load	P 6.00- P 7.00	3 t	price the same for villagers and strangers
	4-wheel donkey- cart load	P10.00- P16.00	3 t	" " " "
Mmankgodi	half a 2-wheel to donkey-cart load	P 7.00	7t	sold on main road passing vehicles
	60kg wheelbarrow load	P 6.00	10t	" " " "
	sledge load	P 7.00	7t	" " " "
	van load	P20.00	7t	collected on request for passing van
Lecheng	2-wheel donkey- cart load	P 9.00- P10.00	5t	intra-village price for non-strangers
	4-wheel donkey-	P20.00	5t	" " " "
	4-wheel donkey- cart load	P10.00	2.5t	price to locals
	4-wheel donkey- cart load	P18.00- P20.00	5t	price to non-locals
Bobonong	2-wheel donkey- cart load	P 4.00- P 6.00	2.5t	price to locals
	2-wheel donkey- cart load	P10.00- P15.00	6t	price to non-locals (at Palapye)
	lorry load	P20.00	2t	sold only to villagers
Masunga	2-wheel donkey-	P 5.00	2.5t	" " " "
	2-wheel donkey- cart load	P 5.00 P 7.00	3t	little trading and all intra-village

Source: ERL, 1985

Table A.5.7.

Scenarios for Future Firewood Use
(x1000 tonnes)

Region*	1983			1990			2000		
	Urban	Rural	Total	Urban	Rural	Total	Urban	Rural	Total
1	21	59	80	30	71	101	47	89	136
2	6	14	20	8	16	24	3	20	23
3	34	48	82	48	57	105	78	69	147
4	11	38	49	15	44	59	27	54	81
5	15	61	76	21	70	91	37	82	119
6	15	41	56	22	48	70	35	63	98
7	20	7	27	30	7	37	52	7	59
8	0	8	8	0	9	9	0	12	12
Rest	8	56	64	11	66	77	17	78	95
Total	130	332	462	185	388	573	306	474	780

Source: ERL, 1985.

*See Table 5.1. for Regions

Kgathi's estimates in 5 scenarios* for Botswana.

	<u>1990</u>	<u>2002</u>
Urban Areas	59- 101	96- 343
Rural Areas	998-1176	668-1686
Total Botswana	1099-1235	1011-1784

*Assumptions for population growth and urbanisation differ.

Source: Kgathi, forthcoming

Table A.5.8.

Calculated Biomass Yields for Vegetation Types

Vegetation Type	Biomass (tonnes/ha (Oven Dried))	Increment (tonnes/ ha/year)
1. Bare ground	-	-
2. Sparse vegetation	3.6 + 4.3	0.3
3. Low Density Woodland	18.9 + 6.6	1.0
4. Mid-Density Woodland	25.9 + 12.7	1.4
5. Higher Density Woodland	48.0 + 10.6	2.1

Table A.5.9.

Distances travelled for wood

No. of km from village	Mmankgodi	Good Hope	Bobonong	Lecheng	Masunga
1-2	Some head-loading		Little wood available	Some head-loading	Some head-loading survey mean: 2.8 km
3-4	Headloading Survey mean: 3.9km	Not much available but <u>moretlwa</u> twigs and live wood	Headloading but no mophane Survey mean: 4.8km	Survey mean: 3.5km	Headloading
5-6	Some head-loading	Survey mean: 5.9km	Headloading - not enough wood for donkey carts	Some house-building wood available	Headloading giving way to donkey-carts
7-8		Important donkey cart-load areas			
9-10	Cartload	A woman died on 17/7/84 because her neck broke trying to headload from 10km away	Family donkey carts get plenty of <u>mophane</u> at 10 km		
11-12			Plenty of wood: tractors, donkey-carts & lorries this far out		
15+	Lots of wood at the lands for fuel and building (20-30km away)	House-building wood c.15km	Ample <u>mophane</u> for commercial collecting at 15-20km out, also for house-building	Plentiful housebuilding wood "about 4hrs away"	

Source: ERL, 1985

APPENDIX A.6.
MINERAL PRODUCTION

Table A.6.1.

Botswana Mineral Production and Estimated value of Mineral Production

YEAR	DIAMONDS		NICKEL-COPPER MATTE					COAL	
	Production (000's carats)	Estimated value	Production of Matte (tonnes)	Nickel (tonnes)	Contained Metal Copper (tonnes)	Cobalt	Estimated value (P'000)	Production (tonnes)	Value (P'000)
1950-1965	-	-	-	-	-	-	-	-	-
1966	-	-	-	-	-	-	-	-	-
1967	1	6	-	-	-	-	-	-	-
1968	11	64	-	-	-	-	-	-	-
1969	31	212	-	-	-	-	-	-	-
1970	583	2 704	-	-	-	-	-	-	-
1971	914	5 540	-	-	-	-	-	-	-
1972	2 446	19 461	-	-	-	-	-	-	-
1973	2 453	23 229	-	-	-	-	-	-	-
1974	2 718	30 135	6 663	2 577	2 752	ND	7,857	20 299	130
1975	2 414	29 583	16 514	6 447	6 504	92	22 185	32 732	310
1976	2 361	33 829	32 506	12 581	12 473	198	51 586	71 248	641
1977	2 691	48 567	30 772	12 094	11 788	165	43 000	224 099	1 719
1978	2 799	78 972	39 517	16 049	14 615	261	51 315	294 039	2 170
1979	4 394	165 719	39 823	16 173	14 563	294	74 068	314 486	2 322
1980	5 101	214 293	40 099	15 442	15 553	226	83 258	371 395	3 461
1981	4 960	202 082	46 565	18 278	17 819	254	79 439	380 698	4 237
1982	7 768	407 147	45 685	17 756	18 375	254	61 172	414 778	4 712
1983	10 731	538 288	48 083	18 216	20 261	223	68 395	395 127	5 357
1984	12 882	874 439	51 845	18 604	21 471	259	77 528	392 851	5 465
TOTAL	65 258	2 688 976	398 122	154 221	156 174	2 226	619 803	3 266 827	33 221

Note: Values shown here are the estimated values of production for the year.
Actual mineral sales and sales revenue are not shown.

Source: Department of Mines, 1985

Table A.6.1. (continued)

Botswana Mineral Production and Estimated value of Mineral Production

YEAR	MANGANESE		GOLD		ASBESTOS		KYANITE		LIMESTONE	
	Production (tonnes)	Value (P'000)	Production (tonnes)	Value (P'000)	Production (tonnes)	Value (P'000)	Production (tonnes)	Value (P'000)	Production (tonnes)	Value (P'000)
1950-1965	117 714	1 150	245.2	217	18 114	3 188	9 366	171	-	-
1966	913	10	-	-	913	10	-	-	-	-
1967	4 253	19	-	-	-	-	-	-	-	-
1968	9 988	123	-	-	-	-	-	-	-	-
1969	22 244	400	-	-	-	-	-	-	-	-
1970	48 311	843	-	-	-	-	-	-	-	-
1971	35 603	432	-	-	-	-	-	-	-	-
1972	687	20	-	-	-	-	-	-	-	-
1973	340	7	-	-	-	-	-	-	-	-
1974	-	-	-	-	-	-	-	-	-	-
1975	-	-	-	-	-	-	-	-	-	-
1976	-	-	-	-	-	-	-	-	-	-
1977	-	-	-	-	-	-	-	-	-	-
1978	-	-	-	-	-	-	-	-	-	-
1979	-	-	-	-	-	-	-	-	-	-
1980	-	-	-	-	-	-	-	-	-	-
1981	-	-	10.3	117	-	-	-	-	-	-
1982	-	-	14.9	168	-	-	-	-	275	6
1983	-	-	11.3	164	-	-	-	-	-	-
1984	-	-	17.87	184	-	-	-	-	43	4
TOTAL	204 053	3 004	299.57	850	19 027	3 198	9 366	171	318	10

Table A.6.1. (continued)

Botswana Mineral Production and Estimated value of Mineral Production

YEAR	TALC		SEMI-PRECIOUS STONES		CRUSHED STONES		SAND AND GRAVEL		Total Value All Minerals (P'000)
	Prod. (Tonnes)	Value (P'000)	Sales (Tonnes)	Value (P'000)	Prod. (M ³)	Value (P'000)	Prod. (M ³)	Value (P'000)	
1950 - 1965	48	1	-	-	-	-	-	-	4 727
1966	-	-	-	-	-	-	-	-	20
1967	73	1	-	-	-	-	-	-	26
1968	124	1	2	-	-	-	-	-	190
1969	51	1	6	4	24 512	31	-	-	648
1970	36	-	13	5	15 786	35	-	-	3 587
1971	130	1	105	34	52 698	235	-	-	6 242
1972	-	-	100	33	68 039	305	-	-	19 818
1973	-	-	73	22	33 476	133	6 055	5	23 526
1974	18	1	37	14	40 071	206	56 655*	62	38 586
1975	142	14	45	22	53 417	319	127 226	211	52 975
1976	144	17	42	10	100 684	382	151 063	198	87 741
1977	288	34	50	16	127 983	527	135 840	227	94 541
1978	313	45	10	3	141 415	1 005	133 553	274	133 936
1979	104	15	5	1	228 526	1 657	229 856	536	244 692
1980	78	19	20	4	222 033	1 861	201 925	769	303 665
1981	-	-	-	-	184 355	1 839	156 921	689	288 403
1982	-	-	1	-	248 671	3 641	74 367	499	478 067
1983	-	-	13	3	441 205	5 082	135 560	726	618 015
1984	-	-	37	16	436 604	2 948	188 498	762	961 346
TOTAL	1 549	151	559	188	2 419 475	20 206	1 597 519	4 958	3 360 028

Source: Department of Mines, Annual Report, 1984.

Table A.6.2.

Employment Mining Sector (Botswana)

	Diamonds	Copper/ Nickel	Coal	Others	Total	As % of formal Employment
1984	3,743	4,270	182	341	8,536	7.8
1983	3,527	4,172	176	383	8,258	8.2
1982	3,406	4,162	176	360	8,104	8.1
1981	3,062	4,273	162	325	7,822	8.0
1980	2,623	4,295	171	255	7,353	8.8
1979	1,918	3,715	164	323	6,120	8.1
1978	1,735	3,248	153	332	5,468	
1977	1,382	3,107	154	317	4,960	
					5,450	9.2
1976					4,525	7.9
1975					4,100	7.9
1974					3,525	7.5
1973					1,675	4.1
1972					825	3.3
1968						

Source: CSO, Department of Mines.

Table A.6.3.

Government Revenue from Mining Sectors
through Department of Mines

	Diamonds	Copper/ Nickel	Coal	Total	Total GoB	Total GoB as % of GoB Revenue
1984/85	207.8	0	0.3	208.1		
1983/84	122.1	0	0.2	122.5		
1982/83	58.8	0	0.2	59.0	99.5	25.3
1981/82	14.8	0	0.2	15.3	114.9	37.2
1980/81	50.6	0.4	0.1	51.3	101.1	33.0
1979/80	50.1	1.8	0.1	52.1		
1978/79						
1977/78	12.7	0.8	0.9	13.6		
1976/77						

Sources: Department of Mines, Annual Reports; Statement of Accounts.

Table A.6.4.

Investments by Mining Sector
(P mln; constant 1979/80 prices)

	Absolute	As % of total investments
1981	150.5	45.3
1980	109.8	36.2
1979	128.8	43.3
1978	87.5	38.8
1977	51.2	27.8
1976	12.9	9.6
1975	30.1	16.6
1974	30.2	16.0
1973	52.8	24.6

Source: National Accounts, 1981/82

Table A.6.5.

Total value of mining production GDP, exports

	(1) mine production	(1) as % of GDP	(1) as % of exports
1984	961.3		79.9
1983	618.0	48.7	67.6
1982	478.1	46.7	65.8
1981	288.4	37.9	64.5
1980	303.7	39.8	81.4
1979	244.7	35.5	68.8
1978	133.9	26.6	68.4
1977	94.5	26.7	57.1
1976	87.7	28.2	58.3
1975	53.0	19.6	51.5
1970	3.6		
1966	0	0	

Source: Department of Mines, CSO, Colclough and McCarthy, 1980.

Table A.6.6.

Production from Diamond Mines

	Tonnes Treated (x1000)			Carats Recovered (x1000)		
	O	L	J	O	L	J
1970				538*		
1971	695			913*		
1972	2701			2446		
1973	2815			2453		
1974	2954			2718		
1975	3048			2414		
1976	3429			2361		
1977	3450	1087		2345	346	
1978	3515	1111		2454	331	
1979	6140	1304		4091	303	
1980	7330	2113		4700	401	
1981	7401	2229		4531	430	
1982	7751	2247	3341	4677	470	2622
1983	7686	2316	4817	4335	543	5853
1984	7703	2470	5000	4677	754	7451

O = Orapa L = Letlhakeng J = Jwaneng * = Including prospecting
Source: Department of Mines, Annual Reports.

Table A.6.7.

Production of BCL

	Ore (1000 tonnes)			Total	Ni	Metal		Exp (1000P)
	Phikwe underg.	Selebi Open	Selebi underg.			Cu	Co	
1974	393.3	267.3	0	661.5	2,577	2,752	0	7,857
5	509.2	620.9	0	1,130.1	6,447	6,564	0	22,185
6	1,112.3	1,001.5	0	2,122.8	12,581	12,473	0	51,586
7	1,115.4	748.1	0	1,900.5	12,094	11,788	0	43,000
8	1,476.7	627.5	0	2,104.2	16,049	14,615	261	51,315
9	1,531.3	596.4	98.8	2,266.6	16,173	14,563	294	74,068
1980	1,568.1	635.8	344.8	2,548.7	15,442	15,553	266	83,258
1	1,629.1	0	826.7	2,445.8	18,278	17,819	254	79,439
2	1,527.5	0	899.6	2,472.1	17,756	18,375	254	61,172
3	1,917.8	0	940.3	2,858.1	18,216	20,261	223	68,395
4	2,184.6	0	922.1	3,106.6	18,604	21,471	259	77,528

Exp estimated value of production
Source: Department of Mines, Annual Reports.

Table A.6.8.

Copper/Nickel Deposits in Selebi-Phikwe (x1000 tonnes ore)

	1977	1980	1984
Phikwe			
proven	22,205	14,891	41,050
probable	9,311	8,351	n.a.
Selebi			
proven	9,955	9,683	22,786
probable	2,682	4,719	n.a.
Selebi-North			
proven	-	n.a.	4,716
probable	-	0	n.a.
Total proven	32,160	24,574	68,552
Total probable	44,153	39,549	n.a.

Source: Department of Mines, Annual Reports.

Table A.6.9.

Air Pollution Standards and Objectives (ug/m³)

	Daily Average	Monthly Average	Annual Average
Botswana	90% below 300	160	80
WHO	100-150		40-60
EEC (desired)	100-150		40-60
USA (health)	99% below 365		80
Sweden	200		
Italy	390		
East Germany	150		
Taiwan	260		130
	<u>TSP</u>		
Botswana	90% below 300	200	200
WHO	100-150		40-60
EEC (desired)	100-150		40-60
USA	99% below 260		75
Sweden	120		
Italy	300		
East Germany	150		

Table A.6.10

Selebi-Phikwe Sulphur Dioxide Data, 1976-1983
 $\mu\text{g}/\text{m}^3$ SO_2 Determined by the Hydrogen Peroxide Absorption Method

Year	Criteria	BCL MONITORING STATION					
		1. Smelter West	2. Smelter East	4. Water Utili- ties	5. , Botsha- belo	6. Nata	7. High Density
1976	3 hr. max	151 900					
	24 hr. max	22 400				2,150	
	Mean	5,180				250	
1977	3 hr. max	72 500	10 900				
	24 hr. max	13 200	3 200		400	1 350	520
	Mean	1 940	230		30	120	70
1978	3 hr. max	28 600	9 180				
	24 hr. max	6 100	1 270	3,000	200	1 100	470
	Mean	1 070	160	200	30	140	60
1979	3 hr. max	17 700	5 930				
	24 hr. max	4 900	4 510	2 560	700	1 670	990
	Mean	1 280	230	240	60	140	80
1980	3 hr. max	140 260	9 870				
	24 hr. max	37 750	3 740	1 980	610	820	670
	Mean	4 130	290	200	60	110	100
1981	3 hr. max	359 960	14 490				
	24 hr. max	127 550	10 080	1 890	1 100	040	500
	Mean	5 410	330	100	50	80	60
1982	3 hr. max						
	24 hr. max	7 770	1 590	1 720	630	1 120	850
	Mean	1 000	170	250	60	140	90
1983	3 hr. max						
	24 hr. max	6 010	2 880	890	940	1 110	1 360
	Mean	1 170	300	200	90	140	140

Table A.6.10

(continued)

Selebi-Phikwe Sulphur Dioxide Data, 1976-1983
 ug/m³ SO₂ Determined by the Hydrogen Peroxide Absorption Method

Year	Criteria	BCL MONITORING STATION			GRB MONITORING STATION			
		8. Low Density	9. Railway Station	10. Slag Tap Floor	5. Hospi- tal	6. Rail- way	9. Town- ship West	10. S/Phikwe Sec. School
1976	3 hr. max							
	24 hr. max		4 800					
	Mean		410					
1977	3 hr. max							
	24 hr. max	800	2 350					
	Mean	80	140					
1978	3 hr. max							
	24 hr. max	580	680					
	Mean	100	140					
1979	3 hr. max			115 870				
	24 hr. max	960	2 030	42 100	350	530	650	
	Mean	100	150	7 430	130	190	180	
1980	3 hr. max			1 231 340				
	24 hr max	480	850	360 650	2 100	3 080	580	
	Mean	70	130	42 630	190	430	70	
1981	3 hr. max			9 054 000				
	24 hr. max	1 180	870	2 415 550	600	990	460	850
	Mean	100	110	75 210	110	140	50	80
1982	3 hr. max							
	24 hr. max	1 320	1 200	930 860	970	1 060	880	970
	Mean	120	200	68 100	100	240	80	130
1983	3 hr. max							
	24 hr. max	760	2 350	68 410	890	2 230	850	1 280
	Mean	130	240	11 870	150	460	140	230

Source: Department of Mines, 1984.

Table A.6.11.

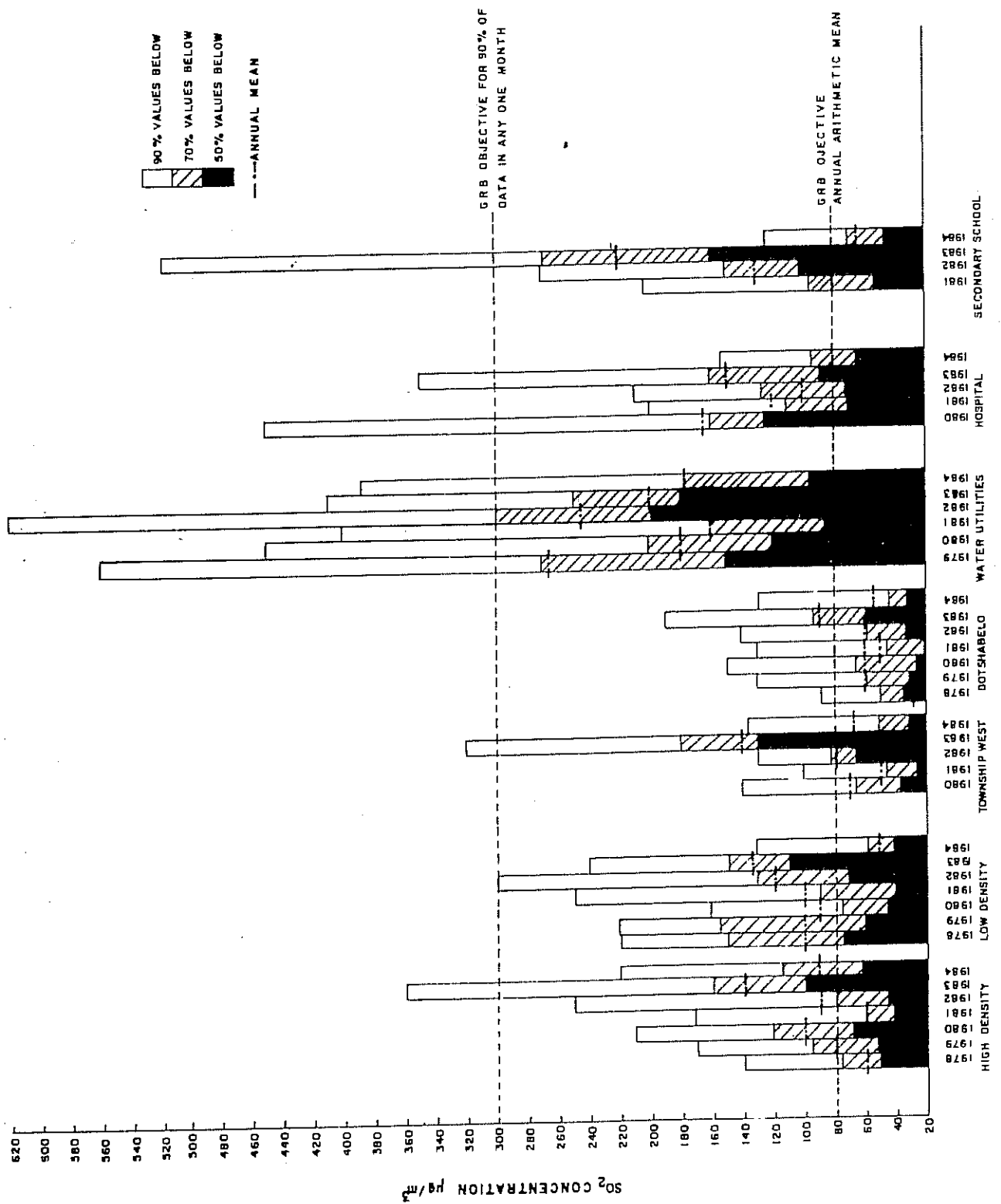
Water Quality Indicators at Two monitoring points BCL (February)

Station 3a	1980		1981		1982		1983		1984		1985	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
pH	7.8	1.5	4.4	1.2	8.1	.38	9.3	.14	7.9	.49	90	.46
TSS	8.2	7.4	14.7	9.9	14.1	13.5	20.8	14.0	10.4	7.7	16.5	16.2
T/H	903	434	857	86.4	250	108	223	19.3	404	73.0	409	156
Ca/H	763	439	626	47.4	143	31.6	168	25.0	314	66.4	281	127
SO ₄ (g/l)	1.05	.44	.96	.09	.19	.07	.19	0.34	.46	.10	.36	.11
Cu ppm	.23	.22	1.58	2.28			.11	.08	.13	.05	.01	.01
Ni. ppm	1.97	.81	8.72	3.64			.06	.14	.23	.63	.04	.03
Fer ppm	1.0	5.3	8.15	11.0							.06	0.05
Mn. ppm	.41	.27	2.39	.75							0.01	0.04

Station 5	1979		1981		1982		1983		1984		1985	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
pH	2.9	2.1	.06	2.3	.26	2.6	.27	2.4	.13	2.3	.15	
TSS		65.3	41.4	50.8	21.1	238	194	97.8	72.1	108	53.8	
TDS	2760	5830	190	5362	186	10186	1129	11450	506	12720	530	
T/H		2226	127	2837	469	2979	179	2935	317	3226	336	
Ca/H		1514	263	1492	280	2421	232	1817	295	1971	442	
SO ₄	1.9	3.6	.05	3.5	109	4.1	.11	4.4	.19	4.9	.282	
Cu ⁴	0.3	.97	.59	.25	.06	.83	.10	.99	.75	2.3	2.08	
Ni	5.2	17.3	4.4	7.8	1.2	21.3	2.98	2.98	15.8	3.60	31.8	6.97
Fer	100.1	398	23.7	331	15.9	435.0	46.0	584.	156	514	19.9	
Mn	10.3	31.1	5.3	31.4	2.97	53.2	33.9	51.1	5.5	32.0	7.82	

Source: BCL Quarterly Reports.

Figure A.6.1.1. SO₂ Concentrations in Residential Areas in Selebi-Phikwe. Source: Department of Mines, 1984



APPENDIX A.7

OTHER PRODUCTIVE ACTIVITIES AND HOUSEHOLD CONSUMPTION

Table A.7.1.
Household Consumption

	absolute (P1 mln)	as % of GDP
1966	28.8	78.3
1971/72	59.1	57.0
1976/77	190.0	61.1
1981/82	465.8	61.3

Source: National Accounts 1981/82, Botswana National Accounts and Selected Indicators, 1966-1976

Table A.7.2.
Production, Imports and Consumption of Energy Sources (Terra Joules)

	Production	Import	Export	Consumption
Firewood	7,653.7	0	0	7,653.7
Electricity	1,480.0	742.5	0	2,222.5
Petroleum	0	6,511.7	0	6,829.6*
LPG	0	137.4	0	123.5*
Coal	10,489.3**	696.0	0	4,897.8

Source: Lahmeyer International Cons. Eng., 1986

Map A.7.1.

Major Public Infrastructure for Water and Electricity

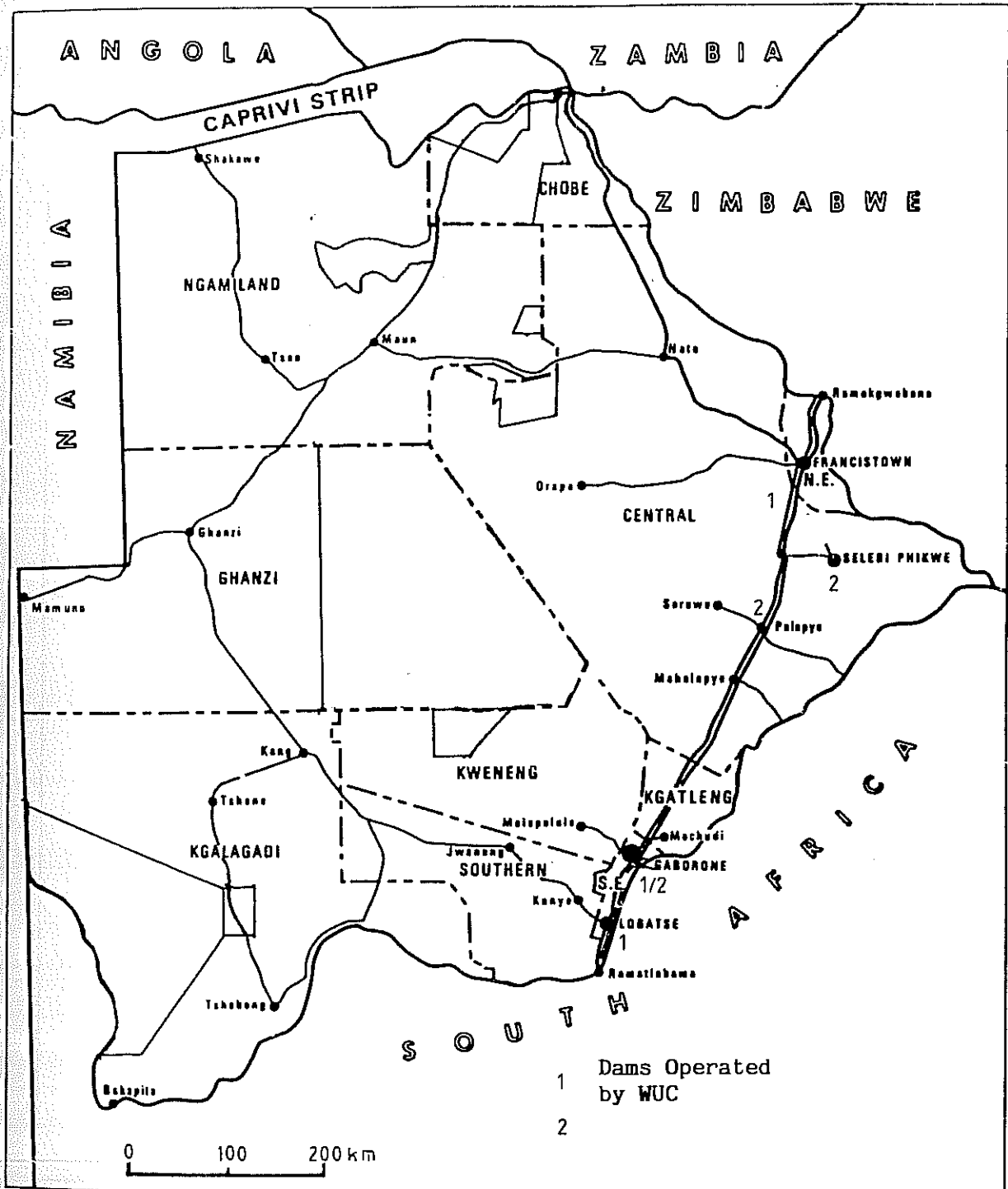
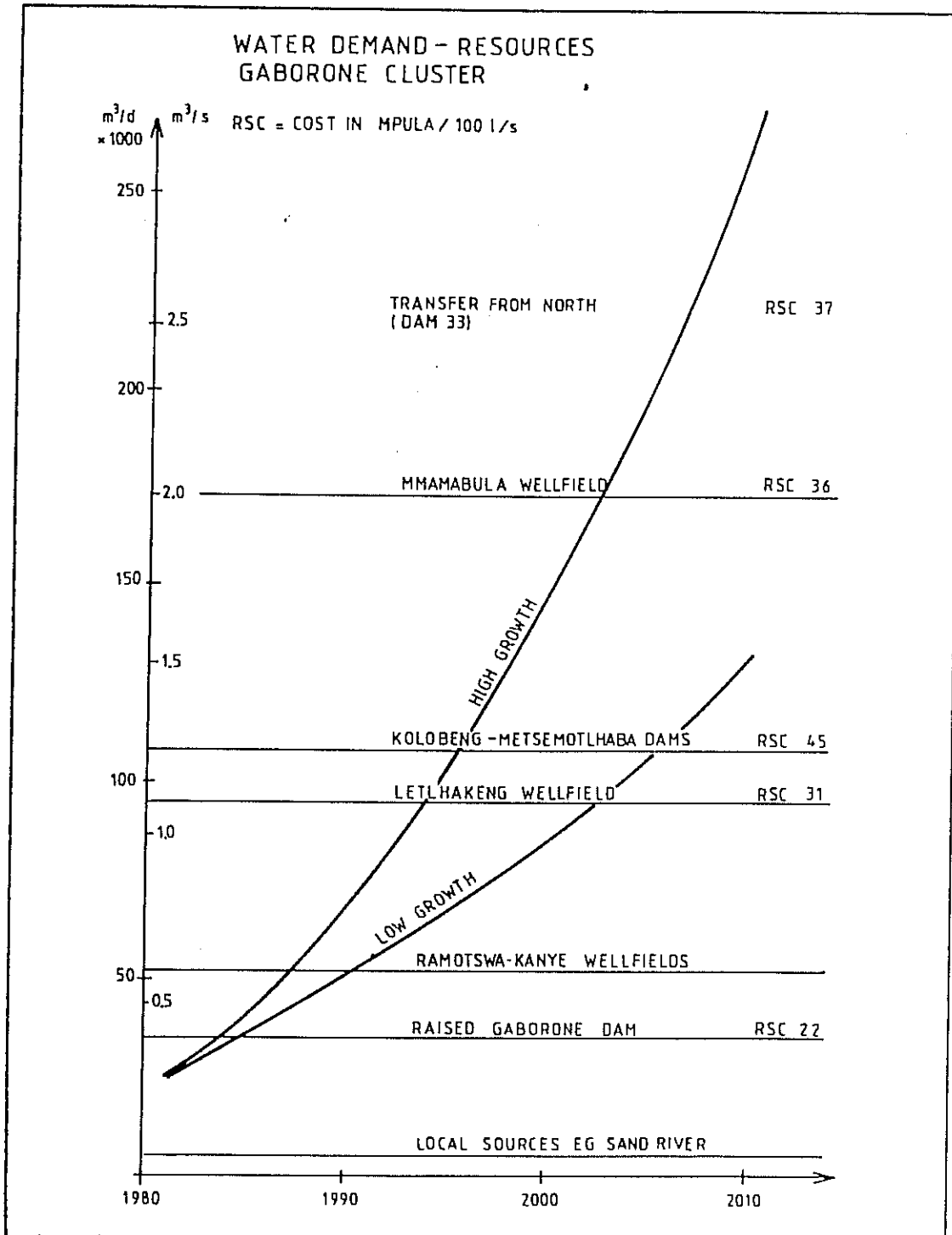


Figure A.7.1.

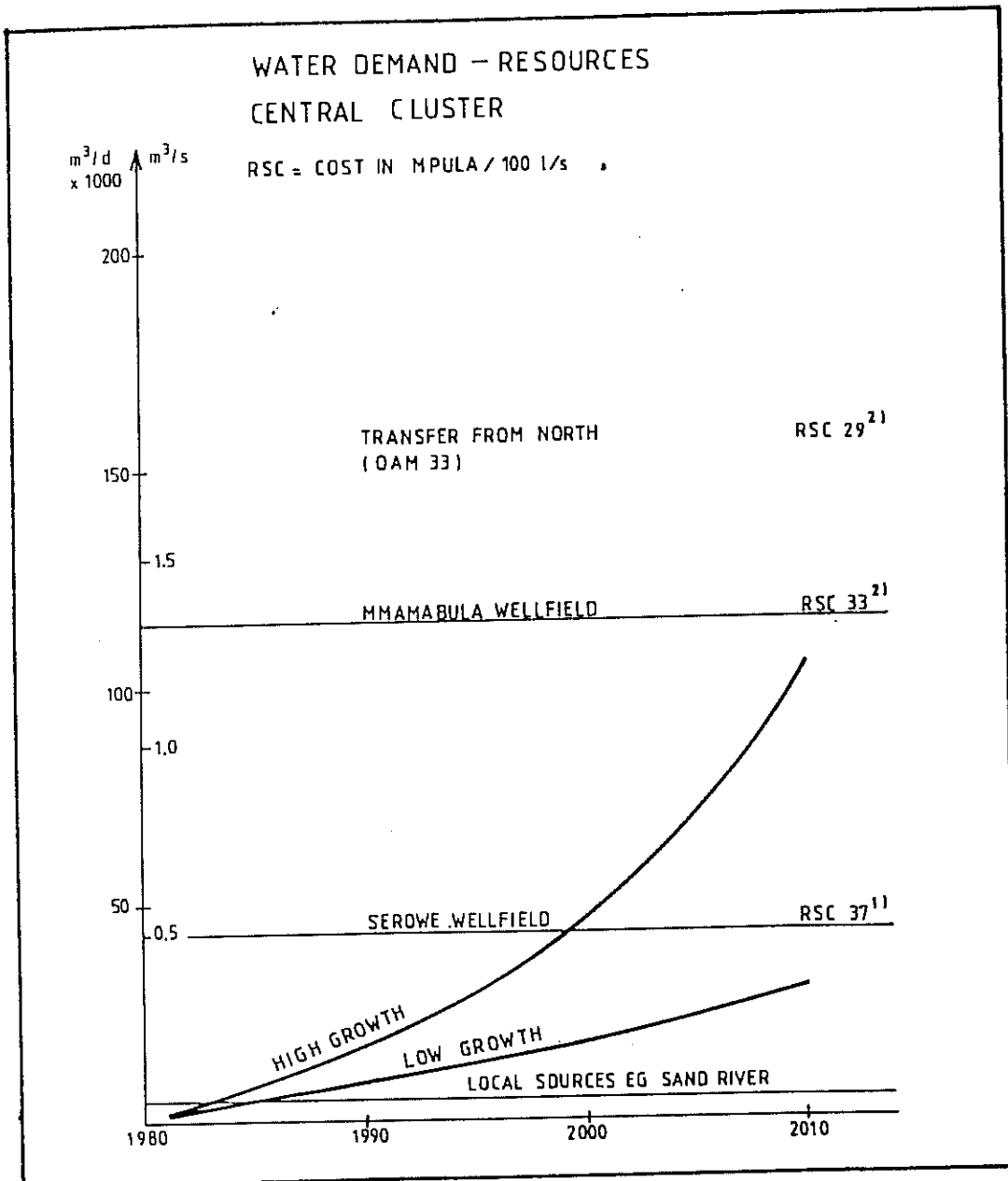
Water Demand and Resources in the Gaborone Cluster



Source: VIAK, 1985

Figure A.7.2.

Water Demand and Resources in the Central Cluster

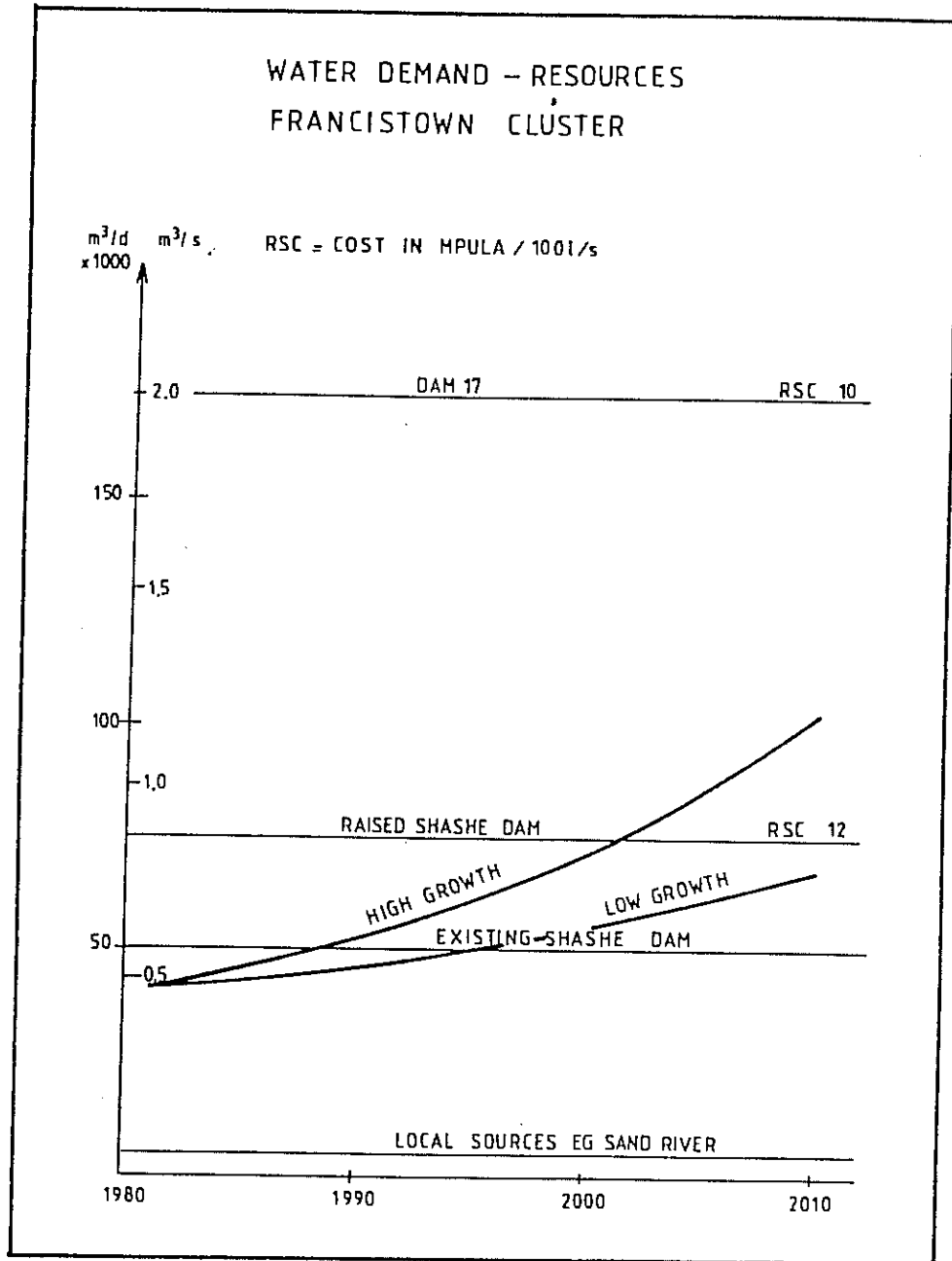


- 1) Priority order based on investments
- 2) RSC-value at Palapye. Costs of pumping to Serowe will increase the value by some 7 M Pula/100 l/s.

Source: VIAK, 1985

Figure A.7.3.

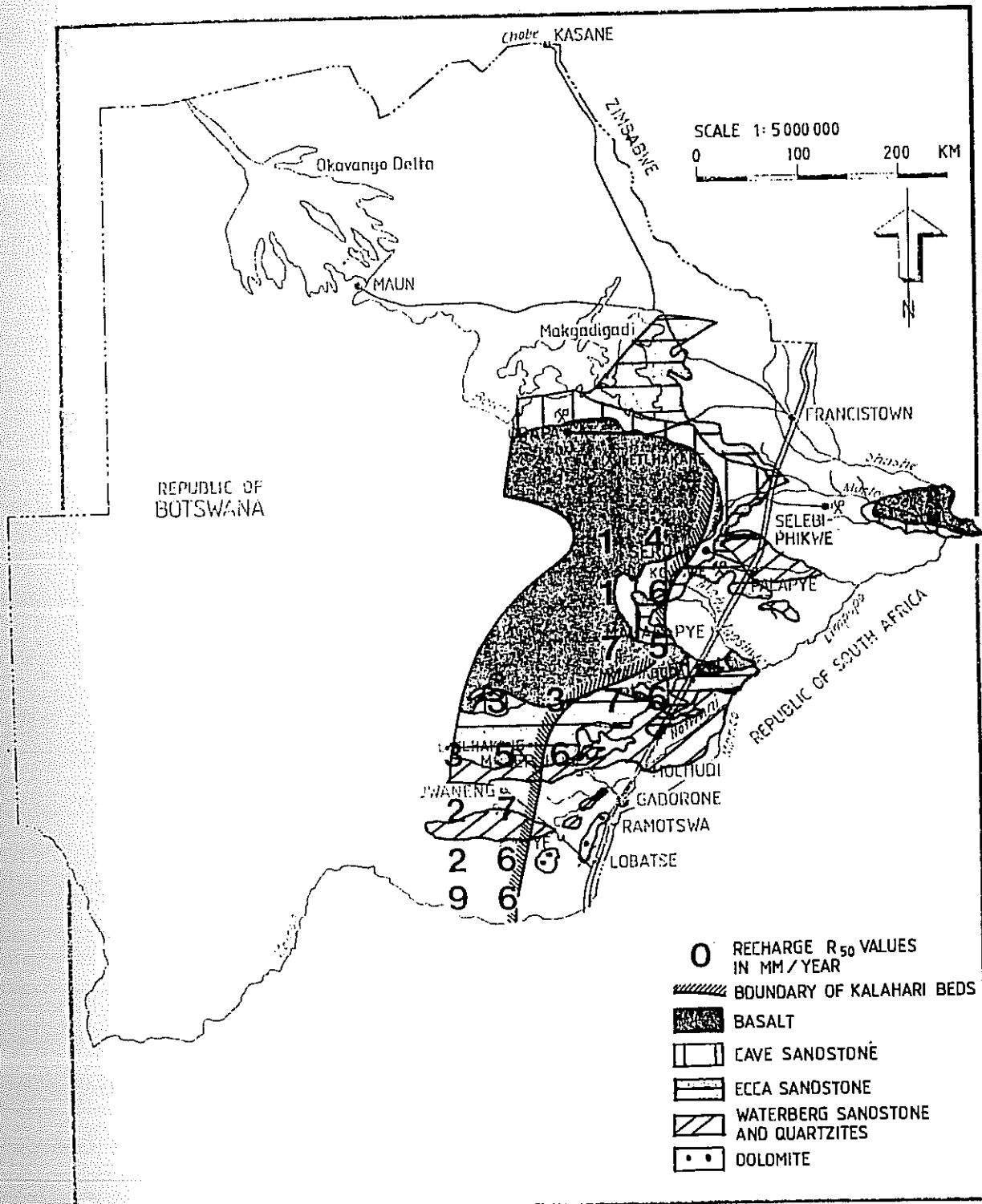
Water Demand and Resources in the Francistown Cluster



Source: VIAK, 1985

Map A.7.2.

Regional Distribution of Recharge Values



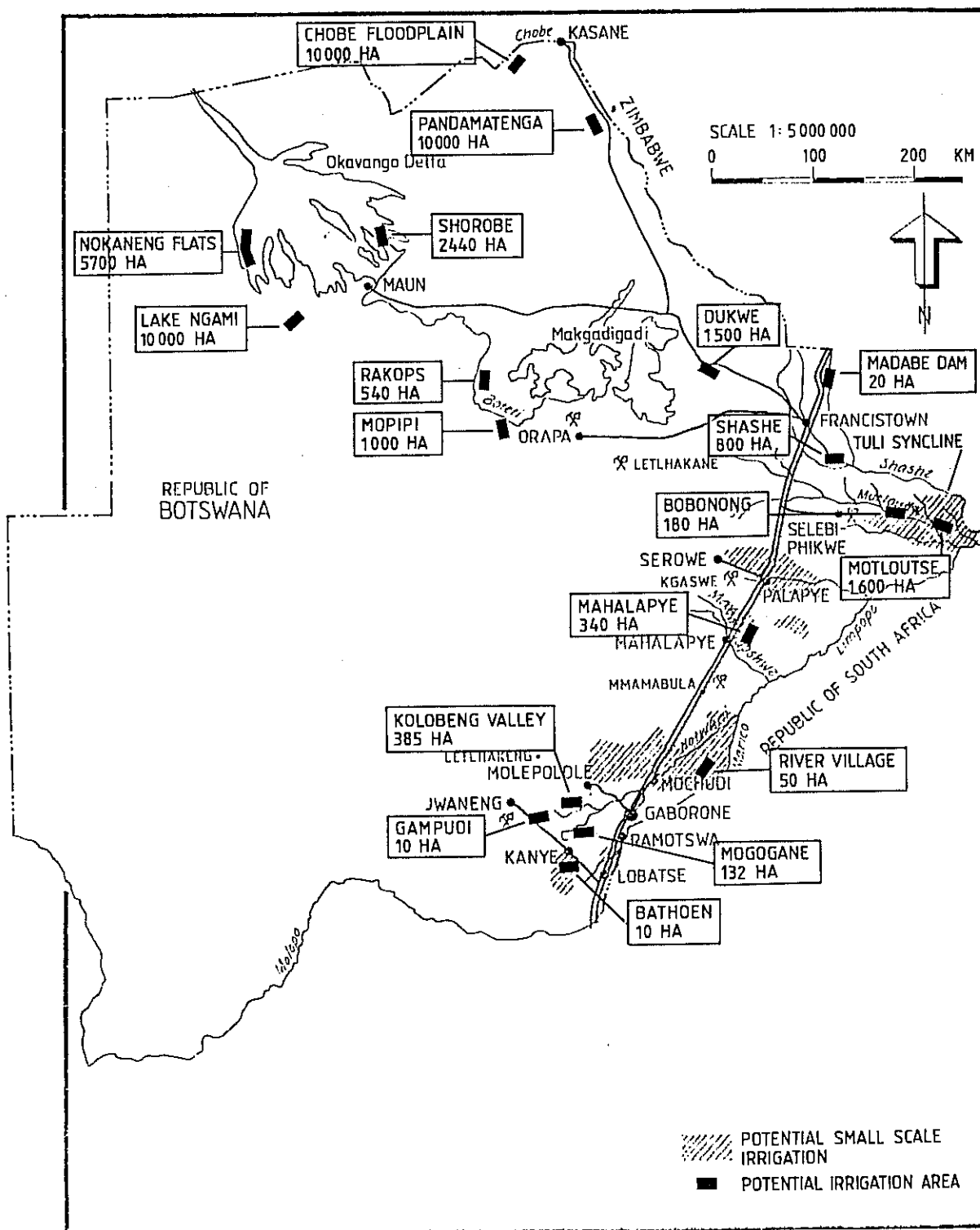
Source: VIAK, 1985

APPENDIX A.8

PRESSURE ON LAND AND WATER RESOURCES

Map A.8.1.

Potential Irrigation Areas
(Identified by the Ministry of Agriculture)



Source: VIAK, 1985

Table A.8.1.

Water Consumption in Gaborone (kℓ/day)

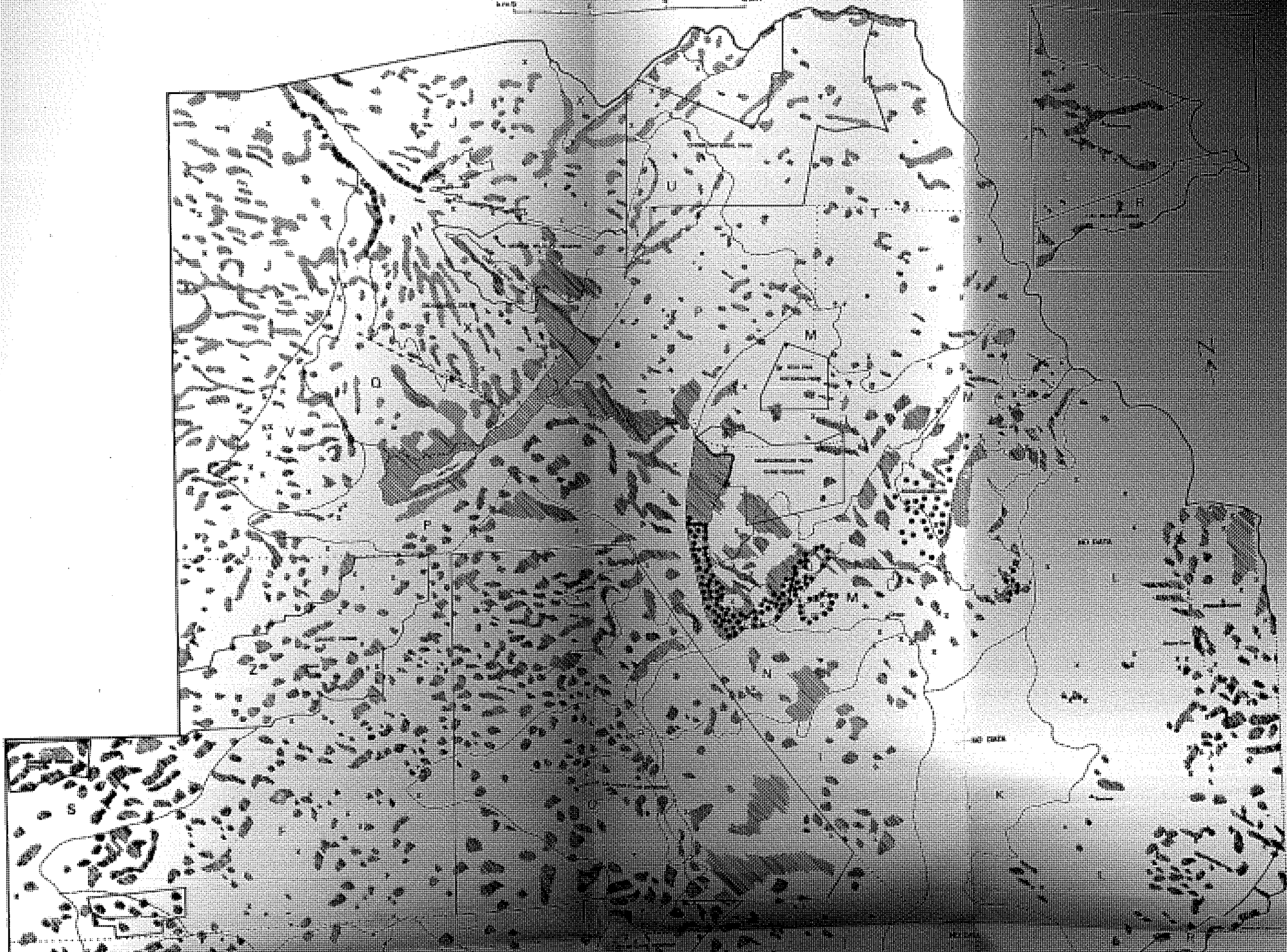
1984/85	9,634	1974/75	5,324
1983/84	9,006	1973/74	4,837
1982/83	16,911	1972/73	4,289
1981/82	13,291	1971/72	3,504
1980/81	11,728	1970/71	4,121
1979/80	11,120	1969/70	3,874
1978/79	9,178	1968/69	3,279
1977/78	7,659	1967/68	2,556
1976/77	6,796	1966/67	1,922
1975/76	5,522	1965/66	1,356

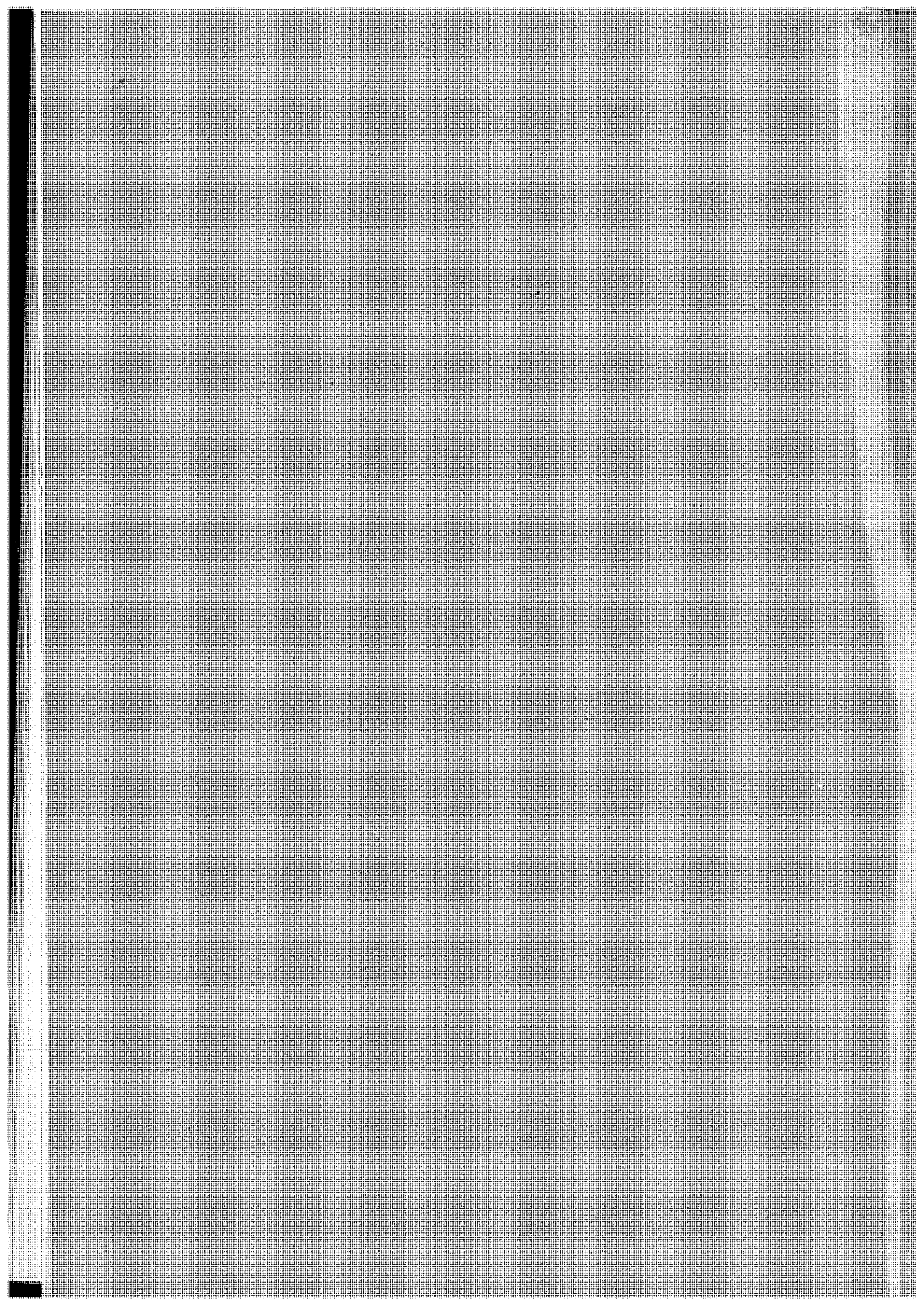
Source: Annual Reports, Water Utilities Corporation

Areas of Botswana Showing Evidence of Range Degradation and Desertification

From Band 7 Landsat Imagery January, 1984

0 10 20 30 40 50 60 70 80 90 100 km





APPENDIX 1
TERMS OF REFERENCE
AND
EXCERPTS FROM PROPOSAL

Invitation to Tender

Natural Resource Mapping for the Kavango Region

The Directorate of Environmental Affairs of the Ministry of Environment and Tourism requires the services of a company to do natural resource mapping of the Okavango Region. Mapping will be based largely on the interpretation of existing digital, geo-corrected LandSat TM images and orthophotos of the region, in addition to field-work to collect sample data. Tenders will be evaluated on the estimated cost of the work and the approach to be taken.

Mapping of resources is required to contribute to the compilation of an Environmental Profile of the Kavango Region, which aims to document the major environmental processes and resources in the region, as well as the major demands placed on those resources. The products to be available on the completion of the Profile will consist of one or more publications which document major environmental issues and processes, as well as a set of environmental which can be used for further analysis and monitoring.

More specifically, resources mapping will do and comply with the following:

1. It will identify the most prominent and important vegetation and soil units in the Region.
2. These units will be delineated and mapped in one or more layers of polygons.
3. Fieldwork will be required to collect sample data for purposes of interpretation and documentation of units.
4. Detailed sets of quantitative descriptive or attribute data will be compiled and linked to the polygon layers in formats which will allow for interrogation and analysis of the data, both as a separate data set and in combination with other sets of data for the region.
5. The attribute data will emphasize the resources values of the units.
6. All data products to be provided by this project will be compatible in ERMAPPER and ArcView data formats.
7. All digital mapped data will conform to a co-ordinate system and projection to be specified by the Environmental Profiles Project.
8. A detailed report on the vegetation and soils of the region will be submitted along with digital information.

Tenders should specify methods and approaches to be taken in the work, as well as describing the phases, timing and delivery of progress and final reports. All data to be collected during the project will become the property of the Ministry of Environment and Tourism. The project will be completed by the 15th of March 1999.

Tenders will be submitted in two envelopes, the first containing details of the methods, approaches and products to be delivered, while the second will provide the tendered price.

Proposed Scope of Work

1 INTRODUCTION

1.1 PROJECT OBJECTIVES

The Directorate of Environmental Affairs, Ministry of Environment and Tourism requires the services of a company to map the natural resources of the Kavango Region. Mapping will be based largely on the interpretation of existing digital, geo-corrected LandSat TM images and orthophotos of the region, in addition to field-work to collect sample data.

Mapping of the natural resources is required to contribute to the compilation of an Environmental Profile of the Kavango Region. The Profile aims to document the major environmental processes and resources in the region, as well as the major demands placed on those resources. The products to be available on completion of the Profile will consist of one or more publications documenting major environmental issues and processes as well as a set of environmental data for use in further analysis and monitoring.

1.2 INTERPRETATION OF ToR

1.2.1 Specific Requirements

The Consultant is requested to adopt an approach to the resource mapping to comply with and satisfy the following end-product requirements:

1. It will identify the most prominent and important vegetation and soil units in the Region;
2. These units will be delineated and mapped in one or more layers of polygons;
3. Fieldwork will be required to collect sample data for purposes of interpretation and documentation of units;
4. Detailed sets of quantitative descriptive or attribute data will be compiled and linked to the polygon layers in formats which will allow for interrogation and analysis of the data, both as a separate data set and in combination with other sets of data for the region;
5. The attribute data will emphasise the resource values of the units;
6. All data products to be provided by this project will be compatible in ERMAPPER and ArcView data formats;
7. All digital mapped data will conform to a co-ordinate system and projection to be specified by the Environmental profiles Project;
8. A detailed report on the vegetation and soils of the region will be submitted along with digital information.

1.2.2 Comments on the Terms of Reference (ToR)

The Terms of Reference for the Natural Resource Mapping of the Kavango Region presents a concise and generally clear overview of the requirements of the task. Several comments are, however, warranted.

- The Consultant understands from paragraph 3 of the Terms of Reference (points 1 to 8) that the principal focus of the natural resource mapping will be to map and provide quantitative descriptions and resource values for identified **vegetation and soil units**.
- Water resources are omitted from the list of natural resources to be mapped. Discussions between the Client and the Consultant have determined that water resources are intentionally excluded from the Terms of Reference.
- The identification, mapping and description of landform units are omitted from the Terms of Reference. The Consultant believes that particularly within the Kavango Region, a land systems approach based on identification of landforms would provide diagnostic information essential to the identification of vegetation and soil unit and to the delineation of boundaries. This point is discussed in Section 1.2.3 below.
- Points 3 and 4 of paragraph 3 state that "fieldwork will be required to collect sample data for purposes of interpretation and documentation of units" and that "detailed sets of quantitative descriptive or attribute data will be compiled...".

Proposed Scope of Work

It is understood that "sample data" refers to vegetation and soil samples.

With respect to the sampling and analysis of soils the Consultant would like to point out that determination of field sampling methodology and laboratory analytical methods both depend upon the type of classification system required by the Client. The Terms of Reference do not specify a classification system. This point is discussed in Section 1.2.3 below.

- Although not specifically requested, the Consultant assumes that laboratory analysis of soil samples would be required for the identification and classification of soils at the soil unit level. An estimation of soil laboratory costs is therefore provided for in the proposed budget.
- Point 5 of paragraph 3 requires "the attribute data (to) emphasise the resource values of the units". The term **resource values** is not defined in the Terms of Reference and is thus open to interpretation. The objective of the Client is to produce an Environmental Profile of Kavango Region, and in view of this the Consultant interprets resource values to be synonymous with those derived from a land evaluation study. The latter approach uses values calculated from single and combined vegetation and soil unit attributes to describe the current status of land resources in terms of limitations and potential for selected types and intensities of use. This point is discussed in Section 1.3 below.

1.2.3 Potential Difficulties

In preliminary discussion of the data capture and identification of vegetation and soil units to be described in the detailed reports, the Consultants have identified expected difficulties in obtaining data on a number of aspects of importance.

The time schedule anticipated for the field collection of plant specimens - October to January - poses a problem with respect to the satisfactory establishment of a vegetation baseline. Such a baseline should be established in the late wet season (late February, March) to ensure accuracy in sample identification and high levels of confidence in the estimation of plant diversity. The ideal time for the field investigation would therefore be after the expected completion of the field investigation phase. Little can be done about this problem unless commencement of the fieldwork is re-scheduled to fit in with the needs of the vegetation survey.

The Terms of Reference omitted to specify a soil classification system. The choice of classification system to employ for this project poses a number of difficulties, all of which have implications with respect to field methodology, cost structure and end-products of the proposed soils investigation. To summarise,

The Consultant understands the main thrust of this project to be aimed at the thematic mapping of land resource potential and its corollary, land vulnerability to external pressures. This being the case the Consultant intends using a land resource evaluation approach. To comply with such an approach the FAO/UNESCO/ISRIC Soil Classification Revised Legend (1991) would be the most appropriate framework to adopt for the provision of a systematic description of the region. Identification of soil units using the FAO Revised Legend for classification would also be required for further analysis which uses FAO procedural guidelines for land evaluation (FAO, 1993).

However, soil surveys of the Kavango Region have to date used the South African Binomial Soil Classification System (MacVicar *et al*, 1977) and the earlier South African National Soil Series Classification System. It should be noted that published reports, data and maps of these soils lack detailed supporting soil profile information, and are in some cases incomplete (maps without legends, reports without supporting data). Only one reconnaissance level survey provides comprehensive information on soil associations of the region (Loxton *et al*, 1971).

With the exception of the FAO-UNESCO Soil Map of the World (at a scale of 1: 5 000 000), soils of the Kavango Region have not been classified according to the FAO/UNESCO/ISRIC Soil Classification Revised Legend (1991). Furthermore, no methodology has been formulated for correlation of soils data between the South African and the FAO classification system for the following reasons:

- The systems were developed with different guidelines for soil profile description,
- Certain soil features receive a different emphasis on parallel definitions,
- Some of the laboratory procedures supporting the RSA systems used in the 1970s were different to current FAO procedures.

In view of the above the options are distinct. If the FAO classification system is opted for, then the mapping of soil resources should be based in the first instance on an unsupervised classification of remotely sensed data to provide soil polygons. A reconnaissance soil survey would then be carried out

Proposed Scope of Work

over the region to transect the polygon boundaries using standard FAO guidelines for description. These samples would be analysed to provide representative profiles for classification and the signatures of these profiles would be employed in a digital image processing exercise for spatial extrapolation purposes. A further short field check should be carried out to verify boundaries.

If the South African Binomial Soil Classification System should be opted for, then available mapped material and reports could be used in conjunction with an unsupervised classification of remotely sensed data to provide a preliminary outline of soil polygons in digital format. This would require permission from Loxton, Venn & Associates, the owners of this material. Copies of these maps are available in Namibia although the Consultant has found them to be stretched and in various scales. A reconnaissance level field survey would be carried out in much the same way to ground truth the polygon boundaries. If this approach is opted for, then further analysis using the FAO system of land evaluation would not be possible as the basic description of soil features do not comply with FAO standard requirements.

1.3 SUMMARY OF GENERAL APPROACH

A land systems approach will be used to map all factors of the physical environment simultaneously. Two principal mapping units will be employed, the land system and the land facet. The land system can be viewed as an area with a recurring pattern of topography, soils and vegetation within a relatively uniform climate. The land facet is an area within which, for most practical purposes, environmental conditions are uniform. Both definitions are rationalisations of units that arise naturally in the course of photo-interpretation; land systems are distinctive patterns extending across one or several photographs, whilst facets are the smallest areas that can be recognised and delineated. The facets within a system are not a random collection of contiguous areas, but are often causally linked by geomorphological processes, origin or groundwater flow.

To establish the mapping framework for the proposed project, a land system survey based on satellite imagery, in conjunction with field traverses and aerial and/or orthophoto interpretation will be conducted to produce a tabular legend showing landforms, vegetation and soils. Comparisons between soil boundaries initially based on satellite imagery with those subsequently derived from phot-interpretation have shown an acceptable measure of agreement. The defining features of each land system will be systematically noted. A high proportion of both defining features and boundaries will be based on landform. This will not only be for practical reasons. It is, in principal, desirable to identify, and as far as possible to define, land systems in terms of landforms in the interests of having a uniform basis to the mapping. In flat area in particular, vegetation will be used. Parametric methods will be used in the field to confirm land facets. The following individual elements will be measured and mapped: altitude, slope angle, profile curvature, plan curvature and aspect. These will be incorporated into a preliminary polygon database to identify landform elements, and further combined into landform patterns. Land facets and systems will thus be identified using an objective and uniform approach. These will be used in the first instance to derive base maps for soils and vegetation. Individual soil and vegetation parameters will be extracted for further analysis using FAO guidelines for land evaluation. Thematic representations of land potential and limitations will be extracted and mapped in consultation with the Client.

Proposed Scope of Work

2 METHODOLOGY

The following describes the various activities to be undertaken to achieve the objectives of the study in terms of objective; methodology; work-plan and anticipated results; and personnel to be used.

2.1 REMOTE SENSING AND IMAGE PROCESSING PROCEDURES.

The following activities are proposed for the remote sensing and image-processing specialist:

1. Check the geo-corrected satellite images for locational accuracy.
2. Choice of optimal band combination (3 bands) for production of false colour composite hardcopy (used for fieldwork and any visual interpretation of soils and vegetation) The best approach is to integrate the image processing classification and visual image interpretation procedures so that the strong points of each method can be used to classify an image.
3. Select appropriate bands for digital classification from cluster analysis.
4. Run unsupervised classification for approximately 24 classes.
5. Filter result to remove isolated pixels.
6. Ground truth classes (using transects, random GPS spot checks, etc) to identify vegetation and soil types for each class produced by the unsupervised classification.
7. Merge and split classes where appropriate.
8. Run supervised classification using selective classes from above observations to determine if improvements can be made to the existing classification.
9. Run accuracy assessment on resulting classification (by using GPS ground observations and field survey transects).
10. Convert resulting classes into GIS polygons and attributes to allow interrogation and analysis of important vegetation and soil types.
11. Production of hardcopy maps showing soils, vegetation and land systems.

As a result of the above process each polygon may only have a single attribute for soils and vegetation (i.e. a soil class or a vegetation type). It is important to investigate the other underlying natural, physical and human factors such as elevation, slope, erodibility, landuse, rainfall, etc. to improve the mapping units and to assign other attributes to the polygons.

The simplest form of spatial analysis is the "aggregation" of multiple polygon classes into single polygon classes by reclassifying the polygon attributes (merging). More complex spatial analysis involves the "disaggregation" of polygons into more complex polygons (splitting) by using multiple themes to generate a more complex resulting theme. This spatial analysis component is ideal for the production of land suitability and land use plans.

2.2 VEGETATION STUDY APPROACH

2.2.1 Review of available information

All information on vegetation resources in the Kavango Region will be reviewed and summarised. This will include published data, reports and data held at government institutions such as the National Botanical Research Institute and Directorate of Forestry. This will allow to

- a) develop an effective stratification for field sampling, and
- b) place particular emphasis on areas hitherto botanically poorly collected.

2.2.2 Preparation of base maps and field sampling strategy

LandSat TM images and orthophotos will be prepared and compared to enable a preliminary interpretation of seemingly homogenous areas, referred to as mapping units. Published sources and data available from the recent forest inventory will be used for a first interpretation of satellite images and orthophotos. Several sampling points will be selected in each mapping unit for the field survey.

Proposed Scope of Work

2.2.3 Field work

Ideally fieldwork will coincide with the peak of the vegetation period. A reconnaissance survey of landforms and vegetation types through a number of predetermined mapping units will allow verification and fine-tuning of these units. Upon completion of the reconnaissance the predetermined mapping units will be revisited and the boundaries redrawn according to the findings in the field. The final selection of several sampling points in each mapping unit for field data collection will then follow. At each sampling point date, GPS position, data to habitat, soil type, landform, potential disturbance and vegetation will be collected using a previously prepared data sheet. Vegetation structure and composition will be determined by estimating average height and canopy cover for each stratum (herb, grass, shrub and tree), and listing of all plant species with corresponding estimate of cover abundance according to the Braun Blanquet method (Kent & Coker 1994). Voucher specimens of unknown plant species will be collected for later identification and deposition in the National Botanical Research Institute.

2.2.4 Data analysis

Field data from several sites representing one mapping unit will be combined to present a species list with cover values characteristic for this mapping unit. An adapted version of Edwards vegetation structural classes (Edwards 1983; Hines & Burke 1997) will be used to determine the vegetation type, while the final boundaries of the vegetation types will be digitised. Attribute tables will be prepared in EXCEL comprising the generalised field data for each mapping unit.

2.2.5 Reporting

The final report will contain a detailed description of vegetation types and interpretation of possible underlying factors determining the spatial distribution of vegetation types in the Kavango Region.

2.3 LANDFORM AND SOILS STUDY

2.3.1 Objectives

To acquire first hand data pertaining to the character and distribution of soil and land unit parameters represented in the project area.

2.3.2 Methodology

Test pits and auger holes will be used to describe and sample the major soil associations within land units identified by remote sensing and from available maps. The ground surveys designed to verify map interpretations should coincide as far as possible.

A soil survey will be carried out to verify the accuracy of soil management units, associations, and complexes identified during map interpretation. The survey will be carried out at reconnaissance level in terms of observation density, and adopt a transect approach. Transects will run as perpendicularly as possible to expected boundaries between mapping units detected.

Three types of observation will be distinguished following FAO/UNESCO/ISRIC guidelines for soil survey and land evaluation in ecological research (1986), as follows:

- shallow surface observations less than 50 cm deep to delineate erosion features, evidence of surface compaction, surface sealing, cracking, topsoil textures and colours, occurrence of boulders and rock outcrops, surface stones, and parent material.
- routine identification augers to 150 cm deep. Effective depth should be determined.
- profile pits will be dug at least twice in each soil management unit and significant land fact identified, subject to limitations of accessibility.

All observations should be located by GPS. Soils will be described in accordance with the FAO Guidelines for Soil Description (1977), the FAO-ISRIC Soil Data Base and Munsell colour charts. Soil characteristics will be determined on representative samples of each shallow significant horizon in all soil pits. The determination of the following properties will be made by field and laboratory analysis:

- ❖ Texture by particle size analysis
- ❖ Colour (moist)
- ❖ Structure

Proposed Scope of Work

- ❖ pH of saturation extract and 1:5 soil-water suspension
- ❖ Organic carbon percentage
- ❖ Cation exchange capacity (mo/100g)
- ❖ Soil fertility status: total nitrogen, total phosphorous, available potassium
- ❖ Exchangeable sodium percentage (ESP)
- ❖ Calcium carbonate percentage
- ❖ Electrical conductivity (ECe) of saturation extract
- ❖ Porosity
- ❖ Bulk density
- ❖ Drainage class
- ❖ Erodibility class

At each observation location the average slope percent will be calculated and significant land facet identified.

All physical, chemical and analytical soil survey results will be entered into a suitable database and presented in standard written and tabular formats.

2.3.3 Anticipated Results

From the soils and land unit field investigation the following themes will be compiled for the project area: land systems/soil management units; erosion status and potential. The function of these maps will be to provide a description of the current environmental status of land resources, and to determine land potential with respect to selected types and intensities of land use and pressure.

2.4 REPORTING

During the normal course of the project the Client will be kept apprised of developments through Progress Reports. These reports will contain a summary of work carried out during the previous month, difficulties experienced, solutions to problems and work to be completed. In some cases material to be included in the draft Final Report will be included in the Progress Reports.

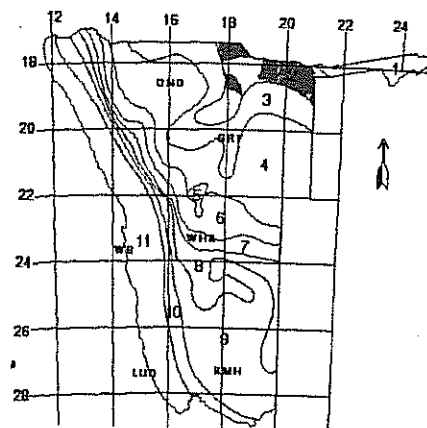
APPENDIX 2
AGROECOLOGICAL ZONES

Agro-ecological Zone description sheet

Map Symbol KAL3-2

Map Name **Kalahari Sands Plateau, stabilized sand drift with few pans, average growing period 91-120 days**

Map Area (km²) 23759



Summary of Landform Information

Landform type	1 Plain
General altitude range	1050 m - 1400 m
Regional slope range	1 -
Relative relief	< 10 m: very low relative relief
Drainage pattern	no preferred orientation
Geological substrata	Kalahari sands
Soter landform	LP Plains
Soter Lithology	UE

Summary of Growing Period Information

	Dominant	Associated	Included
Growing Period Zones	2		

Summary of Soils Information

	Dominant	Associated	Included
Fao Soils Units:	ARh, 40 %, Se	ARo, 30 %, Seh	CLp, 10 %, SRdb/LRdb SNh, 10 %, Sn SNg, 10 %, Sgn

Agricultural Potential

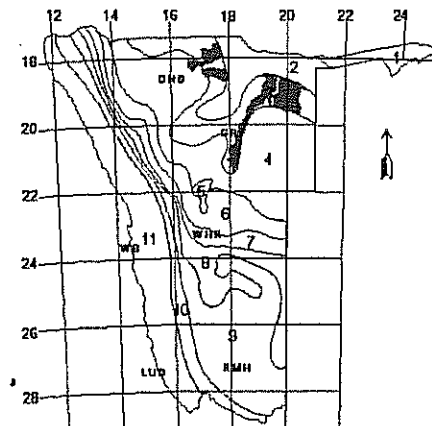
Rank	2
Suitability	Short-maturing crops; Livestock grazing
Cropping Potential	Mainly deep sandy soils; dependable growing period marginal even for drought-resistant crops, owing to the low moisture retention and fertility status of the soils.

Agro-ecological Zone description sheet

Map Symbol KAL3-3

Map Name Kalahari Sands Plateau, stabilized sand drift with few pans, average growing period 61-90 days, dependable growing 60 % of average

Map Area (km²) 76504



Summary of Landform Information

Landform type	1	Plain
General altitude range	1050 m - 1400m	
Regional slope range	1	-
Relative relief	< 10 m: very low relative relief	
Drainage pattern	no preferred orientation	
Geological substrata	Kalahari sands	
Soter landform	LP	Plains
Soter Lithology	UE	

Summary of Growing Period Information

	Dominant	Associated	Included
Growing Period Zones	3		

Summary of Soils Information

	Dominant	Associated	Included
Fao Soils Units:	ARh, 40 %, Se	ARo, 30 %, Seh	CLp, 10 %, SRdb/LRdb SNh, 10 %, Sn SNg, 10 %, Sgn

Agricultural Potential

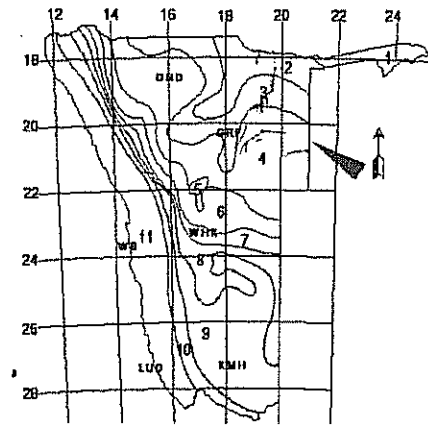
Rank	3
Suitability	Livestock grazing
Cropping Potential	Unsuitable for crop production due to low dependable growing period combined with shallow soils.

Agro-ecological Zone description sheet

Map Symbol KAL5

Map Name Kalahari Sands Plateau, slightly incised
river valleys

Map Area (km²) 5626



Summary of Landform Information

Landform type	1a Alluvial plain
General altitude range	1050 m - 1400m
Regional slope range	1 -
Relative relief	< 10 m: very low relative relief
Drainage pattern	weakly oriented
Geological substrata	Kalahari sands
Soter landform	CV Valleys
Soter Lithology	UF

Summary of Growing Period Information

	Dominant	Associated	Included
Growing Period Zones	3	4/2	

Summary of Soils Information

	Dominant	Associated	Included
Fao Soils Units:	ARo, 34 %, Seh		
	ARh, 33 %, Se		
	CLp, 33 %, SRdb/LRdb		

Agricultural Potential

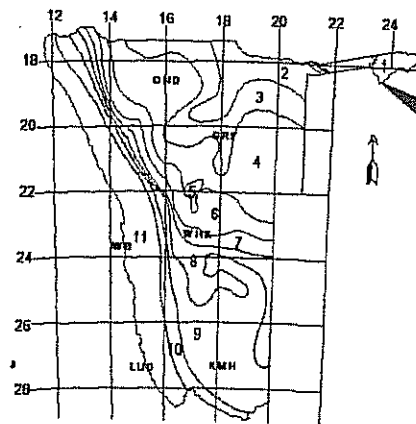
Rank	3
Suitability	Livestock grazing
Cropping Potential	Unsuitable for crop production due to low dependable growing period combined with sandy soils.

Agro-ecological Zone description sheet

Map Symbol KAL6

Map Name **Kalahari Sands Plateau, terrace of the
Okavango and Kwando river systems**

Map Area (km²) 1700



Summary of Landform Information

Landform type	1a Alluvial plain
General altitude range	1000 m - 1100 m
Regional slope range	1 -
Relative relief	< 10 m: very low relative relief
Drainage pattern	no preferred orientation
Geological substrata	Kalahari sands
Soter landform	LP Plains
Soter Lithology	UF

Summary of Growing Period Information

	Dominant	Associated	Included
Growing Period Zones	1	2	

Summary of Soils Information

	Dominant	Associated	Included
Fao Soils Units:	ARh, 25 %, Se		
	ARb, 25 %, Se		
	ARl, 25 %, SLe		
	CMe, 25 %, L		

Agricultural Potential

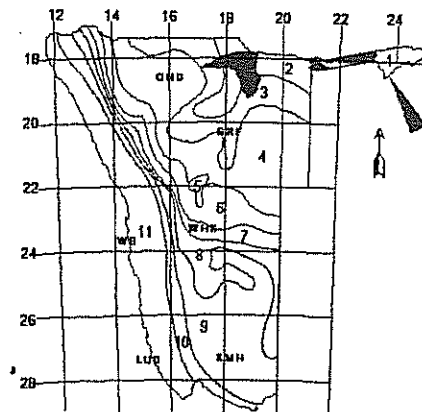
Rank	1
Suitability	Short-maturing crops; Livestock grazing
Cropping Potential	Terrace system of the Okavango and Kwando rivers, probably the most suitable for irrigation. Soils, land slope, surface smoothness, nearness of a permanent water source, commandability of the irrigable area, an already intensive degree of cultivation in the area and potential to increase farmer incomes are factors that earmark this area as a prime target for irrigation development. The main limitation of this AEZ is that it is small. Given the fact that this AEZ is one of the most endowed in terms of rainfall, agricultural research and extension will need to develop and promote techniques of supplementary irrigation rather than full irrigation.

Agro-ecological Zone description sheet

Map Symbol KAL8

Map Name Kalahari Sands Plateau, 'omuramba'-dune association

Map Area (km²) 22937



Summary of Landform Information

Landform type	ls Sand plain
General altitude range	1050 m - 1250m
Regional slope range	1 - 2
Relative relief	10-30 m: low relative relief
Drainage pattern	strongly oriented, parallel
Geological substrata	Kalahari sands
Soter landform	LP Plains
Soter Lithology	UE

Summary of Growing Period Information

	Dominant	Associated	Included
Growing Period Zones	2	3/1	

Summary of Soils Information

	Dominant	Associated	Included
Fao Soils Units:	ARo, 40 %, Seh	ARl, 20 %, SLe CLp, 20 %, SRdb/LRdb	ARh, 10 %, Se Sng, 10 %, Sgn

Agricultural Potential

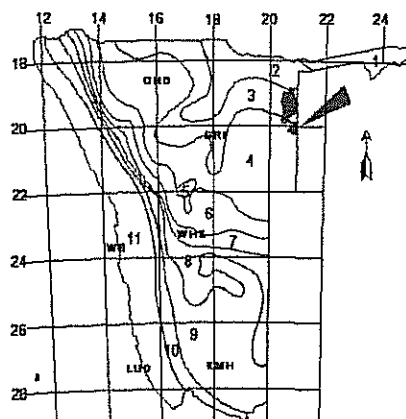
Rank	2
Suitability	Short-maturing crops; Livestock grazing
Cropping Potential	Soils vary from red sands on dune crests to fairly heavy soils in drainage lines between dunes. Potential for cropping higher than indicated by the growing period zone owing to the presence of residual soil moisture in drainage lines.

Agro-ecological Zone description sheet

Map Symbol KAL10

Map Name Kalahari Sands Plateau, Tsumkwe
Panveld

Map Area (km²) 6448



Summary of Landform Information

Landform type	p Pan
General altitude range	1100 m - 1200 m
Regional slope range	1 -
Relative relief	< 10 m: very low relative relief
Drainage pattern	no preferred orientation
Geological substrata	Kalahari sands, metamorphic rocks, basalt
Soter landform	LP Plains
Soter Lithology	UE/MA/IB2

Summary of Growing Period Information

	Dominant	Associated	Included
Growing Period Zones	3		

Summary of Soils Information

	Dominant	Associated	Included
Fao Soils Units:	ARh, 50 %, Se	ROCK 40 %,	LPe, 10 %, LR

Agricultural Potential

Rank	3
Suitability	Livestock grazing
Cropping Potential	Dependable growing periods too short for rainfed cropping, however groundwater sources are more readily accessible than in the Kalahari sands, which may allow supplementary irrigation for garden-scale production of food crops for local consumption.

APPENDIX 3
LABORATORY PROCEDURES

Summary of Laboratory Procedures used for Soils Analysis

Test	Description
SAMPLE PREPARATION	Soils are dried at a temperature not greater than 35 degrees C. The part of the sample retained on a 2mm sieve, called the fine earth fraction, is used for the analysis. The fraction >2mm is referred to as stone and gravel.
TEXTURE and PARTICLE SIZE ANALYSIS (SAND, SILT and CLAY)	Dispersion of soil with sodium hexametaphosphate/ sodium carbonate. Determination of silt and clay by pipette method. Sand fraction determined by sieving to retain >53 micron fraction. Textural Class using the FAO classification system.
EXCHANGEABLE CATIONS & CATION EXCHANGE CAPACITY(CEC)	Extraction with 1M ammonium acetate at pH 7 if pH(H ₂ O)<6.8 & EC<0.4 mS/cm. Extraction with 50:50 ammonium acetate (1M) and ethanol at pH7 if pH(H ₂ O)>6.8 & EC>0.4mS/cm. Calcium, Magnesium, sodium and potassium measured by atomic absorption spectrophotometer.
EXTRACTABLE CATIONS (Available K, Mg, Ca, Na)	Extraction with 1M ammonium acetate at pH 7. Measurement of calcium, magnesium, potassium and sodium by atomic absorption spectrophotometry.
AVAILABLE MICRONUTRIENTS (Zinc, manganese, copper, iron)	Extraction with 0.5M ammonium acetate: 0.5M acetic acid: 0.02M EDTA at pH 4.65 at a 1:5 extraction ratio. Fe, Mn, Cu and Zn measured by atomic absorption spectroscopy. Available calcium, potassium and magnesium can also be measured in the extract.
ELECTRICAL CONDUCTIVITY (Soluble Salt Content)	Measurement in the supernatant of the 1:2.5 soil:water suspension prior to measurement of pH. Units of measurement are S/cm (1 mS=1000uS). High results indicating possible salinity hazard are repeated on the extract of the saturated soil paste.
pH (KCl)	Measured in a 1:2.5 soil: 1M potassium chloride ratio suspension on a mass to volume basis.
pH (water)	Measured in a 1:2.5 soil: water ratio suspension on a mass to volume basis.
EXTRACTABLE ACIDITY	Extraction with 1M KCl and titration of extract to determine acidity.
CARBONATE (field estimation)	Treatment of dry soil with 10% hydrochloric acid and observation of effervescence.
CARBONATE (as Calcium Carbonate)	Reaction of soil with hydrochloric acid and estimation of acid consumed by titration with sodium hydroxide.
SULPHATE (estimation)	Soil water extract from pH/EC measurement made 0.01M with respect to calcium by addition of 1M calcium chloride. Filtered extract reacted with acid barium chloride and turbidity visually compared with standard solution of sulphate-S.
AVAILABLE SULPHUR (as Sulphate)	1:2 weight:volume extraction of soil with 0.01M calcium chloride. Sulphate-S estimated by measuring turbidity at 600nm following treatment with acidified barium chloride.
CHLORIDE SPOT TEST	Soil water extract from pH/EC; amount of chloride estimated by reaction with silver nitrate.
ORGANIC CARBON (Organic Matter Content)	Walkley-Black: Standard and colourimetric methods using sulphuric acid-potassium dichromate oxidation. A factor is included in calculations to take account of incomplete oxidation. Organic matter content calculated as organic-C x 1.74.
AVAILABLE PHOSPHOROUS	Ohlson method: Extraction with sodium bicarbonate. Phosphate measured spectrophotometrically using the phosphomolybdate blue method.
ORGANIC MATTER (Loss On Ignition)	Organic matter is estimated by measuring the weight loss when dried samples are heated in a muffle furnace at 360 degrees C for 4 hours. Further heating at 500°C to ash.
MOISTURE CONTENT & DRY BULK DENSITY	Raw undisturbed samples extracted from profile face by cylindrical cutter of known volume. Samples weighed, oven dried at 105°C for 48 hours and weighed again. Weight loss assumed to be equivalent to pore water fraction. Dry weight assumed to be equivalent to solid fraction mass. Mass/volume calculated.

SOILS ANALYSIS: LABORATORY PROCEDURES

SAMPLE PREPARATION

Reference Method

None

Introduction

It is important that soils be prepared in a standard way for analysis in the laboratory. Most analyses are carried out on air-dried soils that have been crushed and sieved to pass a 2mm mesh sized sieve. This is often termed the "fine earth" fraction. Material greater than 2 mm in diameter is termed "stones and gravel". Some analyses give better results if a small sub-sample is ground more finely say to 60 mesh or $\sim < 0.3$ to 0.4 mm. A few analyses may be carried out field soil that is mixed but not dried. Other physical analyses may be performed using undisturbed cores.

Scope

The procedures outlined may be used for all soils received in the laboratory. Special types of preparation related to analysis of moist samples or to particular methods of grinding should be worked out with the client.

Principle

Soils received in the laboratory are registered and then mixed and placed into pans to dry at room temperature or using mild heat. Dry samples are ground with a pestle in a mortar by hand or using a machine to break up the larger clods, sieved to a uniform size and stored in a plastic container. Stones and gravel are removed by sieving and weighed separately where they constitute a significant proportion of the sample.

Method Validation

Not applicable

Interference and Other Considerations

Drying at even modest temperatures is not recommended since it can affect the extraction of certain elements notably potassium in soils containing micaceous clays and/or vermiculite. Heat may stimulate biological activity and alter pH and measurements of available nitrogen, sulphur and phosphorus. Samples undergoing trace element or heavy metal analysis may require procedures that do not use metal grinding surfaces or containers. Nylon or stainless steel screens are recommended for micronutrient analysis. Certain analytical procedures may stipulate a finer grinding than standard or the use of field moist rather than dried samples. Certain physical measurements related to water holding, aggregation or permeability may need undisturbed soils for the test. Check the analysis request sheet to make sure that special types of preparation are not needed before the samples are subjected to the standard dry and grinding procedures. Moist samples should be stored at 4°C in a refrigerator or cold room in plastic bottles or bags.

Sample Requirements

Samples should be received by the laboratory in a state that is considered suitable for analysis. The following criteria should be met:

- Sample is of sufficient mass and volume for the analyses requested.
- Delivered sample does not show signs of damage or contamination.
- The laboratory and client labelling is sufficient to give it a unique identification.

Equipment and Supplies

- Pens, tape etc. for labelling
- Aluminium or plastic drying pans
- Sieves of various sizes and mesh, 2 mm, 0.5 mm as a minimum
- Large ceramic mortar with pestle
- Mechanically operated mortar or soil grinder
- Forced air drying oven set capable of being set at between room temperature and 60°C
- Dust masks
- Extraction fan
- Range of plastic sample containers between 100 ml to 500 ml in size with screw caps

Reagents

- Solvents such as methanol and acetone or removing marking ink

Safety and Special Precautions

- Fine dust in the sample preparation area constitutes a significant health hazard. Personnel should wear dust masks while grinding samples. The area should be well ventilated. Air-borne dust should be removed using a

strong extraction fan vented outside the grinding room. Gloves should be worn when handling samples suspected of being potentially hazardous due to acidity, alkalinity, salinity or contamination with agricultural or industrial or agricultural chemicals. Care should be taken when using mechanical grinding equipment. Always make sure that the appropriated guards are in place to protect you from any moving parts. Wash hands and vacuum the area to reduce personal contamination.

Test Procedure

- Remove the samples from the transporting bags or boxes and spread them out on clearly labelled drying trays.
- Ensure that the relevant information on tags, labels and bags has been transferred to the laboratory data sheet.
- Check that there is no contamination between samples or from sample containers themselves. Any discrepancies on the integrity of the sample should be noted down for the laboratory personnel.
- A decision for measuring the stone and gravel (the particles >2 mm) should be made now. The guidelines suggested are that if the apparent content of stones and gravel is greater than 20% of the weight then a separation should be carried out. This is important with irrigated soils to give a better estimation of true water holding capacity of different horizons.
- Remove large plant residues and break the clods into small pieces less than 2 cm to accelerate the drying process. Allow the samples to air-dry on the shelves and avoid placing in direct sunlight rays.
- Urgent samples may require fast drying. This can be done by drying in a ventilated oven at a temperature less than 35 °C, although up to 60 °C has been used in soil laboratories. Since heating influences the composition of the soil, this procedure is however discouraged. Some soils may require analysing in field moist condition.
- Mix very wet soil samples each day to expose the wet surfaces. This process accelerates drying and makes drying more uniform throughout the sample.
- The time taken for samples to dry vary widely depending on moisture, clay content, size of sample, humidity and prevailing room temperature. Many sandy samples taken during the dry season are more or less air-dry on arrival while wet compacted clay soils may take over a week.
- If the stones and gravel content is not to be measured make sure that most fragments > 2mm such as shells, organic debris, gravel, schist, weathered rock, calcareous nodules and other concretions are removed before grinding. If the stone and gravel content is to be measured then:
 - * Get the current "Stones and Gravel Analysis Sheet" and fill in the sample number.
 - * Enter the weigh an empty drying dish.
 - * Weigh the dish plus the whole dry soil sample.
 - * Separate out the stones and gravel on a 2mm sieve, pour into the container and re-weigh.
 - * Calculate the stones and gravel as a percentage of the total weight.
 - * The sample < 2mm is termed the "Fine Earth" fraction.
 - * Note the result on the "Laboratory Soil Analysis Data Sheet"
- A variety of grinding methods can be used to reduce the aggregates to < 2mm. Single grained sandy soils may not need any further grinding. Poorly aggregated soils may only need hand grinding using a large mortar and pestle. Well-aggregated or hard-set soils may be ground more easily using the mechanical mortar. Take care to add the sample slowly and empty the mortar when it is about one-half full. The mechanical mortar must be used when very fine grinding is needed. A wooden roller may be useful to crush samples with large hard aggregates.
- The ground sample can then be passed through a 2mm sieve into an empty grinding dish. The objective should be to have at least 95% of the original sample pass through the sieve. The sample can then be mixed with a trowel or scoop and transferred into a labelled plastic container of suitable size. For samples destined for a general analysis the amount of ground sample should be about 500 g.
- Mortars and grinding machinery should be cleaned after every sample to reduce cross-contamination.
- After analysis, the samples must be stored. Farm samples should be stored for 3 months in case some re-analysis is required. Research samples may need to be stored for a year, or until the project is completed. No sample should be thrown away without authorisation from the laboratory supervisor or researcher concerned.
- Evidence suggests that in the dry state most soil characteristics do not change with time. Those most liable to be affected by storage, particularly under damp hot conditions, are nitrogen, phosphorus and pH.

Data Acceptance and Quality Control

There are no quality control criteria established for sample preparation. The temperature of drying ovens and refrigerators should be checked frequently.

Calculation and Presentation of Results

Stones and gravel or fine earth fraction should be quoted as a percentage to one decimal place.

Other References

None.

PARTICLE SIZE ANALYSIS BY THE PIPETTE METHOD

Reference method

This is an original method that generally follows the principles for particle analysis using a sampling pipette outlined in: Miller, W. P. and Miller, D. M. 1987. A micro-pipette method for soil mechanical analysis. Commun. Soil Sci. Plant Anal., 18: 1-15.

Introduction

Particle-size analysis (PSA) is the procedure for separation of the mineral part of the soil into various size fractions and the determination of the proportion of these fractions. The major features of PSA are destruction or dispersion of soil aggregates into discrete units by chemical, mechanical or ultrasonic means and the separation of particles according to size limits by sieving and sedimentation.

Soil particles cover an extreme size range, varying from stones and rocks (exceeding 0.25 m in size) down to clay particles of less than 2 μm . Various systems of size classification have been used to define arbitrary limits and ranges of soil particle size. Soil particles smaller than 2 mm are generally divided into three major sizes: sand (50-2000 μm), silts (2-50 μm) and clays (< 2 μm). Soil texture is based on different combinations of sand, silt and clay separates that make up the particle-size distribution of a soil sample. The proportions of sand, silt and clay together with the organic matter content are important characteristics of soil that affect soil structure, available nutrients and moisture holding and release.

Scope

The method is suitable to determine the proportion of sand, silt and clay in most mineral soils but treatments may be needed for soils with organic carbon contents >2% and soils containing high concentrations of soluble salts and cementing agents such as calcium carbonate and gypsum. The method is not suitable for volcanic ash soils.

Principle

In general a comprehensive particle size analysis can involve several distinct procedures. Firstly it may be desirable to remove or inactivate cementing agents. These may include treatments for organic matter and calcium carbonate and iron or aluminium oxides in some soils. These pre-treatments if carried out are followed by dispersion of the soil sample in an alkaline medium. It may be agreed, however, that for agricultural purposes it is often not relevant or even fundamentally wrong to remove these components. Thus, dependent on the aim of study, all pre-treatments are to be considered optional. For soil characterisation purposes the main methods of treatment involve removal of organic matter by H_2O_2 and carbonates by a mildly acid buffer of pH 5.

The sample is dispersed by shaking with a sodium carbonate/sodium hexametaphosphate solution. Silt and clay sized particles are separated by sampling at a depth of 6 cm after time intervals determined using Stoke's Law of Sedimentation. Sand is separated by wet sieving through a 53 micron sieve. The sand can be further separated into fine, medium and coarse fractions by dry sieving. The amount of very fine sand may be important since it has very high moisture holding and release properties.

An alternative procedure using a hydrometer is also described which outlines different pre-treatment methods. Both the pipette and hydrometer methods are based on Stoke's Law which states that "the terminal velocity of a spherical particle settling under the influence of gravity in a fluid of a given density and viscosity is proportional to the square of the particle radius". For a soil particle falling through water, this equation can be expressed as follows:

$$V = \frac{d^2 g (P_s - P_w)}{18\eta}$$

Where :

- V = Settling velocity of the soil particle through water, cm/sec.
- P_s = Density of the soil particle, g/cm³ (generally taken as 2.65 g/cm³)
- P_w = Density of water, g/cm³ (0.998203 g/cm³ at 20 °C)
- d = Diameter of the soil particle, cm
- g = Acceleration due to gravity (980 cm/s²)
- η = Viscosity of water, poise (1.0019 x 10⁻² poise at 20°C).

Values of viscosity and density of water different temperatures may be obtained from tables in The Handbook of Chemistry and Physics.

Method Validation

The method has been validated against ALASA soils.

Other Notes

Errors may arise due to the presence of organic matter. Soils high in sodium and clay may flocculate if not pre-treated to remove salts. Some of these soils may form gels which may invalidate the results. The presence of

carbonates and cementing agents may provide different results if pre-treatments are not carried out. However, pre-treatment may not be used where comparisons with field hand texturing are required.

Sample requirements

Soils should be air-dried and ground to pass a 2mm sieve. Samples may be stored at low humidity without significant change in the results of particle size analysis.

Equipment and Supplies

- 250ml capacity leak proof polyethylene bottles such as the types with an inner liner and tight fitting screw cap.
- Sampling pipette (e.g. Eppendorf 1000-5000 μ l variable pipette)
- Aluminium weighing dishes
- Reciprocating shaker
- Set of sieves of 53, 106, 250, 500, 1000 μ mesh size for sand fractionation)
- Analytical balance (to weigh to 0.0001 g)

Reagents

- Dispersing Agent: Dissolve 40 g sodium hexametaphosphate (NaPO_3)₆ in about 800 ml of water and then dissolve 10 g of sodium carbonate (Na_2CO_3) and make up to 1000 ml. The solution will be somewhat cloudy and contain a slight sediment. When adding the reagent to the soil suspension it should be agitated frequently to ensure uniformity in the aliquots dispensed.

Safety and Special Precautions

Take care to clean up spills of the alkaline dispersing solution and keep hands clean of this reagent. Bench areas should be cleaned well to avoid cross-contamination with sodium and phosphate.

Test Procedure

- Weigh 20.00 g of each soil into an identical 250ml polyethylene bottle. Add 20 ml of dispersing agent followed by 100 ml of water (tap or de-ionised water). Prepare one blank with no soil. Shake for two separate 30 minute periods at 180 oscillations per minute during the day. Let stand over night. Shake again for 30 minutes in the morning.
- Weigh three sets of dry aluminium weighing dishes. One set for sand plus clay and another for clay should be weighed to 0.0001g accuracy. The third set for the sand fraction need only be weighed to 0.001 g accuracy. No dish is needed for the blank with the sand set.
- Add 80 ml of water and stand bottles in a location at constant temperature and that is vibration free. Read the temperature from a thermometer placed in the blank bottle.
- Adjust the pipette and template so that it samples from a depth of exactly 6cm. This done by inserting a plastic pipette tip, marked at 6 cm, through the styrofoam support until the mark is just at the fluid surface. Note that a bottle containing 208 ml should be used for this purpose. The extra 8ml accounts for the volume occupied by the 20 g soil sample.
- Refer to the table on the following page to determine the sampling time for silt plus clay and for clay alone. It is desirable to carry out the measurements in a temperature controlled room preferably in the 20 to 25 °C range
- Mark the analysis sheet to show the exact sampling time for each bottle. Shake the bottle by hand for 30 seconds, place it rapidly onto the bench, carefully remove the inner lid and allow sedimentation to proceed for the correct time (which will probably be between 19 and 24 seconds). About one second ahead of this time place the sampling template firmly onto the neck of the bottle and withdraw a 5ml sample at the designated time. Place the sample in the aluminium weighing dish and dry in an oven at 100 °C. The drying will take about 3 hours.
- Let the bottles sit undisturbed. In the same way sample the bottles again at the time designated for clay sedimentation. Put the second set of dishes containing the clay sample in the oven and weigh when dry.
- Separate the sand fraction by washing the contents of the bottle onto a 53 μ sieve with several portions of tap water. Wash the sand free of silt, clay and dispersing solution by playing a fine jet of water over the sieve for about 60 seconds. Carefully transfer the washed sand into a weighed aluminium dish and dry at 100 °C over night. Reweigh to determine the sand content.
- Additional separations can be carried out on the dry sand fraction by sieving to separate the following sand fractions:

53 μ to 106 μ	very fine sand
106 μ to 250 μ	fine sand
250 μ to 500 μ	medium sand
500 μ to 2000 μ	coarse and very coarse sand

Temperature (°C)	Sampling Time (sec) for Silt + Clay (<50µ) @ 6 cm	Sampling Time (min) for Clay (<2µ) @ 6 cm
10.0	34.9	363
12.0	33.0	343
14.0	31.2	325
16.0	29.6	308
17.0	28.9	301
18.0	28.1	293
19.0	27.4	286
20.0	26.7	279
21.0	26.1	272
22.0	25.5	265
23.0	24.9	259
24.0	24.3	253
25.0	23.7	247
26.0	23.2	242
27.0	22.7	236
28.0	22.2	231
29.0	21.7	226
30.0	21.3	221
31.0	20.8	217
32.0	20.4	212
33.0	20.0	208
34.0	19.6	204
35.0	19.2	199
36.0	18.8	196

Data Acceptance and Quality Control

Each batch of about 20 samples should contain a standard soil sample [Standard 8117] and one duplicate set. Blind samples such as verified ALASA samples should be included intermittently. Results for the standard sample should be within 2 standard deviations of the mean. Duplicates should agree within 5% of each other or within 2% absolute at lower readings. For low organic matter soils the total recovery of sand + silt + clay is normally in the 97 to 100% range. For soils with greater than 2% organic matter or high soluble salts more variable recovery may be expected. The organic matter extracted by the alkaline dispersing solution will tend to increase the clay and silt results while unhumified organic matter may be recovered with the sand fraction. This might give total recoveries of up to 105%. However, where little interference of this type is shown by the organic matter content you may get recoveries lower than 100% and in line with the amount of organic matter present.

Calculation and Presentation of Results

Calculations may be carried out using the SUNRISE.ex1 program. Note that since we deal with soils of generally very low organic matter content the results are expressed as a % of the sum of sand, silt and clay. Other ways of presenting the results may be more appropriate for soils with high organic matter contents. Manual calculation can be carried out using the following:

$$\text{Total weight of Silt + Clay (SC)} = ((B - A) - C1) \times (G/F)$$

$$\text{Total weight of Clay (Clay)} = ((E - D) - C2) \times (G/F)$$

$$\text{Total weight of Sand (Sand)} = (I - H)$$

$$\text{Recovery as sand, silt and clay (\%)} = (((SC) + (Clay) + (Sand))/J) \times 100$$

$$\text{Clay (\%)} = (Clay) / ((SC) + (Clay) + (Sand)) \times 100$$

$$\text{Silt (\%)} = ((SC) - (Clay)) / ((SC) + (Clay) + (Sand)) \times 100$$

$$\text{Sand (\%)} = (Sand) / ((SC) + (Clay) + (Sand)) \times 100$$

Where:

- A = Weight of empty dish for clay and silt sampling
- B = Weight of dish + clay & silt aliquot
- C1 = Weight of dispersant blank for clay + silt sampling
- C2 = Weight of dispersant blank for clay sampling
- D = Weight of empty dish for clay sampling

- E = Weight of dish + clay aliquot
- F = Aliquot size (usually 5 ml)
- G = Total volume of water + dispersant (usually 200 ml)
- H = Weight of empty dish for sand fraction
- I = Weight of dish + sand fraction
- J = Weight of air-dry soil used (usually 20.00 g)

The results are thus expressed as percentages in terms of the amount of sand + silt + clay recovered. Thus sand, silt and clay will add up to 100%.

Other References

Day, P.R. 1965. Particle fractionation and particle-size analysis. Pages 545-567 in *Methods of Soil Analysis*, C.A. Black, Ed. Agronomy No. 9, Part I, American Society of Agronomy, Madison, WI.

CATION EXCHANGE CAPACITY AND EXCHANGEABLE BASES

Reference Method

van Reeuwijk, L.P. (edit.) 1992. Procedures for Soil Analysis pages 9-1 to 9-11, International Soil Reference and Information Centre, Wageningen, The Netherlands.

Introduction

Cation exchange capacity (CEC) is an important characteristic of soil that is largely defined by the types of clay minerals present and the humus content. It is important as an indication of the capacity of the soil to hold and retain nutrients against leaching. The relationship with clay and organic matter content is an important feature in classifying soils and assessing potential agricultural usefulness. The base saturation, the proportion of the CEC occupied by basic cations, is also a diagnostic criteria for soil classification which indicates the extent of potential acidity in the soil. Once the contribution of organic matter to the CEC is taken into account the magnitude of the residual CEC relative to the clay content is useful in suggesting the type of clay present. The CEC is expressed in meq/100 g of soil or cmol(+)/Kg of soil. Organic matter is generally considered to contribute 200 me/100 g of organic matter. Approximate values in me/100g for different clays and amorphous oxides are as follows:

Iron oxide	< 4
Kaolinite	4 - 15
Illite (mica)	10 - 40
Chlorite	10 - 40
Smectite	80 - 120
Vermiculite	100-150

Some saline and alkaline soils contain particular types of clay minerals, especially vermiculite. Allophones which are composed of poorly crystalline alumino-silicates are prevalent in soils derived from volcanic ash and have a CEC varying from 100 to 200 meq/100 g which is also pH-dependent. The CEC of the silt fraction can be considerable.

Scope

The method described here may be used to estimate the CEC of most soils. The choice of saturating cation or pH of the equilibrating solution may be varied for soils containing certain clays or minerals. It may be difficult to differentiate between exchangeable and soluble cations in soils containing carbonates, gypsum or soluble salts.

Principle

A soil sample is leached with ammonium acetate to remove soluble bases and replace exchangeable bases with ammonium ions. Calcium, magnesium, sodium and potassium are measured in the effluent. The sample is then leached with sodium acetate to saturate the cation exchange complex with sodium ions. The excess sodium is removed by leaching with ethanol and the cation exchange capacity determined by measuring the sodium subsequently de-sorbed by a further leaching with ammonium acetate. A pre-washing step may be carried out to remove soluble salts in highly saline soils. The method described here uses an automatic extractor where the soils are mounted in plastic syringes for the leaching operations.

Method Validation

None.

Special Notes

Application of the described method to calcareous and gypsiferous soils may lead to apparently erroneous results. Dissolution of carbonates gives an over-estimation of exchangeable Ca but may not affect the CEC measurement. Results can be improved to some extent by raising the pH of the sodium and ammonium acetate buffer solutions to 8.2 where the solubility of calcium and magnesium carbonate is reduced. This can also be achieved by using a 1:1 acetate:ethanol buffer at pH 7. However, since the solubility of the carbonates is never reduced to zero the results still remain unreliable. The determination of CEC of saline and alkaline soils also has some problems since such soils often contain carbonates and large amounts of other soluble salts notably sulphates and chlorides. Sodium acetate is a useful extractant since it dissolves less amounts of calcium and magnesium carbonates than does ammonium acetate.

Ammonium acetate at pH 7 has particular advantage for many soils but some saline and alkaline soils, especially those containing vermiculite, fix large amounts of ammonium (NH_4^+) and potassium (K^+) under moist conditions. The fixation of ammonium does not interfere with the extraction of exchangeable bases, but the CEC values obtained by saturation with ammonium acetate for the CEC are low as a result. An inverse relationship exists between the CEC and the amount of ammonium fixed. Sodium seems to be the most appropriate cation for the determination of the CEC in these soils because it has a much smaller ionic radius than either the NH_4^+ or the K^+ ion and is more susceptible to being exchanged. The minerals of the mica family such as weathered biotite and vermiculite that often occur in the semi-arid regions can retain K^+ and NH_4^+ ions between their interlayers. These cations are strongly held and are not easily exchanged. Therefore if NH_4^+ or K^+ salts are used to saturate the cation exchange complex they can be fixed between the interlayers of these 2:1 minerals in an irreversible

manner. This hinders their replacement during the extraction and gives the value of the CEC much smaller than it actually is.

Equipment and Supplies

- SampleTex model 24VE programmable vacuum extractor
- Syringes to go with above extractor
- Volumetric flasks
- Filter pulp
- Pure sand (e.g. acid washed sea-sand, ignited to remove any organic matter)

Reagents

- Ethanol 96 %: Also diluted to 80%.
- Ammonium Acetate Solution, 1 M: Dissolve 385.4 g NH₄AC in de-ionised water. Adjust the pH to 7.0 with ammonium or 1 M acetic acid make to 5 litres. Alternatively for each litre of solution use 58 ml of glacial acetic acid (99%) and 70 ml of concentrated ammonium hydroxide.
- Sodium Chloride, 10 % Solution: Dissolve 100 g of NaCl in de-ionised water and make up to 1000 ml.
- Sodium Acetate Solution, 1 M: Dissolve 680.4 g of NaAc.3H₂O in de-ionised water. Adjust the pH to 7.0 with 1 M sodium hydroxide or 1 M acetic acid and make up to 5000 ml.
- Sodium Hydroxide, 1 M: Dissolve 40 g of NaOH in de-ionised water and make up to 1000 ml.
- Acetic Acid, 1 M: Add 60.05 g or 57.5 ml of acetic acid (CH₃COOH) to about 500 ml of de-ionised water and make up to 1000 ml.

Note: If desired, both acetate solutions may be adjusted to pH 8.2 (for CEC pH 8.2 of calcareous soils). Alternately a mixture of 50:50 ammonium acetate 1 M pH 7 and ethanol could be used instead of NH₄AC pH 7 for displacement of the bases.

Safety and Special Precautions

None identified.

Test Procedure

- Plug the bottom of the sample tube with approx. 1 g of filter pulp and compress with a plunger.
- Weigh 5.00 g air-dry < 2mm soil into a plastic beaker, add 1 tea spoonful of sand and mix well with a spatula.
- In case of very clayey samples or samples with swelling clays (Smectites) two tea-spoonfuls of sand.
- Transfer quantitatively to sample tube and place tube in upper disc of extractor. If necessary, level sample to even thickness with a spatula.
- Prepare a blank sample with pure sand instead of soil.
- Connect sample tube with collecting syringe the plunger of which is inserted in slot of stationary disc of extractor.
- Soluble salt treatment: A distinction can be made on the basis of presence or absence of soluble salts using the conductivity of the pH-H₂O 2:5 suspensions to test this:
 - EC 2.5 > 0.4 mS: soluble salts need to be washed out first with 80% ethanol.
 - EC 2.5 < 0.4 mS: soluble salts negligible and therefore no pre-washing needed.
- **Preliminary treatment for soluble salts**
- Rinse wall of sample tube with some 80% ethanol from wash bottle.
- Carefully fill sample tube to the 25 ml mark with ethanol 80 % and allow to stand for 20 minutes.
- Check tube for entrapped air-bubbles and, if necessary, try to remove these by light tapping against the tube. Should this fail, then carefully disturb soil/sand mixture by probing with a mounting needle.
- If necessary, fill to 25 ml mark again and place reservoir tube on top of sample tube.
- Add about 40 ml ethanol 80 % to reservoir tube collecting syringe. Discard leachate and replace collecting syringe with a clean one. Proceed with test procedure as below.
- Rinse wall of sample tube with some 1 M NH₄OAc. Allow to stand for 20 minutes (omit standing for 20 minutes if pre-washed).
- Check tube for entrapped air-bubbles and, if necessary, try to remove these by light tapping against the tube. Should this fail, then carefully disturb soil/sand mixture with a mounting needle.
- If necessary, fill to 25 ml mark again and place reservoir tube on top of sample tube. Add about 40 ml 1 M NH₄OAc to reservoir tube, start extractor and complete leaching in 4 hours.
- Disconnect collecting syringe, transfer contents quantitatively to 100 ml volumetric flask and make to volume with 1 M NH₄OAc solution (**Leachate A**)
- Measure Ca, Mg, K, and Na in Leachate A.
- If CEC determination is to follow, remove reservoir tube, reset extractor in starting position and replace collecting syringe.

- Possible modification for carbonate/non-saline soils: If the pH of the 2:5 H₂O water extract is > 7 with carbonates present but EC 2.5 < 0.4 mS/cm then no pre-washing is needed, but use a 50:50 mixture of NH₄OAc pH 7 and ethanol to displace the bases instead of using NH₄OAc pH 7 alone, to obviate carbonate dissolution.
- Possible modification with carbonate/saline soils: If the pH of the 2:5 H₂O water extract is > 7 with carbonates present but EC 2.5 > 0.4 mS/cm then do a pre-washing as above followed by a 50:50 mixture of NH₄OAc pH 7 and ethanol to displace the bases instead of using NH₄OAc pH 7 alone, to obviate carbonate dissolution.
- The CEC procedure is done immediately following the determination of exchangeable bases using the same sample and tube.
- Rinse wall of sample tube with some NaOAc/NaCl (0.9/0.1 M) from a wash bottle and carefully fill to 25 ml mark.
- Check tube for entrapped air-bubbles and , if necessary, try to remove these by light tapping against the tube. Should this fail, then carefully probe the soil/sand mixture with a mounting needle.
- Place clean reservoir tube on sample tube and add about 40 ml NaOAc/NaCl.
- Start extractor and leach in 4 hours. Discard the leachate.
- Remove reservoir tube, reset extractor in starting position and replace collecting syringe.
- Rinse wall and outlet of sample tube with ethanol 80 % and carefully fill to 25 ml mark.
- Place clean reservoir tube and add about 40 ml ethanol 80 %.
- Start extractor and leach for 2 hours. Discard the leachate.
- Remove reservoir tube, reset extractor in starting position and replace collecting syringe.
- Rinse wall of sample tube with about 10 ml ethanol 96 % and leach this for 30 minutes (timer position: 2 hours) Discard the leachate.
- Repeat the step before the latter step before discarding leachate. Test this for chloride with a drop of 1 M AgNO₃. If no turbidity develops proceed. If turbidity develops repeat the above step. Remove collecting syringe from those samples that do not need extra washing.
- Reset extractor in starting position and place clean collecting syringe.
- Carefully add 1M NH₄OAc solution to the 25 ml mark of sample tube.
- Start extractor and leach for 8 hours.
- Disconnect collecting syringe and transfer contents quantitatively to 100 ml volumetric flask and make to volume with NH₄OAc 1 M solution, mix. (Leachate B)
- Measure Na in this leachate.

Any anomaly observed in the extracts such as strong coloration (dissolution of humus) or turbidity (colloidal particles) should be recorded. Such anomalies, particularly the latter, may cause erroneous results. In some cases filtering or high-speed centrifuging may be necessary to obtain a clear solution.

Exchangeable Ca, Mg, K, and Na are measured by flame atomic absorption spectrophotometry (AAS) in percolate A. The CEC is measured through Na by AAS in percolate B. For measurement on the AAS La (5000 mg/l or 0.5 %) is introduced to prevent formation of refractory compounds of Ca, Mg and ionization interference of K and Na in the flame.

Calculation and Presentation of Results

$$\text{Exch. Ca (cmol (+)/kg soil)} = \frac{(a-b) \times 10 \times 100 \times \text{mcf}}{10 \times 20.04 \times S}$$

$$\text{Exch. Mg (cmol (+)/kg soil)} = \frac{(a-b) \times 10 \times 100 \times \text{mcf}}{10 \times 12.15 \times S}$$

$$\text{Exch. K (cmol (+)/kg soil)} = \frac{(a-b) \times 2 \times 100 \times \text{mcf}}{10 \times 39.1 \times S}$$

$$\text{Exch. Na (cmol (+)/kg soil)} = \frac{(a-b) \times 2 \times 100 \times \text{mcf}}{10 \times 23.00 \times S}$$

$$\text{Base Saturation (\%)} = \frac{(\text{Ca} + \text{Mg} + \text{K} + \text{Na}) \times 100}{\text{CEC}}$$

- Possible modification for carbonate/non-saline soils: If the pH of the 2:5 H₂O water extract is > 7 with carbonates present but EC 2.5 < 0.4 mS/cm then no pre-washing is needed, but use a 50:50 mixture of NH₄OAc pH 7 and ethanol to displace the bases instead of using NH₄OAc pH 7 alone, to obviate carbonate dissolution.
- Possible modification with carbonate/saline soils: If the pH of the 2:5 H₂O water extract is > 7 with carbonates present but EC 2.5 > 0.4 mS/cm then do a pre-washing as above followed by a 50:50 mixture of NH₄OAc pH 7 and ethanol to displace the bases instead of using NH₄OAc pH 7 alone, to obviate carbonate dissolution.
- The CEC procedure is done immediately following the determination of exchangeable bases using the same sample and tube.
- Rinse wall of sample tube with some NaOAc/NaCl (0.9/0.1 M) from a wash bottle and carefully fill to 25 ml mark.
- Check tube for entrapped air-bubbles and , if necessary, try to remove these by light tapping against the tube. Should this fail, then carefully probe the soil/sand mixture with a mounting needle.
- Place clean reservoir tube on sample tube and add about 40 ml NaOAc/NaCl.
- Start extractor and leach in 4 hours. Discard the leachate.
- Remove reservoir tube, reset extractor in starting position and replace collecting syringe.
- Rinse wall and outlet of sample tube with ethanol 80 % and carefully fill to 25 ml mark.
- Place clean reservoir tube and add about 40 ml ethanol 80 %.
- Start extractor and leach for 2 hours. Discard the leachate.
- Remove reservoir tube, reset extractor in starting position and replace collecting syringe.
- Rinse wall of sample tube with about 10 ml ethanol 96 % and leach this for 30 minutes (timer position: 2 hours) Discard the leachate.
- Repeat the step before the latter step before discarding leachate. Test this for chloride with a drop of 1 M AgNO₃. If no turbidity develops proceed. If turbidity develops repeat the above step. Remove collecting syringe from those samples that do not need extra washing.
- Reset extractor in starting position and place clean collecting syringe.
- Carefully add 1M NH₄OAc solution to the 25 ml mark of sample tube.
- Start extractor and leach for 8 hours.
- Disconnect collecting syringe and transfer contents quantitatively to 100 ml volumetric flask and make to volume with NH₄OAc 1 M solution, mix. (**Leachate B**)
- Measure Na in this leachate.

Any anomaly observed in the extracts such as strong coloration (dissolution of humus) or turbidity (colloidal particles) should be recorded. Such anomalies, particularly the latter, may cause erroneous results. In some cases filtering or high-speed centrifuging may be necessary to obtain a clear solution.

Exchangeable Ca, Mg, K, and Na are measured by flame atomic absorption spectrophotometry (AAS) in percolate A. The CEC is measured through Na by AAS in percolate B. For measurement on the AAS La (5000 mg/l or 0.5 %) is introduced to prevent formation of refractory compounds of Ca, Mg and ionization interference of K and Na in the flame.

Calculation and Presentation of Results

$$\text{Exch. Ca (cmol (+)/kg soil)} = \frac{(a-b) \times 10 \times 100 \times \text{mcf}}{10 \times 20.04 \times S}$$

$$\text{Exch. Mg (cmol (+)/kg soil)} = \frac{(a-b) \times 10 \times 100 \times \text{mcf}}{10 \times 12.15 \times S}$$

$$\text{Exch. K (cmol (+)/kg soil)} = \frac{(a-b) \times 2 \times 100 \times \text{mcf}}{10 \times 39.1 \times S}$$

$$\text{Exch. Na (cmol (+)/kg soil)} = \frac{(a-b) \times 2 \times 100 \times \text{mcf}}{10 \times 23.00 \times S}$$

$$\text{Base Saturation (\%)} = \frac{(\text{Ca} + \text{Mg} + \text{K} + \text{Na}) \times 100}{\text{CEC}}$$

Where:

- a = mg/l Ca, Mg, K, or Na in the diluted sample leachate A
- 10 = the value 10 in the numerator for Ca and Mg represent the dilution factor.
- 2 = the value 2 in the numerator for K and Na represent the dilution factor.
- b = mg/l Ca, Mg, K or Na in the diluted blank leachate A.
- S = air-dry weight of soil in g
- mcf = moisture correction factor (if used).
- 10 = the value 10 in the denominator is a factor to covert from mg/l to cmol (+)/kg
- 100 = the value 100 in the numerator is the total volume of the percolate: change this value accordingly if a greater volume was used. *

The values 20.04, 12.15, 39.10 and 23.00 are the equivalent weights of Ca, Mg, K, and Na, respectively.

$$\text{CEC (cmol (+)/kg)} = \frac{(a-b) \times 10 \times 100 \times \text{mcf}}{10 \times 23 \times S}$$

Where:

- a = mg/l Na in 10x diluted sample leachate B
- b = mg/l Na in 10x diluted blank leachate B
- s = air-dry sample weight in g (5 g).
- mcf = moisture correction factor (if used)

Data Acceptance and Quality Control

Each batch of samples should contain one blank, two duplicate samples and one quality control standard. The results are accepted if the results from the standard sample are within two standard deviations of the historical mean. Duplicate results should be within 10% of each other.

Other References

- Rhoades, J.D. 1982. Cation exchange capacity. Pages 149-157 in A.L. Page et al., Eds. Methods of soil analysis, Agronomy No. 9. 2nd ed. American Society of Agronomy, Madison, WI.
- Thomas, G.W. 1982. Exchangeable cations. Pages 159-165 in A.L. Page et al., Eds. Methods of soil analysis, Agronomy No. 9. 2nd ed. American Society of Agronomy, Madison, WI.

CATIONS EXTRACTABLE BY 1M AMMONIUM ACETATE AT PH 7

Reference Method

Adapted from: Soil Science Society of South Africa (1992). Handbook of Standard Soil Testing Methods for Advisory Purposes. Pages 8-1 to 8-3. P.O. Box 30030, Sunnyside 0132, Pretoria, RSA.

Introduction

The status of available calcium, magnesium and potassium as well as the ratios of these elements and sodium is important in maintaining optimum plant growth. Extraction of these cations with neutral ammonium acetate reflects their nutrient status in the soil.

Scope

The method is applicable to most soils. The procedures described here just outline the extraction step. The measurement of individual cations is the subject of another SOP.

Principle

Soils are extracted with neutral 1M ammonium acetate at an extraction ratio of 1:10. The soluble and exchangeable cations are brought into solution by the high concentration of ammonium ions. The concentration of individual cations can be determined by atomic absorption spectroscopy.

Method Validation

By direct reference to results of ALASA soil samples.

Notes

It is important that extracts be clear of any sediment or fine particulate material. Cloudy extracts may be treated by filtration through fine filter paper (e.g. Whatman No. 42), by standing overnight in a refrigerator or by centrifugation (e.g. Beckman centrifuge 3,000 rpm for 30 minutes).

Sample Requirements

Soils should be air-dried and ground to pass a 2mm mesh sieve. Samples may be stored at low humidity indefinitely without significant change in sodium, calcium, magnesium or potassium. The amount of extractable potassium may increase on drying.

Equipment and Supplies

- Balance to measure to 0.01g
- 250 ml extraction flasks
- Reciprocating shaker
- Filtering rack, filter funnels and test tubes
- Medium fineness filter paper (Whatman 40)
- Volumetric flasks and pipettes
- Atomic absorption/emission spectrophotometer

Reagents

- Ammonium Acetate, 1M, pH 7.0: On a magnetic stirrer in a fume cabinet, dilute 570 ml glacial acetic acid (99.5%) with about 5000 ml of de-ionised water. Add 690 ml concentrated ammonia solution gradually with stirring to the diluted acetic acid. Add 2000 ml of de-ionised water. Allow to cool. Adjust to pH 7.00 with acetic acid or ammonia. Make up to 10000 ml. If made directly from ammonium acetate use 77.8 g per litre and adjust pH with ammonium hydroxide or acetic acid.
- Standard solutions of calcium, sodium, potassium and magnesium, lanthanum solution : (see separate SOP).

Safety and Special Precautions

Take precautions when handling strong acids and alkalis in preparing the ammonium acetate solution.

Test Procedure

- Weigh 5.00 g of air-dry <2mm soil into extraction flasks.
- Add 50 ml ammonium acetate solution from a reagent dispenser and shake at 180 oscillations per minute for 30 minutes.
- Allow to stand for a few minutes and then filter into test tubes.
- Carry out further filtration or centrifugation steps if the extract is not clear.
- Store over night in refrigerator
- Make up suitable dilution in lanthanum and analyse the filtrate for K, Ca, Mg and Na.
- AA method see separate SOP

Data Acceptance and Quality Control

Quality control samples should fall within two standard deviations as calculated on the control sheets. Duplicates will fall within 5% of each other.

Calculation and Presentation of Results

Farm soil results should be quoted to an accuracy of three significant figure. Research samples may be quoted to four significant figures.

Other References

Knudsen, D., Paterson, G.A., and Pratt P.F. 1982. Lithium, sodium and potassium. Pages 225-246 in A.L. Page et al., Eds. Methods of soil analysis, Part 2., 2nd ed. Agronomy No. 9. American Society of Agronomy, Madison, WI.
Lanyon, L.E. and Heald, W.R. 1982. Magnesium, calcium, strontium and barium. Pages 247-262 in A.L. Page et al., Eds. Methods of soil analysis, Part 2., 2nd ed. Agronomy No. 9. American Society of Agronomy, Madison, WI.

ELECTRICAL CONDUCTIVITY IN A SATURATED PASTE OR 2:5 WATER:SOIL EXTRACT

Reference Method

Adapted from: Bower, C.A. and Wilcox L.V. 1965. Soluble Salts, pages 933 to 951 in Methods of Soil Analysis, C.A. Black (ed.), Agronomy No. 9, American Society of Agronomy, Madison, WI.

Introduction

Electrical conductivity (EC) is the property of a liquid medium to transmit an electrical current. EC increases with the concentration of the ions that liquid contains and varies with the nature of the ions. In the soil, the determination of the EC serves to give an idea of the total quantity of soluble salts and the degree of salinity of the soil.

Scope

The method for the measurement of electrical conductivity is applicable to soils, composts, manures and water samples. The saturated extract method is used for saline and/or sodic soils (see SOP Soil-110).

Principle

EC is measured with a conductivity meter with two electrodes placed in a sample of the liquid at a set distance from each other. EC is the inverse of electrical resistivity and is quoted in units based on "mhos" or siemens for example mmhos/cm, μ mhos/cm or S/m [1 s/m = 10 mmhos/cm = 1000 μ S/cm]. The EC of an aqueous salt solution increases with increase in temperature (about 2 % per degree °C) hence EC is referenced to a standard temperature (e.g. 20 or 25 °C).

The content of soluble salts in a soil can be estimated by measuring the EC in a saturated paste, or an extract from a saturated paste or in extracts prepared at varying ratios of soil to water. To prepare a saturated paste extract, water is added to a soil sample until a given mechanical property of the soil is attained equivalent to the liquid limit. The amount of water held at saturation is called the saturation percentage

Method Validation

Not done

Interference and Other Considerations

The results provide readings relative to 25 °C for a standard potassium chloride solution at room temperature. Care should be taken that the sample extracts are also at the same temperature of the standard solution. When pH is to be determined on the same solution, EC is determined first to eliminate the possibility of KCl leaking from the pH electrode into the samples.

Sample Requirements

Soils should be air-dried and ground to pass a 2mm mesh sieve. Samples may be stored at low humidity with little alteration of electrical conductivity results.

Equipment and Supplies

- 100 ml beakers and containers suitable for mixing up to 1 kg of soil.
- Spatula or glass stirring rod
- Analytical balance (0.1 g precision)
- Conductivity meter

Reagents

- Potassium chloride (0.1M): Dissolve 7.456 g of dried KCl in distilled water and make up to 1 L. Store in a refrigerator.
- Potassium chloride (0.01M): Pipette 50 ml of the 0.1M stock KCl solution into a 500 ml volumetric flask and bring to volume with distilled water. Store refrigerated.

Safety and Special Precautions

None

Test Procedure

- Preparation of 2:5 soil:water extract : Weigh 20 g of air dried < 2mm soil into a 100 ml beaker. Add 50 ml of distilled water and stir three times over the course of one hour.
- Preparation of extract from a saturated soil paste: The procedure is outlined in greater detail in SOP Soil-109 (Salinity Analysis). Weigh 200 to 1000 g of air dried < 2mm soil into a strong plastic or metal container. The amount of soil needed depends on the texture of the soil and the amount of extract needed for various analyses. Add distilled water to the soil and stir the mixture until a thick paste is formed which is almost saturated with water. Stir several times over a two hour period, adding extra water if needed. The water content should be adjusted until the soil reaches saturation. This point is marked by three characteristics: (1) the paste glistens as it reflects light, (2) it flows slightly when the container is tipped and (3) it slides cleanly

off a spatula for all soils except those of high clay content. After standing for at least four hours (or overnight) the water content is readjusted if needed and a small sample recovered to determine the moisture content and saturation percentage. The rest of the sample is transferred to a Buchner filter funnel with fine retention filter paper (e.g. Whatman No. 42) and filtered using vacuum. Part of the filtrate is used to determine EC. The remaining filtrate may be used for pH and cation and anion analyses.

- Calibration of the conductivity meter: Add about 30 ml of the 0.01 N KCl calibrating solution to a 50 ml beaker, dip the cell in this solution and adjust reading of the meter to 1.412 ms/cm with the calibration dial. This reading is the specific conductivity of the 0.01 M KCl solution at 25 °C. The meter is now set to make readings.
- Taking Readings: Insert the cell into the extract and read the conductivity. The range scale may need to be changed to obtain the exact EC reading. Rinse the cell with distilled water and dry with paper tissue. Make further readings as above. After all the samples have been determined, wash and dry the cell and store it away.

Data Acceptance and Quality Control

Each run of 24 samples should include one duplicate and one standard soil. Salinity standard 83535 should be used for saturated extracts while the same standard as used for pH should be run with all other soils (812342 or 821834). The meter should be checked with the 0.01M KCl solution every 10 samples and reset if needed. Quality control samples should fall within two standard deviations as calculated on the control sheets. Duplicates will fall within 5% of each other or within 10 μ S/cm for soils of low salinity.

Calculation and Presentation of Results

Results should be quoted in μ S/cm (as whole numbers) or mS/cm (to 0.01 units) for saline soils. To convert results $EC_{(1:2.5)}$ extract into saturated paste value multiply by 2 to 2.5 (more precise conversion should be worked out for local soils. The conversion become inaccurate (normally too low) when $EC_{(1:2.5)}$ is above ~ 1000 μ S/cm and the EC should be measured on a saturated extract.

Other References

Van Reeuwijk L.P. Procedures for Soil Analysis. 3rd Edition, pages 3-1 and 13-1. International Soil Reference and 1992 Information Centre, Wageningen, The Netherlands.

Richards, L.A. (Editor). (1954). Diagnosis and Improvement of Saline and Alkaline Soils. U.S. Dep. Agric. Handbook. No. 60.

PH OF SOIL IN WATER OR 1M POTASSIUM CHLORIDE

Reference Method

Adapted from: Hendershot, W.H., Lalonde, H. and Duquette, M. (1993). Soil reaction and exchangeable acidity. Pages 141-145 in Soil Sampling and Methods of Analysis, M.R. Carter (editor). Canadian Society of Soil Science and Lewis Publishers.

Introduction

The pH in water (pH_w) gives a measurement of dissociated H⁺ ions present in the soil solution and in equilibrium with the other ions. Exchangeable or reserve acidity is represented by the H⁺ ions fixed on the colloidal particles and may be estimated by measuring the pH in a soil: 1M potassium chloride extract (pH_k). The pH_k is normally more acidic than pH_w except in some tropical soils containing sesquioxides.

Scope

The method for the measurement of pH is applicable to soils, composts, manures and water samples. Soluble salts in the soil can be estimated by measuring the electrical conductivity of the water extract (see SOP Soil-112). Exchangeable acidity in soils can be measured by titration of a 1M KCl extract with standard acid (see SOP Soil-113).

Principle

The pH of the soil is potentiometrically measured in the supernatant suspension of a 1:2.5 soil: liquid mixture. The liquid is either water (pH_w) or 1 M KCl solution (pH_k).

Method Validation

By direct reference to results of ALASA soil samples.

Interference and Other Considerations

Buffer solutions should not be stored at room temperature for too long. Any contamination of the buffer container with soil particles may make readings unreliable. The pH 9 and 10 buffer solutions are sensitive to CO₂ and once opened may soon become unreliable. Soils containing carbonates often give unstable readings due to equilibrium reactions with the solution phase and carbon dioxide. In such cases where the pH drifts the reading should be recorded after a set period such as 2 minutes. For the identification of a sulphuric horizon a 1:1 soil : water ratio is used.

Sample Requirements

Soils should be air-dried and ground to pass a 2mm mesh sieve. Samples may be stored at low humidity without significant change in pH. Moisture, high organic matter content and high temperature may change pH on storage.

Equipment and Supplies

- pH meter with glass-calomel combination electrode
- Glass rods, 100 ml plastic beakers
- Analytical balance with 0.1 g precision
- Absorbent paper tissues
- Graduated cylinders (50 ml) or reagent dispenser

Reagents

- Commercial buffer solutions, pH 4.00, 7.00 and 9.00: Or made as below.
- Buffer solution pH 4.00: (20°C: Dissolve 11.8060 g citric acid (C₆H₈O₇) and 10.9468 g disodium phosphate (Na₂HPO₄·12H₂O) in pure de-ionised water and dilute to 1 litre. Or dissolve 2.0423 g of potassium hydrogen-phthalate (KHC₈H₅O₄) in 200 ml of de-ionised water.
- Buffer solution pH 7.00 (20°C): Dissolve 3.3910 g of potassium dihydrogen orthophosphate (KH₂PO₄) and 4.4500 g disodium phosphate (Na₂HPO₄·2H₂O) in de-ionised water and dilute to 1 litre. Or dissolve 0.680 g of potassium dihydrogen - phosphate (KH₂PO₄) and 0.8900 g of disodium hydrogen-phosphate (Na₂HPO₄·2H₂O) in 200 ml of de-ionised water. This give a pH 6.88 buffer.
- Buffer solution pH 9.22 (20°C): Dissolve 0.7627 g of sodium tetraborate (Na₂B₄O₇·10H₂O) in 200 ml of de-ionised water.
- Potassium chloride (1M): Dissolve 74.6 g of dried KCl de-ionised water and make to 1 L.
- Commercial electrode filling solution: Or a saturated potassium chloride solution: Pour 50 ml of de-ionised water into a 100 ml beaker, add KCl crystals, stir, add more crystals until a saturated solution is obtained.

Safety and Special Precautions

None

Test Procedure

- Preparation of electrode

Check to see if the liquid level in the outer section of the electrode is close to the filling hole. If not, detach the electrode carefully, shift the rubber cover down so that the small opening comes free and fill with reference electrode filling solution or a saturated potassium chloride solution.

- Calibrating the pH meter

The pH-meter may be left with power on in standby mode. Otherwise turn it on 30 minutes before use. The electrode and temperature sensor are kept in de-ionised water. Remove the pH calibration standard solutions from the refrigerator sufficiently in advance in order for them to reach ambient temperature. Adjust the temperature regulation to room temperature, remove the combination electrode (or the reference and glass electrodes) from the conservation solution, rinse it with water and wipe with absorbent paper. Put the electrode into the pH 7.00 buffer, set the meter to the calibration mode and adjust the value of the display to that of the buffer. Set the calibration. The second calibration can be done with the pH 4.00 or the pH 9.00 buffer depending upon the expected range of the soil pHs to be measured.

- Preparation of water suspension or potassium chloride suspension

Weigh 20.0 g soil on a top loading balance into 100 ml beaker.

Add 50 ml de-ionised water or 1M KCl from a measuring cylinder or reagent dispenser.

Stir for about 20 seconds three times over a one hour period.

- Reading the pH

Introduce the electrode(s) into the suspension, wait for the reading to stabilise and record the pH on the data sheet to an accuracy of 0.01 unit. The reading is considered stable when it does not change more than 0.1 units per 30 seconds (or 0.02 units per 5 sec.). With neutral and acidic samples this normally takes less than two minutes. With calcareous soils stabilisation may be difficult to achieve, because of non-equilibrium conditions and reaction with atmospheric carbon dioxide. After reading, lift the electrodes out and wash with de-ionised water (wiping with tissue paper is not necessary).

Data Acceptance and Quality Control

In each run of 24 samples include one duplicate and one standard soil (pH Standard 1997 Red, 812342 or 821834). Check the drift of the pH meter with the pH 7.00 solution every 10 samples and reset the meter if needed. Measure the pH of a fresh standard pH solution once during the run. Quality control samples should fall within two standard deviations as calculated on the control sheets. Duplicates will fall within 5% of each other or within 0.2 pH units.

Calculation and Presentation of Results

Farm soil results should be quoted to an accuracy of 0.1 pH unit. Research samples may be quoted to 0.01 pH units.

Other References

Peech, M. 1965. Hydrogen-Ion Activity, pages 914-926 in C.A. Black (ed.) Methods of Soil Analysis, Agronomy No. 9, American Society of Agronomy, Madison, WI.

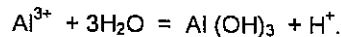
SOIL ACIDITY

Reference Method

Van Reeuwijk L.P. 1992. 11-1 to 11-2, Soil Acidity in Procedures for soil Analysis. 3rd Edition. Int. Soil Reference and Information Centre, Wageningen, The Netherlands.

Introduction

In very acid soils the Al^{3+} ions that constitute part of the clay layers become exchangeable. They are fixed on the exchange complex and together with H^+ ions they form the group of exchangeable cations that cause soil acidity. Exchangeable acidity is due largely to Al^{3+} ions. When the Al^{3+} from the exchange complex passes into the solution, H^+ ions are produced which raise the active acidity and hence decrease the pH.



Since aluminium becomes toxic to plants at high concentrations it is necessary to determine exchangeable acidity ($Al^{3+} + H^+$) in order to estimate the lime requirement of soils needed to increase soil pH to the point where aluminium is no longer soluble. Exchange acidity is also an important parameter for the classification of acidic soils.

There are fundamentally two different methods for the determination of soil acidity.

Exchangeable acidity as acidity ($H^+ + Al^{3+}$) released upon exchange by an unbuffered KCl solution. This may be used to determine the *effective cation exchange capacity* (ECEC) which is defined as sum of bases + (H + Al). When the exchangeable acidity is significant, the Al may be determined separately in the extract as it may be toxic to plants. Because the contribution of H^+ is often (but not always) negligible, some laboratories only determine exchangeable Al. In that case the ECEC is calculated as (sum of bases + Al). This method is described here.

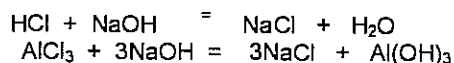
Extractable acidity is the acidity extracted by a $BaCl_2$ -TEA (triethanolamine) buffer solution at pH 8.2. It may be also be called *potential acidity*, *maximal acidity*, or *titratable acidity* and is sometimes is also confusingly referred to as *exchange acidity*. It may be used to calculate the CEC as the sum of bases + extractable acidity.

Scope

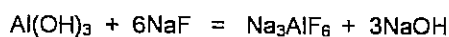
The method is useful to measure exchangeable acidity and aluminium in acid soils with pHw of <5.5. Acidity above this pH is less likely to be a problem to plant growth and little soluble aluminium will be present.

Principle

A neutral 1N potassium chloride solution is used to leach a soil sample of exchangeable hydrogen and aluminium ions. The acidity brought into solution from various sources in the soil is measured by titration with a standard alkali solution, the amount of alkali used being equivalent to the sum of hydrogen and aluminium ions or exchangeable acidity :



When aluminium is complexed with sodium fluoride, an equivalent quantity of alkali is released:



The exchangeable aluminium may then be measured by titrating the released alkali with standard acid.

Method Validation

None carried out.

Interference and Other Considerations

None identified.

Equipment and Supplies

- Burettes
- Pipettes
- 250 ml Erlenmeyer flasks
- Analytical balance (0.01 g accuracy)
- Volumetric flasks (100 ml)
- Filter paper - Whatman No. 41.

Reagents

- Potassium chloride solution, 1M: Dissolve 74.6 g KCl in deionised water and make up to 1000 ml.
- Sodium Hydroxide Solution, 1 M: Dissolve 20 g of NaOH in de-ionised water, cool and make up to 500 ml with de-ionised water in a volumetric flask.
- Sodium Hydroxide Solution, 0.02 M: Dilute 20 ml of 1 M NaOH to 1000 ml with de-ionised water and standardise with 0.05 N oxalic acid. Note: sodium hydroxide standard solutions have a limited life and need to be standardised after storage.
- Hydrochloric acid 1M: Pipette 42 ml concentrated HCl (37%) into a 500 ml volumetric flask containing about 400 ml of de-ionised water and make to volume with de-ionised water.
- Hydrochloric Acid Solution 0.02 M: Dilute 20 ml of 1 M HCl to 1000 ml with de-ionised water and standardise against 0.02 M NaOH.
- Sodium Fluoride Solution, 1 M: Dissolve 41.99 g of NaF in 800 ml de-ionised water and dilute to 1000 ml with de-ionised water. Filter the solution if turbid. Keep in a polyethylene bottle.
- Phenolphthalein indicator solution, 0.1%: Dissolve 100 mg phenolphthalein in 100 ml ethanol 96%.

Safety and Special Precautions

None identified.

Test Procedure

Leaching

- Transfer 10 g air-dried soil < 2mm (accuracy 0.05 g) to a dry filter paper in a funnel placed in a 100 ml volumetric flask. Include two blanks and a reference sample.
- Add 10 portions of 10 ml 1 M KCl solution at 15 minute intervals so that the leaching takes about 2.5 hours.
- After the last portion has leached, remove the funnel and fill the volumetric flask to the mark with 1 M KCl solution and mix.

Determination of Exchangeable Acidity.

- Pipette a 25 ml aliquot of leachate into a 250 ml Erlenmeyer flask and add 5 drops of phenolphthalein solution.
- Titrate with 0.02 M NaOH until the colour turns just permanently pink, wait for 1 minute, record the amount of NaOH used. *Weakening of the pink colour can be caused by the hydroxy-Al precipitate. This can be remedied by adding another drop of phenolphthalein.*
- Save the solution for the determination of exchangeable aluminium as below.

Determination of Exchangeable Aluminium

- Add 10 ml of 1 M NaF to the solution in the Erlenmeyer flask saved as above.
- Titrate with 0.02 M HCl until the pink colour disappears. Set aside while other samples are titrated and see if end point is completely lasting. If there is a considerable amount of aluminium the pink colour may return. If so, add a few more drops of phenolphthalein and continue titrating with acid until the colour goes permanently.

Data Acceptance and Quality Control

Each batch of 24 samples or less should contain two blanks, a set of duplicate samples and one standard soil. At present no in-house standard soil is available. One of the old ALASA samples which has a pHw between 4 and 5 can be used as a standard.

Calculations and Data Presentation

$$\text{Exchangeable acidity (meq/100 g soil)} = \frac{(a-b) \times 4 \times M \times 100 \times \text{mcf}}{s}$$

Where:

- a = ml NaOH needed for percolate (sample)
- b = ml NaOH needed for blank
- M = molarity of NaOH solution
- s = air-dry sample weight in g (10 g).
- 4 = aliquot factor
- mcf = moisture correction factor (if needed)

The "effective CEC" can then be calculated:

"Effective CEC" (ECEC in meq/100 g soil) = Exch. (Na + K + Ca + Mg + acidity)

$$\text{Exchangeable Al (meq/100 g soil)} = \frac{(a-b) \times M \times 4 \times 100 \times \text{mcf}}{s}$$

Where:

- a = ml HCl needed for the leachate sample
- b = ml HCl needed for blank
- M = molarity of HCl solution
- 4 = aliquot factor
- s = air-dry sample weight in g (10 g)
- mcf = moisture correction factor (if needed)

Other References

Thomas, G.W. 1982. Exchangeable cations. Pages 159-165 in A.L. Page et al., Eds. Methods of soil analysis. Agronomy No. 9, 2nd ed. American Society of Agronomy, Madison, WI.

CALCIUM CARBONATE ESTIMATION

Reference Method

Landon, J.R. Ed. (1991). Booker Tropical Soil Manual, Longman Scientific, Harlow, UK.

Introduction

Calcium carbonate accumulates in soils of semi-arid and arid regions due to insufficient leaching of salts from the soil profile. The zone of accumulation generally lies at the depth of moisture penetration during the rainy season. The rising of the water table during the rainy season may result in calcium carbonate accumulation or mobilisation of more soluble carbonates such as magnesium and sodium carbonate. The source of salts are usually the ground water, weathered primary minerals and sometimes liming materials added to reduce soil acidity.

Scope

The method may be used to estimate the carbonate content of soils in the field or laboratory to assist in classification and the interpretation of other analyses related to the fertility.

Principle

The sample is treated with 10% hydrochloric acid to decompose carbonates. The extent of visible and audible effervescence is used to estimate the carbonate content. Most of the reaction will be due to calcium carbonate but also other carbonates such as dolomite (rich in magnesium carbonate) and sodium carbonate will also react with the acid. Magnesium carbonate tends to react less vigorously.

Method Validation

None.

Interference and Other Considerations

Results should be considered as very approximate due to the variable reaction of different carbonates and the effect of particle size. Care should be taken in cleaning the spotting plate well after each completed batch of samples since dried residues from high carbonate soils from previous tests may give acid reactions due to the contaminant residues. Soils that have become hydrophobic may not wet up when treated with acid. This problem may be overcome by applying a few drops of methanol before the hydrochloric acid.

Sample Requirements

Samples should be air-dried and ground to < 2mm. More finely ground samples may give more consistent results. Dried samples stored under low humidity will show no measurable change in free carbonate with time.

Equipment and Supplies

- Porcelain spotting plate.
- Small spoon or measure

Reagents

- Hydrochloric acid 10%: Carefully add 10 ml of concentrated hydrochloric acid to 90 ml of distilled water in a dropping bottle.

Safety and Special Considerations

Take care to clean up any spills of hydrochloric acid. Violent reaction of acid with carbonates tends to produce a fine acidic spray which may spread outside the confines of the spotting plate.

Test Procedure

- Add a small amount of each ground soil (about 1 g) to the wells of the spotting plate.
- Add enough 10% hydrochloric acid to just saturate the soil.
- Observe the amount of effervescence and listen to the bubbling.
- Refer to the table on the next page to score each soil.

Lab. Description	Field Description	Estimated CaCO ₃ Content	Observations
None	Non-calcareous	< 0.5%	None
Very Low (0)	Barely calcareous	0.5 to 1.0%	Slight fizzing sound
Low (+)	Slightly calcareous	1 to 2%	Slight effervescence confined to individual grains, bubbling moderately audible
Medium (++)	Moderately calcareous	2 to 5%	More general effervescence with bubbling easily audible
High (+++)	Calcareous	5 to 10 %	Moderate effervescence with bubbles up to 3mm in diameter, easily audible
Very High (++++)	Very calcareous	> 10%	Strong effervescence with large bubbles up to 7 mm in diameter, easily audible.

Data Acceptance and Quality Control

Reference samples may be included that are known to contain a range of concentrations such as 1%, 5% and >10% calcium carbonate equivalent.

Calculation and Presentation of Results

The method gives a rough approximation of carbonate content. Other methods are available to measure carbonate concentration more precisely. Results should be expressed in terms of the 6 categories outlined above as the laboratory description.

Other References

None

SULPHATE-S BY TURBIDOMETRY

Reference Method

Adapted from: Bardsley, C.E. and Lancaster, J.D. 1960. Determination of reserve sulfur and soluble sulfates in soils. Soil Sci. Soc. Am. Proc., 24: 265-268.

Introduction

Sulphur is an important plant nutrient that occurs in both organic and inorganic form in soils. It is an important component in many surface waters. Soil sulphate soluble in water or dilute salt solutions gives a reliable indication of the available sulphur status of the soil.

Scope

The method described may be used to estimate the sulphate-S content of soil extracts, water samples and plant extracts or acid digests. Soil sulphate status can be estimated by measuring the sulphate in dilute calcium chloride or water extracts.

Principle

Soil is shaken with 0.01M calcium chloride at a 1:2 extraction ratio for 30 minutes and the sulphate-S content in the filtered extract determined by estimating the turbidity produced by the precipitation of barium sulphate under acidic conditions. The same sulphate assay can be used to estimate sulphate in water and in plant extracts and digests.

Method Validation

None

Interference and Other Considerations

The detection limit is about 1 ppm $\text{SO}_4\text{-S}$ and the working range about 100 ppm. The method gives a reasonably reliable estimate of potential sulphur deficiency in soils and the sulphur status of plant leaf tissue if the procedure is carried out carefully. Care must be taken to develop the turbidity in a consistent way each time and to take measurements within a narrow time frame. The inclusion of calcium in the extracting solution helps to give colourless and clear soil extracts. With some saline or fine textured soil refiltering or centrifugation may be needed to ensure that extracts are initially free of turbidity. Measurements made with the 2:5 water extracts from the pH and electrical conductivity test are often cloudy unless treated with calcium chloride. In the future this method may be superseded by one where the sulphate is measured colourimetrically.

Sample Requirements

Soil samples should be air-dried and ground to < 2 mm. When stored at low humidity in cool conditions the amount of extractable sulphate should be stable over time.

Equipment and Supplies

- Analytical balance
- 125 ml Erlenmeyer extraction flasks
- Filter funnels, Whatman No. 40 or 42 filter paper
- Plastic or glass test tubes and test tube rack
- Volumetric flasks, plastic storage bottles
- Shaker set at 120 oscillations per minute
- Automatic dispensing and sampling pipettes

Reagents

- Calcium chloride (0.01M): Dissolve 1.47 g of $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$ or an equivalent amount of the anhydrous salt per litre of de-ionised water.
- Stock sulphate standard (100 ppm): Dissolve 0.5435 g of dried potassium sulphate (K_2SO_4) in about 800 ml of de-ionised water, add a few drops of concentrated hydrochloric acid and dilute to 1000 ml. Store unrefrigerated.
- Working sulphate standards: Make up working standards of 5, 10, 20, 30, 40, 50 $\mu\text{g SO}_4\text{-S/ml}$ by adding 5, 10, 20, 30, 40 and 50 ml of 100 ppm $\text{SO}_4\text{-S}$ standard to 100 ml volumetric flasks and making up to 100 ml with deionised water. Store refrigerated (good for 3 months).
- Acid Seed (20 $\mu\text{g/ml SO}_4\text{-S}$; 10% HCl): Add 20 ml of 100 ppm $\text{SO}_4\text{-S}$ standard to a 100 ml volumetric flask, add 10 mL concentrated hydrochloric acid and make up to 100 ml with de-ionised water. Store unrefrigerated.
- Barium Chloride (20% w/v; ~0.82M): Dissolve 20.0 g $\text{BaCl}_2 \cdot 2\text{H}_2\text{O}$ to 100 ml in de-ionised water. Store unrefrigerated.

Safety and Special Precautions

None identified.

Test Procedure

Soil Extractions

- Weigh 10.00 g of air-dry <2 mm soil into an Erlenmeyer flask
- Prepare two blank flasks without soil
- Add 20 ml 0.01M calcium chloride extractant
- Shake at 120 oscillations per minute for 30 minutes.
- Allow to settle for 15 minutes and filter through filter paper
- Add 2 ml of extract or standards to test tubes
- Add 0.5 ml of acid seed solution
- Add 0.5 ml of barium chloride solution
- Mix on Vortex mixer
- Allow to sit for 5 minutes
- Read absorbance at 620 nm within 10 minutes
- Samples giving readings higher than the top standard should be diluted in calcium chloride and re-run. This is best done by preparing extra tubes with acid seed and 1.8 ml of calcium chloride. To these may be added 0.2 ml of the concentrated extracts (representing a 10 times dilution of the original extract). This can be done during the 5 minutes "sitting" period by which time the likely high readings can be noted. High soil sulphate is invariably correlated with EC 2:5 readings > 500 μ S/cm.

Plant Digests and Water Samples

- A similar procedure may be carried out but using dilutions of acidic extracts of plant ash or undiluted or diluted water samples. With plant measurements be sure to include appropriate blanks as well as blanks spiked with sulphate to test recovery.

Data Acceptance and Quality Control

With each set of 24 or less samples include two blanks, one set of duplicates and one soil standard (Sulphate Standard 8215). The soil standard should be within 2 standard deviations of the mean value and the duplicates within 10% of each other or within 2 ppm at low levels. Blank readings should be within a range encompassing the historical mean.

Calculation and Presentation of Results

The concentration of sulphate-S in solution is calculated from the calibration curve which should be almost linear. The spectrophotometer gives more stable readings if it is blanked using distilled water. The 0 ppm standard then gives a slightly positive reading due to the presence of sulphate in the acid seed. The results for soil sulphur are:

$$\text{SO}_4\text{-S (}\mu\text{g/g)} = \frac{((A \times D) - B) \times 20}{10}$$

Where:

- A = $\text{SO}_4\text{-S/ ml}$ equivalent to absorbance reading for sample
- B = $\text{SO}_4\text{-S/ ml}$ equivalent to absorbance reading for blank
- D = Extra dilution factor
- 20 = ml in original extract (20 ml)
- 10 = sample weight (10 g)

Other References

None.

CHLORIDE SPOT TEST

Reference Method

None.

Introduction

Chloride is required in small amounts for plant growth but can be toxic at high concentrations. Most soils do not contain excessively high concentrations of chloride. However, chloride may be a dominant soluble anion in certain saline soils. Poor quality irrigation water may contain chloride at concentrations detrimental to plant growth.

Scope

The method may be used to estimate the amount of chloride present in soil, water, manure or plant tissue samples in order to assess the likelihood of problems from high salinity in growth media. It is also helpful in cross-checking sample results to balance cations and anions (chloride, sulphate, carbonate, bicarbonate etc.).

Principle

Soil, manure or plant tissue samples are extracted with water and the amount of chloride estimated by reaction with silver nitrate. Chloride in soil samples can be estimated by filtering the water phase from pH and EC tests. Manure should be extracted at a 5:100 ratio when the total salt concentration can be estimated by an EC measurement. Plant tissue (0.5 g) may be extracted with 25 ml of de-ionised water.

Method Validation

None.

Interference and Other Considerations

Similar reaction is given by iodides and bromides. The test provides a rough approximation of chloride content. Other methods are available to determine chloride concentration more precisely.

Sample Requirements

Soil samples should be air-dried and ground to pass a 2 mm sieve. Plant and manure samples should be dried at no more than 80°C and ground to 40 mesh or 1 mm. Soil, plant and manure samples may be stored in the dry state without significant change in chloride content. Water samples should be stored refrigerated.

Equipment and Supplies

- Suitable extraction flasks, beakers etc.
- Plastic funnels and filtration rack
- test tubes
- Filter paper such as Whatman 40,41 or 42.
- Dilutor
- Sampling pipettes

Reagents

- Silver Nitrate 2%: Dissolve 2 g of silver nitrate in de-ionised water, make up to 100 ml and store in brown glass dropping bottle.
- Chloride Standard 1000 ppm: Dissolve 0.525 g of dry potassium chloride in de-ionised water and make up to 250 ml.

Safety and Special Precautions

Due care should be taken in view of the toxicity of soluble silver salts.

Test Procedure

- Prepare water extracts.
- Allow to stand preferably overnight in a refrigerator..
- Filter into test tubes.
- Take a 2 ml aliquot and add 0.5 ml of silver nitrate.
- Compare the turbidity visually with a dilution series containing 10 to 2000 ug of chloride. Dilutions of samples may be needed to get a more precise estimate. The dilution series can be made by adding e.g. 10, 20, 50, 200, 500, 2000 ul of the 1000 ppm standard and making up to 2000 ul. This will provide concentrations, relative to the original extract of 5, 10, 25, 100, 250 and 1000 ppm chloride.
- The method can be made semi-quantitative at the lower end by measuring turbidity at 620 nm. The dilution series should be in the 0-100 ppm range.

Data Acceptance and Quality Control

No specific quality control standards or procedures are available.

Calculation and Presentation of Results

Results may be expressed in terms of a high, medium, low scale or may be expressed as a rough approximation.

Other References

None.

ORGANIC CARBON (COLOURIMETRIC WALKEY-BLACK METHOD)

Reference Method

Adapted from: Sims J.R. and Haby V.A. 1971. Colorimetric determination of soil organic matter. Soil Science 112:137-141.

Introduction

Measurement of organic carbon content gives a way of estimating the organic matter content of the soil. The amount and type of organic matter can be directly related to moisture holding capacity, the reserves of exchangeable cations, storage and supply of plant nutrients such as nitrogen and phosphorus, and the maintenance of stable soil structure and aeration.

Scope

To measure the content of organic carbon in soil to give an estimate of organic matter content and the C:N ratio. The method is suited to the measurement of the organic carbon content of soils low in organic matter content. The method can also be used to measure the organic carbon content of humus extracts, soil water or polluted waters.

Principle

Organic matter is oxidised with an excess of a concentrated oxidising mixture containing sulphuric acid and potassium dichromate. The amount of unused $K_2Cr_2O_7$ is determined colourimetrically at 600 nm. Results are calibrated against glucose.

Method of validation

By sample exchange through the Agri Laboratories Association of Southern Africa (ALASA).

Interference and Other Considerations

Inorganic constituents that are in a reduced state will also be oxidised by the dichromate and cause the result to be too high. The sample weight must be adjusted to contain no more than 2.8 mg-C per sample. The amount taken normally varies between 100 and 500 mg for surface soils and 300 to 600 mg for sub-surface soils or soils with very low organic matter content. A linear response occurs up to about 2.8 mg-C.

Sample Requirements

Soils should be air-dried and ground to pass a 2 mm sieve. Samples may be stored at low humidity without significant change in the result. More consistent results may be obtained if a small sub-sample is ground to 60 mesh (~ < 0.4 mm).

Equipment and Supplies

- Test tubes and test tube racks.
- Digital pipettes or reagent dispensers.
- Spectrophotometer
- Cuvettes (1 cm light path, square, polycarbonate disposable).

A dedicated set of test tubes should be reserved for this analysis. Samples are conveniently done in batches of 48 and held in racks holding 60 test tubes. Glassware and cuvettes should be washed in tap water immediately after use and rinsed in de-ionised water.

Reagents

- Potassium dichromate solution, 1 N: Dissolve 49.04 g $K_2Cr_2O_7$ (dried at 105°C) in de-ionised water in a 1 litre volumetric flask and make to volume with de-ionised water; store in a glass stoppered bottle.
- Concentrated sulphuric acid (Sp. Gr. 1.84) 98 % (w/w).
- Glucose calibration standard (10 mg/ml): A stock solution is prepared by dissolving 1.000 g of dried glucose in a small amount of de-ionised water in a 100 ml volumetric flask and making up to 100 ml with de-ionised water. The stock solution may be stored deep frozen and thawed out when needed.
- Working glucose standards: Batches of calibration standards are prepared by adding 0.1, 0.2, 0.3, 0.4, 0.5 and 0.7 ml of the thawed stock solution to test tubes and drying overnight at 80 °C. The tubes contain equivalent of 1, 2, 3, 4, 5, and 7 mg of glucose or 0.4, 0.8, 1.2, 1.6, 2.0 and 2.8 mg of glucose-C.

Safety and Special Precautions

Care should be taken in handling the sulphuric acid-potassium dichromate mixture. Additions should be made in a fume cabinet. Suitable protective clothing should be worn.

Test Procedure

- Weigh samples of air-dry soil (<2 mm) to 0.001 g accuracy and transfer to 16 x 120 mm test tubes. Tissue culture tubes with screw caps and teflon or PTFE liners are preferred since they can be mixed by hand without leaking. Samples should contain < 2.8 mg-C. In practice this means ~ 500 mg for samples of < 0.5%

C to < 100 mg for samples > 2% C. A default weight of ~ 250 mg should be used where there is no reliable visual way of estimating the carbon content. Sandy soils should be weighed initially at ~ 350 mg while soils with more clay or visible organic litter should be weighed at 150 to 200 mg.

- Add exactly 1 ml of 1 N $K_2Cr_2O_7$ solution from a pipette or accurate dispenser.
- Carefully add 2 ml concentrated H_2SO_4 down the side of the tube, carry this out in a fume hood using a pipette or dispenser. Considerable care is needed as the reaction may be quite violent.
- Mix well using a vortex mixer set at low vibration speed. At this time note any samples that will obviously give a reading in excess of the high standard. They will have a distinct turquoise-green colour. These samples can be re-weighed immediately and treated as above.
- Place the test tubes rack on a piece of thick cardboard in an oven and heat at 80°C for 60 minutes.
- Take the test tubes out and allow to cool. Add 7 ml of de-ionised water. Allow to cool again. Cap and mix carefully by inverting the tube a few times. Place in a refrigerator overnight to allow sediment to settle. The caps should be removed to prevent undue disturbance when aliquots are removed later.
- Remove a sample of ~2.75 ml using a sampling pipette and place into a spectrophotometer cuvette. It is important not to disturb the sediment. Marking the plastic pipette tip to adjust the depth of penetration into the tube will help in this regard. Measure the absorbance at 600 nm. Standard curve shows little variability between runs and readings are very stable. It is important to sample each tube only once as sediment usually appears if tubes are re-sampled.
- The results are calculated from a calibration curve using the glucose standards. Calculations may be done manually or using the SUNRISE spread sheet. The blanks are used to set zero absorbance. The calibration curve is linear with the top standard giving an absorbance of about 0.600 using 1 cm square cuvettes.

13. Quality Control and Data Acceptance

Within each run of 24 samples or less include two blanks, one set of duplicates and one standard soil. The results are accepted if the result for the standard soil is within two standard deviations of the mean and the duplicates are within 5% or 0.05% for samples with very low carbon contents.

14. Calculation and Presentation of Results

A calculation program is available in SUNRISE.XLS

$$\text{Organic-C (\%)} = \text{mg-C in sample} / \text{mg sample} \times 100$$

Conversion of % carbon to % organic matter is done with the following empirical factor of 1.724:

$$\% \text{ Organic matter} = 1.724 \times \% \text{ carbon}$$

Other References

- Walkley, A. and Black, I.A. 1934. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science* 37:29-38.
- DeBolt D.C. 1974. A high sample volume procedure for the colorimetric determination of soil organic matter. *Commun. Soil Sci. Plant Anal.* 5:131-137.

ORGANIC CARBON (STANDARD WALKLEY-BLACK METHOD)

Reference Method

Nelson D.W and Sommers L.E. 1982. Total Carbon. Organic Carbon and Organic Matter, pages 539-579 in A.L. Page et. al. Methods of Soil Analysis Part 2, 2nd ed., Agronomy No. 9, American Society of Agronomy, Madison, WI.

Introduction

Measurement of organic carbon content gives a way of estimating the organic matter content of the soil. The amount and type of organic matter can be directly related to moisture holding capacity, the reserves of exchangeable cations, storage and supply of plant nutrients such as nitrogen and phosphorus, and the maintenance of stable soil structure and aeration.

Scope

To measure the content of organic carbon in soil to give an estimate of organic matter content and the C:N ratio. The method is suited to the measurement of the organic carbon content of all soils except those classified as organic (e.g. ~>20% organic matter). The method can also be adapted to measure the organic carbon content of humus extracts and the soluble carbon content of soil water using a colourimetric variation.

Principle

Organic matter is oxidised with an excess of a concentrated oxidising mixture containing sulphuric acid and potassium dichromate. The amount of unused $K_2Cr_2O_7$ is determined by titration with ferrous ammonium sulphate or ferrous sulphate using a diphenylamine indicator to detect the first appearance of unoxidized ferrous iron. Phosphoric acid is added to form a complex with ferric iron providing a sharper colour change of indicator.

Method validation

By sample exchange through the Agri Laboratories Association of Southern Africa (ALASA).

Interference and Other Considerations

Inorganic constituents that are in a reduced state will also be oxidised by the dichromate and cause the result to be too high. The sample weight must be adjusted so that between about 35 to 75% of the dichromate is used. The amount taken normally varies between 0.25 g to 2.5 g for surface soils and 2 g to 10 g for sub-surface soils or soils with very low organic matter content. Note that in the method it is assumed that only 77% of the organic matter is oxidised and a factor is included in the calculations to take this into account. The efficiency of oxidation will vary between different soils and this introduces an error.

Sample Requirements

Soils should be air-dried and ground to pass a 2 mm sieve. Samples may be stored at low humidity indefinitely. More consistent results may be obtained if a small sub-sample is ground to 60 mesh (~ < 0.4 mm).

Equipment and Supplies

- Burettes, 500 ml Erlenmeyer flasks
- Reagent dispensers 10 ml and 20 ml.

Reagents

- Potassium dichromate solution, 1 N: Dissolve 49.04 g $K_2Cr_2O_7$ (dried at 105°C) in distilled water in a 1 litre volumetric flask and make to volume with distilled water; store in a glass stoppered bottle.
- Concentrated sulphuric acid (Sp. Gr. 1.84) 98 % (w/w).
- Concentrated orthophosphoric acid (H_3PO_4) (Sp. Gr. 1.75).
- Barium diphenylamine sulphonate indicator, 0.16 %: Dissolve 0.16 g of barium diphenylamine sulphonate in 100 ml of distilled water.
- Ferrous sulphate solution 0.5 N: Dissolve 139 g $FeSO_4 \cdot 7H_2O$ in 750ml of water, add 20 ml concentrated H_2SO_4 , transfer to a 1 litre volumetric flask and make to volume with distilled water.
- Or Mohr's salt ($Fe(NH_4)_2(SO_4) \cdot 6H_2O$): Dissolve 196.10 g of pure ferrous ammonium sulphate in 800ml of distilled water in a 1 litre volumetric flask, add 20 ml concentrated H_2SO_4 and make to volume with distilled water.

Safety and Special Precautions

Care should be taken in handling the sulphuric acid-potassium dichromate mixture.

Test Procedure

- Weigh between 0.25 and 5.0 g of air-dry soil (<2 mm) and transfer to a 500 ml Erlenmeyer flask. During the reaction with ferrous sulphate, it is necessary that the drop in the burette reading should be between 7 and 15 ml. All samples in which less than 7 ml or greater than 15 ml of ferrous sulphate 0.5 N were consumed should be repeated.

- Add 10ml 1 N $K_2Cr_2O_7$ solution from a dispenser. Include two blanks (Erlenmeyer flasks without soil) to standardise the ferrous sulphate solution.
- Carefully add 20 ml concentrated H_2SO_4 with measuring cylinder in the fume cupboard and swirl the flask and allow to stand on an asbestos or cork pad for 30 minutes.
- Then add 200 ml distilled water and allow to cool.
- Add 10 ml conc. Orthophosphoric acid and just before titration, add 0.5 ml of barium diphenylamine sulphonate indicator.
- Titrate with 0.5 N ferrous sulphate solution the colour changes to purple or blue then add ferrous sulphate solution drop by drop until the colour flashes to green then continue to a light green end point. The end-point is easily overshoot, in that case add 0.50 ml of the dichromate solution and titrate again dropwise (change calculation accordingly).
- Carry out a blank titration the same way as for the sample.

Quality Control and Data Acceptance

Within each run of 24 samples or less include two blanks, one set of duplicates and one standard soil. The results are accepted if the result for the standard soil is within two standard deviations of the mean and the duplicates are within 5% or 0.05% for samples with very low carbon contents.

Calculation and Presentation of Results

A calculation program is available in SUNRISE.XLS

In this method it is assumed that about 77 percent of the C is oxidised by potassium dichromate, so a correction factor of $100/77 = 1.33$ is used in the calculation.

$$\% C = N \times \frac{V_1 - V_2}{S} \times 0.39 \times mcf$$

Where:

- N = normality of ferrous sulphate solution (from blank titration).
- V_1 = ml ferrous sulphate solution used for blank.
- V_2 = ml ferrous sulphate solution used for sample.
- S = weight of dry-air sample in gram
- 0.39 = $3 \times 10^3 \times 100 \% \times 1.3$ (3 = equivalent weight of carbon).
- mcf = moisture correction factor (if used).

Conversion of % carbon to % organic matter is done with the following empirical factor of 1.724:

$$\% \text{ Organic matter} = 1.724 \times \% \text{ carbon}$$

Other References

Soil Science Society of South Africa. 1990. Handbook of Standard Soil Testing Methods for Advisory Purposes, pages 34-1 to 34-2.

Walkley, A. and Black, I.A. 1934. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Science 37:29-38.

AVAILABLE PHOSPHORUS IN SOIL (OLSEN METHOD)

Reference Methods

Shoenau, J.J. and Karamanos, R.E. 1993. Sodium Bicarbonate-Extractable P, K and N, pages 51-58 in Soil Sampling and Methods of Analysis, M.E. Carter Ed., Canadian Society of Soil Science, Lewis Publishers.
Soil Science Society of South Africa. 1990. Pages 24-1 to 24-3 in Handbook of Standard Soil Testing Methods for Advisory Purposes, SSSSA, Pretoria, RSA.

Introduction

Phosphorus is an essential element for plant nutrition and prediction of the availability of phosphorus in the soil is vital for optimum crop yield. A number of methods have been proposed for the determination of available phosphorus which appear to give rational estimates of the plant available phosphorus under different soil conditions. The Olsen Method is described here is recommended for alkaline to neutral soils.

Scope

The extraction method is recommended for neutral to alkaline soils. As long as criteria for pH control are in place, the colourimetric method can be used to measure phosphate-P in other soil extracts, water samples and acidic extracts or digests of plant tissue and manure.

Principle

The sample is extracted with a 0.5M sodium bicarbonate solution at pH 8.5. Phosphate in the extract is determined colourimetrically by the blue ammonium molybdate method of Murphy and Riley using ascorbic acid as reducing agent.

Method Validation

By direct reference to results of ALASA soil samples.

Sample Requirements

Soils should be air-dried and ground to pass a 2mm mesh sieve. Samples may be stored at low humidity with little change in available-P. Extractable phosphate may be less stable under hot moist storage condition.

Interference and Other Considerations

None identified.

Equipment and Supplies

- Spectrophotometer suitable for measurement at 882 nm.
- Extraction flasks
- Reciprocating shaking machine
- Funnel racks, filter funnels and collecting containers such as plastic or glass test tubes (16x120 mm)
- Whatman No. 40 or 42 filter paper, volumetric flasks and pipettes

Reagents

- **Sodium Bicarbonate Solution, 0.5 M, pH 8.5 (extracting solution):** Dissolve 420 g NaHCO₃ in distilled water and make to 10 litres. Adjust to pH 8.5 by adding 50% NaOH (10 g/20 ml). Check and readjust the pH if the extracting solution has been stored for some time.
- **Sulphuric Acid, 4 M:** Slowly add 56 ml conc. H₂SO₄ (96 %) to about 150 ml of cold distilled water in a 250 ml volumetric flask make up to 250 ml with distilled water.
- **p-nitrophenol indicator:** Dissolve 0.1 g of p-nitrophenol in 100 ml ethanol.
- **Stock Colour Reagent:** Dissolve 12g of (NH₄)₆Mo₇O₂₄.4H₂O in 250 ml of de-ionised water. Dissolve 0.291 g of potassium antimony tartrate (KSbOC₄H₄O₆) in de-ionised water and make to 100 ml. Carefully add, with stirring, 148 ml of concentrated sulphuric acid to 1000 ml of de-ionised water. Add the ammonium molybdate solution and then the potassium antimony tartrate solution to the sulphuric acid and make up to 2000 ml. Store at room temperature. Replace every three months.
- **Working Colour Reagent (made up daily):** Dissolve 1.056 g of ascorbic acid in 200 ml of the stock colour reagent. If the reagent has any blue colour discard and make up again.
- **Washed activated charcoal:** Shake 100 g of activated charcoal with 200 ml of sodium bicarbonate extracting solution. Filter under slight suction through a Buchner funnel. Rinse with fresh extracting solution until free of phosphate (if needed, test portions of filtrate with colour reagent). Oven dry and store in a wide-mouthed plastic container.
- **Standard Phosphate solution, 100 mg/l P:** Dissolve 0.4390 g KH₂PO₄ (dried at 110 °C for 2 hours in an oven) in distilled water in a 1 litre volumetric flask and make to volume with distilled water. Also diluted standards can be made from commercial standards.
- **Standard Phosphate Solution, 4 mg/l P:** Pipette 10 ml of the 100 mg/l P standard solution into a 250 ml volumetric flask and make to volume with extracting solution.

- **Working Standard series:** Pipette into 100 ml volumetric flasks 0-10-20-30-40-50 ml of the 4 mg/l P standard solution. Make to volume with extracting solution. The standard series is 0, 0.4, 0.8, 1.2, 1.6, 2.0 mg/l. Store refrigerated. New working standards should be prepared each month.

Safety and Special Precautions

None identified.

Test Procedure

Soil extracts

- Weigh 5 g of air dry < 2 mm soil (accuracy 0.01 g) into a 125 ml flask. Prepare one blank without any soil.
- Add 1 scoop (about 0.3 g) of activated charcoal and 50 ml of extracting solution and shake for 30 minutes.
- Filter through a Whatman No. 40 or 42 filter paper into clean containers (test tubes or flasks).
- Determine the amount of 4M sulphuric acid needed to change 5 ml of extracting solution from pH 8.5 to pH 5 to 5.5 (colour change of p-nitrophenol from yellow to colourless). This should be about 300 μ L.
- Pipette 5 ml of the standard series, the blanks and the sample extracts into 25 ml volumetric flasks.
- Add about 10 ml de-ionised water and 1 drop of p-nitrophenol indicator.
- Add the determined amount of sulphuric acid and carefully mix (CO_2 evolution).
- If the solution is still yellow add more acid drop-wise until the yellow colour changes to colourless.
- Add 4 ml of colour reagent and mix well to release any more bubbles of carbon dioxide. Add de-ionised water to almost fill the bulb of the flask. Shake again and allow the blue colour to develop for about 30 minutes.
- Fill each flask to the mark with de-ionised water and read absorbance on spectrophotometer at 882 nm. Blank the spectrophotometer with the zero standard.
- Samples that give readings greater than the highest standard should be diluted 5 times (1 part in 4 parts of sodium bicarbonate) and the colour developed as previously described.

Water Samples

- Carry out analysis as for soil extracts.

Plant Leaf Digests

- Use 50 to 200 μ L of the original nitric acid extract from the ashing process. The pH should be adjusted with a few drops ~ 0.5M sodium hydroxide until the p-nitrophenol indicator turns yellow. Dilute the 4M sulphuric acid and add drops until the indicator just turns colourless again. Proceed with the colour development as outlined for soil extracts. Carry out the same procedure with the "ash blank" and an "ash blank" spiked with phosphate-P to test the recovery.

Data Acceptance and Quality Control

In each run of 24 samples include one reagent blanks, one duplicate and one standard soil (P Standard 821834). Check the drift during the colour measurement by inserting the 4th standard between every 12 samples. Quality control samples should fall within two standard deviations as calculated on the control sheets. Duplicates will fall within 5% of each other.

Calculation and Presentation of Results

Results may be calculated manually or using the calculation facilities on the spectrophotometer. Whatever the method, a calibration graph of absorbance against P concentration should be prepared and filed with the results.

$$P(\text{ppm or mg/Kg soil}) = (a - b) \times \frac{50}{1000} \times \frac{1000}{s} \times \text{mcf} = (a - b) \times \frac{50}{s} \times \text{mcf}$$

Where:

- a = mg/l P in the sample extract
- b = mg/l P in blank
- s = sample weight in gram (5 g)
- mcf = Moisture Correction Factor (if determined)
- 50 = ml of extracting solution.

Farm soil results should be quoted to the nearest ppm. Research samples may be quoted to 0.1 ppm.
Conversion factor $\text{P}_2\text{O}_5 = 2.31 \times \text{P}$

Other References

- Murphy, J. and Riley, J.P. 1962. A modified single solution method for the determination of phosphate in natural waters. *Anal. Chim. Acta*, 27: 31-36.
- Olsen, S. R., and L. A. Dean. 1965. Phosphorus pages 1044 - 1046, in C. A. Black (ed.). *Methods of Soil Analysis*, Agronomy No. 9. American Society of Agronomy, Madison, WI.

ORGANIC MATTER BY LOSS-ON-IGNITION

Reference Method

Schulte, E.E., Kaufmann, C., and Peter, J.B. 1991. The influence of sample size and heating time on soil weight loss-on-ignition. *Commun. Soil Sci. Plant Anal.* 22: 159-168.

Introduction

The determination of soil organic matter content is an important since it is directly related to moisture holding capacity, the reserves of exchangeable cations, storage and supply of plant nutrients such as nitrogen and phosphorus, and the maintenance of stable soil structure and aeration. The different components that make up the organic matter in soils are very varied and include plant, animal and microbial residues as well as stabilised products of decomposition generally termed humus. The range of compounds that may be identified include carbohydrates such as simple sugars, fats, and oils as well as more complex polymers in the form of hemicellulose, cellulose, lignin, waxes and resins. Nitrogen containing compounds include proteins, nucleic acids as well as individual amino acids and amines. It is difficult to measure the soil organic matter content precisely due to this complexity. An approximation of organic matter content is given by measuring the weight loss when soil organic matter is removed by burning in a muffle furnace. Other indirect measurements involve separation into fractions using proximate analysis techniques, extraction of humus fractions using strong acids and alkalis, or measuring the organic carbon content and converting this to organic matter using a suitable multiplication factor.

Scope

The method can be used to estimate the organic content of mineral soils, organic soils, manure and plant tissue. Results with mineral soils may require calibration against the results of organic carbon analysis from soils of similar origin using methods that measure the release of carbon dioxide during sample combustion.

Principle

A soil sample is dried at 150 °C and then heated in a muffle furnace at 360 °C. The loss in weight between 150 °C and 360 °C gives an approximation of the total soil organic matter content. Errors may arise when soils contain inorganic constituents that are volatile at the temperature used or do not lose all their bound water at 150 °C. The presence of carbonates should not interfere at the combustion temperature used. A higher combustion temperature of 500 °C is used to ash plant and manure samples for elemental analysis.

Method Validation

Calibration against carbon content measured by the Walkley-Black method and using a high temperature induction furnace is underway using ALASA samples and a set of typical local soils.

Interferences and Other Considerations

Even though a relatively low combustion temperature is used there is still some loss in weight from non-organic soil components. A regression equation should be established to relate the loss-on-ignition results of local soils that have a range of organic matter contents encompassing that in the unknowns with the results of organic carbon analysis using other standard methods such as Walkley-Black oxidation or infra-red detection of carbon dioxide following high temperature combustion for example using a Leco Carbon Analyser. Different calibration curves may be needed for soils originating from different areas.

Sample Requirements

Soils should be air-dried and ground to pass a 2 mm sieve. Samples may be stored at low humidity indefinitely without significant loss of organic matter.

Equipment and Supplies

- Porcelain crucibles of about 50 ml capacity
- Drying oven
- Muffle furnace
- Analytical balance (0.001 g sensitivity)

Reagents

None.

Safety and Special Precautions

Care should be taken when removing samples from the hot muffle furnace. Use gloves and long-handled tongs.

Test Procedure

- Add between 5 to 10 g of sieved soil (< 2 mm) into the crucible that has been previously dried and weighed. Reweigh the soil plus crucible to 0.001 g.
- Dry the sample over-night at 150°C, cool in a desiccator and reweigh.
- Place the crucible into a muffle furnace and bring the temperature to 360 °C. Ash in the furnace at 360 °C for 4 hours. Allow to cool over-night.

- Place warm crucibles in a dessicator and reweigh when cool.

Data Acceptance and Quality Control

With each set of 24 or less samples include one standard soil (1997 Red) and one set of duplicates. ALASA samples of verified LOI may be included intermittently as blind samples.

Calculation and Presentation of Data

Organic matter content should be expressed as a % to the accuracy of 2 decimal places. The percent organic matter in the soil is determined by the formula:

$$\% \text{ Organic Matter (OM)} = \frac{[W150 - W360]}{W150} \times 100,$$

Where: W150 = weight of soil at 150 °C

W360 = weight of soil at 360 °C

The moisture correction factor (mcf) can be determined from the weight difference between air-dry and oven dry weights. This can be used in other analyses to convert results from an air-dry to an oven-dry basis. All these calculations may be found in the excel file SUNRISE.XLS.

Other references

David, M.B. 1988. Use of loss-on-ignition to assess soil organic carbon in forest soils. Commun. Soil Sci. Plant Anal. 19:1593-1599.

Davies, B.E. 1974. Loss-on-ignition as an estimate of soil organic matter. Soil Sci. Soc. Amer. Proc. 38:150-151.

BULK DENSITY

Bulk density is defined as the mass (weight) of a unit volume of dry soil. This volume refers to both the solids and the pores, where:

$$\text{Bulk density} = \frac{\text{weight of oven dry soil (solids only)}}{\text{volume of soil (solids + pores)}}$$

Bulk density measurements are made gravimetrically on soils sampled in undisturbed field conditions.

Test procedure

- A cylindrical steel sampling ring with a bevelled cutting edge is inserted into the profile face at known depths, and carefully extracted without disturbing the contents. Excess soil is sliced off the top and bottom of the ring with a thin blade and the contents are stored in a sealed plastic bag.
- The bag and contents are weighed using a scale of 0.0001g accuracy before opening. The contents are then removed.
- The empty bag together with the sealing material, and the contents emptied out of it, are separately weighed to cross-check the combined weight of the soil solids and pores occupied by water. This measurement is referred to as the 'wet weight'.
- The sample in its 'wet weight' condition is placed in a pre-weighed crucible, oven-dried at 105°C for 48 hours, cooled and re-weighed. The weight of the container is subtracted from the total weight. It is assumed that the oven-dried sample is free of moisture and therefore provides a reliable estimation of the weight of soil solids only.
- The oven-dry weight of the sample is subtracted from the 'wet weight' to determine moisture content under field conditions.
- The volume of the soil sampling ring is calculated to determine a known volume occupied by the soil sample in field conditions.
- The bulk density of each sample is calculated using the oven-dry weight in the equation above.

Soils with a high proportion of pore space to solids have lower bulk densities compared to those that are more compact and contain less pore space. Thus, fine textured surface soils such as silt loams, clays, and clay loams generally have lower bulk densities than sandy soils. The solid particles of fine-textured soils tend to be organised in porous grains or granules, especially if adequate organic matter is present. This condition assures high total pore space and low bulk density. In sandy soils, however, organic matter contents are generally low, solid particles are large relative to the spaces between them, and bulk densities are commonly higher than in the finer textured soils.

Bulk densities of clay, clay loam and silt loam surface soils range from 1 to 1.6 g/cm³, depending on their condition. Sands and sandy loams vary from 1.2 to 1.8 g/cm³. Compact sandy subsoils may have bulk densities of 2.0 g/cm³ or greater.

There is a tendency for the bulk density to rise with profile depth. This can result from a lower organic matter content, less aggregation and root penetration, and compaction caused by the weight of the overlying layers.

Bulk density measurements are used to estimate levels of soil compaction and in the calculation of soil porosity values. The results can be used as reliable indicators of problems relating to root penetration and soil aeration. Factors such as moisture content, organic matter level, root penetration, soil texture and cattle trampling can all affect the bulk density. Trampling for example can increase the bulk density, whereas an increase in organic matter will decrease it. An increase in bulk density of soil may impose stresses on plant root systems insofar as mechanical resistance to root penetration will increase. Air-porosity of the soil will also decrease, possibly restricting air supply to plant roots and facilitating the accumulation of toxic products. Permeability also decreases with increasing density.

Systems of crop and soil management on a soil will also influence its bulk density, particularly of the surface layers. Crop residues or animal manure in large amounts tends to lower the weight figure of surface soils; in contrast intensive cultivation produces the opposite effect (cropping increases the bulk density of top soils).

WATER CONTENT (WEIGHT %)

Knowledge of soil-water relations are essential for a number of reasons: (i) large quantities of water must be supplied to satisfy requirements of growing plants and crops since water is lost by evapo-transpiration. The water must be available when plants need it, and most of it must come from the soil; (ii) water plus dissolved nutrients make up the soil solution; (iii) soil moisture helps control two other important components essential to normal plant growth and crop production.- soil air and soil temperature.

Soil-water content is determined by gravimetric methods. This is the weight of soil samples before and after oven drying for 48 hours at 105°C; the loss in weight on drying is expressed as a percentage of the weight of the oven-dry

soil (w/w%). This test is combined with measurements of bulk density (bulk density is calculated by dividing the volume of the sample into the oven-dry weight).

TOTAL POROSITY

The quantity of pores and their size distribution in a soil (as reflected in estimates of total pore space, coarse porosity and air-filled porosity) are useful general indicators of the physical condition of soils. Apart from quantity and distribution, the tortuosity and continuity of pores are important features influencing aeration, water movement as well as root penetration in soils. However, pore characteristics change with seasons and they are not readily quantifiable in their influence on crop productivity.

For the evaluation of soil potential, a system devised by Jongerius (1957) has been widely employed, using the following classes to describe observations of pore size.

1. Coarse (macro) pores - macropores have diameters greater than 0.1 mm, and their main function is aeration and drainage by gravity flow. They are the pores in which roots proliferate and are visible to the naked eye.
2. Medium (meso) pores - mesopores have diameters from 0.03 to 0.1 mm, and their main function is the conduction of water by rapid capillary flow. They are visible at 10x magnification.
3. Fine (micro) pores - have diameters less than 0.03 mm, and their main function is water retention and slow capillary flow. Micropores are not visible, but their presence can be inferred from observations made from the face of aggregates: when the aggregates have a rough surface, there are many micropores.

For the soil to allow good root penetration, it should contain an adequate number of pores of >0.25 mm diameter; to allow free drainage, at least 10% by volume of the soil in the rooting depth should be composed of interconnected pores > 0.05 mm; and for storage of available water, at least 10% by volume of water should consist of pores with diameter ranging from 0.005 and 0.05 mm.

The total porosity (total pore space) of a soil is calculated from the bulk density and the particle density. The bulk density is obtained from the weight of dry soil over the volume of the cylindrical cutter. The particle density of most soils is normally assumed to be 2.65g/cm³. The total porosity is normally expressed as a volume percentage and is equal the volume % water content at saturation, where:

$$\text{Total porosity (volume \%)} = 1 - (\text{dry bulk density} / \text{particle density}) * 100$$

Total porosity values usually range between 30 and 70% and may be used as a very general indication of the degree of compaction in a soil in the same way as bulk density is used. For example, sands with a total pore space of less than about 40% are liable to restrict root growth due to excessive strength, whilst in clay soils limiting total porosities are higher, and less than 50% can be taken as a corresponding value. Unlike bulk density values however, porosity values can not be used as *conclusive* evidence for over-compaction problems in soil, but rather as indicators of likely risk. The porosity calculation only gives the overall volume percentage of the pore space and does not characterize the size of the individual pores.

APPENDIX 4
SAMPLE SITE LOCATION DATA

Soil Test Pit and Auger Site Co-ordinates

Site No.	Site Type	degS	minS	LATITUDE	degE	minE	LONGITUDE
A1	Test Pit	18	33.263	-18.554383	18	33.453	18.557550
A2	Test Pit	18	32.210	-18.536833	18	12.240	18.204000
A3	Test Pit	18	32.570	-18.542833	18	18.940	18.315667
A4	Test Pit	18	24.560	-18.409333	19	18.070	19.301167
A5	Test Pit	17	37.813	-17.630217	18	8.323	18.138717
A6	Test Pit	17	36.613	-17.610217	18	7.968	18.132800
A7	Test Pit	17	53.741	-17.895683	20	12.740	20.212333
A8	Test Pit	17	53.511	-17.891850	20	15.043	20.250717
A9	Test Pit	17	54.264	-17.904400	20	10.572	20.176200
A10	Test Pit	18	8.900	-18.148333	20	46.335	20.772250
A11	Test Pit	18	9.691	-18.161517	20	46.183	20.769717
A12	Test Pit	18	10.807	-18.181783	20	45.740	20.762333
A13	Test Pit	18	16.526	-18.275433	20	44.836	20.747267
A14	Test Pit	18	22.764	-18.379400	20	43.187	20.719783
A15	Test Pit	18	29.976	-18.499600	20	44.615	20.743583
A16	Test Pit	18	30.049	-18.500817	20	44.469	20.741150
A17	Test Pit	18	30.255	-18.504250	20	44.460	20.741000
A18	Test Pit	18	30.389	-18.506483	20	45.251	20.754183
A19	Test Pit	18	30.300	-18.505000	20	47.912	20.798533
A20	Test Pit	18	32.777	-18.546283	20	56.144	20.935733
A21	Test Pit	18	35.416	-18.590267	20	52.685	20.878083
A22	Test Pit	18	55.293	-18.921550	20	56.345	20.939083
A23	Test Pit	18	58.527	-18.975450	20	55.551	20.925850
A24	Test Pit	18	59.270	-18.987833	20	54.870	20.914500
A25	Test Pit	19	0.905	-19.015083	20	53.194	20.886567
A26	Test Pit	19	6.431	-19.107183	20	42.432	20.707200
A27	Test Pit	19	1.750	-19.029167	20	30.589	20.509817
A28	Test Pit	19	2.120	-19.035333	20	51.150	20.852500
A29	Test Pit	19	2.864	-19.047733	20	19.305	20.321750
A30	Test Pit	18	50.048	-18.834133	20	13.709	20.228483
A31	Test Pit	18	44.098	-18.734967	20	16.753	20.279217
A32	Test Pit	18	42.564	-18.709400	20	9.178	20.152967
A34	Test Pit	18	52.440	-18.874000	19	40.603	19.676717
A35	Test Pit	18	52.124	-18.868733	19	40.940	19.682333
A36	Test Pit	18	51.840	-18.864000	19	37.490	19.624833
A37	Test Pit	18	51.436	-18.857267	19	31.858	19.530967
F1	Test Pit	17	28.964	-17.482733	18	26.814	18.446900
F2	Test Pit	17	30.746	-17.512433	18	23.722	18.395367
F3	Test Pit	17	30.735	-17.512250	18	23.698	18.394967
B1	Auger	17	29.005	-17.483417	18	26.507	18.441783
B2	Auger	17	29.280	-17.488000	18	25.804	18.430067
B3	Auger	17	29.965	-17.499750	18	24.829	18.413817
B4	Auger	17	33.808	-17.563467	18	19.212	18.320200
001	Auger	17	33.263	-17.554383	18	56.799	18.946650
002	Auger	17	36.949	-17.615817	18	16.31	18.271833
003	Auger	17	10.821	-17.680350	18	17.68	18.294667
PH A11	Auger	17	47.992	-17.799867	18	33.425	18.557050
PH A12	Auger	17	48.689	-17.811483	18	43.628	18.727133
004	Auger	17	47.681	-17.794683	18	36.765	18.612750
NCI	Auger	17	47.343	-17.789050	18	50.431	18.840517
005	Auger	17	57.702	-17.961700	18	44.292	18.738200
006	Auger	17	55.384	-17.923067	18	45.251	18.754183
007	Auger	17	59.738	-17.995633	18	43.946	18.732433
008	Auger	18	3.719	-18.061983	18	43.84	18.730667
PH A13	Auger	18	4.4181	-18.073635	18	43.877	18.731283
009	Auger	18	3.404	-18.056733	18	43.884	18.731400
010	Auger	18	11.387	-18.188783	18	43.895	18.731583
011	Auger	18	13.566	-18.226100	18	44.009	18.733483
012	Auger	18	14.558	-18.242633	18	44.014	18.733567
013	Auger	18	19.549	-18.325817	18	44.444	18.740733
014	Auger	18	20.015	-18.333583	18	44.475	18.741250
015	Auger	18	24.005	-18.400083	18	44.789	18.746483
016	Auger	18	29.287	-18.488117	18	44.943	18.749050
017	Auger	18	34.196	-18.569933	18	51.254	18.854233

APPENDIX 5
SOIL CHEMISTRY
AND
PHYSICAL PROPERTIES

Chemical Properties: Raw Data

Unique ID	Site No.	Field Sample ID	Sample Depth (cm)	Organic Matter %	Moisture Content (%)	Phosphorus (mg/kg)	Electrical Conductivity (µS/cm)	CEC (me/100g soil)	pH (H ₂ O)	Organic Carbon %	CaCO ₃ (quant.)	SO ₄ (S µg/g)	Ca (ppm)	Mg (ppm)	K (ppm)	Na (ppm)	Cu (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)
B1	A1	A1B (a)	0-30			1.5	8.9	0.24	5.5	0.12	low pH	16.4	22	7	17	5	<0.5	<0.2	<0.5	0.8
B2	A2	A2B (a)	0-30			0.3	20.8	3.82	6.8	0.28	7.5	1.2	422	161	133	11	<0.5	<0.2	<0.5	<0.5
B3	A3	A3B (a)	0-30	0.13	0.8	0.7	7.0	0.61	5.3	0.17	low pH	3.6	14	58	12	6	<0.5	<0.2	<0.5	0.5
B4	A4	A4B (a)	0-30	0.16	0.2	0.2	12.6	1.88	6.3	0.19	low pH	7.2	203	66	35	6	<0.5	<0.2	<0.5	<0.5
B5	A5	A5B (a)	5-30			0.4	6.5	0.89	5.8	0.18	low pH	5.9	61	63	16	5	<0.5	<0.2	<0.5	0.3
B6	A5	A5B (b)	53-70			0.5	6.3	0.52	5.9	0.12	low pH	8.6	31	36	16	5	<0.5	<0.2	<0.5	1.6
B7	A6	A6B (a)	15-30	0.15	0.5	0.2	13.9	1.55	5.9	0.23	low pH	9.1	120	101	30	7	0.8	<0.2	<0.5	<0.5
B8	A7	Not sampled																		
B8	A8	A8B (a)	0-30	0.15	1.1	0.9	35.7	2.81	8.4	0.24	12.0	7.0	440	53	86	23	<0.5	<0.2	<0.5	<0.5
B9	A8	A8B (b)	30-60	0.32	5.2	0.3	125.2	5.09	8.1	0.26	<1	1.5	596	199	92	54	<0.5	<0.2	<0.5	<0.5
B10	A9	A9B (a)	0-30	0.08	0.4	0.2	6.0	0.47	6.4	0.14	low pH	8.8	54	19	6	5	<0.5	<0.2	<0.5	0.3
B11	A9	A9B (b)	30-60	0.07	0.9	<0.1	30.9	0.26	5.0	0.09	low pH	10.1	22	13	5	5	<0.5	<0.2	<0.5	1.1
B12	A10	A10B (a)	0-30			<0.1	8.9	0.43	5.5	0.29	low pH	14.1	44	12	9	5	<0.5	<0.2	<0.5	1.2
B13	A11	A11B (a)	0-30			<0.1	10.4	0.37	5.1	0.29	low pH	12.2	13	4	10	5	<0.5	<0.2	<0.5	<0.5
B14	A11	A11B (b)	30-60			<0.1	9.9	0.15	4.8	0.11	low pH	8.8	4	2	5	3	<0.5	<0.2	<0.5	<0.5
B15	A11	A11B (c)	>75	0.04	0.4	<0.1	7.8	0.07	4.9	0.05	low pH	2.8	4	2	5	3	<0.5	0.2	<0.5	<0.5
B16	A12	A12B (a)	0-30			0.1	58.2	3.32	7.7	0.27	<1	2.8	508	83	27	6	<0.5	<0.2	<0.5	<0.5
B17	A12	A12B (b)	40-70	0.14	1.9	<0.1	32.0	2.63	7.3	0.14	3.6	5.1	283	137	14	11	<0.5	<0.2	<0.5	<0.5
B18	A12	A12B (c)	80-90	0.11	1.5	<0.1	24.2	1.80	6.3	0.10	low pH	5.4	204	88	12	5	<0.5	<0.2	<0.5	<0.5
B19	A13	A13B (a)	0-25			<0.1	12.3	1.44	5.9	0.22	low pH	2.3	120	89	28	7	<0.5	<0.2	<0.5	0.9
B20	A13	A13B (b)	25-40	0.15	0.6	<0.1	10.2	1.27	5.5	0.14	low pH	9.1	87	93	14	6	<0.5	<0.2	<0.5	2.1
B21	A13	A13B (c)	40-80	0.11	0.7	<0.1	12.3	1.25	5.3	0.03	low pH	4.4	85	92	11	7	<0.5	<0.2	<0.5	1.1
B22	A14	A14B (a)	0-30			<0.1	8.9	0.23	5.5	<0.01	low pH	9.1	24	8	9	3	<0.5	<0.2	<0.5	0.8
B23	A14	A14B (b)	30-70			<0.1	5.4	0.08	5.4	<0.01	low pH	7.0	8	2	2	2	<0.5	<0.2	<0.5	<0.5
B24	A14	A14B (c)	70-90	0.06	3.8	<0.1	55.4	2.64	7.5	<0.01	<1	8.3	73	10	12	496	<0.5	<0.2	0.8	<0.5
B25	A14	A14B (d)	>90	0.01	9.8	<0.1	6.9	0.07	5.8	<0.01	low pH	11.2	5	1	2	6	<0.5	<0.2	<0.5	<0.5
B26	A15	A15B (a)	0-30			0.2	18.9	0.73	6.6	0.09	low pH	16.4	103	20	9	4	<0.5	<0.2	<0.5	1.1
B27	A15	A15B (b)	30-60	0.06	0.2	<0.1	9.0	0.85	6.0	<0.01	low pH	33.0	139	14	6	4	<0.5	<0.2	<0.5	<0.5
B28	A16	A16B (a)	0-30			<0.1	8.8	0.38	5.7	0.04	low pH	18.8	50	12	6	3	<0.5	<0.2	<0.5	<0.5
B29	A16	A16B (b)	30-70	0.04	0.2	<0.1	5.1	0.18	5.2	<0.01	low pH	15.4	17	7	6	3	<0.5	<0.2	<0.5	<0.5
B30	A17	A17B (a)	0-30			<0.1	13.5	1.20	6.4	0.22	low pH	13.5	182	30	9	4	<0.5	0.4	<0.5	<0.5
B31	A17	A17B (b)	30-60	0.08	0.2	<0.1	12.3	0.98	6.8	0.08	<1	14.6	152	23	4	4	<0.5	0.4	<0.5	<0.5
B32	A17	A17B (c)	>60	0.07	0.5	<0.1	15.2	0.64	7.0	<0.01	<1	9.9	95	12	13	7	<0.5	<0.2	<0.5	<0.5
B33	A18	A18B (a)	0-15			1.3	122.4	13.02	6.3	<0.01	66.0	3.0	2160	230	63	13	<0.5	<0.2	<0.5	0.8
B34	A18	A18B (b)	15-35	0.91	8.6	0.8	178.4	36.81	8.3	<0.01	65.9	14.3	7146	84	57	53	<0.5	<0.2	<0.5	1.5
B35	A19	A19B (a)	0-20	1.06	14.3	0.7	6.9	5.26	8.5	<0.01	65.9	64.0	399	79	88	550	<0.5	<0.2	<0.5	<0.5
B36	A20	A20B (a)	0-35			0.1	30.2	2.72	7.0	0.29	<1	19.8	394	80	19	9	<0.5	<0.2	<0.5	<0.5
B37	A20	A20B (b)	40-80	0.15	0.9	0.1	13.1	2.27	6.6	0.10	low pH	14.3	282	96	13	7	<0.5	0.5	<0.5	<0.5
B38	A21	A21B (a)	0-10			0.2	103.6	6.22	8.6	0.29	<1	3.0	1082	40	73	66	<0.5	<0.2	<0.5	<0.5
B39	A21	A21B (b)	10-20	0.12	1.8	<0.1	471.0	5.40	9.9	0.06	<1	6.7	469	19	20	653	<0.5	<0.2	<0.5	<0.5
B40	A21	A21B (c)	20-40	0.11	4.6	0.1	936.0	9.68	10.3	<0.01	<1	13.3	507	51	47	1519	<0.5	<0.2	<0.5	<0.5
B41	A22	A22B (a)	0-20			0.3	10.0	1.20	5.7	0.01	low pH	2.8	103	69	32	8	<0.5	<0.2	<0.5	<0.5
B42	A22	A22B (b)	20-30	0.18	0.9	<0.1	14.9	2.04	6.0	0.05	low pH	1.7	156	123	45	28	<0.5	<0.2	<0.5	1.7
B43	A23	A23B (a)	0-60			<0.1	8.3	0.75	5.5	0.08	low pH	5.4	93	27	9	7	<0.5	<0.2	<0.5	0.5

Chemical Properties: Raw Data

Unique ID	Site No.	Field Sample ID	Sample Depth (cm)	Organic Matter %	Moisture Content (%)	Phosphorus (P mg/kg)	Electrical Conductivity (µS/cm)	CEC (me/100g soil)	pH (H ₂ O)	Organic Carbon %	CaCO ₃ (quant.)	SO ₄ (S pp/g)	Ca (ppm)	Mg (ppm)	K (ppm)	Na (ppm)	Cu (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)
B44	A24	A24B (a)	0-75			<0.1	5.4	0.39	5.6	0.05	low pH	7.2	52	12	6	2	<0.5	<0.2	<0.5	<0.5
B45	A25	A25B (a)	0-75			0.2	81.7	5.44	7.8	0.18	<1	2.3	785	189	34	9	<0.5	<0.2	<0.5	<0.5
B46	A26	A26B (a)	0-8	0.44	0.7	1.6	100.7	10.59	8.1	0.45	23.7	0.9	1913	95	80	8	<0.5	<0.2	<0.5	<0.5
B47	A26	A26B (b)	8-32	0.43	1.9	0.7	176.2	9.00	8.2	0.33	32.3	1.2	1655	66	52	10	<0.5	<0.2	<0.5	<0.5
B48	A26	A26B (c)	32-72	0.43	3.0	0.4	151.2	12.07	8.3	0.14	46.5	1.7	2223	97	37	14	<0.5	<0.2	<0.5	<0.5
B49	A27	A27B (a)	0-15			0.2	48.7	5.06	7.6	0.22	<1	1.2	822	86	74	12	<0.5	<0.2	<0.5	<0.5
B50	A27	A27B (b)	15-40	0.37	2.4	0.1	79.5	6.19	7.7	0.21	<1	1.2	1044	93	64	9	<0.5	<0.2	<0.5	<0.5
B51	A29	A29B (a)	0-30			<0.1	8.0	0.62	5.8	0.12	low pH	6.7	92	16	5	3	<0.5	<0.2	<0.5	<0.5
B52	A30	A30B (a)	0-30			0.1	11.3	0.36	5.4	0.13	low pH	4.9	41	14	8	3	<0.5	<0.2	<0.5	0.3
B53	A30	A30B (b)	30-60	0.05	0.1	<0.1	7.7	0.12	5.1	<0.01	low pH	5.9	11	3	5	4	<0.5	<0.2	<0.5	<0.5
B54	A31	A31B (a)	0-30			<0.1	9.6	1.30	5.9	0.06	low pH	3.6	185	39	11	5	<0.5	<0.2	<0.5	<0.5
B55	A31	A31B (b)	>30-60	0.12	1.1	0.1	13.1	1.45	6.1	<0.01	low pH	5.7	211	42	11	3	<0.5	<0.2	<0.5	<0.5
B56	A32	A32B (a)	0-10			0.1	20.6	1.06	7.0	<0.01	<1	9.3	111	42	22	23	<0.5	<0.2	<0.5	<0.5
B57	A32	A32B (b)	10-30	0.12	1.3	0.1	329.0	7.21	9.8	<0.01	<1	0.8	756	72	58	617	<0.5	<0.2	<0.5	<0.5
B58	A34	A34B (a)	0-42			<0.1	6.1	0.69	5.7	0.08	low pH	7.5	73	31	15	6	<0.5	<0.2	<0.5	<0.5
B59	A34	A34B (b)	42->100	0.07	0.6	<0.1	7.2	0.55	5.6	<0.01	low pH	9.3	45	31	13	6	<0.5	<0.2	<0.5	2.2
B60	A35	A35B (a)	0-35			0.4	191.2	14.21	8.3	<0.01	101.4	4.4	2217	343	98	12	<0.5	<0.2	<0.5	<0.5
B61	A35	A35B (b)	35-70	0.53	4.5	0.4	150.9	12.40	8.4	<0.01	55.4	2.5	1953	282	63	16	<0.5	<0.2	<0.5	<0.5
B62	A35	A35B (c)	>70	0.15	1.0	0.1	92.5	8.79	8.6	0.16	8.7	4.6	1526	128	21	11	<0.5	<0.2	<0.5	0.5
B63	A36	A36B (a)	0-30			0.1	17.1	0.82	6.1	0.05	low pH	10.1	111	26	11	4	<0.5	<0.2	<0.5	1.1
B64	A36	A36B (b)	30-71	0.06	0.3	<0.1	7.1	0.48	5.9	<0.01	low pH	3.8	47	23	9	5	<0.5	<0.2	<0.5	<0.5
B65	A37	A37B (a)	0-20			<0.1	9.6	0.77	5.2	0.11	low pH	9.6	63	39	39	6	<0.5	<0.2	<0.5	<0.5
B66	A37	A37B (b)	20-50	0.15	1.0	<0.1	7.3	0.66	5.3	0.04	low pH	5.7	43	41	36	6	<0.5	<0.2	<0.5	2.5
B67	F1	F1B (a)	0-15			<0.1	32.3	0.26	5.0	0.06	low pH	9.1	25	10	8	4	<0.5	<0.2	1.0	1.5
B68	F1	F1B (b)	15-30			<0.1	16.5	0.11	4.7	<0.01	low pH	8.3	8	4	5	4	<0.5	<0.2	1.0	<0.5
B69	F1	F1B (c)	30-45			0.1	11.5	0.09	4.7	<0.01	low pH	8.0	6	3	5	3	<0.5	<0.2	1.0	<0.5
B70	F2	F2B (a)	0-5			<0.1	34.5	0.39	5.2	0.06	low pH	5.4	49	14	6	2	<0.5	<0.2	<0.5	<0.5
B71	F2	F2B (b)	15-30			<0.1	20.0	0.24	5.1	<0.01	low pH	5.7	24	8	9	5	<0.5	<0.2	<0.5	0.4
B72	F2	F2B (c)	30-45			<0.1	11.9	0.16	4.9	<0.01	low pH	8.8	15	7	5	6	<0.5	<0.2	<0.5	<0.5
B73	F3	F3B (a)	0-15			<0.1	25.6	0.44	5.7	0.06	low pH	10.9	65	11	4	3	<0.5	<0.2	<0.5	<0.5
B74	F3	F3B (b)	15-30			<0.1	13.7	0.29	5.4	0.01	low pH	10.4	38	8	5	3	<0.5	<0.2	<0.5	<0.5
B75	F3	F3B (c)	30-45			<0.1	12.3	0.26	5.3	<0.01	low pH	9.3	33	7	7	4	<0.5	<0.2	<0.5	<0.5

Note: For Calcium Carbonate equivalent, the analysis need not be carried out on soils with a pH (H₂O) < 6.7 as it is assumed to be absent below this pH reading.

Soils of Kavango Region
Data Analysis

Base Relationships (total soil and clay fraction)

Unique ID	Site No.	Field Sample ID	Sample Depth (cm)	Clay %	Organic Matter Content (%)	CEC (total) (me/100g soil)	CEC (clay) (me/100g clay)	Na:CEC (clay) Exchangeable Sodium % (ESP) (me/100g clay)	K:CEC (clay) Exchangeable Potassium % (EFP) (me/100g clay)	Base Saturation % (BSF) (me/100g clay)	Ca:Mg	K:Mg	Sodium Absorption Ratio (SAR)	Na:CEC (total) Exchangeable Sodium % (ESF)	K:CEC (total) Exchangeable Potassium % (EFP)	Base Saturation % (BSF) (me/100g soil)	Total Exchangeable Bases (me/100g soil)
B1	A1	A1B (a)	0-30	5.1		0.24	4.70	0.47	0.92	4.94	1.92	0.75	0.24	9.16	17.90	96.80	0.232
B2	A2	A2B (e)	0-30	9.3		3.82	41.12	0.11	0.93	9.28	1.60	0.29	0.12	1.18	8.89	99.83	3.818
B3	A3	A3B (a)	0-30	5.5	0.13	0.61	11.06	0.23	0.28	5.44	0.15	0.07	0.16	4.27	5.09	98.92	0.602
B4	A4	A4B (a)	0-30	5.9	0.16	1.88	28.45	0.09	0.32	5.88	1.88	0.17	0.09	1.55	5.36	99.61	1.672
B5	A5	A5B (e)	5-30	5.4		0.89	16.49	0.13	0.25	5.36	0.59	0.08	0.11	2.47	4.60	99.27	0.884
B6	A5	A5B (b)	53-70	6.8		0.52	7.63	0.29	0.54	6.72	0.53	0.14	0.14	4.24	7.90	98.87	0.513
B7	A6	A6B (a)	15-30	6.3	0.15	1.55	24.55	0.12	0.31	6.25	0.72	0.09	0.11	1.94	4.98	98.25	1.535
B7	A7	Not sampled				0.00											
B8	A8	A8B (e)	0-30	6.5	0.15	2.91	44.76	0.22	0.38	6.49	5.07	0.39	0.28	3.44	5.81	99.78	2.903
B9	A8	A8B (b)	30-60	14.6	0.32	5.09	34.84	0.67	0.67	14.58	1.83	0.14	0.49	4.62	4.62	99.87	5.080
B10	A9	A9B (a)	0-30	5.3	0.08	0.47	8.86	0.25	0.17	5.23	1.73	0.10	0.15	4.69	3.19	98.61	0.463
B11	A9	A9B (b)	30-60	5.8	0.07	0.26	4.45	0.49	0.28	5.67	1.03	0.12	0.21	8.53	5.04	97.73	0.252
B12	A10	A10B (e)	0-30	4.6		0.43	9.36	0.23	0.11	4.51	3.33	0.11	0.16	5.11	2.32	97.97	0.422
B13	A11	A11B (e)	0-30	4.9		0.37	7.59	0.28	0.30	4.78	2.24	0.23	0.17	5.91	6.18	97.55	0.363
B14	A11	A11B (b)	30-60	5.3		0.15	2.88	0.76	0.90	5.07	1.97	0.79	0.31	14.42	17.04	95.71	0.146
B15	A11	A11B (c)	>75	5.7	0.04	0.07	1.20	1.08	1.08	5.16	1.25	0.81	0.31	18.97	18.97	90.48	0.062
B16	A12	A12B (e)	0-30	6.7		3.32	49.58	0.05	0.14	6.69	3.74	0.10	0.07	0.78	2.08	99.80	3.315
B17	A12	A12B (b)	40-70	7.2	0.14	2.63	36.51	0.13	0.10	7.18	1.26	0.03	0.13	1.83	1.37	99.75	2.622
B18	A12	A12B (c)	60-90	25.3	0.11	1.80	7.11	0.31	0.44	25.21	1.42	0.04	0.07	1.22	1.72	99.64	1.793
B19	A13	A13B (a)	0-25	6.4		1.44	22.50	0.13	0.32	6.36	0.82	0.10	0.12	2.08	5.00	99.44	1.432
B20	A13	A13B (b)	25-40	6.1	0.15	1.27	20.84	0.12	0.17	6.04	0.57	0.05	0.11	2.05	4.83	99.03	1.259
B21	A13	A13B (c)	40-80	7.0	0.11	1.25	17.80	0.17	0.16	6.95	0.56	0.04	0.13	2.41	2.25	99.30	1.237
B22	A14	A14B (a)	0-30	4.7		0.23	4.87	0.27	0.47	4.56	1.82	0.35	0.14	5.68	10.05	96.97	0.222
B23	A14	A14B (b)	30-70	4.7		0.08	1.63	0.55	0.31	4.30	2.50	0.31	0.16	11.76	8.53	91.46	0.070
B24	A14	A14B (c)	70-90	7.1	0.06	2.64	37.23	5.79	0.06	7.08	4.45	0.28	14.43	81.61	0.87	99.69	2.635
B25	A14	A14B (d)	>90	3.0	0.01	0.07	2.35	1.11	1.32	2.72	3.13	3.88	0.64	36.86	43.95	80.73	0.064
B26	A15	A15B (a)	0-30	5.2		0.73	14.00	0.12	0.11	5.14	3.14	0.09	0.09	2.34	2.06	98.80	0.719
B27	A15	A15B (b)	30-60	4.8	0.06	0.85	17.68	0.10	0.08	4.76	6.04	0.13	0.09	2.00	1.77	96.23	0.842
B28	A16	A16B (a)	0-30	4.7		0.38	8.14	0.16	0.18	4.62	2.55	0.15	0.10	3.40	3.92	98.29	0.378
B29	A16	A16B (b)	30-70	5.3	0.04	0.18	3.33	0.39	0.45	5.10	1.49	0.26	0.15	7.36	8.50	96.30	0.170
B30	A17	A17B (a)	0-30	4.7		1.20	25.59	0.07	0.09	4.67	3.70	0.09	0.07	1.41	1.91	98.45	1.186
B31	A17	A17B (b)	30-60	4.8	0.08	0.98	20.48	0.08	0.05	4.76	4.02	0.05	0.08	1.73	1.02	99.27	0.976
B32	A17	A17B (c)	>60	4.7	0.07	0.64	13.67	0.22	0.24	4.65	4.85	0.34	0.18	4.67	5.14	98.98	0.636

Base Relationships (total soil and clay fraction)

Unique ID	Site No.	Field Sample ID	Sample Depth (cm)	Clay %	Organic Matter Content (%)	CEC (total) (me/100g soil)	CEC (clay) (me/100g clay)	Na/CEC (clay) Exchangeable Sodium % (ESP) (me/100g clay)	K/CEC (clay) Exchangeable Potassium % (EPP)	Base Saturation % (BSP) (me/100g clay)	Ca/Mg	K/Mg	Sodium Absorption Ratio (SAR)	Na/CEC (total) Exchangeable Sodium % (ESP)	K/CEC (total) Exchangeable Potassium % (EPP)	Base Saturation % (BSP) (me/100g soil)	Total Exchangeable Bases (me/100g soil)
B33	A18	A18B (a)	0-15	5.7		13.02	228.35	0.02	0.07	5.70	5.77	0.09	0.07	0.44	1.24	99.94	13.008
B34	A18	A18B (b)	15-35	7.1	0.91	38.81	518.38	0.04	0.03	7.10	51.86	0.21	0.17	0.62	0.40	99.97	36.795
B35	A19	A19B (a)	0-20	6.1	1.06	5.26	86.30	2.77	0.28	6.09	3.08	0.35	6.59	45.40	4.27	99.88	5.258
B36	A20	A20B (a)	0-35	6.5		2.72	41.85	0.09	0.12	6.48	3.00	0.07	0.11	1.43	1.80	99.76	2.714
B37	A20	A20B (b)	40-80	6.8	0.15	2.27	33.35	0.09	0.10	6.78	1.79	0.04	0.09	1.32	1.48	99.87	2.260
B38	A21	A21B (a)	0-10	6.0		6.22	103.64	0.28	0.18	5.99	16.49	0.57	0.54	4.62	3.01	99.89	6.212
B39	A21	A21B (b)	10-20	9.4	0.12	5.40	84.34	3.37	0.06	6.39	15.03	0.33	8.03	52.60	0.84	99.88	5.391
B40	A21	A21B (c)	20-40	8.9	0.11	9.88	106.80	6.07	0.11	8.99	6.06	0.29	17.19	68.20	1.24	99.83	9.677
B41	A22	A22B (a)	0-20	7.1		1.20	16.97	0.21	0.48	7.06	0.91	0.14	0.15	2.91	6.81	99.46	1.198
B42	A22	A22B (b)	20-30	8.3	0.18	2.04	24.53	0.50	0.47	8.26	0.77	0.11	0.41	5.99	5.65	99.46	2.025
B43	A23	A23B (a)	0-60	8.0		0.75	12.43	0.24	0.19	5.95	2.10	0.10	0.16	4.02	3.08	99.12	0.739
B44	A24	A24B (a)	0-75	5.3		0.39	7.33	0.12	0.20	5.21	2.65	0.15	0.06	2.32	3.86	98.32	0.382
B45	A25	A25B (a)	0-75	11.4		5.44	47.74	0.08	0.18	11.39	2.83	0.06	0.08	0.72	1.60	99.88	5.436
B46	A26	A26B (a)	0-8	10.0	0.44	10.59	105.91	0.03	0.19	9.99	12.28	0.26	0.05	0.33	1.84	99.94	10.584
B47	A26	A26B (b)	8-32	10.6	0.43	9.00	84.93	0.05	0.16	10.59	15.30	0.25	0.07	0.48	1.48	99.83	8.996
B48	A26	A26B (c)	32-72	16.1	0.43	12.07	74.98	0.08	0.13	16.09	13.98	0.12	0.08	0.51	0.79	99.85	12.066
B49	A27	A27B (a)	0-15	9.5		5.06	52.73	0.10	0.36	9.59	5.83	0.27	0.11	1.03	3.73	99.87	5.056
B50	A27	A27B (b)	15-40	14.5	0.37	6.19	42.70	0.09	0.38	14.48	6.65	0.22	0.07	0.63	2.65	99.89	6.185
B51	A29	A29B (a)	0-30	3.5		0.00											
B52	A30	A30B (a)	0-30	4.0		0.62	17.82	0.07	0.07	3.46	3.51	0.10	0.08	2.08	2.08	98.95	0.617
B53	A30	A30B (b)	30-60	4.3	0.05	0.36	8.97	0.14	0.22	3.93	1.78	0.17	0.10	3.62	5.67	98.37	0.353
B54	A31	A31B (a)	0-30	6.7		0.12	2.71	0.83	0.48	4.06	2.20	0.52	0.28	14.59	11.18	94.39	0.110
B55	A31	A31B (b)	>30-60	6.7	0.12	1.30	19.43	0.11	0.14	6.67	2.89	0.09	0.09	1.69	2.15	89.50	1.295
B56	A32	A32B (a)	0-10	4.7		1.46	21.59	0.06	0.13	6.67	3.07	0.08	0.05	0.90	1.54	99.55	1.440
B57	A32	A32B (b)	10-30	7.5	0.12	1.08	22.59	0.44	0.25	4.67	1.61	0.16	0.47	9.42	5.28	99.38	1.055
B58	A34	A34B (a)	0-42	5.2		0.00											
B59	A34	A34B (b)	42->100	4.3	0.07	0.69	13.26	0.20	0.29	5.15	1.44	0.15	0.15	3.77	5.51	99.05	0.683
B60	A35	A35B (a)	0-35	6.2		0.55	12.61	0.20	0.26	4.20	0.89	0.13	0.17	4.72	5.98	97.68	0.538
B61	A35	A35B (b)	35-70	5.3	0.53	14.21	229.12	0.02	0.11	6.20	3.94	0.09	0.06	0.37	1.77	98.95	14.199
B62	A35	A35B (c)	>70	4.0	0.15	12.40	233.88	0.03	0.07	5.30	4.08	0.07	0.09	0.56	1.30	99.95	12.389
B63	A36	A36B (a)	0-30	4.2		8.79	219.69	0.02	0.02	4.00	7.27	0.05	0.07	0.55	0.61	98.93	8.781
						0.82	19.57	0.09	0.14	4.16	2.61	0.13	0.09	2.07	3.41	98.93	0.813

Base Relationships (total soil and clay fraction)

Unique ID	Site No.	Field Sample ID	Sample Depth (cm)	Clay %	Organic Matter Content (%)	CEC (total) (me/100g soil)	CEC (clay) (me/100g clay)	Na:CEC (clay) Exchangeable Sodium % (ESP) (me/100g clay)	K:CEC (clay) Exchangeable Potassium % (EPP)	Base Saturation % (BSP) (me/100g clay)	Ca/Mg	K/Mg	Sodium Absorption Ratio (SAR)	Na:CEC (total) Exchangeable Sodium % (ESP)	K:CEC (total) Exchangeable Potassium % (EPP)	Base Saturation % (BSP) (me/100g soil)	Total Exchangeable Bases (me/100g soil)
B64	A36	A36B (b)	30-71	4.5	0.06	0.48	10.57	0.21	0.22	4.44	1.24	0.12	0.15	-4.63	4.84	98.63	0.469
B65	A37	A37B (a)	0-20	5.7		0.77	13.47	0.19	0.74	5.65	0.98	0.31	0.15	3.39	13.03	99.15	0.761
B66	A37	A37B (b)	20-50	6.3	0.15	0.68	10.84	0.24	0.85	6.17	0.64	0.27	0.16	3.81	13.47	97.97	0.669
B67	F1	F1B (a)	0-15	4.1		0.26	6.27	0.27	0.32	3.89	1.52	0.24	0.17	6.62	7.78	94.98	0.244
B68	F1	F1B (b)	15-30	4.6		0.11	2.44	0.70	0.53	4.22	1.21	0.39	0.29	15.14	11.58	91.73	0.103
B69	F1	F1B (c)	30-45	4.6		0.09	1.96	0.66	0.66	4.13	1.20	0.52	0.25	14.40	14.40	89.72	0.081
B70	F2	F2B (a)	0-5	3.8		0.39	10.85	0.08	0.14	3.54	2.13	0.13	0.05	2.30	3.84	98.33	0.384
B71	F2	F2B (b)	15-30	3.6		0.24	6.59	0.33	0.35	3.51	1.82	0.35	0.23	9.27	9.70	97.38	0.231
B72	F2	F2B (c)	30-45	3.6		0.18	4.93	0.53	0.26	3.47	1.32	0.23	0.32	14.64	7.32	96.32	0.171
B73	F3	F3B (a)	0-15	3.1		0.44	14.34	0.09	0.07	3.05	3.61	0.11	0.09	2.92	2.25	98.53	0.438
B74	F3	F3B (b)	15-30	3.8		0.29	8.01	0.16	0.16	3.52	2.88	0.20	0.12	4.51	4.51	97.73	0.282
B75	F3	F3B (c)	30-45	4.5		0.26	5.66	0.29	0.31	4.39	2.89	0.32	0.16	6.45	6.83	97.52	0.257

Note 1: CEC (clay) values calculated due to low organic matter content of soils

Note 2: BSP values calculated as proportions of CEC (clay)

Note 3: ESP and EPP values calculated as proportion of CEC (total)

Note 4: Ratios expressed as values proportional to 1 unit of Mg (e.g. 1.88 = 1.88 units of Ca to 1 unit of Mg)

Cation Concentrations

Unique ID	Site No.	Field Sample ID	Sample Depth (cm)	Ca (ppm)	Ca (me/100g)	Mg (ppm)	Mg (me/100g)	K (ppm)	K (me/100g)	Na (ppm)	Na (me/100g)	Cu (ppm)	Cu (me/100g)	Zn (ppm)	Zn (me/100g)	Fe (ppm)	Fe (me/100g)	Mn (ppm)	Mn (me/100g)
B1	A1	A1B (a)	0-30	22	0.110	7	0.057	17	0.043	5	0.022	0.49	0.002	0.19	0.001	0.49	0.003	0.80	0.003
B2	A2	A2B (a)	0-30	422	2.110	161	1.320	133	0.340	11	0.045	0.49	0.002	0.19	0.001	0.49	0.003	0.49	0.002
B3	A3	A3B (a)	0-30	14	0.070	58	0.475	12	0.031	6	0.026	0.49	0.002	0.19	0.001	0.49	0.003	0.50	0.002
B4	A4	A4B (a)	0-30	203	1.015	66	0.541	35	0.090	6	0.026	0.49	0.002	0.19	0.001	0.49	0.003	0.49	0.002
B5	A5	A5B (a)	5-30	61	0.305	63	0.516	16	0.041	5	0.022	0.49	0.002	0.19	0.001	0.49	0.003	0.49	0.002
B6	A5	A5B (b)	53-70	31	0.155	36	0.295	16	0.041	5	0.022	0.49	0.002	0.19	0.001	0.49	0.003	0.30	0.001
B7	A6	A6B (a)	15-30	120	0.600	101	0.828	30	0.077	7	0.030	0.80	0.003	0.19	0.001	0.49	0.003	1.60	0.006
B7	A7	Not sampled																	
B8	A8	A8B (a)	0-30	440	2.200	53	0.434	66	0.169	23	0.100	0.49	0.002	0.19	0.001	0.49	0.003	0.49	0.002
B9	A8	A8B (b)	30-60	596	2.980	199	1.630	92	0.235	54	0.235	0.49	0.002	0.19	0.001	0.49	0.003	0.49	0.002
B10	A9	A9B (a)	0-30	54	0.270	19	0.156	6	0.015	5	0.022	0.49	0.002	0.19	0.001	0.49	0.003	0.49	0.002
B11	A9	A9B (b)	30-60	22	0.110	13	0.107	5	0.013	5	0.022	0.49	0.002	0.19	0.001	0.49	0.003	0.30	0.001
B12	A10	A10B (a)	0-30	60	0.300	11	0.090	4	0.010	5	0.022	0.49	0.002	0.19	0.001	0.49	0.003	1.10	0.004
B13	A11	A11B (a)	0-30	44	0.220	12	0.098	9	0.023	5	0.022	0.49	0.002	0.19	0.001	0.49	0.003	1.20	0.004
B14	A11	A11B (b)	30-60	13	0.065	4	0.033	10	0.026	5	0.022	0.49	0.002	0.19	0.001	0.49	0.003	0.49	0.002
B15	A11	A11B (c)	>75	4	0.020	2	0.016	5	0.013	3	0.013	0.49	0.002	0.19	0.001	0.49	0.003	0.49	0.002
B16	A12	A12B (a)	0-30	508	2.540	83	0.680	27	0.069	6	0.026	0.49	0.002	0.20	0.001	0.49	0.003	0.49	0.002
B17	A12	A12B (b)	40-70	283	1.415	137	1.123	14	0.036	11	0.048	0.49	0.002	0.19	0.001	0.49	0.003	0.49	0.002
B18	A12	A12B (c)	80-90	204	1.020	88	0.720	12	0.031	5	0.022	0.49	0.002	0.19	0.001	0.49	0.003	0.49	0.002
B19	A13	A13B (a)	0-25	120	0.600	89	0.730	28	0.072	7	0.030	0.49	0.002	0.19	0.001	0.49	0.003	0.49	0.002
B20	A13	A13B (b)	25-40	87	0.435	93	0.762	14	0.036	6	0.026	0.49	0.002	0.19	0.001	0.49	0.003	0.90	0.003
B21	A13	A13B (c)	40-80	85	0.425	92	0.754	11	0.028	7	0.030	0.49	0.002	0.19	0.001	0.49	0.003	2.10	0.008
B22	A14	A14B (a)	0-30	24	0.120	8	0.066	9	0.023	3	0.013	0.49	0.002	0.19	0.001	0.49	0.003	1.10	0.004
B23	A14	A14B (b)	30-70	8	0.040	2	0.016	2	0.005	2	0.009	0.49	0.002	0.19	0.001	0.49	0.003	0.60	0.002
B24	A14	A14B (c)	70-90	73	0.365	10	0.082	12	0.023	496	2.157	0.49	0.002	0.19	0.001	0.80	0.004	0.49	0.002
B25	A14	A14B (d)	>90	5	0.025	1	0.008	2	0.031	6	0.026	0.49	0.002	0.19	0.001	0.49	0.003	0.49	0.002
B26	A15	A15B (a)	0-30	103	0.515	20	0.164	9	0.015	4	0.017	0.49	0.002	0.19	0.001	0.49	0.003	1.10	0.004
B27	A15	A15B (b)	30-60	139	0.695	14	0.115	6	0.015	4	0.017	0.49	0.002	0.19	0.001	0.49	0.003	0.49	0.002
B28	A16	A16B (a)	0-30	50	0.250	12	0.098	6	0.015	3	0.013	0.49	0.002	0.19	0.001	0.49	0.003	0.49	0.002
B29	A16	A16B (b)	30-70	17	0.085	7	0.057	6	0.015	3	0.013	0.49	0.002	0.19	0.001	0.49	0.003	0.49	0.002

Cation Concentrations

Unique ID	Site No.	Field Sample ID	Sample Depth (cm)	Ca (ppm)	Ca (me/100g)	Mg (ppm)	Mg (me/100g)	K (ppm)	K (me/100g)	Na (ppm)	Na (me/100g)	Cu (ppm)	Cu (me/100g)	Zn (ppm)	Zn (me/100g)	Fe (ppm)	Fe (me/100g)	Mn (ppm)	Mn (me/100g)
B30	A17	A17B (a)	0-30	182	0.910	30	0.246	9	0.023	4	0.017	0.49	0.002	0.19	0.001	0.49	0.003	0.49	0.002
B31	A17	A17B (b)	30-60	152	0.760	23	0.189	4	0.010	4	0.017	0.49	0.002	0.40	0.001	0.49	0.003	0.49	0.002
B32	A17	A17B (c)	>60	95	0.475	12	0.098	13	0.033	7	0.030	0.49	0.002	0.19	0.001	0.49	0.003	0.49	0.002
B33	A18	A18B (a)	0-15	2180	10.900	230	1.890	63	0.161	13	0.057	0.49	0.002	0.19	0.001	0.49	0.003	0.80	0.003
B34	A18	A18B (b)	15-35	7146	35.730	84	0.689	57	0.146	53	0.230	0.49	0.002	0.19	0.001	0.49	0.003	1.50	0.005
B35	A19	A19B (a)	0-20	399	1.995	79	0.648	88	0.225	550	2.390	0.49	0.002	0.19	0.001	0.49	0.003	0.49	0.002
B36	A20	A20B (a)	0-35	394	1.970	80	0.656	19	0.049	9	0.039	0.49	0.002	0.19	0.001	0.49	0.003	0.49	0.002
B37	A20	A20B (b)	40-80	282	1.410	96	0.787	13	0.033	7	0.030	0.49	0.002	0.50	0.002	0.49	0.003	0.49	0.002
B38	A21	A21B (a)	0-10	1082	5.410	40	0.328	73	0.187	66	0.287	0.49	0.002	0.19	0.001	0.49	0.003	0.49	0.002
B39	A21	A21B (b)	10-20	469	2.345	19	0.166	20	0.051	653	2.839	0.49	0.002	0.19	0.001	0.49	0.003	0.49	0.002
B40	A21	A21B (c)	20-40	507	2.535	51	0.418	47	0.120	1519	6.604	0.49	0.002	0.19	0.001	0.49	0.003	0.49	0.002
B41	A22	A22B (a)	0-20	103	0.515	69	0.566	32	0.082	8	0.035	0.49	0.002	0.19	0.001	0.49	0.003	0.49	0.002
B42	A22	A22B (b)	20-30	156	0.780	123	1.008	45	0.115	28	0.122	0.49	0.002	0.19	0.001	0.49	0.003	1.70	0.006
B43	A23	A23B (a)	0-60	93	0.465	27	0.221	9	0.023	7	0.030	0.49	0.002	0.19	0.001	0.49	0.003	0.50	0.002
B44	A24	A24B (a)	0-75	52	0.260	12	0.098	6	0.015	2	0.009	0.49	0.002	0.19	0.001	0.49	0.003	0.49	0.002
B45	A25	A25B (a)	0-75	785	3.925	169	1.385	34	0.087	9	0.039	0.49	0.002	0.19	0.001	0.49	0.003	0.49	0.002
B46	A26	A26B (a)	0-8	1913	9.565	95	0.779	80	0.205	8	0.035	0.49	0.002	0.19	0.001	0.49	0.003	0.49	0.002
B47	A26	A26B (b)	8-32	1666	8.280	66	0.541	52	0.133	10	0.043	0.49	0.002	0.19	0.001	0.49	0.003	0.49	0.002
B48	A26	A26B (c)	32-72	2223	11.115	97	0.795	37	0.095	14	0.061	0.49	0.002	0.19	0.001	0.49	0.003	0.49	0.002
B49	A27	A27B (a)	0-15	822	4.110	86	0.705	74	0.189	12	0.052	0.49	0.002	0.19	0.001	0.49	0.003	0.49	0.002
B50	A27	A27B (b)	15-40	1044	5.220	93	0.762	64	0.164	9	0.039	0.49	0.002	0.19	0.001	0.49	0.003	0.49	0.002
A28		Not sampled																	
B51	A29	A29B (a)	0-30	92	0.460	16	0.131	5	0.013	3	0.013	0.49	0.002	0.19	0.001	0.49	0.003	0.49	0.002
B52	A30	A30B (a)	0-30	41	0.205	14	0.115	8	0.020	3	0.013	0.49	0.002	0.19	0.001	0.49	0.003	0.30	0.001
B53	A30	A30B (b)	30-60	11	0.055	3	0.025	5	0.013	4	0.017	0.49	0.002	0.19	0.001	0.49	0.003	0.49	0.002
B54	A31	A31B (a)	0-30	185	0.925	39	0.320	11	0.028	5	0.022	0.49	0.002	0.19	0.001	0.49	0.003	0.49	0.002
B55	A31	A31B (b)	>30-60	211	1.055	42	0.344	11	0.028	3	0.013	0.49	0.002	0.19	0.001	0.49	0.003	0.49	0.002
B56	A32	A32B (a)	0-10	111	0.555	42	0.344	22	0.056	23	0.100	0.49	0.002	0.19	0.001	0.49	0.003	0.49	0.002
B57	A32	A32B (b)	10-30	756	3.780	72	0.590	58	0.148	617	2.683	0.49	0.002	0.19	0.001	0.49	0.003	0.49	0.002
A33		Not sampled																	

Cation Concentrations

Unique ID	Site No.	Field Sample ID	Sample Depth (cm)	Ca (ppm)	Ca (me/100g)	Mg (ppm)	Mg (me/100g)	K (ppm)	K (me/100g)	Na (ppm)	Na (me/100g)	Cu (ppm)	Cu (me/100g)	Zn (ppm)	Zn (me/100g)	Fe (ppm)	Fe (me/100g)	Mn (ppm)	Mn (me/100g)
B58	A34	A34B (a)	0-42	73	0.365	31	0.254	15	0.038	6	0.026	0.49	0.002	0.19	0.001	0.49	0.003	0.49	0.002
B59	A34	A34B (b)	42->100	45	0.225	31	0.254	13	0.033	6	0.026	0.49	0.002	0.19	0.001	0.49	0.003	2.20	0.008
B60	A35	A35B (a)	0-35	2217	11.085	343	2.811	98	0.251	12	0.052	0.49	0.002	0.19	0.001	0.49	0.003	0.49	0.002
B61	A35	A35B (b)	35-70	1953	9.765	292	2.393	63	0.161	16	0.070	0.49	0.002	0.19	0.001	0.49	0.003	0.49	0.002
B62	A35	A35B (c)	>70	1526	7.630	128	1.049	21	0.054	11	0.048	0.49	0.002	0.19	0.001	0.49	0.003	0.50	0.002
B63	A36	A36B (a)	0-30	111	0.555	26	0.213	11	0.028	4	0.017	0.49	0.002	0.19	0.001	0.49	0.003	1.10	0.004
B64	A36	A36B (b)	30-71	47	0.235	23	0.189	9	0.023	5	0.022	0.49	0.002	0.19	0.001	0.49	0.003	0.49	0.002
B65	A37	A37B (a)	0-20	63	0.315	39	0.320	39	0.100	6	0.026	0.49	0.002	0.19	0.001	0.49	0.003	0.49	0.002
B66	A37	A37B (b)	20-50	43	0.215	41	0.336	36	0.092	6	0.026	0.49	0.002	0.19	0.001	0.49	0.003	2.50	0.009
B67	F1	F1B (a)	0-15	25	0.125	10	0.082	8	0.020	4	0.017	0.49	0.002	0.19	0.001	1.00	0.005	1.50	0.005
B68	F1	F1B (b)	15-30	8	0.040	4	0.033	5	0.013	4	0.017	0.49	0.002	0.19	0.001	1.00	0.005	0.49	0.002
B69	F1	F1B (c)	30-45	6	0.030	3	0.025	5	0.013	3	0.013	0.49	0.002	0.19	0.001	1.00	0.005	0.49	0.002
B70	F2	F2B (a)	0-5	49	0.245	14	0.115	6	0.015	2	0.009	0.49	0.002	0.19	0.001	0.49	0.003	0.49	0.002
B71	F2	F2B (b)	15-30	24	0.120	8	0.066	9	0.023	5	0.022	0.49	0.002	0.19	0.001	0.49	0.003	0.49	0.002
B72	F2	F2B (c)	30-45	15	0.075	7	0.057	5	0.013	6	0.025	0.49	0.002	0.19	0.001	0.49	0.003	0.40	0.001
B73	F3	F3B (a)	0-15	65	0.325	11	0.090	4	0.010	3	0.013	0.49	0.002	0.19	0.001	0.49	0.003	0.49	0.002
B74	F3	F3B (b)	15-30	38	0.190	8	0.066	5	0.013	3	0.013	0.49	0.002	0.19	0.001	0.49	0.003	0.49	0.002
B75	F3	F3B (c)	30-45	33	0.165	7	0.057	7	0.018	4	0.017	0.49	0.002	0.19	0.001	0.49	0.003	0.49	0.002

Note 1:
ppm/10.equivalent weight = me/100g

Note 2:
Ca: equivalent weight = 20.0
Mg: equivalent weight = 12.2
K: equivalent weight = 39.1
Na: equivalent weight = 23.0
Cu: equivalent weight = 31.8
Fe (ferric): equivalent weight = 18.6
Zn: equivalent weight = 32.7
Mn: equivalent weight = 27.5

Physical Properties: Particle Size Analysis

Unique ID	Site No.	Field Sample ID	Sample Depth (cm)	% Clay (< 2µ)	% Silt (2 - 53µ)	% Sand (53 - 2000µ)	% Gravel (> 2000µ)	% Coarse to Very Coarse Sand (2000 - 500µ)	% Medium Sand (500 - 250µ)	% Fine Sand (250 - 106µ)	% Very Fine Sand (106 - 53µ)	Textural Class
B1	A1	A1B (a)	0-30	5.1	8.2	86.7	trace to null	13.0	39.2	30.1	17.8	sand
B2	A2	A2B (a)	0-30	9.3	12.7	78.1	trace to null	16.0	19.7	44.9	19.4	sandy loam
B3	A3	A3B (a)	0-30	5.5	7.5	87.0	trace to null	19.9	29.3	38.2	12.7	sand
B4	A4	A4B (a)	0-30	5.9	8.2	85.9	trace to null	2.4	29.0	54.4	14.3	loamy sand
B5	A5	A5B (a)	5-30	5.4	9.0	85.7	trace to null	8.4	50.0	35.0	6.7	loamy sand
B6	A5	A5B (b)	53-70	6.8	9.4	83.8	trace to null	5.1	39.6	43.9	11.4	loamy sand
B7	A6	A6B (a)	15-30	6.3	11.3	82.5	trace to null	5.9	43.5	42.4	8.1	loamy sand
B8	A7	not sampled										
B8	A8	A8B (a)	0-30	6.5	12.2	81.3	trace to null	6.4	43.6	42.6	7.4	loamy sand
B9	A8	A8B (b)	30-60	14.6	10.8	74.6	trace to null	6.6	39.0	41.1	13.3	sandy loam
B10	A9	A9B (a)	0-30	5.3	6.4	88.3	trace to null	4.6	49.8	38.2	7.5	sand
B11	A9	A9B (b)	30-60	5.8	7.5	86.7	trace to null	4.5	45.7	39.8	10.0	sand
B12	A10	A10B (a)	0-30	4.6	6.2	89.2	trace to null	1.8	47.6	42.5	8.1	sand
B13	A11	A11B (a)	0-30	4.9	7.1	88.0	trace to null	2.3	51.1	40.3	6.3	sand
B14	A11	A11B (b)	30-60	5.3	6.0	88.7	trace to null	1.3	41.5	48.0	9.2	sand
B15	A11	A11B (c)	>75	5.7	6.1	88.2	trace to null	1.9	42.4	47.7	8.0	sand
B16	A12	A12B (a)	0-30	6.7	10.2	83.1	trace to null	2.2	36.3	52.6	8.9	loamy sand
B17	A12	A12B (b)	40-70	7.2	9.8	83.0	trace to null	1.5	34.9	53.8	9.9	loamy sand
B18	A12	A12B (c)	80-90	5.3	10.2	84.9	trace to null	1.5	34.3	54.1	10.1	loamy sand
B19	A13	A13B (a)	0-25	6.4	7.4	86.2	trace to null	1.7	40.1	48.0	10.2	sand
B20	A13	A13B (b)	25-40	6.1	10.9	83.0	trace to null	1.9	37.7	49.9	10.5	loamy sand
B21	A13	A13B (c)	40-80	7.0	10.2	82.8	trace to null	1.2	37.9	50.8	10.1	loamy sand
B22	A14	A14B (a)	0-30	4.7	6.7	88.6	trace to null	0.9	33.9	54.2	11.0	sand
B23	A14	A14B (b)	30-70	4.7	8.0	87.3	trace to null	1.3	46.9	45.6	6.2	sand
B24	A14	A14B (c)	70-90	7.1	8.8	84.1	trace to null	1.2	32.1	55.1	11.6	loamy sand
B25	A14	A14B (d)	>90	3.0	28.6	68.3	trace to null	0.9	36.6	53.0	9.5	sandy loam
B26	A15	A15B (a)	0-30	5.2	5.7	89.1	trace to null	1.3	35.7	52.8	10.2	sand
B27	A15	A15B (b)	30-60	4.8	7.5	87.6	trace to null	0.7	31.7	54.9	12.7	sand
B28	A16	A16B (a)	0-30	4.7	6.8	88.5	trace to null	1.0	40.9	48.4	9.7	sand
B29	A16	A16B (b)	30-70	5.3	6.2	88.6	trace to null	0.7	33.0	52.6	13.7	sand
B30	A17	A17B (a)	0-30	4.7	7.8	87.5	trace to null	1.3	37.8	46.0	14.9	sand
B31	A17	A17B (b)	30-60	4.8	8.6	86.6	trace to null	1.0	30.2	53.7	15.1	sand
B32	A17	A17B (c)	>60	4.7	7.3	88.0	trace to null	0.9	29.4	54.0	15.7	sand

Physical Properties: Particle Size Analysis

Unique ID	Site No.	Field Sample ID	Sample Depth (cm)	% Clay (< 2µ)	% Silt (2 - 53µ)	% Sand (53 - 2000µ)	% Gravel (> 2000µ)	% Coarse to Very Coarse Sand (2000 - 500µ)	% Medium Sand (500 - 250µ)	% Fine Sand (250 - 106µ)	% Very Fine Sand (106 - 53µ)	Textural Class
B33	A18	A18B (a)	0 - 15	5.7	26.0	68.3	trace to null	18.7	32.6	33.1	15.6	sandy loam
B34	A18	A18B (b)	15 - 35	7.1	37.1	55.8	trace to null	26.1	30.2	28.2	15.4	sandy loam
B35	A19	A19B (a)	0 - 20	6.1	72.5	21.4	trace to null	6.6	23.5	24.6	45.3	silt loam
B36	A20	A20B (a)	0 - 35	6.5	12.0	81.5	trace to null	1.2	39.6	49.0	10.2	loamy sand
B37	A20	A20B (b)	40 - 80	6.8	9.3	83.9	trace to null	1.4	41.9	47.8	8.9	loamy sand
B38	A21	A21B (a)	0 - 10	6.0	11.4	82.6	trace to null	2.3	40.9	48.1	8.7	loamy sand
B39	A21	A21B (b)	10-20	6.4	9.2	84.4	trace to null	1.4	34.5	52.5	11.5	loamy sand
B40	A21	A21B (c)	20 - 40	8.9	10.6	80.5	trace to null	1.7	38.8	49.8	9.7	loamy sand
B41	A22	A22B (a)	0 - 20	7.1	5.9	87.0	trace to null	9.3	32.7	46.7	11.2	sand
B42	A22	A22B (b)	20 - 30	8.3	9.9	81.8	trace to null	8.2	30.8	48.1	12.9	loamy sand
B43	A23	A23B (a)	0 - 60	6.0	8.3	86.7	trace to null	2.1	36.2	49.2	12.5	loamy sand
B44	A24	A24B (a)	0 - 75	5.3	3.0	91.7	trace to null	1.2	35.2	52.1	11.5	sand
B45	A25	A25B (a)	0 - 75	11.4	7.6	81.0	trace to null	1.4	21.5	59.7	17.5	loamy sand
B46	A26	A26B (a)	0 - 8	10.0	16.2	73.9	trace to null	7.6	21.8	50.6	20.1	sandy loam
B47	A26	A26B (b)	8 - 32	10.6	22.1	67.3	trace to null	6.0	21.1	52.5	20.4	sandy loam
B48	A26	A26B (c)	32 - 72	16.1	21.0	62.9	trace to null	6.0	21.3	52.6	20.1	sandy loam
B49	A27	A27B (a)	0 - 15	9.6	8.5	81.9	trace to null	2.1	32.5	54.1	11.3	loamy sand
B50	A27	A27B (b)	15 - 40	14.5	8.0	77.5	trace to null	2.2	28.1	56.2	13.5	loamy sand
A28		not sampled										
B51	A29	A29B (a)	0 - 30	3.5	5.4	91.0	trace to null	1.1	36.2	50.3	12.4	sand
B52	A30	A30B (a)	0 - 30	4.0	3.6	92.4	trace to null	2.0	55.8	35.4	6.7	sand
B53	A30	A30B (b)	30 - 60	4.3	3.4	92.3	trace to null	2.0	49.1	41.2	7.7	sand
B54	A31	A31B (a)	0 - 30	6.7	6.2	87.1	trace to null	0.6	28.6	61.5	9.3	sand
B55	A31	A31B (b)	>30 - 60	6.7	6.2	87.1	trace to null	0.5	26.4	63.4	9.7	sand
B56	A32	A32B (a)	0 - 10	4.7	4.5	90.8	trace to null	0.5	22.7	62.1	14.7	sand
B57	A32	A32B (b)	10 - 30	7.5	6.1	86.4	trace to null	0.4	19.2	63.1	17.3	sand
A33		not sampled										
B58	A34	A34B (a)	0 - 42	5.2	5.3	89.5	trace to null	10.3	43.9	38.7	7.0	sand
B59	A34	A34B (b)	42 - >100	4.3	6.1	89.6	trace to null	10.8	40.6	38.9	8.8	sand
B60	A35	A35B (a)	0 - 35	6.2	32.0	61.8	trace to null	21.6	35.1	27.5	15.8	sandy loam
B61	A35	A35B (b)	35 - 70	5.3	24.6	70.1	trace to null	24.6	42.5	21.7	11.2	sandy loam
B62	A35	A35B (c)	>70	4.0	9.9	86.1	trace to null	23.8	50.6	21.2	4.4	sand
B63	A36	A36B (a)	0 - 30	4.2	6.1	89.8	trace to null	3.5	47.6	39.8	9.2	sand

Physical Properties: Particle Size Analysis

Unique ID	Site No.	Field Sample ID	Sample Depth (cm)	% Clay (< 2 μ)	% Silt (2 - 53 μ)	% Sand (53 - 2000 μ)	% Gravel (> 2000 μ)	% Coarse to Very Coarse Sand (2000 - 500 μ)	% Medium Sand (500 - 250 μ)	% Fine Sand (250 - 106 μ)	% Very Fine Sand (106 - 53 μ)	Textural Class
B64	A36	A36B (b)	30 - 71	4.5	4.7	90.9	trace to null	4.4	45.6	40.2	9.8	sand
B65	A37	A37B (a)	0 - 20	5.7	7.1	87.2	trace to null	7.3	43.3	43.8	5.6	sand
B66	A37	A37B (b)	20 - 50	6.3	7.0	86.7	trace to null	7.0	37.3	44.8	11.0	sand
B67	F1	F1B (a)	0 - 15	4.1	4.3	91.5	trace to null	6.9	52.8	34.7	5.6	sand
B68	F1	F1B (b)	15 - 30	4.6	6.1	89.2	trace to null	7.9	47.4	37.0	7.7	sand
B69	F1	F1B (c)	30 - 45	4.6	5.5	89.9	trace to null	7.2	50.5	35.8	6.5	sand
B70	F2	F2B (a)	0 - 15	3.6	4.7	91.6	trace to null	4.4	52.5	38.0	5.0	sand
B71	F2	F2B (b)	15 - 30	3.6	5.7	90.7	trace to null	3.3	43.9	42.3	10.4	sand
B72	F2	F2B (c)	30 - 45	3.6	4.8	91.6	trace to null	3.6	46.9	42.0	7.5	sand
B73	F3	F3B (a)	0 - 15	3.1	4.8	92.0	trace to null	3.3	47.1	42.9	6.7	sand
B74	F3	F3B (b)	15 - 30	3.6	5.4	91.0	trace to null	5.9	50.6	38.2	5.3	sand
B75	F3	F3B (c)	30 - 45	4.5	4.3	91.2	trace to null	2.8	39.3	45.3	12.5	sand

Note: Sand (53 - 2000 μ), Silt (2 - 53 μ) and Clay (< 2 μ) are expressed as a percentage of the < 2000 μ sample. Sand fractions are expressed as a percentage of the Total Sand Fraction (53 - 2000 μ).

Physical Properties: Analytical Results

Unique ID	Site No.	Field Sample ID	Sample Depth (cm)	Textural Class	Organic Matter % (L.O.I)	Soil Moisture Content %	Dry Bulk Density (g/cm ³)	Total Porosity (volume %)
U1	A1	A1U (a)	5	sand	0.11	0.0	1.56	41.3
U2	A1	A1U (b)	15	sand	0.11	0.1	1.65	37.8
U3	A1	A1U (c)	25	sand	0.09	0.0	1.71	35.4
U4	A2	A2U (a)	5	sandy loam	0.16	0.9	1.46	45.0
U5	A2	A2U (b)	15	sandy loam	0.15	0.9	1.46	44.8
U6	A2	A2U (c)	25	sandy loam	0.17	0.9	1.55	41.6
	A3	not sampled						
	A4	not sampled						
U7	A5	A5U (a)	2.5	loamy sand	0.12	0.2	1.56	41.3
U8	A5	A5U (b)	25	loamy sand	0.10	1.8	1.61	39.2
U9	A5	A5U (c)	60	loamy sand	0.09	0.6	1.49	43.8
	A6	not sampled						
	A7	not sampled						
	A8	not sampled						
	A9	not sampled						
U10	A10	A10U (a)	15	sand	0.13	0.1	1.49	43.9
U11	A11	A11U (a)	15	sand	0.20	0.4	1.31	50.5
U12	A11	A11U (b)	45	sand	0.04	0.1	1.65	37.9
U13	A12	A12U (a)	15	loamy sand	0.11	0.8	1.51	43.1
U14	A13	A13U (a)	15	sand	0.13	0.5	1.39	47.7
U15	A14	A14U (a)	15	sand	0.04	0.1	1.63	38.6
U16	A14	A14U (b)	40	sand	0.01	0.6	1.63	38.5
U17	A15	A15U (a)	15	sand	0.10	0.1	1.62	39.0
U18	A16	A16U (a)	15	sand	0.07	0.1	1.58	40.3
U19	A17	A17U (a)	15	sand	0.12	0.2	1.71	35.5
U20	A18	A18U (a)	15	sandy loam	1.04	8.0	0.93	64.9
	A19	not sampled						
U21	A20	A20U (a)	15	loamy sand	0.21	0.7	1.36	48.7
U22	A21	A21U (a)	10	loamy sand	0.15	0.3	1.33	50.0
U23	A22	A22U (a)	15	sand	0.16	0.7	1.43	46.0
U24	A23	A23U (a)	15	sand	0.11	0.2	1.41	46.7
U25	A24	A24U (a)	15	sand	0.08	0.1	1.67	36.9
U26	A25	A25U (a)	15	loamy sand	0.20	1.9	1.33	49.7
U27	A26	A26U (a)	15	sandy loam	0.31	2.5	1.35	48.9
U28	A27	A27U (a)	15	loamy sand	0.19	1.1	1.40	47.3
	A28	not sampled						
U29	A29	A29U (a)	25	sand	0.12	0.1	1.60	39.6
U30	A30	A30U (a)	15	sand	0.11	0.1	1.59	40.1
U31	A31	A31U (a)	15	sand	0.11	0.3	1.45	45.2
U32	A32	A32U (a)	15	sand	0.05	0.3	1.57	40.6
	A33	not sampled						
U33	A34	A34U (a)	15	sand	0.10	0.3	1.48	44.1
U34	A35	A35U (a)	15	sandy loam	0.79	7.6	1.10	58.6
U35	A36	A36U (a)	15	sand	0.09	0.2	1.53	42.3
U36	A37	A37U (a)	15	sand	0.15	0.4	1.48	44.0
U37	F1	F1U (a)	15	sand	0.13	2.6	1.55	41.4
U38	F1	F1U (b)	30	sand	0.12	2.0	1.57	40.6
U39	F1	F1U (c)	45	sand	0.09	3.1	1.58	40.2
U40	F2	F2U (a)	15	sand	0.08	2.0	1.40	47.1
U41	F2	F2U (b)	30	sand	0.07	1.3	1.70	35.8
U42	F2	F2U (c)	45	sand	0.11	1.7	1.64	38.1
U43	F3	F3U (a)	15	sand	0.08	1.3	1.56	41.3
U44	F3	F3U (b)	30	sand	0.10	1.7	1.68	36.7
U45	F3	F3U (c)	45	sand	0.09	1.3	1.78	32.7

APPENDIX 6
SOIL CLASSIFICATION AND
ENVIRONMENTAL DATA

Soil Classification and Environmental Data

Site Number	FAO Soil Unit Code	Soil Unit	Phase	Profile Characteristics	Effective Depth Range (cm)	FAO Soil Depth Class	Soil Depth Class Code	FAO Soil Textural Class	Estimated Soil Permeability	FAO Soil Permeability Class
A1	AR0	Ferlic Arenosol	Yermic	Deep, well drained sand; soil, easily broken surface crust 4mm thick of surface mineral particles bonded by black amorphous microphytic material (algae ?); no cracks, ochric A horizon, dull orange brown (5YR 6/6) and light grey (2.5Y 6/1) mottles, thin band of black organic fragments at 7cm depth, unconsolidated to very fine granular structure, fine roots and root hairs at 5-25cm depth. Diffuse boundary at 20cm to B horizon, orange (5YR 6/6) medium to fine sand, 10% bright yellowish brown mottles from 20 - > 100cm (10YR 6/6), unconsolidated to very fine granular structure, lacking in cohesion, no evidence of carbonates. No visible lower boundary of B horizon to > 100cm.	>100	Deep	10	1	Well drained	4
A2	CLP	Petric Calcisol	Duripan	Shallow, imperfectly drained sandy loam, hard surface crust of fine clay particles 6mm thick, no cracks. Ochric A horizon, no B horizon, brownish black (7.5YR 3/2) silty fine sand uniform in texture down profile although both packing state and moisture content increases with depth, fine granular structure; no evidence of particle translocation, fine roots in dense mat from 5-20cm, 2-3% small hard slightly calcareous fragments dispersed uniformly throughout horizon in non-calcareous matrix, no evidence of fire. Boundary at +/- 32cm to C horizon of consolidated, weathered calcrete.	25-60	Shallow	5	1	Imperfectly drained	2
A3	APC	Calcic Arenosol	none	Deep, well drained sand, no surface sealing, cracks or crust development. Calcic ochric A horizon, no further horizon differentiation or profile development, bright brown (7.5YR 5/6) unconsolidated medium to fine sand, 5% orange (7.5YR 6/6) mottles evenly dispersed, no structure; very little dead organic matter; a 2cm dense band of small black mottles (diameter range 0.5-1.5mm) centred at 15cm depth (fire); no evidence of root wets; carbonates detected.	>100	Deep	10	1	Well drained	4
A4	ARh	Haplic Arenosol	Yermic	Deep, well drained loamy sand, indistinct crust development 2mm thick of fine mineral particles. Thick ochric A horizon, brown (7.5YR 4/4) matrix with no mottles; occasional coarse fragments of same colour <1%, evidence of fire in loose band of widely spaced black mottles (burnt broken fine roots, thin and elongated in shape - size range 0.5 x 2mm to 2 x 5mm); little profile development, fine crumb structure. Gradual boundary to transitional AC horizon at 30-40cm and beyond 40cm to C horizon, coarser matrix of unconsolidated particles of same colour, no evidence of carbonates.	>100	Deep	10	1	Well drained	4
A5	ARb	Cambic Arenosol	Yermic	Deep, well drained loamy sand; no surface sealing, crusting or cracks, surface cover >70% litter. Thin, parched, bleached brown (7.5YR 4/3) albic/calcic surface E horizon to 6cm depth, structureless coarse sand, no cohesion, no aggregates in matrix, overall colour signature appears greyish white; no evidence of roots, carbonates. Barely distinct colour change at 6cm to ochric A horizon, brown (7.5YR 4/4) where profile begins to show a weak granular structural development with larger unstable platy aggregates (5 mm - 3.5cm size range) down to 53cm depth, horizon eluviated and bleached, no mottles; no evidence of burnt organic matter, fine root hairs covering 25% area down to 20cm, and occasional medium root channels, carbonates detected. Distinct colour change at 53cm to cambic B horizon, reddish brown (5YR 4/6), accompanied by increase in moisture content, no further colour change > 100cm; fine granular structure with coarse single grains accounting for 10% of matrix, fine platy aggregates easily broken, a few medium roots and occasional small, long channels (3cm diameter) made by burrowing animals; no evidence of carbonates. No visible lower boundary to B horizon > 100cm.	>100	Deep	10	1	Well drained	4
A6	ARb	Cambic Arenosol	Duripan	Deep imperfectly drained fine sand, well drained at surface although impeded internal drainage in areas, incipient surface crust formation 1mm thick, no cracks. Banded ochric A horizon, brownish grey (7.5YR 4/1) medium to fine sand, weak granular structure, black organic mottles (diameter range 1 - 2mm) finely but evenly dispersed throughout horizon; no roots. Sharp boundary at 23cm to thin incipient B horizon where a 2cm band of compacted sand cemented to finer particles impedes internal drainage. Below this band brownish grey fine sands predominate again to 61cm depth at which a further compacted and cemented band 1cm thick forms a clearly visible structural boundary with no colour change. Penetration difficult. Auger observations below 61cm indicate a cambic B horizon with a matrix of dull orange (7.5YR 6/4) fine to medium unconsolidated sand and a distinct 2cm layer of coarse black carbon fragments lying at 65-67cm depth. Non calcareous throughout depth. Cemented C horizon at 67cm indicating duripan phase. No further penetration possible.	50-100	Moderately deep	6	1	Imperfectly drained	2
A7	AT0	Dystric Anthrosol	none	Profile not sampled. Field prepared for sowing. Barely discernible crust < 1mm thick, easily broken; clay particles sorted on surface. Horizons disturbed by ploughing. Soil known to be deficient in potassium for irrigated cropping although medium for rainfed cropping. Organic matter low, available Ca, Mg and K also low, low water holding capacity; soil neutral to slightly acidic. See Mishere Agricultural College soil sample results.	50-100	Moderately deep	6	1	Moderately well drained	3

Soil Classification and Environmental Data

Site Number	Soil Salinity Status	Soil Sodicity Status	Land System	Land Facet	Slope Inclination (%)	FAO Slope Class	Slope Aspect	Slope Shape	Micro-topography	Soil Surface Condition	Surface Drainage Status	Erosion/Deposition Status	Estimated Erodibility (E _s SLEMSA)	Erosion-Hazard Potential
A1	Non saline	Non sodic	(1.2) Stabilized dunes - narrow	Western edge of system in broad inter-dune valley	0-2	1	N-S	almost flat plain	Local micro-slopes in N-S alignment	Distinct crust 5mm thick bonded by amorphous black organic material (algae?), evidence of fire (not fast season), no stones	High permeability, crust-induced local surface water movement, no mounds	No evidence of water or wind erosion, no evidence of recent deposition	4	Moderate
A2	Non saline	Non sodic	(2.1) Karst pediplain - shallow sand cover	Slight depression on hard plain	0-2	1	E-W	slightly convex	Flat, rare micro-slopes	Crust >5mm thick of cemented sand and litter materials, no stones, high grass cover and litter, no evidence of fire, saline soil?	Evidence of ponding in patches	Incipient erosion, some re-working and deposition of fine particles both by water movement and wind after crust desiccation	4.5	Moderate
A3	Non saline	Non sodic	(2.1) Karst pediplain - shallow sand cover	Hard plain	0-1	1	E-W	almost flat plain	Flat, rare micro-slopes	10% litter	High surface permeability	No evidence of wind or water erosion	4	Moderate
A4	Non saline	Non sodic	(3.2) Northern sandplain incised by short omuramba	Plain with sand drift littil	0	1	n/a	plain	Flat smooth surface, no micro-slopes	Thin unstable patches of crust, 2mm thick, no sealing, no stones, 15% cover grass and leaf litter	Extremely high permeability, no mounds	No evidence of water erosion, possible wind-induced surface smoothening although no evidence of recent deposition	4	Moderate
A5	Non saline	Non sodic	(1.1) Stabilized dunes - wide dunes	Crest of north-facing wide dune	0-1	1	N	flat to slightly convex	Smooth to slight surface roughness	70% cover leaf litter, no sealing or cracks; no stones, no crustal development	No visible small-scale drainage; site crest of lateral drainage slope of omuramba	No evidence of erosion, no micro-deposition features, land cover high, predominantly grass, shrubs not common, large old trees, rare animal burrows, small animal tracks	4.5	Moderate
A6	Non saline	Non sodic	(3.3) Northern omuramba	Omuramba floor	0	1	n/a	flat	Uneven, slight surface roughness	70% cover leaf litter, incipient crust development, easily broken, 1mm thick, no cracks, no stones; organic matter fragments, not burnt.	No evidence of ponding, no mounds	No evidence of erosion, no micro-deposition features, land cover high.	4.5	Moderate
A7	Non saline	Non sodic	(3.1) Okavango river floodplain and terraces	Dry alluvial plain (not seasonally flooded)	0	1	n/a	flat	Uneven, ploughed bare surface	field prepared for sowing, barely discernible crust development < 1mm thick, easily broken; clay particles sorted on surface; clay; soil known to be deficient in potassium	No visible small-scale drainage	Slight sheet wash, (colluvial) deposits of clay particles on surface from 5% slope located immediately south of site	4	Moderate

Soil Classification and Environmental Data

Site Number	FAO Soil Unit Code	Soil Unit	Phase	Profile Characteristics	Effective Depth Range(cm)	FAO Soil Depth Class	Soil Depth Class Code	FAO Soil Textural Class	Estimated Soil Permeability	FAO Soil Permeability Class
A8	FLd	Cystic Fluvisol	Undic-phreatic	Deep, imperfectly drained alluvial loamy sand to sandy loam, no crust, sealing or cracks. Ochric A horizon greyish yellow brown (10YR 4/2) silty fine sand, unconsolidated to weakly developed very fine platy structure, unstable aggregates, no mottles; surface cover > 70% leaf and grass litter although fine root networks in A horizon are sparse, carbonates detected. Groual, diffuse transitional AB horizon at 25cm deepening to brownish black (10YR 2/2) at 30cm depth, very fine subangular structure, stable aggregates, medium network of fine roots, no carbonates detected, common fine to very fine pores, tonguing of clay particles. Argic B horizon at 30cm, distinctly higher content of illuvial clay to 45cm. Lower boundary to C at 45cm, material indistinct from lower alluvial sediments.	50-100	Moderately deep	8	1	Imperfectly drained	2
A9	ARh	Haplic Arenosol	Yermic	Deep, well to somewhat excessively drained medium to coarse aeolian sand, no crust, sealing or cracks. Ochric A horizon modified by ploughing, bright brown (7.5YR 5/6), unconsolidated, friable, no structural development, 1% black organic mottles evenly distributed and fine quartzite fragments, rare fine pores, few fine to very fine and no medium roots, non calcareous. Distinct boundary at 45cm to B horizon where boundary indicated by in situ colour change to bright yellowish brown (10YR 5/6); otherwise no diagnostic features, unconsolidated sand, <1% black organic fragments, no roots, very rare fine pores, non calcareous.	>100	Deep	10	1	Somewhat excessively drained	5
A10	ARh	Haplic Arenosol	Yermic	Deep, well drained medium to fine aeolian sand, incipient crust development <1mm thick, easily broken, no cracks. Albic surface horizon, greyish yellow brown (10YR 4/2) bleached and friable to 3cm; ochric A horizon with 7-10% black organic nodules and fragments in dense band at 5-8cm depth, unconsolidated, very weak very fine granular structure; rare very fine roots and few fine pores; non calcareous; no further diagnostic properties and no visible boundary to > 1m depth.	>100	Deep	10	1	Well drained	4
A11	ARo	Ferralsic Arenosol	Phreatic	Deep, well drained medium to fine aeolian sand; no crust, sealing or cracks. Ochric A horizon with some indication of umbic properties; greyish brown (7.5YR 4/2) bleached at surface to 2cm, very friable, unconsolidated fine grains, no structural development, fine root mat evenly distributed to 20cm, common medium to large pores, few fine pores; 5% black organic mottles at 11-14cm depth, non calcareous. Smooth distinct boundary at 25cm to B horizon with in situ colour alteration to dull reddish brown (5YR 5/3), friable, very weak very fine granular structure, at 60cm no visible boundary although slight increase in cohesivity, rare (1%) black organic fragments in 1cm band at 45cm, fine to very fine roots, common medium to large pores, few fine pores, non calcareous. Sharp boundary at 75cm to C horizon (parent material), unconsolidated sand drift, dull orange (7YR 7/3), significant increase in moisture content, rare fine roots; common medium to large pores, few fine pores, <1% small (0.5-1mm) black organic mottles. Note: very shallow groundwater levels.	>100	Deep	10	1	Well drained	4
A12	CLh	Haplic Calcisol	Phreatic	Deep, imperfectly drained loamy sand, impeded surface drainage and difficult to penetrate, thin hard crust 4mm thick, no cracks. Ochric/caloric A horizon, dark brown (7.5YR 3/3) dry, loose medium to fine sand with silts and clays, brown stem and bark fragments up to 9mm long at 5-15cm, no black mottles, very fine to fine platy structure, stable aggregates up to 3cm diameter, rounded, common very fine burnt roots at 5-15cm, common fine pores, silty, carbonates detected. Diffuse boundary at 40cm to illuvial B horizon, greyish brown (5YR 4/2) medium to fine sand with decrease in finer particles, weak very fine granular structure, improved drainage but increase in moisture content with depth, few fine pores; few very fine roots, no mottles. Smooth boundary at 60cm to illuvial C horizon, greyish yellow brown (10YR 5/2) loamy sand; increase in fine particles (illuvial), medium to coarse granular structure, further increase in soil moisture, 1% black organic nodules in 5mm band at 67cm depth, irregular soft white slightly calcareous nodules (authigenic) in non calcareous matrix. No visible lower boundary to > 100cm.	50->100	Moderately deep to deep	9	1	Imperfectly drained	2
A13	CLh	Haplic Calcisol	none	Deep, moderately well drained sand to loamy sand, no crustling, sealing or cracks. Ochric A horizon, dark brown (10YR 3/3), very fine subangular blocky structure, medium net of fine to very fine roots, common large pores, 3% organic black mottles. Diffuse boundary to calcic B horizon at 25cm, dull yellowish brown (10YR 4/3), 5% hard white concretions of an average 12mm diameter evenly distributed to 40cm depth, 5% burnt twig and root fragments at 30cm depth, common fine pores. Distinct colour change at 40cm to yellowish brown (10YR 5/6); non calcareous C horizon, no mottles or concretions, very fine to fine subangular structure, common fine pores; no roots, <1% black organic mottles. Structural change at 80cm, no colour change (yellowish brown), significant increase in unconsolidated medium to coarse sand with no structural development, no roots, no visible fine pores. No visible lower boundary.	>100	Deep	10	1	Moderately well drained	3

Soils of Kavango Region
Field Survey

Soil Classification and Environmental Data

Site Number	Soil Salinity Status	Soil Sodicity Status	Land System	Land Facet	Slope Inclination (%)	PAO Slope Class	Slope Aspect	Slope Shape	Micro-topography	Soil Surface Condition	Surface Drainage Status	Erosion/Deposition Status	Estimated Erodibility (Fb value; SLEM/SA)	Erosion Hazard Potential
A8	Non saline	Non sodic	(3.1) Okavango river floodplain and terraces	North-facing river bank	0	1	n/a	flat	Uneven, surface disturbed by animal hooves	surface covered by leaf and grass litter, no crust, sealing or cracks, no stones	imperfect (slow) drainage although no evidence of ponding	extensive river bank (water) erosion, small gully development 0.5-4m long	2.5	High
A9	Non saline	Non sodic	(3.1) Okavango river floodplain and terraces	Crest of oldest north-facing river terrace	9	2	NNE	convex	Flat, smooth	50% cover leaf and grass litter, no crust, sealing or cracks, no stones	High permeability, no visible small-scale drainage except for short-lived, small, anastomosing channels by animal tracks	water erosion alongside animal tracks	3	High
A10	Non saline	Non sodic	(3.2) Northern sandplain incised by short omiramba	sandy plain	0	1	n/a	flat	Hummocky	incipient crust development < 1mm thick, easily broken, no cracks, no stones	High permeability, no visible small-scale drainage	No evidence of wind or water erosion	4.5	Moderate
A11	Non saline	incipient natric B horizon	(3.2) Northern sandplain incised by short omiramba	sandy plain	0	1	n/a	flat	very hummocky, many local micro-allopes	High cover of leaf litter, no crust, sealing or cracks, no stones	High permeability, no visible small-scale drainage	No evidence of wind or water erosion	4.5	Moderate
A12	Non saline	Non sodic	(3.2) Northern sandplain incised by short omiramba	Slight depression on sandy plain with shallow calcrete	1	1	S	flat to imperceptibly concave	Smooth, bowl-shaped	High cover of leaf litter, surface difficult to penetrate (high bulk density ?) overlying loose sand, thin hard crust development 4mm thick	imperfect surface drainage, surface difficult to penetrate	No evidence of wind erosion, scanty deposition of fine material, no ponding	4	Moderate
A13	Non saline	Non sodic	(7.2) Eastern-flowing paleo drainage - sand plain with large parts	Long, gentle south-facing slope, mid-slope position	2	1	S	straight slope	Extensively hummocky, many local micro-allopes	High cover of leaf litter, hummocks stabilized by grass, no crust, sealing or cracks, no stones	Moderately well-drained, no surface channels or hills	No evidence of water or wind erosion, no evidence of recent deposition	4	Moderate

Soil Classification and Environmental Data

Site Number	FAO Soil Unit Code	Soil Unit	Phase	Profile Characteristics	Effective Depth Range(cm)	FAO Soil Depth Class	Soil Depth Class Code	FAO Soil Textural Class	Estimated Soil Permeability	FAO Soil Permeability Class
A14	Sth	Haplic Xanthic Solonch	plreatic	Deep, imperfectly drained sand to sandy loam, thin cemented surface crust 3mm thick, no cracks or stones. Ochric A horizon, greyish brown (7.5YR 5/2) fine sand with some silt, unconsolidated single grains, no structural development, 3% burnt organic molles, <1% fine roots; common medium pores and few fine pores. Clear smooth boundary at 31cm to B horizon indicating both colour and structural changes; colour change to dull yellow orange (10YR 7/2), fine to medium sand, weakly developed coarse granular to fine subangular blocky structure with high proportion of medium and fine single grains, no molles, no roots; visible increase in moisture content with depth from ~7-60cm onwards. Smooth boundary at 70cm to natric B sub-horizon, light grey (10YR 6/2) with 2% dull orange molles; increase in moisture content and slight increase in cohesivity; increase in packing state with weak coarse subangular blocky structure; no roots; soil near to saturated state at base for horizon (90cm depth). Sharp boundary transition to xanthic C horizon, dull yellowish brown (10YR 5/4), high proportion of fine sand and silt; significant increase in both moisture content and in cohesivity, strong coarse to very coarse subangular blocky structure; clay cutans; no roots.	>100	Deep	10	1	Imperfectly drained	2
A15	ARh	Haplic Arenosol	Yermic	Deep, well drained sand, no crusting, sealing or crack. Ochric A horizon, dark reddish brown (5YR 3/3), predominance of unconsolidated fine sands, no structural development, dry, 4% black organic molles at 10cm, 1% live grass seeds at 3-5cm depth; common very fine and presence of fine roots to 20cm, common medium pores. Smooth boundary at 28cm to C horizon, bright reddish brown (5YR 5/6), slightly finer, finer texture although no structural development; dry, <1% black organic molles; no roots. Horizon >100cm depth.	>100	Deep	10	1	Well drained	4
A16	ARh	Haplic Arenosol	Yermic	Deep, well drained sand; no crusting, sealing or cracks. Ochric A horizon, brown (7.5YR 4/3) unconsolidated fine sands, no structural development, dry, 5% black organic molles and larger burnt leaf fragments at 5cm, fine to very fine roots at 4-11cm depth; common medium pores, few fine pores. Diffuse boundary to reddish brown (5YR 4/3), finer sand texture, unconsolidated, no structural development, 1% burnt fine to very fine roots in thin bands (<1cm) at 32cm and again at 45cm depth. Indistinct boundary to C horizon at 46cm, no further horizon differentiation to >100cm depth.	>100	Deep	10	1	Well drained	4
A17	ARb	Cambic Arenosol	Yermic	Deep, moderately well drained colluvial sand, thin crust development 2mm thick of sand cemented by finer dark grey silt and clay particles, no cracks or stones. Crust overlies ochric A horizon of brownish black sand, unconsolidated, single grains with no structure, 3% burnt black organic molles evenly distributed from 6-10cm depth, common fine roots and presence of medium roots; common medium pores, few fine pores. Smooth diffuse boundary at 30cm to B horizon with some evidence of cambic properties (removal of carbonates and decrease of CEC with depth); greyish brown (7.5YR 4/2) fine to very fine sand, 5% dead but not burnt organic fragments evenly distributed to 60cm depth, 3% burnt organic molles at 32-37cm depth; common medium and fine pores. Distinct boundary at 60cm to C horizon, greyish brown (7.5YR 5/2); increase in proportion of medium to fine sand particles; no molles, common medium pores; no horizon differentiation to >100cm.	>100	Deep	10	1	Moderately well drained	3
A18	CLp	Pellic Calcisol	Rudic	Shallow, imperfectly drained sandy loam; discontinuous thin hard crust 3-5mm thick, local cracking and thin lid capping. Thin ochric/calcic A horizon, dark reddish grey (2.5YR 3/1) powdery sandy loam; fine to medium platy structure; small (1-4mm) hard white cemented calcareous fragments and disaggregated grains at accounting for 40% of matrix throughout horizon, common fine to very fine roots to 15cm; common fine to very fine pores, few large pores. Abrupt smooth boundary at 15cm to calcic but non-arqic B horizon, brownish grey (5YR 4/1), weak fine platy to very fine sub-angular structure; large hard white calcareous fragments predominant with common small hard nodules; few fine roots. Hard indurated layer of calcareate at 35cm (petroscalcic C horizon). Further penetration impossible.	25-60	Shallow	5	2	Imperfectly drained	2
A19	SRk	Calcic Solonch	Rudic	Very shallow, very poorly drained silt loam; moisture crust 14-25mm thick (A horizon cemented by calcium carbonate) overlying shallow B horizon of dull yellowish orange (10YR 7/3) powdery silt; no structure; hard white sub-angular cemented calcareous fragments and disaggregated grains accounting for >50% proportion of matrix in horizon, sodium saturation; <1% very fine roots. Hard indurated layer of weathered calcareate (C horizon transitional to bedrock) at 20cm depth. No further penetration possible; nodic phase indurated.	<25	Very shallow	1	1	Impeded drainage	0
A20	APHt	Calc-haplic Arenosol	Yermic	Deep, well drained loamy sand, no crusting, sealing or cracks. Ochric A horizon, very dark reddish brown (5YR 2/3) loamy sand; weakly developed fine to coarse granular structure with predominance of single medium to fine sand grains; dense fine root lattice to 21cm; few black organic molles at 7cm, ~1% hard white calcareous fragments (0.5-1mm) evenly distributed throughout horizon in non-calcareous matrix; calcareous accumulations not sufficient for horizon to be diagnosed as calcareic; common medium and fine pores. Diffuse boundary at 35cm to non-calcareous C horizon, dark reddish brown (5YR 3/4), no molles, coarser texture with common medium sand grains, dry, medium to very coarse granular structure with common single fine and medium sand grains; large pores; few fine roots; large roots at 80cm depth. No visible lower boundary >100cm depth.	>100	Deep	10	1	Well drained	4

Soil Classification and Environmental Data

Site Number	Soil Salinity Status	Soil Sodicity Status	Land System	Land Facet	Slope Inclination (%)	FAO Slope Class	Slope Aspect	Slope Shape	Micro-topography	Soil Surface Condition	Surface Drainage status	Erosion/Deposition Status	Estimated Erodibility (Fb value; SLEMSA)	Erosion Hazard Potential
A14	Non saline	Sodic El lower sub-nertion	(7.2) Eastern-flowing paleo drainage - sand plain with large pans	Well developed pan	0	1	n/a	flat		30% cover of leaf litter, thin grass cover, thin cemented surface crust 3mm thick; no cracks or stones	Impeded drainage. groundwater +1.15m from surface and at surface in low patches	Deposition area; wide, shallow drainage sink	5	Low
A15	Non saline	Non sodic	(7.1) Eastern-flowing paleo drainage - sand plain with small pans	Crest of SW-facing slope of tributary to Kaoudom river channel	8	2	SW	convex	Very uneven surface, high density of local micro-slopes	80% cover leaf litter, no crust, sealing, cracks or stones	Well-drained; no surface channels, some hills	Complete absence of fine materials (wash-out zone ?), local concentrations of coarse sand particles against micro-slope faces	3.5	High
A16	Non saline	Non sodic	(7.4) Eastern-flowing paleo drainage - eastern omiramba	SW-facing slope or tributary to Kaoudom river channel, basal mid-slope position	6	1	SW	straight slope	Hummocky, depressions formed downslope of hummocks with grass culms (not the case where hummocks are bare)	40% cover leaf litter, leaves	Well-drained, incipient surface channels and some mounds	Sheet wash area	3	High
A17	Non saline	Non sodic	(7.4) Eastern-flowing paleo drainage - eastern omiramba	SW-facing slope or tributary to Kaoudom river channel, basal slope position	0.5	1	SW	straight slope	Hummocky, uneven, gentle micro-slopes	50% cover leaf and grass litter, thin crust development 2mm thick, sand mixed with finer dark grey particles; no cracks, no stones, evidence of fire	Imperfect to moderately well drained, evidence of ponding in patches	Sheet wash deposition area	4.5	Moderate
A18	Non saline	Non sodic	(7.4) Eastern-flowing paleo drainage - eastern omiramba	Edge of vlei pan, channel floor	0	1	n/a	flat	Hard, uneven surface, cemented hummocks	Dense grass cover, discrete patches of thin hard crust 3-5mm thick, local cracking and caving at edges of cracks	Pan surface, regular seasonal ponding	Extensive deposition of fine material, calcrete at 30cm below surface	5	Low
A19	Non saline	Sodic throughout profile	(7.4) Eastern-flowing paleo drainage - eastern omiramba	Salt pan, mid channel floor	0	1	n/a	flat	Ridged surface	fare of cover, mature crust development 14-25mm thick, salty; no stones	Pan surface, very poor drainage, ponding	Extensive deposition of fine material, calcrete at 0-5cm below surface	5	Low
A20	Non saline	Non sodic	(7.1) Eastern-flowing paleo drainage - sand plain with small pans	Crest of local rise (incipient dune system ?)	2	1	NW	straight slope	Uneven	High cover leaf litter, no crust, sealing or cracks; no stones, not salty	No visible local drainage channels or rills, high permeability, whole slope aligned E-W and drains in NW direction	No evidence of water or wind erosion, no evidence of recent deposition	4.5	Moderate

Soil Classification and Environmental Data

Site Number	FAO Soil Unit Code	Soil Unit	Phase	Profile Characteristics	Effective Depth Range(cm)	FAO Soil Depth Class	Soil Depth Class Code	FAO Soil Textural Class	Estimated Soil Permeability	FAO Soil Permeability Class
A21	SNK	Calcic Solonch	none	Moderately deep, imperfectly drained loamy sand, thin hard crust 1-3mm thick, local crusting. Thin ochric A horizon of dark reddish grey (2.5YR 3/1) fine sand and silt, 3% black organic mottles at 6-8cm, very weak subangular blocky structure with single grain unconsolidated sands; common medium pores; fine roots and leaf fragments at 5-10cm. Abrupt boundary at 10cm to eluvial B horizon, brownish grey (7.5YR 4/1) with significant increase in soil moisture content, fine to very coarse granular structure; common medium pores; few fine roots and leaf fragments at 10-15cm; no mottles. Wavy boundary at 20cm to natric B sub-horizon, dark reddish brown (5YR 3/3) finer textured silty sand, fine prismatic structure; increase in cohesivity, moist; no mottles, accumulation of sodium. C horizon compact and consolidated below 48cm.	25-50	Shallow	5	2	Imperfectly drained	2
A22	ARB	Cambic Arenosol	Fragipan	Shallow, imperfectly drained sand overlying hard clays; continuous thin hard crust 4-6mm thick, no cracks. Thin ochric A horizon of brown (7.5YR 4/3) dry sand, no mottles; medium granular to medium subangular blocky structure with unconsolidated fine sand grains, <1% fine roots, common medium pores. Clear smooth boundary at 20cm to illuvial B horizon with evidence of cambic properties; greyish yellow brown (10YR 5/2) loamy sand, no mottles; moderate hard medium platy to medium subangular blocky structure; common medium and fine roots, few fine roots. Abrupt boundary at 30cm to hard, compact consolidated clays with extremely high penetration resistance - a buried B horizon of fine-particle deposits, not a C horizon.	25-50	Shallow	5	2	Imperfectly drained	2
A23	ARH	Haplic Arenosol	Yermic	Moderately deep well drained loamy sand, discontinuous crust 2-3mm thick, burnt organic particles bonded to underside of crust. Little profile development. Thick ochric A horizon, dull reddish brown (5YR 4/4) fine loamy sand with high internal drainage, weak fine to medium granular structure, 3% burnt organic mottles evenly distributed to 25cm depth, few very fine roots, common medium pores, few fine pores. Gradual diffuse boundary to C horizon at 75cm to fine aeolian sand. No visible lower boundary > 100cm.	>100	Deep	10	1	Well drained	4
A24	ARH	Haplic Arenosol	Yermic	Deep, somewhat excessively well drained sand, no crusting, sealing or cracks. Very little profile development. Ochric A horizon; dull reddish brown (5YR 4/4) fine to very fine sand, 2% burnt organic fragments and particles throughout profile, few very fine roots, common medium and large pores. At 45cm depth very gradual transition to C horizon marked by increase in colour value to 5YR 5/4. No visible lower boundary.	>100	Deep	10	1	Somewhat excessively drained	5
A25	ARC	Calcic Arenosol	Yermic	Moderately deep, imperfectly drained, loamy sand. Note: Terminalia Roundles woodland outside 'normal' range. Hard surface crust of fine clay particles up to 5mm thick, no cracks. Ochric A horizon, calcareous below 1cm depth, dark brown (10YR 3/2) loamy sand throughout profile, single horizon with development limited to very gradual progressive increase in particle consolidation and poorer internal drainage with depth, although no evidence of particle translocation, medium subangular blocky structure, hard white sub-angular cemented calcareous fragments evenly distributed and accounting for ~4-30% proportion of matrix; common fine pores; few fine roots. Gradual very broad lower boundary to consolidated C horizon at 75cm, highly resistant to further penetration.	50-100	Moderately Deep	8	1	Imperfectly drained	2
A26	CL1p	Hyper-Luvis Calcisol	Duripan	Moderately deep, imperfectly drained sandy loam; significant crust 8mm thick of fine cemented calcareous material, difficult to penetrate or break. Thin ochric A horizon of brownish black (10YR 2/2) sandy loam; upper particles cemented to underside of crust, medium angular blocky structure with loosely packed fine sand particles to 8cm depth; small (1-5mm) hard white cemented calcareous fragments and disaggregated grains accounting for 20% of matrix throughout horizon; common fine roots; common medium and fine pores. Abrupt boundary at 8cm to B horizon, greyish yellow brown (10YR 4/2) fine sand with increase in silt, fine subangular blocky structure, small white disaggregated calcareous grains accounting for 10% of matrix; dense mat of fine roots; common fine pores, decrease in internal drainage between 8-32cm depth. Sharp boundary at 32cm to argic B sub-horizon, greyish brown (5YR 5/2) fine sand with silt and increase in illuvial clay particles; medium to coarse subangular blocky structure with loosely packed fine sand; internal drainage improved; large, consolidated white calcareous fragments with common disaggregated calcareous grains accounting for >40% of matrix; few fine roots to 40cm, common fine	50-100	Moderately Deep	8	2	Imperfectly drained	2
A27	CL1p/Alip	Luvis Calcisol / Haplic Alisol	Duripan	Shallow, moderate to imperfectly drained loamy sand; insignificant, thin patchy crust, no cracks. Thin ochric A horizon of brownish black (10YR 2/2) loamy sand, dry, unconsolidated to weak-very fine granular structure; no mottles; common fine roots; common medium and large pores. Smooth boundary at 15cm to B horizon with evidence of argic properties; brighter chroma (10YR 2/3); very coarse granular structure; aggregated; significant increase in clay content and slight increase in moisture content; few very fine roots, common fine pores. Abrupt boundary at 40cm to impervious, indurated C horizon of consolidated silts and clays, possibly petrocyclic.	25-50	Shallow	6	2	Imperfectly drained	2

Soil Classification and Environmental Data

Site Number	Soil Salinity Status	Soil Sodicity Status	Land System	Land Facet	Slope Inclination (%)	FAO Slope Class	Slope Aspect	Slope Shape	Micro-topography	Soil Surface Condition	Surface Drainage Status	Erosion/Deposition Status	Estimated Erodibility (Fb value) SLEM(SA)	Erosion Hazard Potential
A21	Non saline	Non sodic	(7.1) Eastern-flowing paleo drainage - sand plain with small pans	Base of long gentle slope (incipient dune system?)	2	1	SE	straight slope	Uneven	30% cover of leaf litter, thin grass cover, thin hard surface crust 1-3mm thick, no stones, occasional cracks	Runoff slope, moist to wet soil at 40cm depth, elephant waterhole in vicinity	No strong evidence of erosion although widespread surface deposition of sand particles; hard crust would increase runoff potential down this long gentle slope; shallow subsurface calcrete (?)	4	Moderate
A22	Non saline	Non sodic	(7.4) Eastern-flowing paleo drainage - eastern amiramba	Edge of major drainage (amiramba) channel	1	1	SW	straight slope	High density of micro-slopes running parallel to slope direction	Low litter and grass cover, continuous surface crusting 4-6mm thick, no cracks, no stones	Base of runoff slope; high density of rills, and larger runoff channels evident, no gullies (yet)	Sand deposition on surface, very shallow soil/penetrable below 30cm.	3	High
A23	Non saline	Non sodic	(7.3) Eastern-flowing paleo drainage - hard pan	Sandy valley aligned NW-SE direction (paleo-surface - deflation zone)	0	1	n/a	flat	Small hummock redevelopment around grass clumps, widespread, otherwise smooth	Low litter and grass cover, discontinuous surface crust 2-3mm thick; evidence of fire, burnt organic particles bonded in crust	Suspected slow initial surface infiltration although freely drained below crust	No evidence of erosion, no recent deposition	4	Moderate
A24	Non saline	Non sodic	(7.3) Eastern-flowing paleo drainage - hard pan	Flattened dune crest (deflation zone)	0	1	n/a	flat	Uneven	25% cover leaf litter, no stones; angular charcoal fragments on surface and throughout profile (0-75cm depth)	No visible local drainage channels or rills; high permeability	No evidence of erosion, no recent deposition	4	Moderate
A25	Non saline	Non sodic	(7.3) Eastern-flowing paleo drainage - hard pan	Paleo surface; flattened crest underlain by shallow calcrete	0	1	n/a	top of gentle convex slope	Irregular, not smooth, no hummocks	High cover of leaf litter, Terminalia Prunoides woodland outside its 'normal' range	Imperfectly drained, progressively slower with soil depth; increase in soil compaction with depth	No evidence of wind or water erosion, no recent deposition	4.5	Moderate
A26	Non saline	Non sodic	(7.3) Eastern-flowing paleo drainage - hard pan	Paleo-surface; desiccating pan on crest of local rise in gently undulating area	0	1	n/a	top of gentle convex slope	Slightly uneven	Significant crust development (+/- 5mm thick) of fine, cemented calcareous material, difficult to penetrate or otherwise break; no stones	Drainage through surface impeded; internal drainage impeded down to 32cm depth below which it improves significantly	Old deposition area; currently a runoff zone although no evidence of wind or water erosion, no recent deposition	4.5	Moderate
A27	Non saline	Non sodic	(7.2) Eastern-flowing paleo drainage - trans hard pan to sand plain with large pans	Crest of long gently sloping rise	1	1	NW-SE	slightly convex	Extensively hummocky, many local micro-slopes	30% cover litter, very little to no micro-crust development, no cracks	Imperfect to moderately well drained at surface; impeded internal drainage at 42cm depth (horizon of compacted silt?)	Extensive sheet-wash	3	High

Soil Classification and Environmental Data

Site Number	FAO Soil Unit Code	Soil Unit	Phase	Profile Characteristics	Effective Depth Range(cm)	FAO Soil Depth Class	Soil Depth Class Code	FAO Soil Textural Class	Estimated Soil Permeability	FAO Soil Permeability Class
A28	CL1p/Alnp	Luvic Calcisol / Haplic Alisol	Duripan	As site A27	25-50	Shallow	5	2	Imperfectly drained	2
A29	ARb	Haplic Arenosol	Yermic	Deep, excessively well drained sand, no crusting, sealing or cracks. Ochric A horizon, dark reddish brown (5YR 3/2) unconsolidated medium to fine sand; 2% black organic mottles at 7-11 cm depth, common fine roots to 18cm, common medium and large pores. Diffuse boundary at 18cm to unspecified C horizon of aeolian sand > 100cm depth.	> 100	Deep	10	1	Excessively drained	6
A30	ARo	Ferralic Arenosol	Yermic	Deep, excessively well drained sand, no crusting, sealing or cracks. Thin albic/ochric EA surface horizon, greyish brown (5YR 4/2) unconsolidated medium to fine sand; 7% black organic mottles at 8-14 cm depth, common fine roots to 19cm, common medium and large pores. Clear smooth boundary with evidence of structural changes to B horizon at 30cm, dull orange (7.5YR 6/4), unconsolidated to very fine granular structure, 1% black organic particles in thin (1cm) band at 35cm, few fine roots, common medium and large pores. Boundary to transitional BC horizon at 36cm, no further colour change although gradual loss of structure to unconsolidated aeolian sand evident down horizon. No visible lower boundary > 100cm.	> 100	Deep	10	1	Excessively drained	6
A31	ARud	Cambic Arenosol	Duripan	Deep, imperfectly drained sand; no crusting, sealing or cracks. Ochric A horizon, brown (7.5YR 4/2), fine sand; very fine granular structure; firm, slightly compacted and cohesive; evidence of animal tracks and hoof churns; surface drainage good, few very fine roots, no mottles. Smooth boundary at 31cm to B horizon with some evidence of cambic properties; dull yellowish brown (10YR 4/3) sand, no change in texture although significant increase in packing state and moisture content. Internal drainage imperfect, fine to coarse granular structure, no mottles; few fine roots; common medium pores. Diffuse boundary to transitional BC horizon at 75cm, consolidated sand layer, no change in texture or colour. Boundary to strongly cemented C horizon at 90cm, slightly calcareous. No visible lower boundary.	50-> 100	Moderately deep to deep	9	1	Imperfectly drained	2
A32	SHik	Calc-Haplic Solonch	Duripan	Very shallow sand with impeded drainage. Note: area of Makalari Plains. Extensive surface cementation; continuous crust 15mm thick, consolidated sand layer cemented to underside of crust 30mm thick. Thin ochric A horizon of dull yellowish brown (10YR 6/4) fine sand; unconsolidated to medium granular structure; internal drainage below crust good, 1% black organic mottles at 8cm, very few fine roots, common medium pores. Abrupt boundary to matrix B horizon at 10cm, lower chroma and colour value (10YR 4/3); texture slightly coarser with decrease in proportion of silt and clay; hard medium granular to fine subangular blocky structure; increase in packing state and impeded internal drainage below 15cm; very few fine roots, rare black organic mottles. Structural boundary at 20cm to consolidated C horizon; massive compact angular blocky structure (>100mm), difficult to penetrate or otherwise break. Calcareous throughout profile, all base concentrations increase with depth.	<25	Very shallow	1	1	Impeded drainage	0
A34	ARo	Ferralic Arenosol	Yermic	Deep, somewhat excessively well drained aeolian sand; no crusting, sealing or cracks. Very little profile development. Deep ochric A horizon of dark reddish brown (5YR 3/2) medium to fine sand, rare burnt organic fragments and particles throughout horizon, few very fine roots; common medium to large pores. Clear smooth boundary at 42cm to B horizon with some ferralic properties; reddish brown (5YR 4/6) medium to fine sand, little textural difference, rare very fine roots at 42-47cm, no mottles; common medium to large pores. Diffuse, barely visible boundary at 60cm to a C horizon of firm, slightly compacted sand, no textural or colour change. No visible lower boundary.	>100	Deep	10	1	Somewhat excessively drained	5
A35	CLh	Haplic Calcisol	Yermic	Deep, imperfectly drained alluvial sandy loam overlying aeolian sand, hard continuous crust 4mm thick, no cracks. Calcic A horizon, brownish black (10YR 2/2) powdery sandy loam with high proportion of silt; weakly developed fine granular to medium clay structure; slow internal drainage; high proportion of soil, highly calcareous aggregations in calcareous matrix, rare very fine roots to 24cm, common fine pores. Diffuse boundary to B horizon at 36cm to sandy loam with brighter colour value (10YR 3/2), increase in medium sand particles, fine granular structure, impeded drainage, decrease with depth in proportions of soil, highly calcareous aggregations and large hard highly calcareous aggregations in calcareous matrix, rare fine to medium roots to 37cm, common fine pores. Distinct boundary at 70cm to C horizon of dark brown (10YR 2/2) sand, low proportion of silt, consolidated calcareous fragments and disaggregated particles in slightly calcareous matrix, internal drainage improved, no roots, common medium and large pores, few fine pores. No visible lower boundary to > 100cm.	> 100	Deep	10	1	Imperfectly drained	2

Soil Classification and Environmental Data

Site Number	Soil Salinity Status	Soil Sodicity Status	Land System	Land Facet	Slope Inclination (%)	FAO Slope Class	Slope Aspect	Slope Shape	Micro-topography	Soil Surface Condition	Surface Drainage Status	Erosion/Deposition Status	Estimated Erodibility (Fb value; SLEMSA)	Erosion Hazard Potential
A28	Non saline	Non sodic	(7.32) Eastern-flowing paleo drainage - transitional hard pan to sand plain with large pans	Head of tributary to main Omuramba channel, mid channel position, base of gentle slope	0.5	1	S	slightly concave	Extensively hummocky, many local micro-slopes	30% cover litter, very little to no crust development, no cracks, no stones	Imperfect	No evidence of erosion, no recent deposition	4.5	Moderate
A29	Non saline	Non sodic	(7.32) Eastern-flowing paleo drainage - transitional hard pan to sand plain with large pans	Sandy plain	0	1	n/a	flat	Uneven	High cover of leaf litter, no crust, sealing or cracks, no stones; Burkea woodland	Excessively well drained, no visible drainage channels	No evidence of erosion, no recent deposition	5	Low
A30	Non saline	Incipient natric B horizon	(7.2) Eastern-flowing paleo drainage - sand plain with large pans	Eastern edge of water divide, long gentle slope, crest position	1	1	E	concave	Uneven	High cover of leaf litter, no crust, sealing or cracks, no stones	Excessively well drained, no visible drainage channels	No evidence of wind or water erosion, no recent deposition	4.5	Moderate
A31	Non saline	Non sodic	(6.1) Ephemeral catchment divide - high plain	Water divide area, elevated plain with local depressions, low position	1	1	NE	almost flat plain	Uneven, high density of shallow, wide runoff channels (width range 50-30cm)	Surface cleared of litter along runoff channels between stable grassed clumps, no crust, sealing or cracks, no stones, no evidence of fire	Surface well drained, subsurface drainage imperfect, shallow runoff channels widespread	Ample evidence of water erosion, denudation surface, no gullies	3.5	High
A32	Non saline	Natric B horizon	(6.1) Ephemeral catchment divide - high plain	Water divide area, elevated plain with local depressions, crest of rise	0.5	1	E	flat to slightly convex	Hummocky, shallow, wide runoff channels	Extensive surface cementation, continuous crust 15mm thick, consolidated sand layer below crust 30mm thick, no stones	Impaired surface drainage, free internal drainage from 5-12cm depth, further impeded drainage below 15cm	Denudation surface, moderate water erosion (runoff channels), no gullies	4	Moderate
A34	Non saline	Non sodic	(4.1) Omatako Omuramba - main channel and tributaries	Main channel/tributary confluence, channel floor position	2	1	NW-SE	concave	Localized hummocks, otherwise flat and smooth	High cover of grasses and shrubs, no cracks, sealing or stones	Well drained, no visible drainage channels	Recent deposition of sandy material (colluvial)	4.5	Moderate
A35	Non saline	Non sodic	(4.1) Omatako Omuramba - main channel and tributaries	Main channel floor	0	1	n/a	flat	Flat, hard, smooth	Low cover tufted grasses, hard, crusted surface (4mm thick), continuous, no stones, no cracks	Impeded drainage, wide shallow drainage sink	Recent deposition fine sand and silt material	5	Low

Soil Classification and Environmental Data

Site Number	FAO Soil Unit Code	Soil Unit	Phase	Profile Characteristics	Effective Depth Range(cm)	FAO Soil Depth Class	Soil Depth Class Code	FAO Soil Textural Class	Estimated Soil Permeability	FAO Soil Permeability Class
A36	ARc	Calcic Arenosol	Yermic	Deep, moderately well drained sand; continuous thin, hard crust 3mm thick, no cracks. Ochric, slightly calcareous A horizon; dark brown (10YR 3/3) medium to fine sand with silt; very fine granular to very fine platy structure; rare fine roots, common fine pores; <1% black organic matter at 5-9cm. Smooth boundary at 30cm to C horizon of dull brown (5YR 4/4) medium to fine aeolian sand; good internal drainage. Unconsolidated to weakly developed fine granular structure; no mottles; no roots, common medium pores, no visible boundary to > 100cm depth.	>100	Deep	10	1	Moderately well drained	3
A37	ARu	Ferralic Arenosol	Yermic	Deep, well drained sand; continuous incipient crust 1mm thick, no cracks. Ochric A horizon, brown (7.5YR 4/6) medium to fine sand with silt and clay; unconsolidated to very fine crumb structure; dense root mat bound into 5mm thick fibrous layer with silt and clays at 3cm depth; 2% black organic fragments and particles at 7-11cm. Smooth boundary at 20cm to transitional BC horizon with some ferralic properties (texture too coarse to be diagnostic of ferralic horizon); reddish brown (5YR 4/8) sand; no change in texture although slightly coarser handling properties; unconsolidated, no structural development; freely drained; no roots, no mottles; common medium pores. No visible lower boundary to > 100cm.	>100	Deep	10	1	Well drained	4
F1	AR0	Ferralic Arenosol	Yermic	Deep, excessively well drained sand; no crusting, sealing or cracks. Thick ochric A horizon, brown (7.5YR 4/6) medium sand, common black organic mottles and fragments in dense band between 5-7cm depth; weakly developed coarse granular structure, very friable, non sticky, non plastic; few fine pores, non calcareous, few fine to very fine roots. Smooth diffuse boundary at 15cm to B horizon with some ferralic properties (texture too coarse to be diagnostic of ferralic horizon). No textural difference although colour change to reddish brown (5YR 4/6). Very weak very coarse crumb structure, slightly hard, friable, non calcareous; rare fine roots. Smooth boundary at 30cm to C horizon of bright reddish brown (5YR 5/6) loamy sand, loose, very coarse crumb structure, slightly hard, friable, non calcareous; no roots. No visible lower boundary to > 100cm.	>100	Deep	10	1	Excessively drained	6
F2	ARh	Haplic Arenosol	Yermic	Deep, excessively well drained sand; no crusting, sealing or cracks. Thin ochric A horizon of brown (7.5YR 4/6) sand with little clay or silt content; grey coat permeable colour certainly produced by recent fire; very coarse crumb structure, easily broken; non calcareous; 10% black organic matter; common fine to very fine roots, common medium and large pores. Abrupt boundary at 15cm to dull brown (7.5YR 5/3) sand with coarser texture; unconsolidated, to weak fine crumb structure; non calcareous; non sticky; 3% black organic matter at 15-18cm depth; common very fine roots, common large pores. Smooth boundary to transitional AC horizon of dull orange (7.5YR 6/4) unconsolidated sand; slightly compact; no structural development; no roots; no mottles; common large pores. No visible lower boundary to > 100cm.	>100	Deep	10	1	Excessively drained	6
F3	ARh	Haplic Arenosol	Yermic	Deep, excessively well drained sand; no crusting, sealing or cracks. Ochric A horizon of brown (7.5YR 4/4) sand with little clay or silt content; coarse crumb structure, easily broken; 3% black organic matter; few fine roots, common medium and large pores; non calcareous. Smooth boundary at 15cm to transitional AC horizon of dull orange (7.5YR 6/4) unconsolidated sand; no structural development; no mottles; few fine roots; common medium and large pores; non calcareous. Diffuse boundary at 32cm to unspecified C horizon, no colour change or textural differences; medium crumb structure, easily broken, slight increase in packing state; 3% black organic matter at 32-35cm; common medium pores. No visible lower boundary to > 100cm.	>100	Deep	10	1	Excessively drained	6

Soil Classification and Environmental Data

Site Number	Soil Salinity Status	Soil Sodic Status	Land System	Land Facet	Slope Inclination (%)	FAO Slope Class	Slope Aspect	Slope Shape	Micro-topography	Soil Surface Condition	Surface Drainage Status	Erosion/Deposition status	Estimated Erodibility (E _s value, SLEMSA)	Erosion Hazard Potential
A36	Non saline	Non sodic	(4.1) Omatako Omuramba - main channel and tributaries	Western boundary, mid reaches, side slope	5	1	NE-SW	straight slope	High density of micro-slopes running parallel to slope direction	Medium cover of leaf litter, continuous thin hard crust 3mm thick	Moderately well drained, evidence of sheet runoff	Minor development of sheet wash surfaces	3.5	High
A37	Non saline	Non sodic	(4.2) Omatako Omuramba - lower catchment slopes	Western edge of ephemeral river system on crest of NW-SE aligned dune	4	1	NW-SE	convex	Medium density of micro-slopes running parallel to slope direction	High cover of leaf litter, continuous thin crust 1mm thick, no cracks or stones	Well drained, incipient development of shallow drainage channels	Minor development of sheet wash surfaces	3.5	High
F1	Non saline	Incipient natric B horizon	(3.1) Okavango river floodplain and terraces	Crest of oldest north-facing river terrace bordering sand plain hinterland	4	1	NE	straight slope	Uneven, micro-slopes around shrubs	High cover of leaf litter, burnt twigs, tree & shrub branches, no crusting or sealing, no evidence of salt	No visible drainage lines; soil highly permeable	Evidence of water and wind erosion, not severe; sand particle accumulations against surface debris and hummocks (in prevailing wind direction?) & minor sheet wash effect	3.5	High
F2	Non saline	Incipient natric C sub-horizon	(3.2) Northern sandplain incised by short omuramba	Sand drift plain, NW Kavango south of oldest terrace, recent fire	1.5	1	S	straight slope	Uneven, local micro-slopes	High cover of burnt twigs, a recent high temperature fire, no crusting, sealing or cracks, no salt	No visible drainage lines; soil highly permeable	No evidence of water or wind erosion, no evidence of recent deposition	4.5	Moderate
F3	Non saline	Non sodic	(3.2) Northern sandplain incised by short omuramba	Sand drift plain, NW Kavango south of oldest terrace	1.5	1	S	straight slope	Uneven, minor hummocks around shrubs	High cover of burnt twigs, a recent high temperature fire, no crusting, sealing or cracks, no salt	No visible drainage lines; soil highly permeable	No evidence of wind erosion; rain splash (slight cementation & pitted surface) and minor sheet wash effects	4.5	Moderate

APPENDIX 7
SOILS ANALYSIS:
TEST SITE SUMMARIES

SOILS OF KAVANGO REGION

SOILS ANALYSIS Site Summary		Site No	Date	Lat	Long	Land System	Land Facet	Slope %	Slope Class	Aspect	Slope Shape																																				
A1		18°33.263'S	25-Apr-99	18°33.453'E	(1.2) Stabilized dunes - narrow	Inter-dune valley	0-2	1	N-S	almost flat plain																																					
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	% < 2µ clay	% 2 - 50µ silt	% 53 - 2000µ sand	% > 2000µ gravel	% 2000 - 500µ vcs/ks	% 500 - 250µ ms	% 250 - 106µ fs	% 106 - 53µ vfs	FAO Textural Class																																				
B1	A1B (a)	0-30	5.1	6.2	86.7	trace to null	13.0	39.2	30.1	17.8	1																																				
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Colour (moist)	Texture	OM % (L.O.I)	Moist Cont %	P (Olsen mg/kg)	ECe (µS/cm)	pH (H ₂ O)	OrgC % (Walkley-Black)	CaCO ₃ (quant)																																				
B1	A1B (a)	0-30	10YR 6/4 dull orange brown	sand	Not analysed	Not analysed	1.5	8.9	5.5	0.12	low pH																																				
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	SO ₄ (S µg/g Turbid)	Ca (ppm)	Mg (ppm)	K (ppm)	Na (ppm)	Cu (ppm)	Zn (ppm)	Fa (ppm)	Mn (ppm)																																				
B1	A1B (b)	0-30	16.4	22	7	17	5.0	<0.5	<0.2	<0.5	0.8																																				
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	CECtotal (me/100g)	Clay %	CECclay (me/100g)	Tot Exch Bases (me/100g)	BSP (me/100g)	BSP (me/100g clay)	ESP (me/100g clay)	ESP (me/100g clay)	SAR																																				
B1	A1B (b)	0-30	0.24	5.10	4.70	0.230	96.80	6.09	9.179	0.468	0.238																																				
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Ca:Mg	K:Mg	K:CEC total (EPP)	K:CEC (clay)	Salinity	Sodicity (ESP > 15)	Sodicity (Na > 1me/100g)	FAO Depth Class																																					
B1	A1B (a)	0-30	1.92	0.75	17.90	0.92	N/A	N/A	N/A	Deep																																					
Und Lab ID	Und Field ID	Und Depth (cm)	OM % (L.O.I)	Moist Cont %	Dry BD (g/cm ³)	Porosity (vol %)	FAO Classification		RSA Classification																																						
U1	A1U (a)	5	0.11	0.0	1.56	41.3	Group	Unit	Phase																																						
U2	A1U (b)	15	0.11	0.1	1.65	37.8	Arenosol		Ferralic																																						
U3	A1U (c)	25	0.09	0.0	1.71	35.4	Arenosol		Ferralic																																						
Micro-topography						Soil Surface Condition						Surface Drainage						Erosion / Deposition																													
Local micro-slopes in N-S alignment												Distinct crust 4mm thick bonded by amorphous black organic material (algae ?); evidence of fire (not last season); no stones												High permeability; crust-induced local surface water movement; no rills.												No evidence of water or wind erosion; no evidence of recent deposition											
Horizon	Depth (cm)											Profile Description																																			
Au1	0-7											Deep, well drained sand; soft, easily broken surface crust 4mm thick of surface mineral particles bonded by black amorphous mycrophytic material (algae ?); no cracks, no salt; ochric A horizon, dull orange brown (10YR 6/4) with 10% orange (5YR 6/8) and light grey (2.5Y 8/1) mottles; thin band of black organic fragments at 7cm depth, unconsolidated to very fine granular structure; fine roots and root hairs at 5-25cm depth. Diffuse boundary at 20cm to B horizon, orange (5YR 6/8) medium to fine sand; 10% bright yellowish brown mottles from 20 - >100cm (10YR 6/6); unconsolidated to very fine granular structure, lacking in cohesion; no evidence of carbonates. No visible lower boundary of B horizon to >100cm.																																			
Ah	7-8																																														
Au2	8-20																																														
Bg	20-> 100																																														

SOILS OF KAVANGO REGION

SOILS ANALYSIS Site Summary		Site No	Date	Lat	Long	Land System	Land Facet	Slope %	Slope Class	Aspect	Slope Shape
A2		A2	25-Apr-99	18°32.21'S	18°12.24'E	(2.1) Karsl pediplain - shallow sand cover	Slight depression on hard plain	0-2	1	E-W	slightly convex
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	% < 2µ clay	% 2 - 53µ silt	% 53 - 2000µ sand	% > 2000µ gravel	% 2000 - 500µ vcs/cs	% 500 - 250µ ms	% 250 - 106µ fs	% 106 - 53µ vfs	FAO Textural Class
B2	A2B (a)	0-30	9.3	12.7	78.1	trace to null	16.0	19.7	44.9	19.4	1
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Colour (moist)	Texture	OM % (L.O.I)	Moist Cont %	P (Olsen mg/kg)	ECE (µS/cm)	pH (H ₂ O)	OrgC % (Walkley-Black)	CaCO ₃ (quant)
B2	A2B (a)	0-30	7.5YR 3/2 brownish black	sandy loam	Not analysed	Not analysed	0.3	20.8	6.8	0.28	7.5
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	SO ₄ (S µg/g Turbid)	Ca (ppm)	Mg (ppm)	K (ppm)	Na (ppm)	Cu (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)
B2	A2B (a)	0-30	1.2	422	161	133	11	<0.5	<0.2	<0.5	<0.5
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	CECtotal (me/100g)	Clay %	CECclay (me/100g)	Tot Exch Bases (me/100g)	BSP (me/100g)	BSP (me/100g clay)	ESP (me/100g)	ESP (me/100g clay)	SAR
B2	A2B (a)	0-30	3.82	9.30	41.12	3.818	99.83	9.28	1.177	0.109	0.115
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Ca:Mg	K:Mg	K:CEC total (EPP)	K:CEC (clay)	Salinity	Sodicity (ESP *15)	Sodicity (Na ⁺ me/100g)	FAO Depth Class	
B2	A2B (a)	0-30	1.60	0.26	8.89	0.83	N/A	N/A	N/A	Shallow	
Und Lab ID	Und Field ID	Und Depth (cm)	OM % (L.O.I)	Moist Cont %	Dry BD (g/cm3)	Porosity (vol %)	Group	FAO Classification	Phase	RSA Classification	
U4	A2U (a)	5	0.16	0.9	1.46	45.0					
U5	A2U (b)	15	0.15	0.9	1.46	44.8					
U6	A2U (c)	25	0.17	0.9	1.55	41.6					
Micro-topography		Soil Surface Condition		Surface Drainage		Erosion / Deposition					
Flat; rare micro-slopes		Crust >5mm thick of cemented sand and finer materials; no stones; high grass cover and litter; no evidence of fire; saline soil ?		Evidence of ponding in patches		Incipient erosion; some re-working and deposition of fine particles both by water movement and wind after crust desiccation					
Horizon	Depth (cm)	Profile Description									
Act	0-1										
AK1	1-5										
AK2	5-20	Shallow, imperfectly drained sandy loam; hard surface crust of fine clay particles 6mm thick; no cracks. Ochric A horizon, no B horizon; brownish black (7.5YR 3/2) silty fine sand uniform in texture down profile although both packing state and moisture content increases with depth; fine granular structure; no evidence of particle translocation; fine roots in dense mat from 5-20cm; 2-3% small hard slightly calcareous fragments dispersed uniformly throughout horizon in non-calcareous matrix; no evidence of fire. Boundary at +/- 32cm to C horizon of consolidated, weathered calcrete.									
Crw	20-32										
Crk	32+										

SOILS OF KAVANGO REGION

SOILS ANALYSIS Site Summary		Site No	Date	Lat	Long	Land System	Land Facet	Slope %	Slope Class	Aspect	Slope Shape
		A3	25-Apr-99	18°32.57'S	18°18.94'E	(2.1) Karst pediplain - shallow sand cover	Hard plain	0-1	1	E-W	almost flat plain
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	% < 2µ clay	% 2 - 5µ silt	% 53 - 200µ sand	% > 200µ gravel	% 2000 - 500µ vcs/cs	% 500 - 250µ ms	% 250 - 106µ fs	% 106 - 53µ vfs	FAO Textural Class
B3	A3B (a)	0-30	5.5	7.5	87.0	trace to null	19.9	29.3	38.2	12.7	1
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Colour (moist)	Texture	OM % (L.O.I)	Molst Cont %	P (Olsen mg/kg)	ECe (µS/cm)	pH (H ₂ O)	OrgC % (Walkley-Black)	CaCO ₃ (quant)
B3	A3B (a)	0-30	7.5YR 5/6 bright brown	sand	0.13	0.8	0.7	7.0	5.3	0.17	low pH
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	SO ₄ (S µg/g Turbid)	Ca (ppm)	Mg (ppm)	K (ppm)	Na (ppm)	Cu (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)
B3	A3B (a)	0-30	3.6	14	58	12	6	<0.5	<0.2	<0.5	0.5
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	CECtotal (me/100g)	Clay %	CECclay (me/100g)	Total Exch Bases (me/100g)	BSP (me/100g)	BSP (me/100g clay)	ESP (me/100g)	ESP (me/100g clay)	SAR
B3	A3B (a)	0-30	0.61	5.50	11.06	0.602	98.92	5.44	4.272	0.235	0.158
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Ca:Mg	K:Mg	K:CEC Total (EPP)	K:CEC (clay)	Salinity	Sodicity (ESP > 15)	Sodicity (Na > 1me/100g)	FAO Depth Class	
B3	A3B (a)	0-30	0.15	0.07	5.09	0.28	N/A	N/A	N/A	Deep	
Und Lab ID	Und Field ID	Und Depth (cm)	OM % (L.O.I)	Molst Cont %	Dry BD (g/cm ³)	Porosity (vol %)	FAO Classification		RSA Classification		
N/A	not sampled	N/A	N/A	N/A	N/A	N/A	Group	Unit	Phase		
N/A	N/A	N/A	N/A	N/A	N/A	N/A	Arenosol	Calcaric	n/a	Portsmouth ?	
N/A	N/A	N/A	N/A	N/A	N/A	N/A	Surface Drainage		Erosion / Deposition		
Micro-topography											
Flat, rare micro-slopes			10% litter			High surface permeability			No evidence of wind or water erosion		
Horizon											
Depth (cm)		Profile Description									
Agk1	0-14	Deep, well drained sand; no surface sealing, cracks or crust development. Calcaric ochric A horizon, no further horizon differentiation or profile development; bright brown (7.5YR 5/6) unconsolidated medium to fine sand; 5% orange (7.5YR 6/8) mottles evenly dispersed; no structure; very little dead organic matter; a 2cm dense band of small black mottles (diameter range 0.5-1.5mm) centred at 15cm depth (fire); no evidence of root webs; carbonates detected.									
Ahp	14-16										
Agk2	16->100										

SOILS OF KAVANGO REGION

SOILS ANALYSIS Site Summary		Site No	Date	Lat	Long	Land System	Land Facet	Slope %	Slope Class	Aspect	Slope Shape
A4		A4	26-Apr-99	18°24.56'S	19°18.07'E	(3.2) Northern sandplain incised by short miramba	Plain - sand drift Infill	0	1	n/a	plain
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	% < 2µ clay	% 2 - 53µ silt	% 53 - 2000µ sand	% > 2000µ gravel	% 2000 - 500µ ves/cs	% 500 - 250µ ms	% 250 - 10µ fs	% 105 - 5µ v/fs	FAO Textural Class
B4	A4B (a)	0-30	5.9	8.2	85.9	Trace to null	2.4	29.0	54.4	14.3	1
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Colour (moist)	Texture	OM % (L.O.I)	Moist Cont %	P (Olsen mg/kg)	ECe (µS/cm)	pH (H ₂ O)	OrgC % (Walkley-Black)	CaCO ₃ (quant)
B4	A4B (a)	0-30	7.5YR 4/4 brown	loamy sand	0.16	0.2	0.2	12.6	6.3	0.19	low pH
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	SO ₄ (S µg/g Turbid)	Ca (ppm)	Mg (ppm)	K (ppm)	Na (ppm)	Cu (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)
B4	A4B (a)	0-30	7.2	203	66	35	6	<0.5	<0.2	<0.5	<0.5
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	CECtotal (me/100g)	Clay %	CECclay (me/100g)	T of Exch Bases (me/100g)	BSP (me/100g)	BSP (me/100g clay)	ESP (me/100g)	ESP (me/100g clay)	SNR
B4	A4B (a)	0-30	1.68	5.90	28.45	1.672	99.61	5.88	1.549	0.091	0.094
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Ca:Mg	K:Mg	K:CEC total (EPP)	K:CEC (clay)	Salinity	Sodicity (ESP * 15)	Sodicity (Na>1me/100g)	FAO Depth Class	
B4	A4B (a)	0-30	1.88	0.17	5.36	0.32	N/A	N/A	N/A	Deep	
Und Lab ID	Und Field ID	Und Depth (cm)	OM % (L.O.I)	Moist Cont %	Dry BD (g/cm ³)	Porosity (vol %)	FAO Classification		RSA Classification		
N/A	N/A	N/A	N/A	N/A	N/A	N/A	Group	Unit	Phase		
N/A	N/A	N/A	N/A	N/A	N/A	N/A	Arenosol	Haplic	Yermic	Fernwood ?	
Micro-topography		Soil Surface Condition		Surface Drainage		Erosion / Deposition					
Flat smooth surface, no micro-slopes		Thin unstable patches of crust, 2mm thick; no sealing; no stones; 15% cover grass and leaf litter		Extremely high permeability; no fills		No evidence of water erosion; possible wind-induced surface smoothing although no evidence of recent deposition					
Horizon	Depth (cm)	Profile Description									
Ap1 Ap1C Cu	0-30 30-40 40-> 100	Deep, well drained loamy sand; indistinct crust development 2mm thick of fine mineral particles. Thick ochric A horizon; brown (7.5YR 4/4) matrix with no mottles; occasional coarse fragments of same colour <1%; evidence of fire in loose band of widely spaced black mottles (burnt broken fine roots, thin and elongated in shape - size range 0.5 x 2mm to 2 x 9mm); little profile development; fine crumb structure. Gradual boundary to transitional AC horizon at 30-40cm and beyond 40cm to C horizon; coarser matrix of unconsolidated particles of same colour; no evidence of carbonates.									

SOILS OF KAVANGO REGION

SOILS ANALYSIS Site Summary		Site No	Date	Lat	Long	Land System	Land Facet	Slope %	Slope Class	Aspect	Slope Shape
A5		A5	27-Apr-99	17°37'813"S	18°08'329"E	(1.1) Stabilized dunes - wide dunes	Crest of N-facing wide dune	0-1	1	N	flat to slightly convex
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	% < 2µ clay	% 2 - 53µ silt	% 53 - 2000µ sand	% > 200µ gravel	% 2000 - 500µ w/secs	% 500 - 250µ ms	% 250 - 106µ fs	% 106 - 53µ v/s	FAO Textural Class
B5	A5B (a)	5-30	5.4	9.0	85.7	trace to null	8.4	50.0	35.0	6.7	1
B6	A5B (b)	53-70	6.8	9.4	83.8	trace to null	5.1	39.6	43.9	11.4	1
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Colour (moist)	Texture	OM % (L.O.I)	Moist Cont %	P (Olsen mg/kg)	ECe (µS/cm)	pH (H ₂ O)	OrgC % (Walkley-Black)	CaCO ₃ (quant)
B5	A5B (a)	5-30	7.5YR 4/4 brown	loamy sand	Not analysed	Not analysed	0.4	6.5	5.8	0.18	low pH
B6	A5B (b)	53-70	5YR 4/6 reddish brown	loamy sand	Not analysed	Not analysed	0.5	6.3	5.9	0.12	low pH
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	SO ₄ (S µg/g Turbid)	Ca (ppm)	Mg (ppm)	K (ppm)	Na (ppm)	Cu (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)
B5	A5B (a)	5-30	5.9	61	63	16	5	<0.5	<0.2	<0.5	<0.5
B6	A5B (b)	53-70	8.6	31	36	16	5	<0.5	<0.2	<0.5	0.3
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	CEC total (me/100g)	Clay %	CEC clay (me/100g)	Total Exch Bases (me/100g)	BSP (me/100g)	BSP (me/100g clay)	ESP (me/100g clay)	ESP (me/100g clay)	SAR
B5	A5B (a)	5-30	0.89	5.40	16.49	0.884	99.27	5.36	2.470	0.133	0.107
B6	A5B (b)	53-70	0.52	6.80	7.63	0.513	98.87	6.72	4.240	0.288	0.145
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Ca/Mg	K/Mg	K:CEC total (EPP)	K:CEC (clay)	Salinity	Sodicity (ESP >15)	Sodicity (Na>1me/100g)	FAO Depth Class	
B5	A5B (a)	5-30	0.59	0.08	4.60	0.25	No	No	No	Deep	
B6	A5B (b)	53-70	0.53	0.14	7.90	0.54	No	No	No	Deep	
Und Lab ID	Und Field ID	Und Depth (cm)	OM % (L.O.I)	Moist Cont %	Dry BD (g/cm ³)	Porosity (vol %)	FAO Classification		RSA Classification		
U7	A5U (a)	0 - 5	0.12	0.2	1.56	41.3	Group	Unjl	Phase		
U8	A5U (b)	25	0.10	1.8	1.61	39.2	Arenosol	Cambic	Yermic	Gaudam ?	
U9	A5U (c)	60	0.09	0.6	1.49	43.8					
Micro-topography		Soil Surface Condition		Surface Drainage		Erosion / Deposition					
Smooth to slight surface roughness		70% cover leaf litter; no sealing or cracks; no stones; no crustal development		No visible small-scale drainage; site on crest of lateral drainage slope of omuramba		No evidence of erosion; no micro-deposition features; land cover high, predominantly grass; shrubs not common; large old trees; rare animal burrows, small animal tracks.					
Horizon	Depth (cm)	Profile Description									
Ek	0-6	Deep, well drained loamy sand; no surface sealing, crusting or cracks; surface cover >70% litter. Thin, parched, bleached brown (7.5YR 4/3) albi/calcic surface E horizon to 6cm depth; structureless coarse sand, no cohesion; no aggregates in matrix; overall colour signature appears greyish white; no evidence of roots; carbonates. Barely distinct colour change at 6cm to ochric A horizon, brown (7.5YR 4/4) where profile begins to show a weak granular structural development with larger unstable platy aggregates (5 mm - 2.5cm size range) down to 53cm depth; horizon eluviated and bleached; no mottles; no evidence of burnt organic matter; fine root hairs covering 25% area down to 20cm, and occasional medium root channels; carbonates detected. Distinct colour change at 53cm to cambic B horizon, reddish brown (5YR 4/6), accompanied by increase in moisture content; no further colour change >100cm: fine granular structure with coarse single grains accounting for 10% of matrix; fine platy aggregates easily broken; a few medium roots and occasional small, long channels (2cm diameter) made by burrowing animals; no evidence of carbonates. No visible lower boundary to B horizon >100cm.									

SOILS OF KAVANGO REGION

SOILS ANALYSIS Site Summary		Site No	Date	Lat	Long	Land System	Land Facet	Slope %	Slope Class	Aspect	Slope Shape
A6		A6	27-Apr-99	17°36.613'S	18°07.968'	(3.3) Northern Omuramba	Omuramba floor	0	1	n/a	flat
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	% < 2µ clay	% 2 - 5µ silt	% 53 - 2000µ sand	% > 2000µ gravel	% 2000 - 500µ vcs/cs	% 500 - 250µ ms	% 250 - 106µ fs	% 106 - 53µ vfs	FAO Textural Class
B7	A6B (a)	15-30	6.3	11.3	82.5	trace to null	5.9	43.5	42.4	8.1	1
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Colour (moist)	Texture	OM % (L.O.I)	Moist Cont %	P (Olsen mg/kg)	ECe (µS/cm)	pH (H ₂ O)	OrgC % (Walkley-Black)	CaCO ₃ (quant)
B7	A6B (a)	15-30	7.5YR 4/1 brownish grey	loamy sand	0.15	0.5	0.2	13.9	5.9	0.23	low pH
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	SO ₄ (S µg/g Turbid)	Ca (ppm)	Mg (ppm)	K (ppm)	Na (ppm)	Cu (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)
B7	A6B (a)	15-30	9.1	120	101	30	7	0.8	<0.2	<0.5	1.6
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	CECtotal (me/100g)	Clay %	CECclay (me/100g)	Tot Exch Bases (me/100g)	BSP (me/100g)	BSP (me/100g clay)	ESP (me/100g)	ESP (me/100g clay)	SAR
B7	A6B (a)	15-30	1.55	6.30	24.55	1.535	99.25	6.25	1.940	0.122	0.114
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Ca:Mg	K:Mg	K:CEC total (EPP)	K:CEC (clay)	Salinity	Sodicity (ESP > 15)	Sodicity (Na > 1me/100g)	FAO Depth Class	
B7	A6B (a)	15-30	0.72	0.09	4.98	0.31	No	No	No	Moderately Deep	
Und Lab ID	Und Field ID	Und Depth (cm)	OM % (L.O.I)	Moist Cont %	Dry BD (g/cm ³)	Porosity (vol %)	FAO Classification	FAO Classification	FAO Classification	RSA Classification	
N/A	not sampled	N/A	N/A	N/A	N/A	N/A	Group	Unit	Phase		
N/A	N/A	N/A	N/A	N/A	N/A	N/A	Arenosol	Combic	Duripan	Fernwood/Okavango intergrade	
N/A	N/A	N/A	N/A	N/A	N/A	N/A	Surface Drainage		Erosion / Deposition		
<p>Uneven; slight surface roughness</p> <p>70% cover leaf litter; incipient crust development, easily broken, 1mm thick; no cracks; no stones; organic matter fragments, not burnt.</p> <p>No evidence of ponding; no rills</p> <p>No evidence of erosion; no micro-deposition features; land cover high.</p>											
Horizon	Depth (cm)	Profile Description									
Ap	1-23	Deep imperfectly drained fine sand; well drained at surface although impeded internal drainage in areas; incipient surface crust formation 1mm thick, no cracks. Banded ochre A horizon, brownish grey (7.5YR 4/1) medium to fine sand; weak granular structure; black organic molles (diameter range 1 - 2mm) thinly but evenly dispersed throughout horizon; no roots. Sharp boundary at 23cm to thin incipient B horizon where a 2cm band of compacted sand cemented to finer particles impedes internal drainage. Below this band brownish grey fine sands predominate again to 61cm depth at which a further compacted and cemented band 1cm thick forms a clearly visible structural boundary with no colour change. Penetration difficult. Auger observations below 61cm indicate a cambic B horizon with a matrix of dull orange (7.5YR 6/4) fine to medium unconsolidated sand and a distinct 2cm layer of coarse black carbon fragments lying at 65-67cm depth. Non calcareous throughout depth. Cemented C horizon at 67cm indicating duripan phase. No further penetration possible.									
Bmwf	23-25										
Abp	25-61										
Bmw2	61-62										
Ew	62-65										
Bp	65-67										
Cmw	67+										

SOILS OF KAVANGO REGION

SOILS ANALYSIS Site Summary		Site No	Date	Lat	Long	Land System	Land Facet	Slope %	Slope Class	Aspect	Slope Shape
		A7	28-Apr-99	17°53.741'S	20°12.740'E	(3.1) Okavango river floodplain and terraces	Dry alluvial plain (not seasonally flooded)	0	1	n/a	flat
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	% < 2µ clay	% 2 - 53µ silt	% 53 - 2000µ sand	% > 2000µ gravel	% 2000 - 5000µ vcs/ks	% 500 - 250µ ms	% 250 - 10µ fs	% 105 - 53µ v/s	FAO Textural Class
N/A	not sampled	N/A	3	2	95	N/A	N/A	N/A	N/A	N/A	1
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Colour (moist)	Texture	OM % (L.O.I)	Moist Cont %	P (Olsen ppm)	ECe (µS/cm)	pH (H ₂ O)	OrgC % (Walkley-Black)	CaCO ₃ (quant)
N/A	not sampled	N/A	N/A	sand	0.30	N/A	18.0	29.0	5.5		
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	SO ₄ (S µg/g Turbid)	Ca (ppm)	Mg (ppm)	K (ppm)	Na (ppm)	Cu (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)
N/A	not sampled	N/A	N/A	218	36	44	26				
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	CEC total (me/100g)	Clay %	CEC clay (me/100g)	Tot Exch Bases (me/100g)	BSP (me/100g)	BSP (me/100g clay)	ESP (me/100g)	ESP (me/100g clay)	SAR
N/A	not sampled	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Ca/Mg	K/Mg	K:CEC total (EPP)	K:CEC (clay)	Salinity	Sodicity (ESP > 15)	Sodicity (Na > (me/100g))	Sodicity (Na > (me/100g))	FAO Depth Class
N/A	not sampled	N/A	N/A	N/A	N/A	N/A	no	no	no	no	Deep
Und Lab ID	Und Field ID	Und Depth (cm)	OM % (L.O.I)	Moist Cont %	Dry BD (g/cm ³)	Porosity (vol %)	FAO Classification		RSA Classification		
N/A	not sampled	N/A	N/A	N/A	N/A	N/A	Group	Uptil	Phase		
N/A	N/A	N/A	N/A	N/A	N/A	N/A	Anthrosol (form. Cambisol ?)	Dystic	n/a		Clovelly ?
N/A	N/A	N/A	N/A	N/A	N/A	N/A					
Micro-topography		Surface Drainage									
Uneven; ploughed bare surface		Erosion / Deposition									
		Slight sheet wash; (colluvial) deposits of clay particles on surface from 5% slope located immediately south of site									
Horizon		Profile Description									
P	>60cm	Profile not sampled. Field prepared for sowing. Barely discernible crust < 1mm thick, easily broken; clay particles sorted on surface. Horizons disturbed by ploughing. Soil known to be deficient in potassium for irrigated cropping although medium for rainfed cropping. Organic matter low; available Ca, Mg and K also low; low water holding capacity; soil neutral to slightly acidic. See Mashere Agricultural College soil sample results.									

SOILS OF KAVANGO REGION

SOILS ANALYSIS Site Summary		Site No	Date	Lat	Long	Land System	Land Facet	Slope %	Slope Class	Aspect	Slope Shape
		A8	28-Apr-99	17°53.511'S	20°15.043'E	(3.1) Okavango river floodplain and terraces	North-facing river bank	0	1	n/a	flat
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	% < 2µ clay	% 2 - 53µ silt	% 53 - 2000µ sand	% > 2000µ gravel	% 2000 - 5000µ vs/CS	% 500 - 250µ ms	% 250 - 106µ fs	% 106 - 53µ v/s	FAO Textural Class
B8	ABB (a)	0-30	6.5	12.2	81.3	trace to null	6.4	43.6	42.6	7.4	
B9	ABB (b)	30-60	14.6	10.8	74.6	trace to null	6.6	39.0	41.1	13.3	1
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Colour (moist)	Texture	OM % (L.O.I)	Molal Cont %	P (Olsen mg/kg)	ECe (µS/cm)	pH (H ₂ O)	OrgC % (Walkley-Black)	CaCO ₃ (quant)
B8	ABB (a)	0-30	10YR 4/2 greyish yellow brown	loamy sand	0.15	1.1	0.9	35.7	8.4	0.24	12.0
B9	ABB (b)	30-60	10YR 2/2 brownish black	sandy loam	0.32	5.2	0.3	125.2	8.1	0.26	<1
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	SO ₄ (S µg/g Turbid)	Ca (ppm)	Mg (ppm)	K (ppm)	Na (ppm)	Cu (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)
B8	ABB (a)	0-30	7.0	440	53	56	23	<0.5	<0.2	<0.5	<0.5
B9	ABB (b)	30-60	1.5	596	199	92	54	<0.5	<0.2	<0.5	<0.5
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	CEC total (me/100g)	Clay %	CEC clay (me/100g)	Tot Exch Bases (me/100g)	BSP (me/100g)	BSP (me/100g clay)	ESP (me/100g)	ESP (me/100g clay)	SAR
B8	ABB (a)	0-30	2.91	6.60	44.76	2.903	99.78	6.49	3.437	0.223	0.276
B9	ABB (b)	30-60	5.09	14.60	34.84	5.080	99.87	14.58	4.620	0.675	0.489
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Ca/Mg	K/Mg	K:CEC total (EPP)	K:CEC (clay)	Salinity	Sodicity (ESP > 15)	Sodicity (Na>Tme/100g)	FAO Depth Class	
B8	ABB (a)	0-30	5.07	0.39	5.81	0.38	No	No	No	Moderately Deep	
B9	ABB (b)	30-60	1.83	0.14	4.62	0.67	No	No	No		
Und Lab ID	Und Field ID	Und Depth (cm)	OM % (L.O.I)	Moist Cont %	Dry BD (g/cm ³)	Porosity (vol %)	Group	Urtill	Phase	RSA Classification	
N/A	not sampled	N/A	N/A	N/A	N/A	N/A					
N/A	N/A	N/A	N/A	N/A	N/A	N/A	Fluvisol	Dystric	Inundic/Phtreatic	Okavango ?	
N/A	N/A	N/A	N/A	N/A	N/A	N/A					
Micro-topography		Surface Drainage									
Uneven; surface disturbed by animal hooves		Soil Surface Condition									
		Surface covered by leaf and grass litter; no crust, sealing or cracks; no stones									
		Imperfect (slow) drainage although no evidence of ponding									
		Erosion / Deposition									
		Extensive river bank (water) erosion; small gully development 0.5-4m long									
Horizon	Depth (cm)	Profile Description									
Ak1	0-25	Deep, imperfectly drained alluvial loamy sand to sandy loam; no crust, sealing or cracks. Ochric A horizon greyish yellow brown (10YR 4/2) silty fine sand; unconsolidated to weakly developed very fine platy structure; unstable aggregates; no mottles; surface cover > 70% leaf and grass litter although fine root networks in A horizon are sparse; carbonates detected. Gradual, diffuse transitional AB horizon at 25cm deepening to brownish black (10YR 2/2) at 30cm depth; very fine subangular structure; stable aggregates; medium network of fine roots; no carbonates detected; common fine to very fine pores; tonguing of clay particles. Argic B horizon at 30cm; distinctly higher content of illuvial clay to 45cm. Lower boundary to C at 45cm; material indistinct from lower alluvial sediments.									
BA	25-30										
BW	30-45										
Cu	45+										

SOILS OF KAVANGO REGION

SOILS ANALYSIS Site Summary		Site No	Date	Lat	Long	Land System	Land Facet	Slope %	Slope Class	Aspect	Slope Shape
A9			28-Apr-99	17°54.264'S	20°10.572'E	(3.1) Okavango river floodplain and terraces	Crest of oldest north-facing river terrace	9	2	NNE	convex
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	% < 2µ clay	% 2 - 5µ silt	% 53 - 200µ sand	% > 200µ gravel	% 200 - 500µ vcs/cs	% 500 - 250µ ms	% 250 - 106µ fs	% 106 - 53µ vfs	FAO Textural Class
B10	A9B (a)	0-30	5.3	6.4	88.3	trace to null	4.6	49.8	38.2	7.5	
B11	A9B (b)	30-60	5.8	7.5	86.7	trace to null	4.5	45.7	39.8	10.0	1
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Colour (moist)	Texture	OM % (L.O.I)	Molst Cont %	P (Olsen mg/kg)	ECe (µS/cm)	pH (H ₂ O)	OrgC % (Walkley-Black)	CaCO ₃ (quant)
B10	A9B (a)	0-30	7.5YR 5/6 bright brown	sand	0.08	0.4	0.2	6.0	6.4	0.14	low pH
B11	A9B (b)	30-60	10YR 6/6 bright yellowish brown	sand	0.07	0.9	< 0.1	30.9	5.0	0.09	low pH
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	SO ₄ (S ug/g Turbid)	Ca (ppm)	Mg (ppm)	K (ppm)	Na (ppm)	Cu (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)
B10	A9B (a)	0-30	8.8	54	19	6	5	< 0.5	< 0.2	< 0.5	< 0.5
B11	A9B (b)	30-60	10.1	22	13	5	5	< 0.5	< 0.2	< 0.5	0.3
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	CECtotal (me/100g)	Clay %	CECclay (me/100g)	Total Exch Bases (me/100g)	BSP (me/100g)	BSP (me/100g clay)	ESP (me/100g)	ESP (me/100g clay)	SAR
B10	A9B (a)	0-30	0.47	5.30	8.86	0.463	98.61	5.23	4.665	0.248	0.149
B11	A9B (b)	30-60	0.26	5.80	4.45	0.252	97.73	5.67	8.532	0.495	0.209
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Ca:Mg	K:Mg	K:CEC total (EPP)	K:CEC (clay)	Salinity	Sodicity (ESP > 15)	Sodicity (Na>1me/100g)	FAO Depth Class	
B10	A9B (a)	0-30	1.73	0.10	3.19	0.17	No	No	No	Deep	
B11	A9B (b)	30-60	1.03	0.12	5.04	0.29	No	No	No	Deep	
Und Lab ID	Und Field ID	Und Depth (cm)	OM % (L.O.I)	Moist Cont %	Dry BD (g/cm ³)	Porosity (vol %)	FAO Classification	FAO Classification	FAO Classification	RSA Classification	
N/A	not sampled	N/A	N/A	N/A	N/A	N/A	Group	Unit	Phase		
N/A	N/A	N/A	N/A	N/A	N/A	N/A	Arenosol	Haplic	Yermic	Sandspruit ?	
N/A	N/A	N/A	N/A	N/A	N/A	N/A					
Micro-topography		Soil Surface Condition									
Flat, smooth		50% cover leaf and grass litter; no crust, sealing or cracks; no stones									
Erosion / Deposition		water erosion alongside animal tracks									
Horizon	Depth (cm)	Profile Description									
Ap	0-49	Deep, well to somewhat excessively drained medium to coarse aeolian sand; no crust, sealing or cracks. Ochric A horizon modified by ploughing, bright brown (7.5YR 5/6), unconsolidated, friable, no structural development. 1% black organic mottles evenly distributed and fine quartzite fragments, rare fine pores, few fine to very fine and no medium roots, non calcareous. Distinct boundary at 49cm									
Bw	49->100	B horizon where boundary indicated by in situ colour change to bright yellowish brown (10YR 6/6); otherwise no diagnostic features, unconsolidated sand; <1% black organic fragments, no roots, very rare fine pores, non calcareous.									

SOILS OF KAVANGO REGION

SOILS ANALYSIS Site Summary		Site No	Date	Lat	Long	Land System	Land Facet	Slope %	Slope Class	Aspect	Slope Shape
A10		A10	28-Apr-99	18°08.900'S	20°46.335'E	(3.2) Northern sandplain incised by short omiramba	sandy plain	0	1	n/a	flat
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	% < 2µ clay	% 2 - 5µ silt	% 53 - 2000µ sand	% > 2000µ gravel	% 2000 - 500µ vcs/fs	% 500 - 250µ ms	% 250 - 106µ fs	% 106 - 53µ vcs	FAO Textural Class
B12	A10B (a)	0-30	4.6	6.2	89.2	trace to null	1.8	47.6	42.5	8.1	1
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Colour (moist)	Texture	OM % (L.O.I)	Moist Cont %	P (Clisen mg/kg)	ECe (µS/cm)	pH (H ₂ O)	OrgC % (Walkley-Black)	CaCO ₃ (quant)
B12	A10B (a)	0-30	10YR 4/2 greyish yellow brown	sand	Not analysed	Not analysed	< 0.1	8.9	5.5	0.28	low pH
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	SO ₄ (S µg/g Turbid)	Ca (ppm)	Mg (ppm)	K (ppm)	Na (ppm)	Cu (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)
B12	A10B (a)	0-30	20.1	60	11	4	5	< 0.5	< 0.2	< 0.5	1.1
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	CECtotal (me/100g)	Clay %	CECclay (me/100g)	Total Exch Bases (me/100g)	BSP (me/100g)	BSP (me/100g clay)	ESP (me/100g)	ESP (me/100g clay)	SAR
B12	A10B (a)	0-30	0.43	4.60	9.36	0.422	97.97	4.51	5.107	0.235	0.156
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Ca/Mg	K/Mg	K:CEC total (EPP)	K:CEC (clay)	Salinity	Sodicity (ESP > 5)	Sodicity (Na > 1me/100g)	FAO Deph Class	
B12	A10B (a)	0-30	3.33	0.11	2.32	0.11	No	No	No	Deep	
Undr Lab ID	Undr Field ID	Undr Depth (cm)	OM % (L.O.I)	Moist Cont %	Dry BD (g/cm ³)	Porosity (vol %)	FAO Classification		RSA Classification		
U10	A10U (a)	15	0.13	0.1	1.49	43.9	Group	Unit	Phase		
Micro-topography		Soil Surface Condition		Surface Drainage		Erosion / Deposition					
Hummocky		Incipient crust development < 1mm thick, easily broken; no cracks; no stones		High permeability; no visible small-scale drainage		No evidence of wind or water erosion					
Horizon		Depth (cm)		Profile Description							
E	0-3	Deep, well drained medium to fine aeolian sand; incipient crust development < 1mm thick, easily broken, no cracks. Albic surface horizon, greyish yellow brown (10YR 4/2) bleached and friable to 3cm;									
Au1	3-5	ochric A horizon with 7-10% black organic mottles and fragments in dense band at 5-8cm depth; unconsolidated, very weak very fine granular structure, rare very fine roots and few fine pores; non									
Ap	4-8	calcareous; no further diagnostic properties and no visible boundary to > 1m depth.									
Au2	8->100										

SOILS OF KAVANGO REGION

SOILS ANALYSIS Site Summary		Site No	Date	Lat	Long	Land System	Land Facet	Slope %	Slope Class	Aspect	Slope Shape
A11		A11	29-Apr-99	18°09.691'S	20°46.193'E	(3.2) Northern sandplain incised by short omiramba	sandy plain	0	1	n/a	flat
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	% < 2µ clay	% 2 - 5µ silt	% 53 - 2000µ sand	% > 2000µ gravel	% 2000 - 500µ vcs/cs	% 500 - 250µ ms	% 250 - 100µ fs	% 106 - 53µ vfs	FAO Textural Class
B13	A11B (a)	0-30	4.9	7.1	88.0	trace to null	2.3	51.1	40.3	6.3	
B14	A11B (b)	30-60	5.3	6.0	88.7	trace to null	1.3	41.5	48.0	9.2	1
B15	A11B (c)	>75	5.7	6.1	88.2	trace to null	1.9	42.4	47.7	6.0	
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Colour (moist)	Texture	OM % (L.O.I)	Moist Cont %	P (Olsen mg/kg)	ECe (µS/cm)	pH (H ₂ O)	OrgC % (Walkley-Black)	CaCO ₃ (quant)
B13	A11B (a)	0-30	7.5YR 4/2 greyish brown	sand	Not analysed	Not analysed	< 0.1	10.4	5.1	0.29	low pH
B14	A11B (b)	30-60	5YR 5/3 dull reddish brown	sand	Not analysed	Not analysed	< 0.1	9.9	4.8	0.11	low pH
B15	A11B (c)	>75	7.5YR 7/3 dull orange	sand	0.04	0.4	< 0.1	7.8	4.9	0.06	low pH
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	SO ₄ (S µg/g Turbid)	Ca (ppm)	Mg (ppm)	K (ppm)	Na (ppm)	Cu (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)
B13	A11B (a)	0-30	14.1	44	12	9	5	<0.5	<0.2	<0.5	1.2
B14	A11B (b)	30-60	12.2	13	4	10	5	<0.5	<0.2	<0.5	<0.5
B15	A11B (c)	>75	8.8	4	2	5	3	<0.5	<0.2	<0.5	<0.5
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	CECtotal (me/100g)	Clay %	CECclay (me/100g)	Tol Exch Bases (me/100g)	BSP (me/100g)	BSP (me/100g clay)	ESP (me/100g)	ESP (me/100g clay)	SAR
B13	A11B (a)	0-30	0.37	4.90	7.59	0.363	97.55	4.78	5.912	0.290	0.172
B14	A11B (b)	30-60	0.15	5.30	2.88	0.146	95.71	5.07	14.423	0.764	0.311
B15	A11B (c)	>75	0.07	5.70	1.20	0.082	90.46	5.16	18.968	1.081	0.306
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Ca:Mg	K:Mg	K:CEC total (EPP)	K:CEC (clay)	Salinity	Sodicity (ESP > 15)	Sodicity (Na>1me/100g)	FAO Depth Class	
B13	A11B (a)	0-30	2.24	0.23	6.18	0.30	No	No	No	Deep	
B14	A11B (b)	30-60	1.97	0.79	17.04	0.90	No	Yes	No		
B15	A11B (c)	>75	1.25	0.81	18.97	1.08	No	Yes	No		
Und Lab ID	Und Field ID	Und Depth (cm)	OM % (L.O.I)	Moist Cont %	Dry BD (g/cm ³)	Porosity (vol %)	FAO Classification		RSA Classification		
U11	A11U (a)	15	0.20	0.4	1.31	50.5	Group	Unit	Phase		
U12	A11U (b)	45	0.04	0.1	1.65	37.9	Arenosol	Ferralsol	Pheallic	Gaudam ?	
Micro-topography		Soil Surface Condition		Surface Drainage		Erosion / Deposition					
Very hummocky; many local micro-slopes		High cover of leaf litter; no crust, sealing or cracks; no stones		High permeability; no visible small-scale drainage		No evidence of wind or water erosion					
Horizon	Depth (cm)	Profile Description									
Ap1	0-11	Deep, well drained medium to fine acolian sand; no crust, sealing or cracks. Ochric A horizon with some indication of umbric properties; greyish brown (7.5YR 4/2) bleached at surface to 2cm, very friable; unconsolidated free grains, no structural development, fine root mat evenly distributed to 20cm, common medium to large pores, few fine pores; 5% black organic mottles at 11-14cm depth; non calcareous. Smooth distinct boundary at 25cm to B horizon with in situ colour alteration to dull reddish brown (5YR 5/3); friable, very weak very fine granular structure; at 60cm no visible boundary although slight increase in cohesivity; rare (1%) black organic fragments in 1cm band at 45cm; fine to very fine roots, common medium to large pores, few fine pores; non calcareous. Sharp boundary at 75cm to C horizon (parent material, unconsolidated sand drift); dull orange (7YR 7/3), significant increase in moisture content; rare fine roots; common medium to large pores, few fine pores; <1% small (0.5-1mm) black organic mottles. Note: very shallow groundwater levels.									

SOILS OF KAVANGO REGION

SOILS ANALYSIS Site Summary		Site No.	Date	Lat	Long	Land System	Land Facet	Slope %	Slope Class	Aspect	Slope Shape	
Site Summary		A12	29-Apr-99	18°10.907S	20°45.740E	(3.2) Northern sandplain incised by short omiramba	Slight depression on sandveld plain - shallow calcare	1	1	S	flat to imperceptibly concave	
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	% < 2µ clay	% 53 - 2000µ sand	% 2 - 50µ silt	% > 2000µ gravel	% 2000 - 500µ vss/cs	% 500 - 250µ ms	% 250 - 106µ fs	% 106 - 53µ vfe	FAO Textural Class	
B16	A12B (a)	0-30	6.7	83.1	10.2	trace to null	2.2	36.3	52.6	8.9		
B17	A12B (b)	40-70	7.2	83.0	9.8	trace to null	1.5	34.9	53.8	9.9	1	
B18	A12B (c)	80-90	5.3	84.9	10.2	trace to null	1.5	34.3	54.1	10.1		
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Colour (moist)	OM % (L.O.I)	Texture	Moist Cont %	P (Olsen mg/kg)	ECe (µS/cm)	pH (H ₂ O)	OrgC % (Walkley-Black)	CaCO ₃ (quant)	
B16	A12B (a)	0-30	7.5YR 3/3 dark brown	Not analysed	loamy sand	Not analysed	0.1	58.2	7.7	0.27	<1	
B17	A12B (b)	40-70	5YR 4/2 greyish brown	0.14	loamy sand	1.9	< 0.1	32.0	7.3	0.14	3.6	
B18	A12B (c)	80-90	10YR 5/2 greyish yellow brown	0.11	loamy sand	1.5	< 0.1	24.2	6.3	0.10	low pH	
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	SO ₄ (S µg/g Turbid)	Ca (ppm)	Mg (ppm)	K (ppm)	Na (ppm)	Cu (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)	
B16	A12B (a)	0-30	2.8	508	83	27	6	<0.5	0.2	<0.5	<0.5	
B17	A12B (b)	40-70	5.1	283	137	14	11	<0.5	<0.2	<0.5	<0.5	
B18	A12B (c)	80-90	5.4	204	88	12	5	<0.5	<0.2	<0.5	<0.5	
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	CECtotal (me/100g)	Clay %	CECclay (me/100g)	Tot Exch Bases (me/100g)	BSP (me/100g)	BSP (me/100g clay)	ESP (me/100g)	ESP (me/100g clay)	SAR	
B16	A12B (a)	0-30	3.32	6.70	49.58	3.315	99.80	6.69	0.783	0.052	0.065	
B17	A12B (b)	40-70	2.63	7.20	36.51	2.622	99.75	7.18	1.826	0.131	0.134	
B18	A12B (c)	80-90	1.80	25.30	7.11	1.793	99.64	25.21	1.223	0.309	0.074	
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Ca:Mg	K:Mg	K:CEC total (EPP)	K:CEC (clay)	Salinity	Sodicity (ESP >15)	Sodicity (Na >1me/100g)	FAO Depth Class		
B16	A12B (a)	0-30	3.74	0.10	2.08	0.14	No	No	No		Deep	
B17	A12B (b)	40-70	1.26	0.03	1.37	0.10	No	No	No			
B18	A12B (c)	80-90	1.42	0.04	1.72	0.44	No	No	No			
Und Lab ID	Und Field ID	Und Depth (cm)	OM % (L.O.I)	Moist Cont %	Dry BD (g/cm ³)	Porosity (vol %)	FAO Classification	Group	Calcisol	Haplic	Phase	RSA Classification
U13	A12U (a)	15	0.11	0.8	1.51	43.1						
Micro-topography			Soil Surface Condition			Surface Drainage			Erosion / Deposition			
Smooth; bowl-shaped			High cover of leaf litter; surface difficult to penetrate (high bulk density ?) overlying loose sand; thin hard crust development 4mm thick			Imperfect surface drainage; surface difficult to penetrate			No evidence of wind erosion; scanty deposition of fine material; no ponding			
Horizon	Depth (cm)	Profile Description										
Ak1	0-5											
Apk	5-15	Deep, imperfectly drained loamy sand; impeded surface drainage and difficult to penetrate; thin hard crust 4mm thick, no cracks. Ochric/caliche A horizon, dark brown (7.5YR 3/3) dry, loose medium to fine sand with silts and clays; brown stem and bark fragments up to 9mm long at 5-15cm; no black mottles; very fine to fine platy structure; stable aggregates up to 3cm diameter, rounded; common very fine burnt roots at 5-15cm, common fine pores; salty, carbonates detected. Diffuse boundary at 40cm to eluviated B horizon, greyish brown (5YR 4/2) medium to fine sand with decrease in finer particles; weak very fine granular structure; improved drainage but increase in moisture content with depth; few fine pores; few very fine roots; no mottles. Smooth boundary at 80cm to illuvial C horizon, greyish yellow brown (10YR 5/2) loamy sand; increase in fine particles (illuvial); medium to coarse granular structure; further increase in soil moisture; 1% black organic mottles in 5mm band at 87cm depth; irregular soft white slightly calcareous nodules (authigenic) in non calcareous matrix. No visible lower boundary to >100cm.										
Ak2	15-40											
Bk	40-80											
Ck1	80-87											
Chk	87-88											
Ck2	88+											

SOILS OF KAVANGO REGION

SOILS ANALYSIS Site Summary		Site No	Date	Lat	Long	Land System	Land Facet	Slope %	Slope Class	Aspect	Slope Shape
A13		29-Apr-98	18°16.526'S	20°44.839'E	(7.2) Eastern-flowing paleo drainage - sand plain with large pans	Long, gentle south-facing slope; midslope position	2	1	S	straight slope	
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	% < 2µ silt	% 53 - 2000µ sand	% > 2000µ gravel	% 2000 - 500µ vcs/cs	% 500 - 250µ ms	% 250 - 106µ fs	% 106 - 53µ vfs	FAO Textural Class	
B19	A13B (a)	0-25	7.4	88.2	trace to null	1.7	40.1	48.0	10.2		
B20	A13B (b)	25 - 40	10.9	83.0	trace to null	1.9	37.7	49.9	10.5	1	
B21	A13B (c)	40 - 80	10.2	82.8	trace to null	1.2	37.9	50.8	10.1		
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Colour (moist)	OM % (L.O.I)	Moist Cont %	P (Olsen mg/kg)	ECe (µS/cm)	pH (H ₂ O)	OrgC % (Walkley-Black)	CaCO ₃ (quant)	
B19	A13B (a)	0-25	10YR 3/3 dark brown	Not analysed	Not analysed	< 0.1	12.3	5.9	0.22	low pH	
B20	A13B (b)	25 - 40	10YR 4/3 dull yellowish brown	0.15	0.6	< 0.1	10.2	5.5	0.14	low pH	
B21	A13B (c)	40 - 80	10YR 5/6 yellowish brown	0.11	0.7	< 0.1	12.3	5.3	0.03	low pH	
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	SO ₄ (S µg/g Turbid)	Mg (ppm)	K (ppm)	Na (ppm)	Cu (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)	
B19	A13B (a)	0-25	2.3	89	28	7	<0.5	<0.2	<0.5	0.9	
B20	A13B (b)	25 - 40	9.1	93	14	6	<0.5	<0.2	<0.5	2.1	
B21	A13B (c)	40 - 80	4.4	92	11	7	<0.5	<0.2	<0.5	1.1	
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	CECtotal (me/100g)	CECclay (me/100g)	Tot Exch Bases (me/100g)	BSP (me/100g)	BSP (me/100g clay)	ESP (me/100g)	ESP (me/100g clay)	SAR	
B19	A13B (a)	0-25	1.44	22.50	1.432	99.44	6.36	2.083	0.133	0.118	
B20	A13B (b)	25 - 40	1.27	20.84	1.259	99.03	6.04	2.045	0.125	0.107	
B21	A13B (c)	40 - 80	1.25	17.80	1.237	99.30	6.95	2.408	0.169	0.125	
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Ca/Mg	K/Mg	K/CEC (clay)	Salinity	Sodicity (ESP > 15)	Sodicity (Na > 1me/100g)	FAO Depth Class		
B19	A13B (a)	0-25	0.82	0.10	0.32	No	No	No			
B20	A13B (b)	25 - 40	0.57	0.05	0.17	No	No	No	Deep		
B21	A13B (c)	40 - 80	0.56	0.04	0.18	No	No	No			
Und Lab ID	Und Field ID	Und Depth (cm)	OM % (L.O.I)	Moist Cont %	Dry BD (g/cm ³)	Porosity (vol %)	FAO Classification		RSA Classification		
U14	A13U (a)	15	0.13	0.5	1.39	47.7	Group	Unit	Phase		
							Calcisol	Haplic	n/a	Calcareous Sandspult ?	
Micro-topography		Soil Surface Condition		Surface Drainage		Erosion / Deposition					
Extensively hummocky; many local micro-slopes		High cover of leaf litter; hummocks stabilized by grass caps; no crust, sealing or cracks; no stones		Moderately well-drained; no surface channels or fills		No evidence of water or wind erosion; no evidence of recent deposition					
Horizon	Depth (cm)	Profile Description									
Au	0-25	Deep, moderately well drained sand to loamy sand; no crusting, sealing or cracks. Ochric A horizon, dark brown (10YR 3/3), very fine subangular blocky structure, medium net of fine to very fine roots, common large pores, 3% organic black mottles. Diffuse boundary to calcic B horizon at 25cm, dull yellowish brown (10YR 4/3); 5% hard white concretions of an average 12mm diameter evenly distributed to 40cm depth; 5% burnt twig and root fragments at 30cm depth, common fine pores. Disinct colour change at 40cm to yellowish brown (10YR 5/6); non calcareous C horizon, no mottles or concretions; very fine to fine subangular structure; common fine pores; no roots; <1% black organic mottles. Structural change at 80cm, no colour change (yellowish brown), significant increase in unconsolidated medium to coarse sand with no structural development; no roots; no visible fine pores. No visible lower boundary.									
Bck1	25-30										
Bh	30-32										
Bck2	33-40										
Cw1	40-80										
Cw2	80+										

SOILS OF KAVANGO REGION

SOILS ANALYSIS Site Summary		Site No	Date	Lat	Long	Land System	Land Facet	Slope %	Slope Class	Aspect	Slope Shape		
A14		29-Apr-99	18°22.764'S	20°43.187'E	(7.2) Eastern-flowing paleo drainage - sand plain with large pans	Well developed pan	0	1	n/a	flat			
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	% < 2µ clay	% 2 - 5µ silt	% 53 - 2000µ sand	% > 2000µ gravel	% 2000 - 5000µ ycs/ics	% 500 - 250µ ms	% 250 - 106µ fs	% 106 - 53µ vfs	FAO Textural Class		
B22	A14B (a)	0 - 30	4.7	6.7	89.6	Trace to null	0.9	33.9	54.2	11.0			
B23	A14B (b)	30 - 70	4.7	8.0	87.3	Trace to null	1.3	46.9	45.6	6.2			
B24	A14B (c)	70-90	7.1	8.8	84.1	Trace to null	1.2	32.1	55.1	11.6	1		
B25	A14B (d)	>90	3.0	28.6	69.3	Trace to null	0.9	36.8	53.0	9.5			
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Colour (moist)	Texture	OM % (L.O.I)	Moist Cont. %	P (Clean mg/kg)	ECe (µS/cm)	pH (H ₂ O)	OrgC % (Walkley-Black)	CaCO ₃ (quant)		
B22	A14B (a)	0 - 30	7.5YR 5/2 greyish brown	sand	Not analysed	Not analysed	< 0.1	8.9	5.5	<0.01	low pH		
B23	A14B (b)	30 - 70	10YR 7/2 dull yellow orange	sand	Not analysed	Not analysed	< 0.1	5.4	5.4	<0.01	low pH		
B24	A14B (c)	70-90	10YR 8/2 light grey	loamy sand	0.06	3.8	< 0.1	55.4	7.5	<0.01	<1		
B25	A14B (d)	>90	10YR 5/4 dull yellowish brown	sandy loam	0.01	9.8	< 0.1	6.9	5.8	<0.01	low pH		
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	SO ₄ (S µg/g Turbid)	Ca (ppm)	Mg (ppm)	K (ppm)	Na (ppm)	Cu (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)		
B22	A14B (a)	0 - 30	9.1	24	8	9	3	<0.5	<0.2	<0.5	0.8		
B23	A14B (b)	30 - 70	7.0	8	2	2	2	<0.5	<0.2	<0.5	<0.5		
B24	A14B (c)	70-90	8.3	73	10	12	496	<0.5	<0.2	0.8	<0.5		
B25	A14B (d)	>90	11.2	5	1	2	6	<0.5	<0.2	<0.5	<0.5		
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	CECtotal (me/100g)	Clay %	CECclay (me/100g)	Tot Exch Bases (me/100g)	BSP (me/100g)	BSP (me/100g clay)	ESP (me/100g)	ESP (me/100g clay)	SAR		
B22	A14B (a)	0 - 30	0.23	4.70	4.87	0.222	96.97	4.56	5.678	0.267	0.135		
B23	A14B (b)	30 - 70	0.08	4.70	1.63	0.070	91.46	4.30	11.759	0.553	0.164		
B24	A14B (c)	70-90	2.64	7.10	37.23	2.635	99.69	7.08	81.605	5.794	14.426		
B25	A14B (d)	>90	0.07	3.00	2.35	0.064	90.73	2.72	36.959	1.106	0.640		
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Ca:Mg	K:Mg	KCECtotal (EPP)	KCEC (clay)	Salinity	Sodicity (ESP >15)	Sodicity (Na>1me/100g)	FAO Depth Class			
B22	A14B (a)	0 - 30	1.82	0.35	10.05	0.47	No	No	No				
B23	A14B (b)	30 - 70	2.50	0.31	6.53	0.31	No	No	No	Deep			
B24	A14B (c)	70-90	4.45	0.28	0.87	0.06	No	Yes	Yes				
B25	A14B (d)	>90	3.13	3.88	43.95	1.32	No	Yes	No				
Und Lab ID	Und Field ID	Und Depth (cm)	OM % (L.O.I)	Moist Cont. %	Dry BD (g/cm ³)	Porosity (vol. %)	FAO Classification		RSA Classification				
U15	A14U (a)	15	0.04	0.1	1.63	38.6	Group	Unit	Phase				
U16	A14U (b)	40	0.01	0.5	1.63	38.5	Solonetz	Haplic-xanthic	Phreatic	7			
Micro-topography		Soil Surface Condition					Surface Drainage					Erosion / Deposition	
N/A		30% cover of leaf litter, thin grass cover, thin, cemented surface crust 3mm thick; no cracks or stones					Impeded drainage; groundwater +/- 1.5m from surface and at surface in low patches					Deposition area; wide, shallow drainage sink	
Horizon	Depth (cm)	Profile Description											
Au	0-31	Deep, imperfectly drained sand to sandy loam; thin cemented surface crust 3mm thick, no cracks or stones. Ochric A horizon, greyish brown (7.5YR 5/2) fine sand with some silt; unconsolidated single grains, no structural development; 3% burnt organic mottles, <1% fine roots; common medium pores and few fine pores. Clear smooth boundary at 31cm to B horizon indicating both colour and structural changes; colour change to dull yellow orange (10YR 7/2), fine to medium sand; weakly developed coarse granular to fine subangular blocky structure with high proportion of medium and fine single grains, no mottles; no roots; visible increase in moisture content with depth from +/-60cm onwards. Smooth boundary at 70cm to natric B sub-horizon, light grey (10YR 8/2) with 2% dull orange mottles; increase in moisture content and slight increase in cohesivity; increase in packing state with weak coarse subangular blocky structure; no roots; soil near to saturated state at base of horizon (90cm depth). Sharp boundary transition to xanthic C horizon, dull yellowish brown (10YR 5/4), high proportion of fine sand and silt; significant increase in both moisture content and in cohesivity, strong coarse to very coarse subangular blocky structure; clay cutans; no roots. Shallow groundwater estimated at +/- 180cm below soil surface. Non calcareous throughout profile.											
Bw	31-70												
Bgn	70-90												
Cr	90+												

SOILS OF KAVANGO REGION

SOILS ANALYSIS Site Summary		Site No	Date	Lat	Long	Land System	Land Facet	Slope %	Slope Class	Aspect	Slope Shape
A15		A15	30-Apr-99	18°29.976'S	20°14.615'E	(7.1) Eastern-flowing paleo drainage - sand plain with small pans	Crest SW-facing slope, tributary to Kaudom river	8	2	SW	convex
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	% < 2µ clay	% 53 - 2000µ sand	% > 2000µ gravel	% 2000 - 500µ vcs/cls	% 500 - 250µ ms	% 250 - 106µ fs	% 106 - 53µ vfs	FAO Textural Class	
B26	A15B (a)	0 - 30	5.2	89.1	trace to null	1.3	35.7	52.8	10.2	1	
B27	A15B (b)	30 - 60	4.8	87.6	trace to null	0.7	31.7	54.9	12.7	1	
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Colour (moist)	Texture	OM % (L.O.I)	P (Olsen mg/kg)	ECe (µS/cm)	pH (H ₂ O)	OrgC % (Walkley-Black)	CaCO ₃ (quant)	
B26	A15B (a)	0 - 30	5YR 3/3 dark reddish brown	sand	Not analysed	0.2	18.9	6.6	0.09	low pH	
B27	A15B (b)	30 - 60	5YR 5/6 bright reddish brown	sand	0.06	0.4	9.0	6.0	<0.01	low pH	
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	SO ₄ (S µg/g Turbid)	Ca (ppm)	Mg (ppm)	K (ppm)	Cu (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)	
B26	A15B (a)	0 - 30	16.4	103	20	9	<0.5	<0.2	<0.5	1.1	
B27	A15B (b)	30 - 60	33.0	139	14	6	<0.5	<0.2	<0.5	<0.5	
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	CECtotal (me/100g)	Clay %	CECclay (me/100g)	Total Exch Bases (me/100g)	BSP (me/100g)	BSP (me/100g clay)	ESP (me/100g clay)	SAR	
B26	A15B (a)	0 - 30	0.73	5.20	14.00	0.719	98.80	5.14	2.336	0.121	
B27	A15B (b)	30 - 60	0.85	4.80	17.68	0.842	99.23	4.76	2.003	0.086	
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Ca:Mg	K:Mg	K:CEC total (EPP)	K:CEC (clay)	Salinity	Sodicity (ESP > 15)	Sodicity (Na > 1me/100g)	FAO Depth Class	
B26	A15B (a)	0 - 30	3.14	0.09	2.06	0.11	No	No	No	Deep	
B27	A15B (b)	30 - 60	6.04	0.13	1.77	0.08	No	No	No	Deep	
Und Lab ID	Und Field ID	Und Depth (cm)	OM % (L.O.I)	Moist Cont %	Dry BD (g/cm ³)	Porosity (vol %)	FAO Classification		RSA Classification		
U17	A15U (a)	15	0.10	0.1	1.62	39.0	Group	Unit	Phase		
Micro-topography		Soil Surface Condition		Surface Drainage		Erosion / Deposition					
Very uneven surface, high density of local microtopography		80% cover leaf litter, no crust, sealing, cracks or stones		Well-drained; no surface channels, some rills		Complete absence of fine materials (wash-out zone ?); local concentrations of coarse sand particles against micro-slope faces					
Horizon	Depth (cm)	Profile Description									
Au1	0-10	Deep, well drained sand; no crusting, sealing or crack. Ochric A horizon, dark reddish brown (5YR 3/3); predominance of unconsolidated fine sands, no structural development; dry; 4% black organic mottles at 10cm, 1% live grass seeds at 3-5cm depth; common very fine and presence of fine roots to 28cm; common medium pores. Smooth boundary at 28cm to C horizon, bright reddish brown (5YR 5/6), slightly finer, firmer texture although no structural development; dry; <1% black organic mottles; no roots. Horizon > 100cm depth.									
Au2	10-13										
Cw	13-28										
	28->100										

SOILS OF KAVANGO REGION

SOILS ANALYSIS Site Summary		Site No	Date	Lat	Long	Land System	Land Facet	Slope %	Slope Class	Aspect	Slope Shape	
A16		18°30.049'S	30-Apr-99	20°44.469E	(7.4) Eastern-flowing paleo drainage - eastern omiramba position	SW-facing slope, tributary to Kaoudom river; mid-slope position	6	1	SW	straight slope		
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	% < 2µ clay	% 2 - 53µ silt	% 53 - 2000µ sand	% > 2000µ gravel	% 2000 - 500µ ves/cs	% 500 - 250µ ms	% 250 - 106µ fs	% 106 - 53µ vfs	FAO Textural Class	
B28	A16B (a)	0 - 30	4.7	6.8	88.5	trace to null	1.0	40.9	48.4	9.7	1	
B29	A16B (b)	30 - 70	5.3	6.2	88.6	trace to null	0.7	33.0	52.6	13.7		
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Colour (moist)	Texture	OM % (L.O.I)	Moist Cont %	P (Olsen mg/kg)	ECe (µS/cm)	pH (H ₂ O)	OrgC % (Walkley-Black)	CaCO ₃ (quant)	
B28	A16B (a)	0 - 30	7.5YR 4/3 brown	sand	Not analysed	Not analysed	< 0.1	8.8	5.7	0.04	low pH	
B29	A16B (b)	30 - 70	5YR 4/6 reddish brown	sand	0.04	0.2	< 0.1	5.1	5.2	< 0.01	low pH	
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	SO ₄ (S µg/g Turbid)	Ca (ppm)	Mg (ppm)	K (ppm)	Na (ppm)	Cu (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)	
B28	A16B (a)	0 - 30	18.8	50	12	6	3	< 0.5	< 0.2	< 0.5	< 0.5	
B29	A16B (b)	30 - 70	15.4	17	7	6	3	< 0.5	< 0.2	< 0.5	< 0.5	
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	CEC total (me/100g)	Clay %	CEC clay (me/100g)	Total Exch Bases (me/100g)	BSP (me/100g)	BSP (me/100g clay)	ESP (me/100g clay)	ESP (me/100g clay)	SAR	
B28	A16B (a)	0 - 30	0.38	4.70	8.14	0.376	98.29	4.62	3.398	0.160	0.099	
B29	A16B (b)	30 - 70	0.18	5.30	3.33	0.170	96.30	5.10	7.364	0.390	0.155	
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Ca/Mg	K/Mg	K:CEC total (EPP)	K:CEC (clay)	Salinity	Sodicity (ESP > 15)	Sodicity (Na>1me/100g)	FAO Depth Class		
B28	A16B (a)	0 - 30	2.55	0.15	3.92	0.18	No	No	No	Deep		
B29	A16B (b)	30 - 70	1.49	0.26	8.50	0.45	No	No	No	Deep		
Und Lab ID	Und Field ID	Und Depth (cm)	OM % (L.O.I)	Moist Cont %	Dry BD (g/cm ³)	Porosity (vol %)	FAO Classification		RSA Classification			
U18	A16J (a)	15	0.07	0.1	1.58	40.3	Group	Unit	Phase	Gaudam ?		
Micro-topography			Soil Surface Condition				Arenosol		Haplic	Anthric (new)	Gaudam ?	
Hummocky; depressions formed downslope of hummocks with grass caps (not the case where hummocks are bare)			40% cover leaf litter; trees				Surface Drainage		Erosion / Deposition			
			Well-drained; incipient surface channels and some rills						Sheet wash area			
Horizon			Depth (cm)				Profile Description					
Au1	0-9		Deep, well drained sand, no crusting, sealing or cracks. Ochric A horizon, brown (7.5YR 4/3) unconsolidated fine sands, no structural development; dry; 5% black organic mottles and larger burnt leaf fragments at 9cm, fine to very fine roots at 4-11cm depth; common medium pores, few fine pores. Diffuse boundary to reddish brown (5YR 4/8); finer sand texture, unconsolidated, no structural development; 1% burnt fine to very fine roots in thin bands (<1cm) at 32cm and again at 45cm depth. Indisict boundary to C horizon at 46cm; no further horizon differentiation to > 100cm depth.									
Ah1	9-11											
Ah2	11-32											
Ah3	32-33											
Au3	33-45											
Ah3	45-46											
Cw	46->100											

SOILS OF KAVANGO REGION

SOILS ANALYSIS Site Summary		Site No	Date	Lat	Long	Land System	Land Facet	Slope %	Slope Class	Aspect	Slope Shape
A17		18°30.255'S	30-Apr-99	18°30.255'S	20°44.460'E	(7.4) Eastern-flowing paleo drainage - eastern ombimba	SW-facing slope of tributary to Kaoudom river channel; basal slope position	0.5	1	SW	straight slope
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	% < 2µ clay	% 2 - 5µ silt	% 53 - 2000µ sand	% > 2000µ gravel	% 2000 - 500µ ves/cs	% 500 - 250µ ms	% 250 - 106µ fs	% 106 - 53µ vfs	FAO Textural Class
B30	A17B (a)	0 - 30	4.7	7.8	87.5	trace to null	1.3	37.8	46.0	14.9	1
B31	A17B (b)	30 - 60	4.8	8.6	86.6	trace to null	1.0	30.2	53.7	15.1	
B32	A17B (c)	> 60	4.7	7.3	88.0	trace to null	0.9	29.4	54.0	15.7	
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Colour (moist)	Texture	OM % (L.O.I)	Moist Cont %	P (Olsen mg/kg)	ECe (µS/cm)	pH (H ₂ O)	OrgC % (Walkley-Black)	CaCO ₃ (quant)
B30	A17B (a)	0 - 30	7.5YR 3/2 brownish black	sand	Not analysed	Not analysed	< 0.1	13.5	6.4	0.22	low pH
B31	A17B (b)	30 - 60	7.5YR 4/2 greyish brown	sand	0.08	0.2	< 0.1	12.3	6.8	0.08	< 1
B32	A17B (c)	> 60	7.5YR 5/2 greyish brown	sand	0.07	0.5	< 0.1	15.2	7.0	< 0.01	< 1
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	SO ₄ (S µg/g Turbid)	Ca (ppm)	Mg (ppm)	K (ppm)	Na (ppm)	Cu (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)
B30	A17B (a)	0 - 30	13.5	182	30	9	4	< 0.5	< 0.2	< 0.5	< 0.5
B31	A17B (b)	30 - 60	14.6	152	23	4	4	< 0.5	0.4	< 0.5	< 0.5
B32	A17B (c)	> 60	9.9	95	12	13	7	< 0.5	< 0.2	< 0.5	< 0.5
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	CECtotal (me/100g)	Clay %	CECclay (me/100g)	Tot Exch Bases (me/100g)	BSP (me/100g)	BSP (me/100g clay)	ESP (me/100g)	ESP (me/100g clay)	SAR
B30	A17B (a)	0 - 30	1.20	4.70	25.59	1.196	99.46	4.67	1.414	0.066	0.072
B31	A17B (b)	30 - 60	0.98	4.80	20.48	0.976	99.27	4.76	1.729	0.083	0.080
B32	A17B (c)	> 60	0.64	4.70	13.67	0.636	98.98	4.65	4.669	0.219	0.180
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Ca:Mg	K:Mg	K:CEC total (EPP)	K:CEC (clay)	Salinity	Sodicity (ESP x15)	Sodicity (Na>1me/100g)	FAO Depth Class	
B30	A17B (a)	0 - 30	3.70	0.09	1.91	0.09	No	No	No	Deep	
B31	A17B (b)	30 - 60	4.02	0.05	1.02	0.05	No	No	No		
B32	A17B (c)	> 60	4.85	0.34	5.14	0.24	No	No	No		
Und Lab ID	Und Field ID	Und Depth (cm)	OM % (L.O.I)	Moist Cont %	Dry BD (g/cm ³)	Porosity (vol %)	FAO Classification	FAO Classification	FAO Classification	RSA Classification	
U19	A17U (a)	15	0.12	0.2	1.71	35.5	Group	Urtill	Phase		
Micro-topography		Soil Surface Condition		Surface Drainage		Erosion / Deposition					
Hummocks; uneven; gentle micro-slopes		50% cover leaf and grass litter; thin crust development 2mm thick, sand mixed with finer dark grey particles; no cracks; no stones; evidence of fire.		imperfect to moderately well drained; evidence of ponding in patches		Sheet wash deposition area					
Horizon	Depth (cm)	Profile Description									
Au1	0-6										
Au1	6-10	Deep, moderately well drained colluvial sand; thin crust development 2mm thick of sand cemented by finer dark grey silt and clay particles; no cracks or stones. Crust overlies chric A horizon of brownish black sand; unconsolidated, single grains with no structure; 3% burnt black organic mollies evenly distributed from 6-10cm depth; common fine roots and presence of medium roots; common medium pores, few fine pores. Smooth diffuse boundary at 30cm to B horizon with some evidence of cambic properties (removal of carbonates and decrease of CEC with depth); greyish brown (7.5YR 4/2) fine to very fine sand; 5% dead but not burnt organic fragments evenly distributed to 60cm depth; 3% burnt organic mollies at 32-37cm depth; common medium and fine pores. Distinct boundary at 60cm to C horizon; greyish brown (7.5YR 5/2); increase in proportion of medium to fine sand particles; no mollies; common medium pores; no horizon differentiation to > 100cm.									
Au2	10-30										
Blw1	30-32										
Bl1	32-37										
Blw2	37-60										
Cw	60+										

SOILS OF KAVANGO REGION

SOILS ANALYSIS Site Summary		Site No	Date	Lat	Long	Land System	Land Facet	Slope %	Slope Class	Aspect	Slope Shape
		A18	30-Apr-99	18°30.389'S	20°45.251'E	(7.4) Eastern-flowing paleo drainage - eastern omiramba	Edge of vlei pan; channel floor	0	1	n/a	flat
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	% < 2µ clay	% 2 - 53µ silt	% 53 - 2000µ sand	% > 2000µ gravel	% 2000 - 500µ vcs/cs	% 500 - 250µ ms	% 250 - 106µ fs	% 106 - 53µ vfs	FAO Textural Class
B33	A18B (a)	0 - 15	5.7	26.0	58.3	trace to null	18.7	32.6	33.1	15.6	2
B34	A18B (b)	15 - 35	7.1	37.1	55.8	trace to null	26.1	30.2	28.2	15.4	
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Colour (moist)	Texture	OM % (L.O.I)	Mbist Cont %	P (Olsen mg/kg)	ECe (µS/cm)	pH (H ₂ O)	OrgC % (Walkley-Black)	CaCO ₃ (quant)
B33	A18B (a)	0 - 15	2.5YR 3/1 dark reddish grey	sandy loam	Not analysed	Not analysed	1.3	122.4	8.3	<0.01	66.0
B34	A18B (b)	15 - 35	5YR 4/1 brownish grey	sandy loam	0.91	8.6	0.8	178.4	8.3	<0.01	65.9
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	SO ₄ (S µg/g Turbid)	Ca (ppm)	Mg (ppm)	K (ppm)	Na (ppm)	Cu (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)
B33	A18B (a)	0 - 15	3.0	2180	230	63	13	<0.5	<0.2	<0.5	0.8
B34	A18B (b)	15 - 35	14.3	7146	84	57	53	<0.5	<0.2	<0.5	1.5
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	CECtotal (me/100g)	Clay %	CECclay (me/100g)	Tot Exch Bases (me/100g)	BSP (me/100g)	BSP (me/100g clay)	ESP (me/100g)	ESP (me/100g clay)	SAR
B33	A18B (a)	0 - 15	13.02	5.70	228.35	13.006	99.94	5.70	0.438	0.025	0.071
B34	A18B (b)	15 - 35	36.81	7.10	518.38	36.795	99.97	7.10	0.625	0.044	0.171
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Ca:Mg	K:Mg	K:CEC total (EPP)	K:CEC (clay)	Salinity	Sodicity (ESP > 15)	Sodicity (Na > 1me/100g) ¹	FAO Depth Class	
B33	A18B (a)	0 - 15	5.77	0.09	1.24	0.07	No	No	No	Shallow	
B34	A18B (b)	15 - 35	51.86	0.21	0.40	0.03	No	No	No		
Und Lab ID	Und Field ID	Und Depth (cm)	OM % (L.O.I)	Moist Cont %	Dry BD (g/cm ³)	Porosity (vol %)	Group	FAO Classification	Phase	RSA Classification	
U20	A18U (a)	15	1.04	8.0	0.93	64.9	Calcisol	Calcisol	Rudic	?	
Micro-topography			Soil Surface Condition			Surface Drainage			Erosion / Deposition		
Hard, uneven surface; cemented hummocks			Dense grass cover; discrete patches of thin hard crust 3-5mm thick; local cracking and curling at edges of cracks			pan surface; regular seasonal ponding			Extensive deposition of fine material; calcrete at 30cm below surface		
Horizon	Depth (cm)	Profile Description									
Ack Bwk Cm	0-15 15-35 35+	Shallow imperfectly drained sandy loam; discontinuous thin hard crust 3-5mm thick, local cracking and 'lin lid' curling. Thin ochric/calciic A horizon, dark reddish grey (2.5YR 3/1) powdery sandy loam; fine to medium platy structure; small (1-4mm) hard white cemented calcareous fragments and disaggregated grains at accounting for 40% of matrix throughout horizon; common fine to very fine roots to 15cm; common fine to very fine pores, few large pores. Abrupt smooth boundary at 15cm to calcic but non-argic B horizon, brownish grey (5YR 4/1); weak fine platy to very fine sub-angular structure; large hard white calcareous fragments predominant with common small hard nodules; few fine roots. Hard indurated layer of calcrete at 35cm (petrocalcic C horizon). Further penetration impossible.									

SOILS OF KAVANGO REGION

SOILS ANALYSIS Site Summary		Site No	Date	Lat	Long	Land System	Land Facet	Slope %	Slope Class	Aspect	Slope Shape
		A20	30-Apr-99	18°32.777'S	20°56.144'E	(7.1) Eastern-flowing paleo drainage - sand plain with small pans	Crest of local rise (incipient dune system?)	2	1	NW	straight slope
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	% < 2µ clay	% 2 - 53µ silt	% 53 - 2000µ sand	% > 200µ gravel	% 2000 - 500µ vcs/cs	% 500 - 250µ ms	% 250 - 106µ fs	% 105 - 53µ vfs	FAO Textural Class
B36	A20B (a)	0 - 35	6.5	12.0	81.5	Trace to null	1.2	39.6	49.0	10.2	1
B37	A20B (b)	40 - 80	6.8	9.3	83.9	Trace to null	1.4	41.9	47.8	8.9	
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Colour (moist)	Texture	OM % (L.O.I)	Moist Cont %	P (Olsen mg/kg)	ECe (µS/cm)	pH (H ₂ O)	OrgC % (Walkley-Black)	CaCO ₃ (quant)
B36	A20B (a)	0 - 35	5YR 2/3 very dark reddish brown	loamy sand	Not analysed	Not analysed	0.1	30.2	7.0	0.29	<1
B37	A20B (b)	40 - 80	5YR 3/4 dark reddish brown	loamy sand	0.15	0.9	0.1	13.1	6.6	0.10	low pH
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	SO ₂ (S µg/g Turbid)	Ca (ppm)	Mg (ppm)	K (ppm)	Na (ppm)	Cu (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)
B36	A20B (a)	0 - 35	19.8	394	80	19	9	<0.5	<0.2	<0.5	<0.5
B37	A20B (b)	40 - 80	14.3	282	96	13	7	<0.5	0.5	<0.5	<0.5
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	CEC total (me/100g)	Clay %	CEC clay (me/100g)	Tot Exch Bases (me/100g)	BSP (me/100g clay)	BSP (me/100g clay)	ESP (me/100g clay)	ESP (me/100g clay)	SAR
B36	A20B (a)	0 - 35	2.72	6.50	41.85	2.714	6.48	99.76	1.434	0.093	0.108
B37	A20B (b)	40 - 80	2.27	6.80	33.35	2.260	6.78	99.67	1.323	0.090	0.092
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Ca/Mg	K/Mg	K:CEC total (ERP)	Sodicity	Sodicity (ESP > 15)	Sodicity (Na > (me/100g) ~)	Sodicity	FAO Depth Class	
B36	A20B (a)	0 - 35	3.00	0.07	1.80	No	No	No	No	Deep	
B37	A20B (b)	40 - 80	1.79	0.04	1.46	No	No	No	No		
Und Lab ID	Und Field ID	Und Depth (cm)	OM % (L.O.I)	Moist Cont %	Dry BD (g/cm ³)	Porosity (vol %)	FAO Classification	FAO Classification	FAO Classification	RSA Classification	
U21	A20U (a)	15	0.21	0.7	1.36	48.7	Ufll	Ufll	Ufll		
Micro-topography		Soil Surface Condition									
Uneven		High cover leaf litter; no crust, sealing or cracks; no stones; not salty									
Horizon		Profile Description									
Ack1	0-7	Deep, well drained loamy sand; no crusting, sealing or cracks. Ochric A horizon, very dark reddish brown (5YR 2/3) loamy sand; weakly developed fine to coarse granular structure with predominance of single medium to fine sand grains; dense fine root lattice to 21cm; few black organic mottles at 7cm; +/- 1% hard white calcareous fragments (0.5-1mm) evenly distributed throughout horizon in non-calcareous matrix; calcareous accumulations not sufficient for horizon to be diagnosed as calcareic; common medium and fine pores. Diffuse boundary at 35cm to non-calcareous C horizon, dark reddish brown (5YR 3/4); no mottles; coarser texture with common medium sand grains; dry; medium to very coarse granular structure with common single fine and medium sand grains; large pores; few fine roots, large roots at 80cm depth. No visible lower boundary >100cm depth.									
Ah	7-10										
Ack2	10-35										
Cw	35->100										
Erosion / Deposition		No evidence of water or wind erosion; no evidence of recent deposition									

SOILS OF KAVANGO REGION

SOILS ANALYSIS Site Summary		Site No	Date	Lat	Long	Land System	Land Facet	Slope %	Slope Class	Aspect	Slope Shape
A21		A21	30-Apr-99	18°35.4'16"S	20°52.685'E	(7.1) Eastern-flowing paleo drainage - sand plain with small pans system?	Base of long gentle slope (incipient dune system?)	2	1	SE	straight slope
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	% < 2µ clay	% 2 - 53µ silt	% 53 - 2000µ sand	% > 2000µ gravel	% 2000 - 5000µ vcs/cs	% 500 - 250µ ms	% 250 - 106µ fs	% 106 - 53µ vfs	FAO Textural Class
B38	A21B (a)	0 - 10	6.0	11.4	82.6	Trace to null	2.3	40.9	48.1	8.7	
B39	A21B (b)	10-20	6.4	9.2	84.4	Trace to null	1.4	34.5	52.5	11.5	2
B40	A21B (c)	20 - 40	8.9	10.6	80.5	Trace to null	1.7	38.8	49.8	9.7	
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Colour (moist)	Texture	OM % (L.O.I)	Moist. Cont %	P (Olsen mg/kg)	ECe (µS/cm)	pH (H ₂ O)	OrgC % (Walkley-Black)	CaCO ₃ (quant)
B38	A21B (a)	0 - 10	2.5YR 3/1 dark reddish grey	loamy sand	Not analysed	Not analysed	0.2	103.6	8.6	0.29	<1
B39	A21B (b)	10-20	5YR 4/1 brownish grey	loamy sand	0.12	1.8	<0.1	471.0	9.9	0.06	<1
B40	A21B (c)	20 - 40	5YR 3/3 dark reddish brown	loamy sand	0.11	4.6	0.1	938.0	10.3	<0.01	<1
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	SO ₄ (S µg/g Turbid)	Ca (ppm)	Mg (ppm)	K (ppm)	Na (ppm)	Cu (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)
B38	A21B (a)	0 - 10	3.0	1082	40	73	66	<0.5	<0.2	<0.5	<0.5
B39	A21B (b)	10-20	6.7	469	19	20	653	<0.5	<0.2	<0.5	<0.5
B40	A21B (c)	20 - 40	13.3	507	51	47	1519	<0.5	<0.2	<0.5	<0.5
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	CECtotal (me/100g)	Clay %	CECclay (me/100g)	Tot Exch Bases (me/100g)	BSP (me/100g)	BSP (me/100g clay)	ESP (me/100g clay)	ESP (me/100g)	SAR
B38	A21B (a)	0 - 10	6.22	6.00	103.64	6.212	99.89	5.99	0.277	4.615	0.536
B39	A21B (b)	10-20	5.40	6.40	84.34	5.391	99.88	6.39	3.366	52.598	8.029
B40	A21B (c)	20 - 40	9.68	8.90	108.80	9.677	99.93	8.89	6.070	68.198	17.187
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Ca:Mg	K:Mg	K:CEC total (EPP)	K:CEC (clay)	Salinity	Sodicity (ESP > 15)	Sodicity (Na>1me/100g)	FAO Depth Class	
B38	A21B (a)	0 - 10	16.49	0.57	3.01	0.18	No	No	No	Moderately Deep	
B39	A21B (b)	10-20	15.03	0.33	0.94	0.06	No	Yes	Yes		
B40	A21B (c)	20 - 40	6.06	0.29	1.24	0.11	No	Yes	Yes		
Und Lab ID	Und Field ID	Und Depth (cm)	OM % (L.O.I)	Moist Cont %	Dry BD (g/cm ³)	Porosity (vol %)	FAO Classification	FAO Classification	Phase	RSA Classification	
U22	A21U (a)	10	0.15	0.3	1.33	50.0	Group	Unit	Phase		
Micro-topography			Soil Surface Condition			Surface Drainage			Erosion / Deposition		
Uneven	30% cover of leaf litter, thin grass cover, thin hard surface crust 1-3mm thick; no stones, occasional cracks in vicinity		Runoff slope, moist to wet soil at 40cm depth; elephant waterhole in vicinity			No strong evidence of erosion although widespread surface deposition of sand particles; hard crust would increase runoff potential down this long gentle slope; shallow subsurface calcrete (?)					
Horizon	Depth (cm)	Profile Description									
Ak1	0-6	Moderately deep. Imperfectly drained loamy sand; thin hard crust 1-3mm thick; local cracking. Thin ochric/calciic A horizon of dark reddish grey (2.5YR 3/1) fine sand and silt, 3% black organic mottles at 6-8cm; very weak subangular blocky structure with single grain unconsolidated sands; common medium pores; fine roots and leaf fragments at 5-10cm. Abrupt boundary at 10cm to eluvial B horizon, brownish grey (7.5YR 4/1) with significant increase in soil moisture content; fine to very coarse granular structure; common medium pores; few fine roots and leaf fragments at 10-15cm; no mottles. Wavy boundary at 20cm to natric B sub-horizon, dark reddish brown (5YR 3/3) finer textured silty sand; fine prismatic structure; increase in cohesivity; moist; no roots; accumulation of sodium. C horizon compact and consolidated below 40cm.									
Ak2	6-8										
Bw	8-10										
Bnw	10-20										
Cm	20-40										
	40+										

SOILS OF KAVANGO REGION

SOILS ANALYSIS Site Summary		Site No	Date	Lat	Long	Land System	Land Facet	Slope %	Slope Class	Aspect	Slope Shape
		A22	01-May-99	18°55.293'S	20°56.345'E	(7.4) Eastern-flowing paleo drainage - eastern omiramba	Edge of major drainage channel	1	1	SW	straight slope
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	% < 2µ clay	% 53 - 2000µ sand	% > 2000µ gravel	% 2000 - 5000µ ves/cs	% 500 - 250µ ms	% 250 - 100µ fs	% 106 - 53µ vfs	FAO Textural Class	
B41	A22B (a)	0 - 20	7.1	87.0	trace to null	9.3	32.7	46.7	11.2		
B42	A22B (b)	20 - 30	8.3	81.8	trace to null	8.2	30.8	48.1	12.9		2
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Colour (moist)	Texture	OM % (L.O.I)	P (Olsen mg/kg)	ECe (µS/cm)	pH (H ₂ O)	OrgC % (Walkley-Black)	CaCO ₃ (quant)	
B41	A22B (a)	0 - 20	7.5YR 4/3 brown	sand	Not analysed	0.3	10.0	5.7	0.01	low pH	
B42	A22B (b)	20 - 30	10YR 5/2 greyish yellow brown	loamy sand	0.18	< 0.1	14.9	6.0	0.05	low pH	
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	SO ₄ (S µg/g Turbid)	Ca (ppm)	Mg (ppm)	K (ppm)	Cl (ppm)	Na (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)
B41	A22B (a)	0 - 20	2.8	103	69	32	<0.5	8	<0.2	<0.5	<0.5
B42	A22B (b)	20 - 30	1.7	156	123	45	<0.5	28	<0.2	<0.5	1.7
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	CEC total (me/100g)	Clay %	CEC clay (me/100g)	Tot Exch Bases (me/100g)	BSP (me/100g clay)	BSP (me/100g)	ESP (me/100g clay)	ESP (me/100g clay)	SAR
B41	A22B (a)	0 - 20	1.20	7.10	16.97	1.198	7.06	99.46	2.906	0.206	0.150
B42	A22B (b)	20 - 30	2.04	8.30	24.53	2.025	8.26	99.46	5.992	0.497	0.407
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Ca:Mg	K:Mg	K:CEC total (EPP)	K:CEC (clay)	Sodicity (ESP > 15)	Salinity	Sodicity (Na>1me/100g)	FAO Depth Class	
B41	A22B (a)	0 - 20	0.91	0.14	6.81	0.48	No	No	No	Moderately Deep	
B42	A22B (b)	20 - 30	0.77	0.11	5.65	0.47	No	No	No		
Und Lab ID	Und Field ID	Und Depth (cm)	OM % (L.O.I)	Moist Cont %	Dry BD (g/cm3)	Porosity (vol %)	FAO Classification	Group	Ufrit	Phase	RSA Classification
U23	A22U (a)	15	0.16	0.7	1.43	46.0		Arenosol	Cambic	Fragipan	?
Micro-topography		Soil Surface Condition									
High density of micro-slopes running parallel to slope direction		Surface Drainage									
		Erosion / Deposition									
		Sand deposition on surface; very shallow soil impenetrable below 30cm.									
Horizon		Profile Description									
Au2	0-20	Shallow, imperfectly drained sand overlying hard clays; continuous thin hard crust 4-6mm thick, no cracks. Thin ochric A horizon of brown (7.5YR 4/3) dry sand; no mottles; medium granular to medium subangular blocky structure with unconsolidated fine sand grains; <1% fine roots; common medium pores. Clear smooth boundary at 20cm to illuvial B horizon with evidence of cambic properties; greyish yellow brown (10YR 5/2) loamy sand; no mottles; moderate hard medium platy to medium subangular blocky structure; common medium and fine pores; few fine roots. Abrupt boundary at 30cm to hard, compact consolidated clays with extremely high penetration resistance - a buried B horizon of fine-particle deposits, not a C horizon.									
Bu	20-30										
Bm	30+										

SOILS OF KAVANGO REGION

SOILS ANALYSIS Site Summary		Site No.	Date	Lat	Long	Land System	Land Facet	Slope %	Slope Class	Aspect	Slope Shape
A23		18°58.527'S	20°55.551'E	(7-3) Eastern-flowing paleo drainage - hard pan	Sandy valley NW-SE direction (paleo-surface deflation zone2)	0	1	n/a	flat		
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	% < 2µ clay	% 2 - 50µ silt	% 53 - 2000µ sand	% > 2000µ gravel	% 2000 - 500µ vcs/cs	% 500 - 250µ ms	% 250 - 106µ fs	% 105 - 53µ vfs	FAO Textural Class
B43	A23B (a)	0 - 60	6.0	8.3	85.7	trace to null	2.1	36.2	49.2	12.5	1
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Colour (moist)	Texture	OM% (L.O.I)	Moist Cont %	P (Olsen mg/kg)	ECe (µS/cm)	pH (H ₂ O)	OrgC % (Walkley-Black)	CaCO ₃ (quant)
B43	A23B (a)	0 - 60	5YR 4/4 dull reddish brown	loamy sand	Not analysed	Not analysed	< 0.1	8.3	5.5	0.08	low pH
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	SO ₄ (S µg/g Turbid)	Ca (ppm)	Mg (ppm)	K (ppm)	Na (ppm)	Cu (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)
B43	A23B (a)	0 - 60	5.4	93	27	9	7	<0.5	<0.2	<0.5	0.5
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	CECtotal (me/100g)	Clay %	CECclay (me/100g)	Total Exch Bases (me/100g)	BSP (me/100g)	BSP (me/100g clay)	ESP (me/100g)	ESP (me/100g clay)	SAR
B43	A23B (a)	0 - 60	0.75	6.00	12.43	0.739	99.12	5.95	4.024	0.241	0.164
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Ca/Mg	K/Mg	K/CEC total (EPP)	K/CEC (clay)	Salinity	Sodicity (ESP > 15)	Sodicity (Na>1me/100g)	FAO Depth Class	
B43	A23B (a)	0 - 60	2.10	0.10	3.08	0.19	No	No	No	Deep	
Und Lab ID	Und Field ID	Und Depth (cm)	OM % (L.O.I)	Moist Cont %	Dry BD (g/cm ³)	Porosity (vol %)	FAO Classification		RSA Classification		
U24	A23U (a)	15	0.11	0.2	1.41	46.7	Group	Unit	Phase		
							Arenosol	Haplic	Yermic	Gaudam ?	
Micro-topography			Soil Surface Condition			Surface Drainage			Erosion / Deposition		
Small hummock development around grass clumps, widespread; otherwise smooth			Low litter and grass cover, discontinuous surface crust 2-3mm thick; evidence of fire, burnt organic particles bonded in crust			Suspected slow initial surface infiltration although freely drained below crust			No evidence of erosion; no recent deposition		
Horizon			Depth (cm)			Profile Description					
Ach	0-2		Moderately deep well drained loamy sand; discontinuous crust 2-3mm thick, burnt organic particles bonded to underside of crust. Little profile development. Thick ochric A horizon, dull reddish brown								
Ah	2-25		(5YR 4/4) fine loamy sand with high internal drainage; weak fine to medium granular structure; 2% burnt organic matter evenly distributed to 25cm depth; few very fine roots; common medium pores, few fine pores. Gradual diffuse boundary to C horizon at 75cm to fine aeolian sand. No visible lower boundary >100cm.								
Au	25-75										
Cu	75+										

SOILS OF KAVANGO REGION

SOILS ANALYSIS Site Summary		Site No	Date	Lat	Long	Land System	Land Facet	Slope %	Slope Class	Aspect	Slope Shape
A24		A24	01-May-99	18°59.270'S	20°54.870'E	(7.3) Eastern-flowing paleo drainage - hard pan	Flattened dune crest (deflation zone)	0	1	n/a	flat
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	% < 2µ clay	% 2 - 5µ silt	% 53 - 200µ sand	% > 200µ gravel	% 2000 - 500µ vcs/cs	% 500 - 250µ ms	% 250 - 106µ fs	% 106 - 53µ vfs	FAO Textural Class
B44	A24B (a)	0 - 75	5.3	3.0	91.7	trace to null	1.2	35.2	52.1	11.5	1
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Colour (moist)	Texture	OM % (L.O.I)	Molst Cont %	P (Olsen mg/kg)	ECe (µS/cm)	pH (H ₂ O)	OrgC % (Walkley-Black)	CaCO ₃ (quant)
B44	A24B (a)	0 - 75	5YR 4/4 dull reddish brown	sand	Not analysed	Not analysed	< 0.1	5.4	5.6	0.05	low pH
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	SO ₄ (S µg/g Turbid)	Ca (ppm)	Mg (ppm)	K (ppm)	Na (ppm)	Cu (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)
B44	A24B (a)	0 - 75	7.2	52	12	6	2	<0.5	<0.2	<0.5	<0.5
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	CECtotal (me/100g)	Clay %	CECclay (me/100g)	Tot Exch Bases (me/100g)	BSP (me/100g)	BSP (me/100g clay)	ESP (me/100g clay)	ESP (me/100g)	SAR
B44	A24B (a)	0 - 75	0.39	5.30	7.33	0.382	98.32	5.21	2.316	0.123	0.055
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Ca:Mg	K:Mg	K:CEC total (EPP)	K:CEC (clay)	Salinity	Sodicity (ESP _s (5))	Sodicity (Na>1me/100g)	FAO Depth Class	
B44	A24B (a)	0 - 75	2.65	0.15	3.86	0.20	No	No	No	Deep	
Und Lab ID	Und Field ID	Und Depth (cm)	OM % (L.O.I)	Moist Cont %	Dry BD (g/cm ³)	Porosity (vol %)	FAO Classification		RSA Classification		
U25	A24LU (a)	15	0.08	0.1	1.67	36.9	Group	Uhlit	Phase		
							Arenosol	Heplic	Yermic	Gaudam ?	
Micro-topography		Soil Surface Condition		Surface Drainage		Erosion / Deposition					
Uneven		25% cover leaf litter; no stones; angular charcoal fragments on surface and throughout profile (0-75cm depth)		No visible local drainage channels or rills; high permeability		No evidence of erosion; no recent deposition					
Horizon		Depth (cm)		Profile Description							
Ahp Cw		0-45 45->100		Deep, somewhat excessively well drained sand; no crusting, sealing or cracks. Very little profile development. Ochric A horizon; dull reddish brown (5YR 4/4) fine to very fine sand; 2% burnt organic fragments and particles throughout profile; few very fine roots; common medium and large pores. At 45cm depth very gradual transition to C horizon marked by increase in colour value to 5YR 5/4. No visible lower boundary.							

SOILS OF KAVANGO REGION

SOILS ANALYSIS Site Summary		Site No	Date	Lat	Long	Land System	Land Facet	Slope %	Slope Class	Aspect	Slope Shape
A25		A25	01-May-99	19°00.905'S	20°53.194'E	(7.3) Eastern-flowing paleo drainage - hard pan	Paleo-surface, flattened 'crest' undertain by shallow calcrete	0	1	n/a	top of gentle convex slope
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	% < 2µ clay	% 2 - 5µ silt	% 53 - 2000µ sand	% > 2000µ gravel	% 2000 - 500µ vcs/cs	% 500 - 250µ ms	% 250 - 106µ fs	% 106 - 53µ vrs	FAO Textural Class
B45	A25B (a)	0 - 75	11.4	7.6	81.0	Trace to null	1.4	21.5	59.7	17.5	1
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Colour (moist)	Texture	OM % (L.O.I)	Moist Cont %	P (Olsen mg/kg)	ECa (µS/cm)	pH (H ₂ O)	OrgC % (Walkley-Black)	CaCO ₃ (quant)
B45	A25B (a)	0 - 75	10YR 3/2 dark brown	loamy sand	Not analysed	Not analysed	0.2	81.7	7.8	0.18	<1
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	SO ₄ (S µg/g Turbid)	Ca (ppm)	Mg (ppm)	K (ppm)	Na (ppm)	Cu (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)
B45	A25B (a)	0 - 75	2.3	785	169	34	9	<0.5	<0.2	<0.5	<0.5
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	CECtotal (me/100g)	Clay %	CECclay (me/100g)	Tot Exch Bases (me/100g)	BSP (me/100g clay)	BSP (me/100g clay)	ESP (me/100g clay)	ESP (me/100g clay)	SAR
B45	A25B (a)	0 - 75	5.44	11.40	47.74	5.436	99.88	11.39	0.717	0.092	0.076
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Ca:Mg	K:Mg	K:CEC total (EPP)	K:CEC (clay)	Salinity	Sodicity (ESP > 15)	Sodicity (Na > 1me/100g)	FAO Depth Class	
B45	A25B (a)	0 - 75	2.83	0.06	1.60	0.18	No	No	No	Deep	
Und Lab ID	Und Field ID	Und Depth (cm)	OM % (L.O.I)	Moist Cont %	Dry BD (g/cm ³)	Porosity (vol %)	FAO Classification		RSA Classification		
U26	A25U (a)	15	0.20	1.9	1.33	49.7	Group	Unit	Phase		
Micro-topography		Soil Surface Condition									
Irregular; not smooth, no hummocks		High cover of leaf litter; Terminalia Prunoides woodland outside its 'normal' range									
Horizon		Depth (cm)	Profile Description								
Am	0-1	Moderately deep, imperfectly drained, loamy sand. Note: Terminalia Prunoides woodland outside 'normal' range. Hard surface crust of fine clay particles up to 5mm thick; no cracks. Ochric A horizon, calcareous below 1cm depth; dark brown (10YR 3/2) loamy sand throughout profile; single horizon with development limited to very gradual progressive increase in particle consolidation and poorer internal drainage with depth, although no evidence of particle translocation; medium subangular blocky structure; hard white sub-angular cemented calcareous fragments evenly distributed and accounting for +/- 20% proportion of matrix; common fine pores; few fine roots. Gradual very broad lower boundary to consolidated C horizon at 75cm; highly resistant to further penetration.									
Ap	1-45										
Act	45-75										
Cmk	75+										
		No evidence of wind or water erosion; no recent deposition									

SOILS OF KAVANGO REGION

SOILS ANALYSIS Site Summary		Site No	Date	Lat	Long	Land System	Land Facet	Slope %	Slope Class	Aspect	Slope Shape
A26		A26	02-May-99	19°06.431'S	20°42.432'E	(7.3) Eastern-flowing paleo drainage - hard pan	Paleo surface, desiccating pan on crest in gently undulating area	0	1	n/a	lop of gentle convex slope
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	% < 2µ clay	% 2 - 53µ silt	% 53 - 2000µ sand	% > 2000µ gravel	% 2000 - 500µ vcs/cs	% 500 - 250µ ms	% 250 - 106µ fs	% 106 - 53µ vfs	FAO Textural Class
B46	A26B (a)	0 - 8	10.0	16.2	73.9	trace to null	7.6	21.8	50.6	20.1	
B47	A26B (b)	8 - 32	10.6	22.1	67.3	trace to null	6.0	21.1	52.5	20.4	
B48	A26B (c)	32 - 72	16.1	21.0	62.9	trace to null	6.0	21.3	52.6	20.1	2
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Colour (moist)	Texture	OM % (L.O.I)	Molst Cont %	P (Olsen mg/kg)	ECe (µS/cm)	pH (H ₂ O)	OrgC % (Walkley-Black)	CaCO ₃ (quant)
B46	A26B (a)	0 - 8	10YR 3/2 brownish black	sandy loam	0.44	0.7	1.6	100.7	8.1	0.45	23.7
B47	A26B (b)	8 - 32	10YR 4/2 greyish yellow brown	sandy loam	0.43	1.9	0.7	176.2	8.2	0.33	32.3
B48	A26B (c)	32 - 72	5YR 5/2 greyish brown	sandy loam	0.43	3.0	0.4	151.2	8.3	0.14	46.5
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	SO ₄ (S µg/g Turbid)	Ca (ppm)	Mg (ppm)	K (ppm)	Na (ppm)	Cu (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)
B46	A26B (a)	0 - 8	0.9	1913	95	80	8	<0.5	<0.2	<0.5	<0.5
B47	A26B (b)	8 - 32	1.2	1656	66	52	10	<0.5	<0.2	<0.5	<0.5
B48	A26B (c)	32 - 72	1.7	2223	97	37	14	<0.5	<0.2	<0.5	<0.5
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	CECtotal (me/100g)	Clay %	CECclay (me/100g)	Tot Exch Bases (me/100g)	BSP (me/100g)	BSP (me/100g clay)	ESP (me/100g clay)	ESP (me/100g)	SAR
B46	A26B (a)	0 - 8	10.59	10.00	105.91	10.584	99.94	9.99	0.330	0.033	0.048
B47	A26B (b)	8 - 32	9.00	10.60	84.93	8.996	99.93	10.59	0.476	0.051	0.065
B48	A26B (c)	32 - 72	12.07	16.10	74.98	12.056	99.95	16.09	0.506	0.081	0.079
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Ca:Mg	K:Mg	K:CEC total (EPP)	K:CEC (clay)	Salinity	Sodicity (ESP > 15)	Sodicity (Na>1me/100g)	FAO Depth Class	
B46	A26B (a)	0 - 8	12.28	0.26	1.94	0.19	No	No	No		
B47	A26B (b)	8 - 32	15.30	0.25	1.48	0.16	No	No	No	Moderately Deep	
B48	A26B (c)	32 - 72	13.98	0.12	0.79	0.13	No	No	No		
Undr Lab ID	Undr Field ID	Undr Depth (cm)	OM % (L.O.I)	Molst Cont %	Dry BD (g/cm ³)	Porosity (vol %)	FAO Classification		RSA Classification		
U27	A26U (a)	15	0.31	2.5	1.35	48.9	Group	Unit	Phase	?	
Micro-topography		Soil Surface Condition		Surface Drainage		Erosion / Deposition					
Slightly uneven		Significant crust development (+/- 5mm thick) of fine, cemented calcareous material, difficult to penetrate or otherwise break; no stones		Drainage through surface impeded; internal drainage impeded down to 32cm depth below which it improves significantly		Old deposition area; currently a runoff zone although no evidence of wind or water erosion; no recent deposition					
Horizon	Depth (cm)	Profile Description									
Ack	0-1	Moderately deep, imperfectly drained sandy loam; significant crust 5mm thick of fine cemented calcareous material, difficult to penetrate or break. Thin ochric A horizon of brownish black (10YR 3/2)									
Al	1-8	sandy loam; upper particles cemented to underside of crust; medium angular blocky structure with loosely packed fine sand particles to 8cm depth; small (1-5mm) hard white cemented calcareous fragments and disaggregated grains accounting for 20% of matrix throughout horizon; common fine roots; common medium and fine pores. Abrupt boundary at 8cm to B horizon, greyish yellow brown (10YR 4/2) fine sand with increase in silt; fine subangular blocky structure; small white disaggregated calcareous grains accounting for 10% of matrix; dense mat of fine roots; common fine pores; decrease in internal drainage between 8-32cm depth. Sharp boundary at 32cm to argic B sub-horizon, greyish brown (5YR 5/2) fine sand with silt and increase in illuvial clay particles; medium to coarse subangular blocky structure with loosely packed fine sand; internal drainage improved; large, consolidated white calcareous fragments with common disaggregated calcareous grains accounting for >40% of matrix; few fine roots to 40cm; common fine pores. Hard, indurated, retro-calcic C horizon at 72cm depth. No further penetration possible.									
Bkw	8-32										
Blk	32-72										
Ckm	72+										

SOILS OF KAVANGO REGION

SOILS ANALYSIS Site Summary		Site No	Date	Lat	Long	Land System	Land Facet	Slope %	Slope Class	Aspect	Slope Shape
A27		A27	02-May-99	19°01.750'S	20°30.589'E	(7.312) Eastern-flowing paleo drainage - trans. hard pan to sand plain with large pans	Crest of long gently sloping rise	1	1	NM-SE	slightly convex
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	% < 2µ clay	% 2 - 5µ silt	% 53 - 200µ sand	% > 200µ gravel	% 2000 - 500µ vcs/cs	% 500 - 250µ ms	% 250 - 106µ fs	% 106 - 63µ vfs	FAO Textural Class
B49	A27B (a)	0 - 15	9.6	6.5	81.9	trace to null	2.1	32.5	54.1	11.3	
B50	A27B (b)	15 - 40	14.5	8.0	77.5	trace to null	2.2	28.1	56.2	13.5	2
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Colour (moist)	Texture	OM % (L.O.I)	Moist Cont %	P (Olsen mg/kg)	ECE (µS/cm)	pH (H ₂ O)	OrgC % (Walkley-Black)	CaCO ₃ (quant)
B49	A27B (a)	0 - 15	10YR 2/2 brownish black	loamy sand	Not analysed	Not analysed	0.2	48.7	7.6	0.22	<1
B50	A27B (b)	15 - 40	10YR 2/3 brownish black	loamy sand	0.37	2.4	0.1	79.5	7.7	0.21	<1
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	SO ₄ (S µg/g Turbid)	Ca (ppm)	Mg (ppm)	K (ppm)	Na (ppm)	Cu (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)
B49	A27B (a)	0 - 15	1.2	822	86	74	12	<0.5	<0.2	<0.5	<0.5
B50	A27B (b)	15 - 40	1.2	1044	93	64	9	<0.5	<0.2	<0.5	<0.5
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	CECtotal (me/100g)	Clay %	CECclay (me/100g)	Tot Exch Bases (me/100g)	BSP (me/100g)	BSP (me/100g clay)	ESP (me/100g clay)	ESP (me/100g clay)	SAR
B49	A27B (a)	0 - 15	5.06	9.60	52.73	5.056	99.87	9.59	1.027	0.099	0.106
B50	A27B (b)	15 - 40	6.19	14.50	42.70	6.185	99.89	14.48	0.630	0.091	0.072
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Ca:Mg	K:Mg	K:CEC total (EPP)	K:CEC (clay)	Salinity	Sodicity (ESP > 15)	Sodicity (Na > 1me/100g)	FAO Depth Class	
B49	A27B (a)	0 - 15	5.83	0.27	3.73	0.36	No	No	No	Moderately Deep	
B50	A27B (b)	15 - 40	6.85	0.22	2.55	0.38	No	No	No		
Und Lab ID	Und Field ID	Und Depth (cm)	OM % (L.O.I)	Moist Cont %	Dry BD (g/cm ³)	Porosity (vol %)	FAO Classification	Unit	Phase	RSA Classification	
U28	A27U (a)	15	0.19	1.1	1.40	47.3	Luvisol	Duripan		?	
Micro-topography			Soil Surface Condition			Surface Drainage			Erosion / Deposition		
Extensively hummocky; many local micro-slopes			30% cover litter; very little to no crust development, no cracks			Imperfect to moderately well drained at surface; Impeded internal drainage at 42cm depth (horizon of compacted silts)			Extensive sheet-wash		
Horizon	Depth (cm)	Profile Description									
Ak	0-15	Shallow, moderate to imperfectly drained loamy sand; insignificant, thin patchy crust, no cracks. Thin ochric A horizon of brownish black (10YR 2/2) loamy sand; dry; unconsolidated to weak very fine granular structure; no mottles; common fine roots; common medium and large pores. Smooth boundary at 15cm to B horizon with evidence of argic properties; brighter chroma (10YR 2/3); very coarse granular structure; aggregated; significant increase in clay content and slight increase in moisture content; few very fine roots; common fine pores. Abrupt boundary at 40cm to impeneetrable, indurated C horizon of consolidated silts and clays, possibly petrocalcic.									
Blk	15-40										
Ckm	40+										

SOILS OF KAVANGO REGION

SOILS ANALYSIS Site Summary		Site No.	Date	Lat	Long	Land System	Land Facet	Slope %	Slope Class	Aspect	Slope Shape
A28		02-May-99	19°02.12'S	20°51.15'E	(7.32) Eastern-flowing paleo drainage - transitional hard pan to sand plain with large pans	Head of tributary to main channel; mid channel, base of gentle slope	0.5	1	S	slightly concave	
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	% < 2µ clay	% 2 - 53µ silt	% 53 - 2000µ sand	% > 2000µ gravel	% 2000 - 500µ vcs/cs	% 500 - 250µ fs	% 250 - 106µ fs	% 106 - 53µ vifs	FAO Textural Class
N/A	not sampled	N/A									2
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Colour (moist)	Texture	OM % (L.O.I)	Moist Cont %	P (Clasen mg/kg)	ECe (µS/cm)	pH (H ₂ O)	OrgC % (Walkley-Black)	CaCO ₃ (quant)
N/A	not sampled	N/A									
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	SO ₄ (S µg/g Turbid)	Ca (ppm)	Mg (ppm)	K (ppm)	Na (ppm)	Cu (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)
N/A	not sampled	N/A									
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	CECtotal (me/100g)	Clay %	CEC clay (me/100g)	Tot Exch Bases (me/100g)	BSP (me/100g)	BSP (me/100g clay)	ESP (me/100g)	ESP (me/100g clay)	SAR
N/A	not sampled	N/A									
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Ca:Mg	K:Mg	K:CEC total (EPP)	K:CEC (clay)	Salinity	Sodicity (ESP > 15)	Sodicity (Na>1me/100g)	Sodicity	FAO Depth Class
N/A	not sampled	N/A									Moderately Deep
Und Lab ID	Und Field ID	Und Depth (cm)	OM % (L.O.I)	Moist Cont %	Dry BD (g/cm ³)	Porosity (vol %)	FAO Classification	FAO Classification	Phase	RSA Classification	
N/A	not sampled	N/A	N/A	N/A	N/A	N/A	Group	Unit	Phase		
							Caltsol	Luvic	Duripan		?
Micro-topography		Soil Surface Condition		Surface Drainage		Erosion / Deposition					
Extensively hummocky; many local micro-slopes		30% cover litter; very little to no crust development, no cracks; no stones		imperfect		No evidence of erosion; no recent deposition					
Horizon	Depth (cm)	Profile Description									
As site 27		As site A27									

SOILS OF KAVANGO REGION

SOILS ANALYSIS Site Summary		Site No	Date	Lat	Long	Land System	Land Parcel	Slope %	Slope Class	Aspect	Slope Shape
A29		02-May-99	19°02.864'S	20°19.309'E	(7.3/2) Eastern-flowing paleo drainage - transitional hard pan to sand plain with large pans	Sandy plain (resembles 7.2)	0	1	n/a	flat	
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	% < 2µ clay	% 2 - 5µ silt	% 53 - 200µ sand	% > 200µ gravel	% 2000 - 500µ vcs/vs	% 500 - 250µ ms	% 250 - 106µ fs	% 106 - 53µ vfs	FAO Textural Class
B51	A29B (a)	0 - 30	3.5	5.4	91.0	Trace to null	1.1	36.2	50.3	12.4	1
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Colour (moist)	Texture	OM % (L.O.I)	Moist Cont %	P (Olsen mg/kg)	Ece (µS/cm)	pH (H ₂ O)	OrgC % (Walkley-Black)	CaCO ₃ (quant)
B51	A29B (a)	0 - 30	5YR 3/2 dark reddish brown	sand	Not analysed	Not analysed	< 0.1	8.0	5.8	0.12	low pH
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	SO ₄ (S µg/g Turbid)	Ca (ppm)	Mg (ppm)	K (ppm)	Na (ppm)	Cu (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)
B51	A29B (a)	0 - 30	6.7	92	16	5	3	<0.5	<0.2	<0.5	<0.5
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	CECtotal (me/100g)	Clay %	CECclay (me/100g)	Total Exch Bases (me/100g)	BSP (me/100g)	BSP (me/100g clay)	ESP (me/100g)	ESP (me/100g clay)	SAR
B51	A29B (a)	0 - 30	0.62	3.50	17.82	0.617	98.95	3.46	2.085	0.073	0.076
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Ca:Mg	K:Mg	K:CEC total (EPP)	K:CEC (clay)	Salinity	Sodicity (ESP x15)	Sodicity (Na>me/100g)	FAO Depth Class	
B51	A29B (a)	0 - 30	3.51	0.10	2.08	0.07	No	No	No	Deep	
Und Lab ID	Und Field ID	Und Depth (cm)	OM % (L.O.I)	Moist Cont %	Dry BD (g/cm ³)	Porosity (vol %)	FAO Classification		RSA Classification		
U29	A29U (a)	25	0.12	0.1	1.60	39.6	Group	Unit	Phase		
Micro-topography		Soil Surface Condition		Surface Drainage		Erosion / Deposition					
Uneven		High cover of leaf litter; no crust, sealing or cracks; no stones; Burkea woodland		Excessively well drained; no visible drainage channels		Excessively well drained; no visible drainage channels					
Horizon		Depth (cm)		Profile Description							
Au1	0-7	Deep, excessively well drained sand; no crusting, sealing or cracks. Ochric A horizon, dark reddish brown (6YR 3/2) unconsolidated medium to fine sand; 2% black organic molts at 7-11 cm depth;									
Ah	7-11										
Au2	11-18										
Cu	18->100										

SOILS OF KAVANGO REGION

SOILS ANALYSIS Site Summary		Site No	Date	Lat	Long	Land System	Land Facet	Slope %	Slope Class	Aspect	Slope Shape
A30		A30	03-May-99	18°50.046'S	20°13.709'E	(7.2) Eastern-flowing paleo drainage - sand plain with large pans	Eastern edge of water divide; long gentle slope, crest position	1	1	E	concave
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	% < 2µ clay	% 2 - 5µ silt	% 53 - 200µ sand	% > 2000µ gravel	% 2000 - 500µ vcs/cs	% 500 - 250µ ms	% 250 - 106µ fs	% 105 - 53µ vfs	FAO Textural Class
B52	A30B (a)	0 - 30	4.0	3.6	92.4	trace to null	2.0	55.8	35.4	6.7	
B53	A30B (b)	30 - 60	4.3	3.4	92.3	trace to null	2.0	49.1	41.2	7.7	1
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Colour (moist)	Texture	OM % (L.O.I)	Moist Cont %	P (Olsen mg/kg)	Ece (µS/cm)	pH (H ₂ O)	OrgC % (Walkley-Black)	CaCO ₃ (quant)
B52	A30B (a)	0 - 30	5YR 4/2 greyish brown	sand	Not analysed	Not analysed	0.1	11.3	5.4	0.13	low pH
B53	A30B (b)	30 - 60	7.5YR 6/4 dull orange	sand	0.05	0.1	< 0.1	7.7	5.1	< 0.01	low pH
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	SO ₄ (S µg/g Turbid)	Ca (ppm)	Mg (ppm)	K (ppm)	Na (ppm)	Cu (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)
B52	A30B (a)	0 - 30	4.9	4.1	14	8	3	< 0.5	< 0.2	< 0.5	0.3
B53	A30B (b)	30 - 60	5.9	11	3	5	4	< 0.5	< 0.2	< 0.5	< 0.5
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	CECtotal (me/100g)	Clay %	CEClay (me/100g)	Tot Exch Bases (me/100g)	BSP (me/100g clay)	BSP (me/100g)	ESP (me/100g clay)	ESP (me/100g)	SAR
B52	A30B (a)	0 - 30	0.36	4.00	8.97	0.353	98.37	3.93	0.145	3.623	0.103
B53	A30B (b)	30 - 60	0.12	4.30	2.71	0.110	94.39	4.06	0.627	14.587	0.276
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Ca:Mg	K:Mg	K:CEC total (EPP)	K:CEC (clay)	Salinity	Sodicity (ESP × 15)	Sodicity (Na > 1me/100g)	FAO Depth Class	
B52	A30B (a)	0 - 30	1.78	0.17	5.57	0.22	No	No	No	Deep	
B53	A30B (b)	30 - 60	2.20	0.52	11.16	0.48	No	Yes	No	Deep	
Undr Lab ID	Undr Field ID	Undr Depth (cm)	OM % (L.O.I)	Moist Cont %	Dry BD (g/cm ³)	Porosity (vol %)	Group	Unit	Phase	FAO Classification	RSA Classification
U30	A30U (a)	15	0.11	0.1	1.59	40.1	Arenosol	Ferralsol	Yermic		Sandspruit ?
Micro-topography			Soil Surface Condition			Surface Drainage			Erosion / Deposition		
Uneven			High cover of leaf litter; no crust, sealing or cracks; no stones			Excessively well drained; no visible drainage channels			No evidence of wind or water erosion; no recent deposition		
Horizon	Depth (cm)	Profile Description									
EA	0-8										
Ah	8-14	Deep, excessively well drained sand; no crusting, sealing or cracks. Thin albic/ochric EA surface horizon, greyish brown (5YR 4/2) unconsolidated medium to fine sand; 7% black organic mollics at 8-14 cm depth; common fine roots to 19cm; common medium and large pores. Clear smooth boundary with evidence of structural changes to B horizon at 30cm; dull orange (7.5YR 6/4); unconsolidated to very fine granular structure; 1% black organic particles in thin (1cm) band at 35cm; few fine roots; common medium and large pores. Boundary to transitional BC horizon at 36cm; no further colour change although gradual loss of structure to unconsolidated aeolian sand evident down horizon. No visible lower boundary > 100cm.									
Au	14-30										
Bu	30-35										
Bhw	35-36										
BwC	36-> 100										

SOILS OF KAVANGO REGION

SOILS ANALYSIS Site Summary		Site No	Date	Lat	Long	Land System	Land Facet	Slope %	Slope Class	Aspect	Slope Shape
A31		A31	03-May-99	18°44.098S	20°16.753E	(5.1) Ephemeral catchment divide - high plain	Elevated plain with local depressions; low position	1	1	NE	almost flat plain
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	% < 2µ clay	% 2 - 53µ silt	% 53 - 2000µ sand	% > 2000µ gravel	% 2000 - 500µ vcs/cs	% 500 - 250µ fs	% 250 - 106µ fs	% 106 - 53µ vfs	FAO Textural Class
B54	A31B (a)	0 - 30	6.7	6.2	87.1	trace to null	0.6	28.6	61.5	9.3	
B55	A31B (b)	>30 - 60	6.7	6.2	87.1	trace to null	0.5	26.4	63.4	9.7	1
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Colour (moist)	Texture	OM % (L.O.I)	Moist Cont %	P (Olsen; mg/kg)	ECa (µS/cm)	pH (H ₂ O)	OrgC % (Walkley-Black)	CaCO ₃ (quant)
B54	A31B (a)	0 - 30	7.5YR 4/3 brown	sand	Not analysed	Not analysed	< 0.1	9.6	5.9	0.06	low pH
B55	A31B (b)	>30 - 60	7.5YR 5/4 dull brown	sand	0.12	1.1	0.1	13.1	6.1	<0.01	low pH
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	SO ₄ (S µg/g Turbid)	Ca (ppm)	Mg (ppm)	K (ppm)	Na (ppm)	Cu (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)
B54	A31B (a)	0 - 30	3.6	186	39	11	5	<0.5	<0.2	<0.5	<0.5
B55	A31B (b)	>30 - 60	5.7	211	42	11	3	<0.5	<0.2	<0.5	<0.5
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	CECtotal (me/100g)	Clay %	CECclay (me/100g)	Tot Exch Bases (me/100g)	BSP (me/100g)	BSP (me/100g clay)	ESP (me/100g clay)	ESP (me/100g)	SAR
B54	A31B (a)	0 - 30	1.30	6.70	19.43	1.295	99.50	6.67	0.113	0.113	0.087
B55	A31B (b)	>30 - 60	1.45	6.70	21.59	1.440	99.55	6.67	0.060	0.060	0.049
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Ca/Mg	K/Mg	K/CEC total (EPP)	Salinity	Sodicity (ESP > 15)	Sodicity (Na > 1me/100g)	Sodicity Class	FAO Depth Class	
B54	A31B (a)	0 - 30	2.89	0.09	2.15	No	No	No	No	Moderately Deep	
B55	A31B (b)	>30 - 60	3.07	0.08	1.94	No	No	No	No		
Und Lab ID	Und Field ID	Und Depth (cm)	OM % (L.O.I)	Moist Cont %	Dry BD (g/cm ³)	Porosity (vol %)	FAO Classification	Group	Util	Phase	RSA Classification
U31	A31U (a)	15	0.11	0.3	1.45	45.2		Arenosol	Cambic	Duripan	Sandspruit ?
Micro-topography		Soil Surface Condition		Surface Drainage		Erosion / Deposition					
Uneven; high density of shallow, wide runoff channels (width range 50-90cm)		Surface cleared of litter along runoff channels between stable grassed clumps; no crust, sealing or cracks; no stones; no evidence of fine		Surface well drained; subsurface drainage imperfect; shallow runoff channels widespread		Ample evidence of water erosion; denudation surface; no gullies					
Horizon	Depth (cm)	Profile Description									
Ap	0-31	Deep, imperfectly drained sand; no crusting, sealing or cracks. Ochric A horizon; brown (7.5YR 4/3) fine sand; very fine granular structure; firm, slightly compacted and cohesive; evidence of animal tracks and hoof churns; surface drainage good; few very fine roots; no molluscs. Smooth boundary at 31cm to B horizon with some evidence of cambic properties; dull yellowish brown (10YR 4/3) sand; no change in texture although significant increase in packing state and moisture content; internal drainage imperfect; fine to coarse granular structure; no mollics; few fine roots; common medium pores. Diffuse boundary to transitional BC horizon at 75cm; consolidated sand layer; no change in texture or colour. Boundary to strongly cemented C horizon at 90cm, slightly calcareous. No visible lower boundary.									
Bw	31-75										
BC m	75-90										
Cm	90->100										

SOILS OF KAVANGO REGION

SOILS ANALYSIS Site Summary		Site No	Date	Lat	Long	Land System (5.1) Ephemeral catchment divide - high plain	Land Facet	Slope %	Slope Class	Aspect	Slope Shape
A32		A32	03-May-99	18°42.564'S	20°09.178'E	Elevated plain with local depressions, top of rise		0.5	1	E	flat to slightly convex
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	% < 2µ clay	% 2 - 53µ silt	% 53 - 2000µ sand	% > 2000µ gravel	% 2000 - 500µ vcs/cs	% 500 - 250µ ms	% 250 - 106µ fs	% 106 - 53µ vfs	FAO Textural Class
B56	A32B (a)	0 - 10	4.7	4.5	90.8	trace to null	0.5	22.7	62.1	14.7	1
B57	A32B (b)	10 - 30	7.5	6.1	86.4	trace to null	0.4	19.2	63.1	17.3	1
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Colour (moist)	Texture	OM % (L.O.I)	Moist Cont %	P (Olsen, mg/kg)	ECe (µS/cm)	pH (H ₂ O)	OrgC % (Walkley-Black)	CaCO ₃ (quant)
B56	A32B (a)	0 - 10	10YR 5/4 dull yellowish brown	sand	Not analysed	Not analysed	0.1	20.6	7.0	<0.01	<1
B57	A32B (b)	10 - 30	10YR 4/3 dull yellowish brown	sand	0.12	1.3	0.1	329.0	9.8	<0.01	<1
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	SO ₄ (S µg/g Turbid)	Ca (ppm)	Mg (ppm)	K (ppm)	Na (ppm)	Cu (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)
B56	A32B (a)	0 - 10	9.3	111	42	22	23	<0.5	<0.2	<0.5	<0.5
B57	A32B (b)	10 - 30	0.8	756	72	58	617	<0.5	<0.2	<0.5	<0.5
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	CEC total (me/100g)	Clay %	CEC clay (me/100g)	Tot Exch Bases (me/100g)	BSP (me/100g clay)	ESP (me/100g clay)	ESP (me/100g)	ESP (me/100g clay)	SAR
B56	A32B (a)	0 - 10	1.06	4.70	22.59	1.055	99.38	4.67	9.420	0.443	0.472
B57	A32B (b)	10 - 30	7.21	7.50	96.10	7.201	99.91	7.49	37.225	2.792	5.739
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Ca/Mg	K/Mg	K:CEC total (EPP)	K:CEC (clay)	Salinity	Sodicity (ESP > 15)	Sodicity (Na > 1me/100g)	FAO Depth Class	
B56	A32B (a)	0 - 10	1.61	0.16	5.28	0.25	No	No	No	Shallow	
B57	A32B (b)	10 - 30	6.41	0.25	2.05	0.15	No	Yes	Yes	Shallow	
Und Lab ID	Und Field ID	Und Depth (cm)	OM % (L.O.I)	Moist Cont %	Dry BD (g/cm ³)	Porosity (vol %)	FAO Classification	FAO Classification	FAO Classification	RSA Classification	
U32	A32U (a)	15	0.05	0.3	1.57	40.6	Group	Unit	Phase		
Micro-topography		Soil Surface Condition									
Hummocky; shallow, wide runoff channels		Extensive surface cementation; continuous crust 15mm thick; consolidated sand layer below crust 30mm thick; no stones									
Surface Drainage		Impeded surface drainage; free internal drainage from 5-12cm depth; further impeded drainage below 15cm									
Erosion / Deposition		Denudation surface; moderate water erosion (runoff channels); no gullies									
Profile Description		Solonetz Calci-Haplic Duripan ?									
Horizon	Depth (cm)	Profile Description									
Am	0-3	Very shallow sand with impeded drainage. Note: area of Makalali Palms. Extensive surface cementation; continuous crust 15mm thick, consolidated sand layer cemented to underside of crust 30mm thick. Thin ochre A horizon of dull yellowish brown (10YR 5/4) fine sand; unconsolidated to medium granular structure; internal drainage below crust good; 1% black organic mottles at 8cm; very few fine roots; common medium pores. Abrupt boundary to natric B horizon at 10cm; lower chroma and colour value (10YR 4/3); texture slightly coarser with decrease in proportion of silt and clay; hard medium granular to fine subangular blocky structure; increase in packing state and impeded internal drainage below 15cm; very few fine roots; rare black organic mottles. Structural boundary at 20cm to consolidated C horizon; massive compact angular blocky structure (>100mm), difficult to penetrate or otherwise break. Calcareous throughout profile; all base concentrations increase with depth.									
Au2	3-8										
Ap	8-10										
Bw1	10-15										
Bw2	15-20										
Cm	20+										

SOILS OF KAVANGO REGION

SOILS ANALYSIS Site Summary		Site No	Date	Lat	Long	Land System	Land Facet	Slope %	Slope Class	Aspect	Slope Shape
		A33-non-existent	04-May-99	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	% < 2µ silt	% 53 - 2000µ sand	% > 2000µ gravel	% 2000 - 500µ veg/ks	% 500 - 250µ ms	% 250 - 106µ fs	% 106 - 53µ v/s	FAO Textural Class	
N/A	not sampled	N/A									
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Colour (moist)	Texture	OM % (L.O.I)	Moist Cont %	P (Olsen mg/kg)	Ece (µS/cm)	pH (H ₂ O)	OrgC % (Walkley-Black)	CaCO ₃ (quant)
N/A	not sampled	N/A									
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	SO ₄ (S µg/g Turbid)	Ca (ppm)	Mg (ppm)	K (ppm)	Na (ppm)	Cu (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)
N/A	not sampled	N/A									
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	CECtotal (me/100g)	Clay %	CECclay (me/100g)	Total Exch Bases (me/100g)	BSP (me/100g)	BSP (me/100g clay)	ESP (me/100g clay)	ESP (me/100g clay)	SAR
N/A	not sampled	N/A									
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Ca/Mg	K/Mg	K:CEC total (EPP)	K:CEC (clay)	Salinity	Sodicity (ESP > 15)	Sodicity (Na > 1me/100g)	Sodicity (Na > 1me/100g)	FAO Depth Class
N/A	not sampled	N/A									
Und Lab ID	Und Field ID	Und Depth (cm)	OM % (L.O.I)	Moist Cont %	Dry BD (g/cm ³)	Porosity (vol %)	FAO Classification	FAO Classification	FAO Classification	RSA Classification	
N/A	not sampled	N/A	N/A	N/A	N/A	N/A	Group	Unit	Phase		
		Soil Surface Condition			Surface Drainage			Erosion / Deposition			
N/A		N/A		N/A							
Horizon	Depth	Profile Description									
		Non-existent									

SOILS OF KAVANGO REGION

SOILS ANALYSIS Site Summary		Site No	Date	Lat	Long	Land System	Land Facet	Slope %	Slope Class	Aspect	Slope Shape
		A34	04-May-99	18°52.440'S	19°40.603'E	(4.1) Omatako omuramba - main channel and tributaries	Main channel/tributary confluence; floor	2	1	NW-SE	concave
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	% < 2µ clay	% 2 - 53µ silt	% 53 - 2000µ sand	% > 2000µ gravel	% 2000 - 500µ vscs	% 500 - 250µ ms	% 250 - 166µ fs	% 105 - 53µ vfs	FAO Textural Class
B58	A34B (a)	0 - 42	5.2	5.3	89.5	trace to null	10.3	43.9	38.7	7.0	1
B59	A34B (b)	42 - >100	4.3	6.1	89.6	trace to null	10.8	40.6	38.9	9.8	1
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Colour (moist)	Texture	OM % (L.O.I)	Moist Cont %	P (Olsen mg/kg)	ECe (µS/cm)	pH (H ₂ O)	OrgC % (Walkley-Black)	CaCO ₃ (quant)
B58	A34B (a)	0 - 42	5YR 3/2 dark reddish brown	sand	Not analysed	Not analysed	< 0.1	6.1	5.7	0.08	low pH
B59	A34B (b)	42 - >100	5YR 4/5 reddish brown	sand	0.07	0.6	< 0.1	7.2	5.6	<0.01	low pH
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	SO ₄ (S µg/g Turbid)	Ca (ppm)	Mg (ppm)	K (ppm)	Na (ppm)	Cu (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)
B58	A34B (a)	0 - 42	7.5	73	31	15	6	<0.5	<0.2	<0.5	<0.5
B59	A34B (b)	42 - >100	9.3	45	31	13	6	<0.5	<0.2	<0.5	2.2
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	CECtotal (me/100g)	Clay %	CECclay (me/100g)	Total Exch Bases (me/100g)	BSP (me/100g)	BSP (me/100g clay)	ESP (me/100g)	ESP (me/100g clay)	SAR
B58	A34B (a)	0 - 42	0.69	5.20	13.25	0.663	99.05	5.15	3.771	0.196	0.148
B59	A34B (b)	42 - >100	0.55	4.30	12.81	0.538	97.68	4.20	4.721	0.203	0.169
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Ca:Mg	K: Mg	K:CEC (total) (EPP)	K:CEC (clay)	Salinity	Sodicity (ESP >15)	Sodicity (Na > 1me/100g)	FAO Depth Class	
B58	A34B (a)	0 - 42	1.44	0.15	5.51	0.29	No	No	No	Deep	
B59	A34B (b)	42 - >100	0.89	0.13	5.99	0.26	No	No	No	Deep	
Und Lab ID	Und Field ID	Und Depth (cm)	OM % (L.O.I)	Moist Cont %	Dry BD (g/cm ³)	Porosity (vol %)	FAO Classification	FAO Classification	FAO Classification	RSA Classification	
U33	A34U (a)	15	0.10	0.3	1.48	44.1	Group	Unit	Phase		
Micro-topography		Soil Surface Condition									
Localized hummocks, otherwise flat and smooth		High cover of grasses and shrubs; no cracks, sealing or stones									
Erosion / Deposition		Recent deposition of sandy material (colluvial)									
Profile Description											
Horizon	Depth (cm)	Profile Description									
Au2	0-42	Deep, somewhat excessively well drained aeolian sand; no crusting, sealing or cracks. Very little profile development. Deep ochric A horizon of dark reddish brown (5YR 3/2) medium to fine sand; rare burnt organic fragments and particles throughout horizon; few very fine roots; common medium to large pores. Clear smooth boundary at 42cm to B horizon with some ferrallitic properties; reddish brown (5YR 4/6) medium to fine sand, little textural difference; rare very fine roots at 42-47cm; no mollic; common medium to large pores. Diffuse, barely visible boundary at 80cm to a C horizon of firm, slightly compacted sand; no textural or colour change. No visible lower boundary.									
Bp	42-47										
Bw	47-80										
Cw	80+										

SOILS OF KAVANGO REGION

SOILS ANALYSIS Site Summary		Site No	Date	Lat	Long	Land System	Land Facet	Slope %	Slope Class	Aspect	Slope Shape
A35		A35	04-May-99	18°52.124'S	19°40.940'E	(4.1) Omatako omuramba - main channel and tributaries	Main channel floor	0	1	n/a	flat
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	% < 2µ clay	% 2 - 53µ silt	% 53 - 2000µ sand	% > 2000µ gravel	% 2000 - 500µ vcs/cs	% 500 - 250µ ms	% 250 - 106µ fs	% 106 - 53µ vfs	FAO Textural Class
B60	A35B (a)	0 - 35	6.2	32.0	61.8	trace to null	21.6	35.1	27.5	15.8	
B61	A35B (b)	35 - 70	5.3	24.6	70.1	trace to null	24.6	42.5	21.7	11.2	1
B62	A35B (c)	>70	4.0	9.9	86.1	trace to null	23.8	50.6	21.2	4.4	
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Colour (moist)	Texture	OM % (L.O.I)	Moist Cont %	P (Olsen mg/kg)	ECe (µS/cm)	pH (H ₂ O)	OrgC % (Walkley-Black)	CaCO ₃ (quant)
B60	A35B (a)	0 - 35	10YR 2/2 brownish black	sandy loam	Not analysed	Not analysed	0.4	191.2	8.3	<0.01	101.4
B61	A35B (b)	35 - 70	10YR 3/2 brownish black	sandy loam	0.53	4.5	0.4	150.9	6.4	<0.01	55.4
B62	A35B (c)	>70	10YR 3/3 dark brown	sand	0.15	1.0	0.1	92.5	6.6	0.16	8.7
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	SO ₄ (S) µg/g Turbid	Ca (ppm)	Mg (ppm)	K (ppm)	Na (ppm)	Cu (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)
B60	A35B (a)	0 - 35	4.4	2217	343	98	12	<0.5	<0.2	<0.5	<0.5
B61	A35B (b)	35 - 70	2.5	1953	292	63	16	<0.5	<0.2	<0.5	<0.5
B62	A35B (c)	>70	4.6	1526	128	21	11	<0.5	<0.2	<0.5	0.5
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	CECtotal (me/100g)	Clay %	CECclay (me/100g)	Tot Exch Bases (me/100g)	BSP (me/100g)	BSP (me/100g clay)	ESP (me/100g)	ESP (me/100g clay)	SAR
B60	A35B (a)	0 - 35	14.21	6.20	229.12	14.199	99.95	6.20	0.366	0.023	0.063
B61	A35B (b)	35 - 70	12.40	5.30	233.88	12.389	99.95	5.30	0.565	0.030	0.089
B62	A35B (c)	>70	8.79	4.00	219.69	8.781	99.93	4.00	0.546	0.022	0.073
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Ca:Mg	K:Mg	K:CEC total (EPP)	K:CEC (clay)	Salinity	Sodicity (ESP * 15)	Sodicity (Na > 1me/100g)	FAO Depth Class	
B60	A35B (a)	0 - 35	3.94	0.09	1.77	0.11	No	No	No	Deep	
B61	A35B (b)	35 - 70	4.08	0.07	1.30	0.07	No	No	No		
B62	A35B (c)	>70	7.27	0.05	0.61	0.02	No	No	No		
Und Lab ID	Und Field ID	Und Depth (cm)	OM % (L.O.I)	Moist Cont %	Dry BD (g/cm ³)	Porosity (vol %)	FAO Classification		RSA Classification		
U34	A35U (a)	15	0.79	7.5	1.10	58.6	Group	Ufhl	Phase		
Micro-topography			Soil Surface Condition			Surface Drainage			Erosion / Deposition		
Flat, hard, smooth			Low cover tufted grasses; hard, crusted surface (4mm thick), continuous; no stones; no cracks			Impeded drainage; wide shallow drainage sink			Recent deposition fine sand and silty material		
Horizon	Depth (cm)	Profile Description									
Ack	0-1	Deep, imperfectly drained alluvial sandy loam overlying aeolian sand; hard continuous crusted surface 4mm thick, no cracks. Calcic A horizon; brownish black (10YR 2/2) powdery sandy loam with high proportion of silt; weakly developed fine granular to medium platy structure; slow internal drainage; high proportion of soft, highly calcareous aggregates in calcareous matrix; rare very fine roots to 24cm; common fine pores. Diffuse boundary to B horizon at 35cm to sandy loam with brighter colour value (10YR 3/2); increase in medium sand particles; fine granular structure; imperfect drainage; decrease with depth in proportions of soft, highly calcareous aggregates and large hard highly calcareous aggregates in calcareous matrix; rare fine to medium roots to 37cm; common fine pores. Distinct boundary at 70cm to C horizon of dark brown (10YR 3/3) sand; low proportion of small, consolidated calcareous fragments and disaggregated particles in slightly calcareous matrix; internal drainage improved; no roots; common medium and large pores; few fine pores. No visible lower boundary to >100cm.									
Bkw	1-35										
Bkw	35-70										
Ckw	70->100										

SOILS OF KAVANGO REGION

SOILS ANALYSIS Site Summary		Site No	Date	Lat	Long	Land System	Land Facet	Slope %	Slope Class	Aspect	Slope Shape
A36		A36	04-May-99	16°51.840'S	19°37.490'E	(4.1) Omatako omuramba - main channel and tributaries	Western tributary; mid-reaches, side slope	5	1	NE-SW	straight slope
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	% < 2µ clay	% 2 - 53µ silt	% 53 - 2000µ sand	% > 2000µ gravel	% 2000 - 500µ vcs/cs	% 500 - 250µ ms	% 250 - 108µ fs	% 105 - 53µ vfs	FAO Textural Class
B63	A36B (a)	0 - 30	4.2	6.1	89.8	trace to null	3.5	47.6	39.8	9.2	1
B64	A36B (b)	30 - 71	4.5	4.7	90.9	trace to null	4.4	45.6	40.2	9.8	1
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Colour (moist)	Texture	OM % (L.O.I)	Moist Cont %	P (Olsen mg/kg)	Ece (µS/cm)	pH (H ₂ O)	OrgC % (Walkley-Black)	CaCO ₃ (quant)
B63	A36B (a)	0 - 30	10YR 3/3 dark brown	sand	Not analysed	Not analysed	0.1	17.1	6.1	0.05	low pH
B64	A36B (b)	30 - 71	7.5 YR 5/4 dull brown	sand	0.06	0.3	< 0.1	7.1	5.9	< 0.01	low pH
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	SO ₂ (S µg/g Turbid)	Ca (ppm)	Mg (ppm)	K (ppm)	Na (ppm)	Cu (ppm)	Zn (ppm)	Fe (ppm)	Min (ppm)
B63	A36B (a)	0 - 30	10.1	111	26	11	4	< 0.5	< 0.2	< 0.5	1.1
B64	A36B (b)	30 - 71	3.8	47	23	9	5	< 0.5	< 0.2	< 0.5	< 0.5
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	CEC total (me/100g)	Clay %	CEC clay (me/100g)	Tot Exch Bases (me/100g)	BSP (me/100g)	BSP (me/100g clay)	ESP (me/100g clay)	ESP (me/100g clay)	SAR
B63	A36B (a)	0 - 30	0.82	4.20	19.57	0.813	98.93	4.16	2.069	0.087	0.089
B64	A36B (b)	30 - 71	0.46	4.50	10.57	0.469	98.63	4.44	4.626	0.208	0.149
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Ca/Mg	K/Mg	K:CEC total (EPP)	K:CEC (clay)	Salinity	Sodicity (ESP > 15)	Sodicity (Na > 1me/100g)	FAO Depth Class	
B63	A36B (a)	0 - 30	2.61	0.13	3.41	0.14	No	No	No	Deep	
B64	A36B (b)	30 - 71	1.24	0.12	4.84	0.22	No	No	No	Deep	
Und Lab ID	Und Field ID	Und Depth (cm)	OM % (L.O.I)	Moist Cont %	Dry BD (g/cm3)	Porosity (vol %)	FAO Classification	FAO Classification	Phase	RSA Classification	
U35	A36U (a)	15	0.09	0.2	1.53	42.3	Group	Unit	Phase		
Micro-topography		Soil Surface Condition									
High density of micro-slopes running parallel to slope direction		Medium cover of leaf litter; continuous thin hard crust 3mm thick									
Horizon		Profile Description									
Au1	0-6	Deep, moderately well drained sand; continuous thin, hard crust 3mm thick, no cracks. Ochric, slightly calcareous A horizon; dark brown (10YR 3/3) medium to fine sand with silt; very fine granular to very fine platy structure; rare fine roots; common fine pores; <1% black organic mollics at 6-9cm. Smooth boundary at 30cm to C horizon of dull brown (5YR 4/4) medium to fine aeolian sand; good internal drainage; unconsolidated to weakly developed fine granular structure; no mollics; no roots; common medium pores; no visible boundary to >100cm depth.									
Ap	6-9										
Au2	9-30										
BC w	30->100										
Micro-topography		Surface Drainage									
High density of micro-slopes running parallel to slope direction		Moderately well drained; evidence of sheet runoff									
Horizon		Erosion / Deposition									
		Minor development of sheet wash surfaces									

SOILS OF KAVANGO REGION

SOILS ANALYSIS Site Summary		Site No	Date	Lat	Long	Land System	Land Facet	Slope %	Slope Class	Aspect	Slope Shape
A37		A37	04-May-99	18°51'436"S	19°31'868"E	(4.2) Omatako omuramba - lower catchment slopes	Western edge of drainage; crest NW-SE aligned dune	4	1	NW-SE	convex
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	% < 2µ clay	% 2 - 53µ silt	% 53 - 2000µ sand	% > 2000µ gravel	% 2000 - 500µ vcs/ks	% 500 - 250µ fs	% 250 - 106µ fs	% 106 - 53µ vfs	FAO Textural Class
B65	A37B (a)	0 - 20	5.7	7.1	87.2	trace to null	7.3	43.3	43.8	5.6	
B66	A37B (b)	20 - 50	6.3	7.0	86.7	trace to null	7.0	37.3	44.8	11.0	1
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Colour (moist)	Texture	OM % (L.O.I)	Moist Cont %	P (Olsen mg/kg)	ECa (µS/cm)	pH (H ₂ O)	OrgC % (Walkley-Black)	CaCO ₃ (quart)
B65	A37B (a)	0 - 20	7.5YR 4/6 brown	sand	Not analysed	Not analysed	< 0.1	9.6	5.2	0.11	low pH
B66	A37B (b)	20 - 50	5YR 4/8 reddish brown	sand	0.15	1.0	< 0.1	7.3	5.3	0.04	low pH
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	SO ₄ (S) µg/g Turbid	Ca (ppm)	Mg (ppm)	K (ppm)	Na (ppm)	Cu (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)
B65	A37B (a)	0 - 20	9.6	63	39	39	6	< 0.5	< 0.2	< 0.5	< 0.5
B66	A37B (b)	20 - 50	5.7	43	41	36	6	< 0.5	< 0.2	< 0.5	2.5
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	CECtotal (me/100g)	Clay %	CECclay (me/100g)	Tot Exch Bases (me/100g)	BSP (me/100g)	BSP (me/100g clay)	ESP (me/100g clay)	ESP (me/100g clay)	SAR
B65	A37B (a)	0 - 20	0.77	5.70	13.47	99.15	99.15	5.65	3.387	0.193	0.146
B66	A37B (b)	20 - 50	0.68	6.30	10.84	97.97	97.97	6.17	3.808	0.240	0.157
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Ca:Mg	K:Mg	K:CEC total (ERP)	Salinity	Sodicity (ESP > 15)	Sodicity (Na > 1me/100g)	Sodicity (Na > 1me/100g)	FAO Depth Class	
B65	A37B (a)	0 - 20	0.98	0.31	13.03	No	No	No	No		
B66	A37B (b)	20 - 50	0.64	0.27	13.47	No	No	No	No	Deep	
Und Lab ID	Und Field ID	Und Depth (cm)	OM % (L.O.I)	Moist Cont %	Dry BD (g/cm ³)	Porosity (vol %)	FAO Classification	FAO Classification	FAO Classification	RSA Classification	
U36	A37U (a)	15	0.15	0.4	1.48	44.0	Group	Unit	Phase		
Micro-topography		Soil Surface Condition		Surface Drainage		Erosion / Deposition					
Medium density of micro-slopes running parallel to slope direction		High cover of leaf litter; continuous thin crust 1mm thick; continuous; no cracks or stones		Surface Drainage		Minor development of shallow drainage channels		Minor development of sheet wash surfaces			
Horizon	Depth (cm)	Profile Description									
Au1	0-7	Deep, well drained sand; continuous incipient crust 1mm thick, no cracks. Ochric A horizon, brown (7.5YR 4/6), medium to fine sand with silt and clay; unconsolidated to very fine crumb structure; dense root mat bound into 5mm thick fibrous layer with silts and clays at 3cm depth; 2% black organic fragments and particles at 7-11cm. Smooth boundary at 20cm to transitional BC horizon with some ferrallitic properties (texture too coarse to be diagnostic of ferrallitic horizon); reddish brown (5YR 4/8) sand; no change in texture although slightly coarser handling properties; unconsolidated, no structural development; freely drained; no roots; no mottles; common medium pores. No visible lower boundary to > 100cm.									
Ap	7-11										
Au2	11-20										
BCw	20->100										

SOILS OF KAVANGO REGION

SOILS ANALYSIS Site Summary		Site No	Date	Lat	Long	Land System	Land Facet	Slope %	Slope Class	Aspect	Slope Shape
F1		17°28.964'S	07-Feb-99	17°28.964'S	18°26.814'E	(3.1) Okavango river floodplain and terraces	Crest of N-facing terrace bordering sand plain	4	1	NE	straight slope
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	% < 2µ clay	% 2 - 50µ silt	% 53 - 2000µ sand	% > 2000µ gravel	% 2000 - 500µ ves/cs	% 500 - 250µ ms	% 250 - 100µ fs	% 105 - 53µ fs	FAO Textural Class.
B67	F1B (a)	0 - 15	4.1	4.3	91.5	trace to null	6.9	52.8	34.7	5.6	
B68	F1B (b)	15 - 30	4.6	5.1	89.2	trace to null	7.9	47.4	37.0	7.7	1
B69	F1B (c)	30 - 45	4.6	5.6	89.9	trace to null	7.2	50.5	35.8	6.5	
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Colour (moist)	Texture	OM % (L.O.I)	Moist Cont %	P (Olsen mg/kg)	Ece (µS/cm)	pH (H ₂ O)	OrgC % (Walkley-Black)	CaCO ₃ (quant)
B67	F1B (a)	0 - 15	7.5YR 4/6 brown	sand	Not analysed	Not analysed	< 0.1	32.3	5.0	0.06	low pH
B68	F1B (b)	15 - 30	5YR 4/6 reddish brown	sand	Not analysed	Not analysed	< 0.1	16.5	4.7	<0.01	low pH
B69	F1B (c)	30 - 45	5YR 5/6 bright reddish brown	sand	Not analysed	Not analysed	0.1	11.5	4.7	<0.01	low pH
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	SO ₄ (S-µg/g Turbid)	Ca (ppm)	Mg (ppm)	K (ppm)	Na (ppm)	Cu (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)
B67	F1B (a)	0 - 15	9.1	25	10	8	4	<0.5	<0.2	1.0	1.5
B68	F1B (b)	15 - 30	8.3	8	4	5	4	<0.5	<0.2	1.0	<0.5
B69	F1B (c)	30 - 45	8.0	6	3	5	3	<0.5	<0.2	1.0	<0.5
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	CECtotal (me/100g)	Clay %	CECclay (me/100g)	Tot Exch Bases (me/100g)	BSP (me/100g)	BSP (me/100g clay)	ESP (me/100g)	ESP (me/100g clay)	SAR
B67	F1B (a)	0 - 15	0.26	4.10	6.27	0.244	94.96	3.89	6.516	0.271	0.171
B68	F1B (b)	15 - 30	0.11	4.60	2.44	0.103	91.73	4.22	15.141	0.696	0.288
B69	F1B (c)	30 - 45	0.09	4.60	1.96	0.081	89.72	4.13	14.400	0.662	0.250
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Ca:Mg	K:Mg	K:CEC total (EPP)	K:CEC (clay)	Salinity	Sodicity (ESP > 15)	Sodicity (Na > 1me/100g)	FAO Depth Class	
B67	F1B (a)	0 - 15	1.52	0.24	7.78	0.32	No	No	No	Deep	
B68	F1B (b)	15 - 30	1.21	0.39	11.98	0.53	No	Yes	No		
B69	F1B (c)	30 - 45	1.20	0.52	14.40	0.66	No	Yes	No		
Und Lab ID	Und Field ID	Und Depth (cm)	OM % (L.O.I)	Moist Cont %	Dry BD (g/cm ³)	Porosity (vol %)	FAO Classification		Erosion / Deposition		
U37	F1U (a)	15	0.13	2.6	1.55	41.4	Group	Unit	Phase		
U38	F1U (b)	30	0.12	2.0	1.57	40.6	Arenosol	Ferralsol	Yermic	Gaudam ?	
U39	F1U (c)	45	0.09	3.1	1.58	40.2	Surface Drainage				
Micro-topography											
Uneven; micro-slopes around shrubs			High cover of leaf litter, burnt twigs, tree & shrub branches; no crusting or sealing; no evidence of soil			No visible drainage lines; soil highly permeable			Evidence of water and wind erosion, not severe; sand particle accumulations against surface detritus and hummocks (in prevailing wind direction?) & minor sheet wash effect		
Horizon	Depth (cm)	Profile Description									
Au1	0-5	Deep, excessively well drained sand; no crusting, sealing or cracks. Thick ochric A horizon, brown (7.5YR 4/6) medium sand; common black organic mottles and fragments in dense band between 5-7cm depth; weakly developed coarse granular structure, very friable, non sticky, non plastic; few fine pores, non calcareous, few fine to very fine roots. Smooth diffuse boundary at 15cm to B horizon with some ferrallitic properties (texture too coarse to be diagnostic of ferrallitic horizon). No textural difference although colour change to reddish brown (5YR 4/6); very weak very coarse crumb structure, slightly hard, friable, non calcareous; rare fine roots. Smooth boundary at 30cm to C horizon of bright reddish brown (5YR 5/6) loamy sand; loose, very coarse crumb structure, slightly hard, friable, non calcareous; no roots. No visible lower boundary to > 100cm.									
Ap	5-7										
Au2	7-15										
Bw	15-30										
BCw	30->100										

SOILS OF KAVANGO REGION

SOILS ANALYSIS Site Summary		Site No	Date	Lat	Long	Land System	Land Facet	Slope %	Slope Class	Aspect	Slope Shape
F2			07-Feb-99	17°30.746'S	18°23.722'E	(9.2) Northern sandplain incised by short omramba	Sand drift plain, NW Kavango south of oldest terrace; recent fire	1.5	1	S	straight slope
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	% < 2µ clay	% 2 - 63µ silt	% 53 - 2000µ sand	% > 2000µ gravel	% 2000 - 5000µ Viscs	% 500 - 250µ ms	% 250 - 106µ fs	% 106 - 53µ Vfs	FAO Textural Class
B70	F2B (a)	0 - 15	3.6	4.7	91.6	trace to null	4.4	52.5	38.0	5.0	
B71	F2B (b)	15 - 30	3.6	5.7	90.7	trace to null	3.3	43.9	42.3	10.4	1
B72	F2B (c)	30 - 45	3.6	4.8	91.6	trace to null	3.6	46.9	42.0	7.5	
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Colour (moist)	Texture	OM % (L.O.I)	Molst Cont %	P (Olsen mg/kg)	ECE (µS/cm)	pH (H ₂ O)	OrgC % (Walkley-Black)	CaCO ₃ (quant)
B70	F2B (a)	0 - 15	5YR 5/2 greyish brown	sand	Not analysed	Not analysed	< 0.1	34.5	5.2	0.06	low pH
B71	F2B (b)	15 - 30	7.5YR 5/3 dull brown	sand	Not analysed	Not analysed	< 0.1	20.0	5.1	< 0.01	low pH
B72	F2B (c)	30 - 45	7.5YR 6/4 dull orange	sand	Not analysed	Not analysed	< 0.1	11.9	4.9	< 0.01	low pH
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	SO ₄ (S µg/g Turbid)	Ca (ppm)	Mg (ppm)	K (ppm)	Na (ppm)	Cu (ppm)	Zn (ppm)	Fe (ppm)	Mn (ppm)
B70	F2B (a)	0 - 15	5.4	49	14	6	2	< 0.5	< 0.2	< 0.5	< 0.5
B71	F2B (b)	15 - 30	5.7	24	8	9	5	< 0.5	< 0.2	< 0.5	0.4
B72	F2B (c)	30 - 45	8.8	15	7	5	6	< 0.5	< 0.2	< 0.5	< 0.5
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	CEC total (me/100g)	Clay %	CEC clay (me/100g)	Tot Exch Bases (me/100g)	BSP (me/100g)	BSP (me/100g clay)	ESP (me/100g)	ESP (me/100g clay)	SAR
B70	F2B (a)	0 - 15	0.39	3.60	10.85	0.384	98.33	3.54	2.305	0.083	0.065
B71	F2B (b)	15 - 30	0.24	3.60	6.59	0.231	97.38	3.51	9.274	0.334	0.226
B72	F2B (c)	30 - 45	0.18	3.60	4.93	0.171	96.32	3.47	14.645	0.527	0.321
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Ce:Mg	K:Mg	K:CEC total (EPR)	K:CEC (clay)	Salinity	Sodicity (ESP > 15)	Sodicity (Max > (me/100g) *	FAO Depth Class	
B70	F2B (a)	0 - 15	2.13	0.13	3.84	0.14	No	No	No	Deep	
B71	F2B (b)	15 - 30	1.82	0.35	9.70	0.35	No	No	No		
B72	F2B (c)	30 - 45	1.32	0.23	7.32	0.26	No	Yes	No		
Und Lab ID	Und Field ID	Und Depth (cm)	OM % (L.O.I)	Molst Cont %	Dry BD (g/cm ³)	Porosity (vol %)	FAO Classification		RSA Classification		
U40	F2U (a)	15	0.08	2.0	1.40	47.1	Group	Uhlil	Phase		
U41	F2U (b)	30	0.07	1.3	1.70	35.8	Arenosol	Haplic	Yermic	Sandspruit ?	
U42	F2U (c)	45	0.11	1.7	1.64	38.1	Surface Drainage		Erosion / Deposition		
Micro-topography			Soil Surface Condition				Surface Drainage				
Uneven; local micro-slopes			High cover of burnt twigs, a recent high temperature fire; no crusting, sealing or cracks; no salt				No visible drainage lines; soil highly permeable				
			No evidence of water or wind erosion; no evidence of recent deposition								
Horizon	Depth (cm)	Profile Description									
Ap1	0-15	Deep, excessively well drained sand; no crusting, sealing or cracks. Thin ochric A horizon of brown (7.5YR 4/6) sand with little clay or silt content; grey cast permealing colour certainly produced by recent fire; very coarse crumb structure, easily broken; non calcareous; 10% black organic mollics; common fine to very fine roots; common medium and large pores. Abrupt boundary at 15cm to dull brown (7.5YR 5/3) sand with coarser texture; unconsolidated, to weak fine crumb structure; non calcareous; non sticky; 3% black organic mollics at 15-18cm depth; common very fine roots; common large pores. Smooth boundary to transitional AC horizon of dull orange (7.5YR 6/4) unconsolidated sand; slightly compact; no structural development; no roots; no mollics; common large pores. No visible lower boundary to > 100cm.									
Ap2w	15-18										
AC w	18->100										

SOILS OF KAVANGO REGION

SOILS ANALYSIS Site Summary		Site No	Date	Lat	Long	Land System	Land Facet	Slope %	Slope Class	Aspect	Slope Shape
F3			07-Feb-99	17°30'735S	18°23'698E	(3.2) Northern sandplain incised by short omiramba	Sand drift plain, NW/Kavango south of oldest terrace	1.5	1	S	straight slope
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	% < 2µ silt	% 53 - 2000µ sand	% > 2000µ gravel	% 2000 - 500µ ves/cs	% 500 - 250µ ms	% 250 - 100µ fs	% 106 - 53µ vs	FAO Textural Class	
B73	F3B (a)	0 - 15	3.1	92.0	trace to null	3.3	47.1	42.9	6.7		
B74	F3B (b)	15 - 30	5.4	91.0	trace to null	5.9	50.6	38.2	5.3		1
B75	F3B (c)	30 - 45	4.3	91.2	trace to null	2.8	39.3	45.3	12.5		
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Colour (moist)	Texture	OM % (L.O.I)	P (Olsen mg/kg)	ECe (µS/cm)	pH (H ₂ O)	OrgC % (Walkley-Black)	CaCO ₃ (quant)	
B73	F3B (a)	0 - 15	7.5YR 4/4 brown	sand	Not analysed	< 0.1	25.6	5.7	0.06		low pH
B74	F3B (b)	15 - 30	7.5YR 6/4 dull orange	sand	Not analysed	< 0.1	13.7	5.4	0.01		low pH
B75	F3B (c)	30 - 45	7.5YR 6/4 dull orange	sand	Not analysed	< 0.1	12.3	5.3	< 0.01		low pH
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	SO ₄ (S) (µg/g Turbid)	Ca (ppm)	Mg (ppm)	K (ppm)	Na (ppm)	Cu (ppm)	Zn (ppm)	Fe (ppm)	Min (ppm)
B73	F3B (a)	0 - 15	10.9	65	11	4	3	< 0.5	< 0.2	< 0.5	< 0.5
B74	F3B (b)	15 - 30	10.4	38	8	5	3	< 0.5	< 0.2	< 0.5	< 0.5
B75	F3B (c)	30 - 45	9.3	33	7	7	4	< 0.5	< 0.2	< 0.5	< 0.5
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	CEC total (me/100g)	Clay %	CEC clay (me/100g)	Tot Exch Bases (me/100g)	BSP (me/100g clay)	BSP (me/100g clay)	ESP (me/100g clay)	ESP (me/100g clay)	SAR
B73	F3B (a)	0 - 15	0.44	3.10	14.34	0.438	98.53	3.05	2.924	0.091	0.091
B74	F3B (b)	15 - 30	0.29	3.60	8.01	0.282	97.73	3.52	4.505	0.162	0.115
B75	F3B (c)	30 - 45	0.26	4.50	5.86	0.257	97.52	4.39	6.451	0.290	0.165
Bulk Lab ID	Bulk Field ID	Bulk Depth (cm)	Ca/Mg	K/Mg	K:CEC total (EPP)	K:CEC (clay)	Salinity	Sodicity (ESP * 15)	Sodicity (Na > 1me/100g)	FAO Depth Class	
B73	F3B (a)	0 - 15	3.61	0.11	2.25	0.07	No	No	No		
B74	F3B (b)	15 - 30	2.88	0.20	4.51	0.16	No	No	No	Deep	
B75	F3B (c)	30 - 45	2.89	0.32	6.83	0.31	No	No	No		
Und Lab ID	Und Field ID	Und Depth (cm)	OM % (L.O.I)	Moist Cont %	Dry BD (g/cm ³)	Porosity (vol %)	FAO Classification		RSA Classification		
U43	F3U (a)	15	0.08	1.3	1.56	41.3	Group	Unit			
U44	F3U (b)	30	0.10	1.7	1.68	36.7	Arenosol	Haplic	Yermic	Sandspruit ?	
U45	F3U (c)	45	0.09	1.3	1.78	32.7	Surface Drainage		Erosion / Deposition		
Micro-topography			Soil Surface Condition			Surface Drainage			Erosion / Deposition		
Uneven; minor hummocks around shrubs			High cover of burnt twigs, a recent high temperature fire; no crusting, sealing or cracks; no salt			No visible drainage lines; soil highly permeable			No evidence of wind erosion; rain splash (slight cementation & pitted surface) and minor sheet wash effects		
Horizon	Depth (cm)	Profile Description									
Au	0-15	Deep, excessively well drained sand; no crusting, sealing or cracks. Ochric A horizon of brown (7.5YR 4/4) sand with little clay or silt content; coarse crumb structure, easily broken; 3% black organic mottles; few fine roots; common medium and large pores; non calcareous. Smooth boundary at 15cm to transitional AC horizon of dull orange (7.5YR 6/4) unconsolidated sand; no structural development; no mottles; few fine roots; common medium and large pores; non calcareous. Diffuse boundary at 32cm to unspecified C horizon, no colour change or textural differences; medium crumb structure, easily broken; slight increase in packing state; 3% black organic mottles at 32-35cm; common medium pores. No visible lower boundary to > 100cm.									
AC w	15-32										
Cpw	32-35										
Cu	35->100										

